
R G U H S · M O D E L A N S W E R B A N K

RGUHS MD/MS Anatomy — Paper IV



M O D E L A N S W E R B A N K

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883 recurring topics · Textbook-grounded model answers · cited Recent Advances

G R O U N D E D I N :

Gray's Anatomy (Standring) 41e — spine text
BD Chaurasia · AK Datta · Moore's Clinically Oriented Anatomy — gross anatomy
Langman · Moore (Developing Human) · Larsen — embryology
Thompson & Thompson · Gangane — genetics
Junqueira · Ross · IB Singh — histology
Bancroft · Pranab Dey — microscopy & histotechniques
Halder · Govt Museum Handbook — organ donation & body preservation
Snell · Vishram Singh · IB Singh — neuroanatomy



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Contents

Spinal cord & tracts.....9

Describe the blood supply of the spinal cord.....	9
Blood supply of spinal cord.....	14
Blood supply to spinal cord and applied aspects.....	19
Brown – Sequard syndrome.....	23
Central canal of spinal cord.....	28
Descending tract of spinal cord.....	32
Describe the ascending tracts of the spinal cord.....	38
Laminar organization in spinal cord.....	42

Brainstem & cranial nerve nuclei.....47

Lateral medullary syndrome.....	47
Neurobiotaxis.....	52
Abducent nerve.....	57
Corpora Quadrigemina.....	62
Cranial nerve nuclei in the brain stem.....	66
Describe in detail about "Reticular formation of brain stem".....	72
Describe the clinical features of the lesions of facial nerve at different levels.....	79
Facial nerve nuclear complex and connections.....	85
Describe the facial nerve under a) Nuclei b) course of motor root c) effects of lesions of motor root at various levels.....	90
Describe the reticular formation of the brainstem.....	96
Discuss about the cranial nerve nuclei in hind brain.....	102
Facial nerve.....	108
Give a detailed account of medulla oblongata with its applied aspects.....	114
Inferior colliculus.....	119
Interpeduncular fossa.....	125
Lateral and medial medullary syndrome.....	130
Medial longitudinal bundle.....	135
Neuro-biotaxis.....	140
Nuclei of trigeminal nerve.....	145
Nucleus ambiguus.....	150
Red nucleus.....	155
Substantia Nigra.....	160
Superior colliculus.....	165

Cerebellum.....170

Cerebellar peduncles.....	170
Connections of cerebellum.....	174

Connections, blood supply and applied anatomy of cerebellum.....	179
Describe the cerebellum and its functions. What is cerebellar intention tremor?.....	184
Inferior cerebellar peduncle.....	190
Intra cerebellar nuclei.....	195
Middle cerebellar peduncle.....	200
Nuclei of Cerebellum.....	206
Signs and symptoms of cerebellar disease.....	211
Vermis of cerebellum.....	216
Archicerebellum, Paleocerebellum and Neocerebellum — Connections and Blood Supply of the Cerebellum.....	220
Diencephalon (thalamus & hypothalamus).....	225
Lateral geniculate body.....	226
Classify thalamic nuclei, connections and functions.....	230
Describe the hypothalamus and its nuclear subdivisions.....	235
Describe the various nuclei of the thalamus. Mention its connections.....	242
Epithalamus.....	247
Hypothalamic nuclei.....	252
Hypothalamohypophyseal tract.....	257
Metathalamus.....	263
Subthalamus.....	268
Thalamic nuclei and connections.....	273
Thalamic nuclei.....	278
Cerebrum, cortex & white matter.....	282
Describe the internal capsule.....	283
White Matter of Cerebrum.....	288
Classify the white matter of cerebrum, describe internal capsule and its applied aspect?.....	293
Classify the white matter of the cerebrum. Describe parts, relations, arterial supply, fibre components and applied aspects of internal capsule.....	298
Classify white matter of cerebrum. Describe parts, relations, fibre components of internal capsule.....	303
Commissural fibers of the cerebrum.....	309
Corona radiata.....	314
Describe in detail about the Functional areas of cerebrum and its applied anatomy.....	318
Describe the cortical areas.....	324
Describe the internal capsule in detail.....	330
Functional areas of cerebrum.....	335
Name the parts, arterial supply, structure and functional areas of the cerebral hemisphere.....	341
Speech areas of brain.....	347
Speech areas of the brain.....	353

Striate cortex.....	358
Visual areas.....	363
Basal ganglia & limbic system.....	368
Describe the anatomy of limbic system.....	369
Basal ganglia.....	374
Basal nuclei.....	381
Caudate nucleus.....	387
Describe in detail about the Limbic system.....	392
Describe in detail the limbic system.....	397
Describe the areas of brain involved in parkinsonism disorder.....	402
Describe the Basal nuclei in detail.....	408
Describe the gross anatomy and applied anatomy of basal nuclei.....	413
Describe the parts, connections and functions of extra pyramidal system. What are the presenting symptoms due to lesions in the various parts of the extra-pyramidal system.....	419
Hippocampal formation.....	425
Hippocampus.....	430
Lentiform nucleus.....	436
Limbic system.....	440
Ventricles, meninges, CSF & blood supply.....	445
Subarachnoid Cisterns.....	445
Blood brain barrier.....	449
Cerebrospinal fluid.....	454
Choroid fissure of lateral ventricle.....	459
Choroid plexus.....	463
Choroid plexus of ventricles and circulation of CSF.....	468
Circle of Willis.....	473
Describe in detail about "Lateral ventricle".....	477
Describe lateral ventricle in detail.....	483
Describe lateral ventricle under the following headings -Location and extent. -Relations and boundaries. -Contents and applied aspects.....	488
Describe the blood supply of the cerebrum. Give its applied anatomy.....	493
Describe the fourth ventricle in detail.....	498
Describe the Lateral ventricle of the brain in detail.....	503
Describe the third ventricle in detail.....	508
Describe the ventricles of the brain.....	512
Cerebrospinal Fluid: Formation, Circulation, Biochemistry and Clinical Significance.....	518
IV Ventricle.....	522
Lateral ventricle.....	527
Lateral ventricle of brain.....	532

Modifications of spinal pia mater.....	537
Pia mater.....	540
Tela Choroidea (Telachoroidia).....	546
Third ventricle.....	550
Sensory, motor & special-sense pathways.....	555
Describe the auditory pathway.....	555
Medial lemniscus.....	560
Describe the pyramidal tract in detail.....	565
Describe the Spinothalamic tracts in detail.....	570
Give an account of nerve pathways involved in conduction of somatic pain. Discuss its clinical significance.....	576
Optic radiation.....	582
Taste pathway.....	586
Trigeminal Lemniscus.....	591
Visual pathway and the defects produced in lesions in its pathway.....	596
Radiological & cross-sectional anatomy.....	601
C T Scan.....	602
Contrast X-rays.....	607
Cross sectional anatomy at the level of L1 vertebra (labeled diagram only).....	612
Functional MRI.....	616
MRI.....	622
PET scan.....	626
PET scanning.....	632
Ultra sound.....	637
Abdominal ultrasound.....	643
Anatomical basis of C.T. scan procedure and pictures.....	647
Anatomy of ultrasound guided FNAC.....	654
Ascending and Descending Pyelography.....	658
Bone scan & its applications.....	663
Carotid angiogram.....	668
Cerebral angiography.....	673
Color Doppler Scan.....	678
Computed tomography and its usefulness in learning anatomy.....	684
Coronary arteriograms.....	689
Cross section of the abdomen at the level of L1.....	694
Cross section of the midbrain at the level of superior colliculus.....	698
Cross section of thorax at T4 level.....	703
Cross sectional anatomy at the level of C2 vertebra (labeled diagram only).....	707

Cross sectional anatomy at the level of L1 vertebra (labeled diagram).....	713
Cross sectional anatomy at the level of the sternal angle.....	717
Cross sectional anatomy of Pons at the level of Facial colliculus.....	722
Cross sectional anatomy of thorax at the level of T4.....	727
Cross sectional anatomy of Upper pons.....	731
CT scan.....	736
Describe in detail about the Radiological techniques used in Abdomen and pelvis.....	741
Describe in detail about the Radiological techniques used in Thorax.....	747
Describe the section of the midbrain at the level of the superior colliculi.....	752
Describe the structure of mid brain at the level of superior colliculus.....	756
Cross-Sectional Anatomy of the Upper Limb at the Middle of the Arm.....	761
Draw and label the cross sectional anatomy at the level of L1 vertebra.....	766
Draw the diagram of transverse section at the level of T4 vertebra.....	771
Horizontal section at the level of L-1 vertebra.....	776
Horizontal section of cerebrum.....	780
Horizontal section through abdomen at the level of L4.....	785
Hysterosalpingography.....	789
Intravenous pyelography.....	794
Labeled diagram of the cross sectional cord at the mid thoracic junction.....	798
Magnetic resonance imaging (MRI) and its usefulness in learning anatomy.....	803
Magnetic Resonance Imaging (MRI).....	808
Medulla at motor and sensory decussation.....	814
MRI (magnetic resonance imaging).....	819
Principles of MRI.....	823
Section at the level of T4 vertebra.....	828
Section at Transpyloric plane.....	832
Sectional study of midbrain.....	837
Sections of cerebrum at the level of interventricular formation.....	842
Sequential axial CT images.....	846
T2W MR images.....	851
Thyroid scanning.....	857
Ultra sonography.....	862
Write short notes on cholecystography.....	867
Xero radiography.....	872
Applied & clinical anatomy.....	876
Branchial cyst.....	876
Cervical Rib.....	881
Claw hand.....	886

Anal fistulas.....	892
Anatomical basis of haemoptysis.....	897
Applied anatomy of the shoulder joint.....	902
Applied anatomy of Thoracic inlet.....	907
Applied anatomy of thyroid gland.....	911
Applied aspects of innervations of urinary bladder.....	918
Applied aspects of venous drainage of lower limb.....	923
Blood supply of Thyroid gland and its clinical importance.....	927
Branches of vagus nerve in the thorax and neck.....	932
Cardiac plexus.....	938
Clinical anatomy of femoral canal.....	942
Clinical anatomy of peritoneal recesses.....	947
Clinical anatomy of Prostate.....	953
Clinical anatomy of thoracoabdominal diaphragm.....	960
Clinical examination of Vagus nerve.....	965
Clinical importance of vascular segments of liver.....	971
Describe the anatomical basis of neurological conditions associated with urinary bladder.....	976
Describe the applied anatomy associated with various deformities of the foot.....	982
Describe the boundaries and contents of the inguinal canal. Add a note on inguinal hernias.....	987
Describe the nerve supply to urinary bladder and discuss the neurological disorders.....	992
Describe the surgical anatomy of portal vein.....	998
Describe the surgical anatomy of the retropharyngeal space.....	1003
Discuss in detail the surgical anatomy of anal canal.....	1008
Discuss the applied anatomy of ischiorectal fossa.....	1013
Erb's paralysis.....	1017
Fascial spaces in Palm and their surgical importance.....	1022
Gastroscopy.....	1027
Give the surgical (Applied) anatomy of anal fissure.....	1033
Glial Cells.....	1037
Hepato renal pouch.....	1043
Inferior constrictor muscle of pharynx.....	1047
Inguinal canal and its applied anatomy.....	1051
Inguinal hernia.....	1057
Injuries of brachial plexus.....	1063
Injuries of median nerve.....	1069
List the clinical features and their anatomical basis of a) Complete transection of spinal cord caudal to the arm level b) Brown–Séguard syndrome.....	1074
Mastoid antrum.....	1080

Perforating veins.....	1085
Persistent vitello – intestinal duct.....	1089
Phrenic nerve.....	1094
Porto– systemic anastomosis and clinical importance.....	1101
Surgical anatomy of inguinal canal.....	1105
Surgical anatomy of Palatine Tonsil.....	1110
Surgical anatomy of peritoneum.....	1115
Surgical anatomy of rectus sheath.....	1122
Trendelenburg's Test for Varicose Veins.....	1127
Various approaches to the prostate gland.....	1131
Wallenberg's syndrome.....	1137
Wrist drop.....	1141
Recent advances in anatomical sciences.....	1147
Frozen embryo.....	1147
Sono elastography.....	1152
Stem cell isolation and applications.....	1157
Comparative & applied embryology.....	1161
In vitro fertilization.....	1162

Spinal cord & tracts



Describe the blood supply of the spinal cord

Asked in: Paper IV 04-Aug-2021 · Paper IV Nov 2016 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction — The spinal cord is supplied by **three longitudinal arterial channels** — a single **anterior spinal artery** and paired **posterior spinal arteries** — that arise intracranially from the vertebral arteries but are far too small to nourish the whole cord length by themselves. They are therefore reinforced at irregular segmental intervals by **radicular and segmental medullary (radiculomedullary) arteries**, the largest of which is the **great anterior segmental medullary artery of Adamkiewicz**. Venous drainage mirrors the arterial pattern via six longitudinal channels draining into the internal vertebral (epidural) venous plexus. This dual-source, watershed-prone circulation explains the clinical importance of the **anterior spinal artery syndrome** and of cord ischaemia following aortic surgery.

1. The three longitudinal spinal arteries

- ▶ **Anterior spinal artery (ASA)** — a single midline vessel formed in the posterior cranial fossa by the union (fusion) of the two anterior spinal branches, one from each vertebral artery. It descends through the foramen magnum and runs the entire length of the cord embedded in the pia mater of the **anterior median fissure**, terminating in an anastomotic plexus around the conus medullaris.
- ▶ **Posterior spinal arteries (PSA)** — paired vessels arising either directly from the intracranial (4th) part of the vertebral artery or indirectly from the **posterior inferior cerebellar artery (PICA)**. Each descends as two rami — one anterior and one posterior to the dorsal (posterior) nerve roots — along the **posterolateral sulcus**, i.e. the line of attachment of the dorsal rootlets.
- ▶ Both systems anastomose over the conus medullaris and are interconnected on the cord surface by a fine pial arterial network, the **arterial vasocorona**.

2. Segmental reinforcement — radicular and segmental medullary arteries

Because blood from the vertebral arteries reaches only as far as the cervical cord, the rest of the cord depends entirely on segmental feeders that enter through the intervertebral foramina.

- ▶ **Source vessels** (craniocaudal sequence): vertebral and ascending/deep cervical arteries (cervical cord) → posterior intercostal arteries (thoracic cord) → lumbar arteries (lumbar cord) → lateral sacral arteries (sacral cord).
- ▶ Each segmental artery gives an **anterior and a posterior radicular artery** that run along the corresponding nerve root. **Most radicular arteries are small** and end merely by supplying the nerve root and dorsal root ganglion (entering at both ganglionic poles).
- ▶ A few, mainly at the **lower cervical, lower thoracic and upper lumbar levels**, are large enough to reach the anterior median fissure and join the ASA — these are the **anterior (and posterior) segmental medullary/radiculomedullary feeder arteries**, concentrated at the **cervical and lumbosacral enlargements** where cord metabolic demand is greatest.

- ▶ **Great anterior segmental medullary artery of Adamkiewicz (arteria radicularis magna)** — the largest and most important of these feeders:
 - Arises from a spinal branch of one of the lower posterior intercostal arteries (T9–T11), the subcostal artery (T12), or occasionally an upper lumbar artery (L1–L2).
 - Is **unilateral**, entering on the **left side in about 65% of individuals** (Moore).
 - May supply as much as the **lower two-thirds of the cord**, including the lumbosacral enlargement, by sending an ascending branch to reinforce the ASA and a descending branch that joins the ramus of the posterior spinal artery.

3. Intrinsic (intramedullary) distribution

Within the cord substance, the two arterial systems divide the cross-section unequally:

Territory	Feeding artery / route	Structures supplied
Anterior ~two-thirds (central territory)	Central (sulcal) branches of the ASA — enter the anterior median fissure and alternate to the right and left sides	Anterior and lateral grey columns, base/central part of the posterior grey column, anterior and lateral white funiculi — i.e. corticospinal and spinothalamic tracts
Posterior ~one-third (peripheral territory)	Radial (peripheral) branches of the two posterior spinal arteries and the pial (arterial vasocorona) plexus	Apex/dorsal nucleus of the posterior grey column, posterior white column (fasciculus gracilis and cuneatus), and the peripheral rim of the lateral and anterior white columns

- ▶ The **arterial vasocorona** (pial plexus) supplies the more peripheral white matter not reached by central branches and provides collateral anastomoses between the anterior and posterior systems.
- ▶ The longitudinal and intramedullary arteries behave functionally as **end-arteries**, though some territorial overlap exists.

4. Watershed zones and spinal cord ischaemia

- ▶ The **mid-to-upper thoracic cord** is the classic watershed region, lying farthest from both the cervical/upper-thoracic radicular reinforcements above and the artery of Adamkiewicz below.
- ▶ **Gray's Anatomy** designates T4–T9 as the "critical vascular zone" of the cord, where interference with the circulation is most likely to cause paraplegia.
- ▶ **Snell** notes the posterior spinal arteries are especially small in the upper thoracic region (making the first three thoracic segments vulnerable), while the ASA itself may be extremely small in the upper and lower thoracic segments — rendering the **4th thoracic and 1st lumbar segments** particularly liable to ischaemic necrosis.
- ▶ **IB Singh's** account frames the same principle differently: since vertebral-derived flow (via the ASA/PSA) reaches only the cervical cord, and the arteria radicularis magna supplies the lower thoracic, lumbar and sacral cord, the intervening **T1–T4 segments** constitute the watershed-infarct zone.

- ▶ All descriptions converge on one teaching point: the region between the last major cervical/upper-thoracic feeder and the artery of Adamkiewicz is thin-margined and hypotension-sensitive.

5. Venous drainage

- ▶ Intramedullary veins drain into a circumferential pial network, the **coronal venous plexus** (**venous vasocorona**), within which **six longitudinal channels** are recognised:
 - One **anteromedian** and one **posteromedian** channel (in the midline sulci).
 - Paired **anterolateral** and paired **posterolateral** channels (alongside the ventral and dorsal nerve roots respectively).
- ▶ Only the **anterior spinal vein** (draining the central grey matter via sulcal veins) is consistently complete and is largest in calibre in the lumbosacral region; the posterior spinal vein is often plexiform.
- ▶ These channels drain segmentally via **anterior and posterior radicular/radiculomedullary veins** into the **internal vertebral (epidural) venous plexus**, and thence into intervertebral veins → external vertebral venous plexuses → the **caval and azygos venous systems**. Superiorly they communicate with the cerebellar veins and cranial venous sinuses.

□ Fig 11.1 — Blood supply of spinal cord (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.597)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw (i) a schematic longitudinal view of the cord with the vertebral artery and its branches, and (ii) a small cross-sectional inset. Label:

- ▶ Vertebral artery (intracranial/4th part) → anterior spinal artery (union of two branches) in the anterior median fissure
- ▶ Two posterior spinal arteries, one on each posterolateral sulcus (anterior and posterior rami to the dorsal roots)
- ▶ Segmental arteries at cervical (vertebral/ascending & deep cervical), thoracic (posterior intercostal) and lumbar/sacral (lumbar/lateral sacral) levels, each giving anterior and posterior radicular arteries
- ▶ Cervical enlargement and lumbosacral enlargement, marking sites of maximal segmental medullary reinforcement
- ▶ Great anterior segmental medullary artery of Adamkiewicz entering between T9 and L2 (usually left side), joining the ASA
- ▶ Arterial vasocorona encircling the cord surface; anastomotic plexus at the conus medullaris
- ▶ Cross-section inset: anterior two-thirds territory (ASA, central/sulcal branches) shaded separately from the posterior one-third territory (PSA + vasocorona, radial branches), with corticospinal/spinothalamic tracts labelled anteriorly and fasciculus gracilis/cuneatus labelled posteriorly

Applied / Clinical anatomy

- ▶ **Anterior spinal artery syndrome** (thrombosis/occlusion of the ASA, e.g. after aortic cross-clamping, aortic aneurysm/dissection, severe hypotension, or nerve-block procedures): bilateral loss of corticospinal tract function (paraplegia/tetraplegia below the lesion), bilateral loss of pain and temperature (spinothalamic tracts), and bladder/bowel involvement (descending autonomic pathways) — with **preservation of proprioception, vibration and fine touch** because the posterior columns are supplied by the intact posterior spinal arteries.
- ▶ **Posterior spinal artery thrombosis** is much rarer (protected by the rich vasocorona anastomoses) and produces isolated posterior-column loss — impaired proprioception and vibration sense with a sensory (locomotor) ataxia; motor power, pain and temperature are preserved.
- ▶ **Thoracoabdominal aortic aneurysm repair / aortic cross-clamping**: interruption of the artery of Adamkiewicz or of segmental medullary flow to the mid-thoracic watershed zone is a recognised cause of post-operative paraplegia; pre-operative localisation of the artery of Adamkiewicz by **CT/MR angiography or spinal digital subtraction angiography**, together with intra-operative **motor/somatosensory evoked-potential monitoring**, is used to reduce this risk.
- ▶ **Vertebral fracture-dislocation** can compress or tear the segmental/radicular vessels at that level, compounding the neurological deficit of the bony injury itself.

- ▶ Because arterial supply is segmental and irregular, myelography/spinal angiography and cross-sectional imaging (CT/MRI) are used to define individual vascular anatomy before spinal surgery in the thoracolumbar region.

High-yield exam pointers

- ▶ **3 longitudinal arteries:** 1 anterior spinal + 2 posterior spinal, all ultimately from the vertebral arteries; reinforced by segmental radicular/radiculomedullary arteries — a **name-the-vessels** favourite.
- ▶ **Anterior 2/3 vs posterior 1/3 rule** — ASA (central/sulcal branches) supplies the anterior two-thirds; PSA + vasocorona supply the posterior one-third.
- ▶ **Artery of Adamkiewicz (arteria radicularis magna)** — largest anterior segmental medullary feeder; from T9–L2 (commonly a lower intercostal/subcostal artery); left-sided in ~65%; supplies the lower two-thirds of the cord/lumbosacral enlargement.
- ▶ **Watershed zone** — mid/upper-thoracic cord (variously described as T1–T4 or T4–T9 across texts) is most vulnerable to ischaemia in hypotension or aortic surgery.
- ▶ **Anterior spinal artery syndrome** — bilateral motor loss + bilateral pain/temperature loss + preserved proprioception/vibration — a classic applied-anatomy short answer.
- ▶ **Venous drainage** — 6 longitudinal channels (1 antero-median, 1 postero-median, 2 antero-lateral, 2 postero-lateral) → venous vasocorona → radicular veins → internal vertebral (epidural) venous plexus → azygos/caval systems.
- ▶ Arteries behave as **functional end-arteries** despite pial anastomoses — hence the cord's vulnerability to segmental vascular compromise.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; BD Chaurasia Human Anatomy Vol 3–4 8e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; IB Singh Textbook of Anatomy Vol 3 6e.



Blood supply of spinal cord

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction The spinal cord, though continuous above with the medulla oblongata, has a comparatively precarious blood supply of its own. It is perfused by a longitudinal system of three arterial channels — one anterior and two posterior spinal arteries — that arise intracranially from the vertebral arteries but are far too slender to nourish the entire length of the cord unaided. Adequate perfusion therefore depends on segmental reinforcement all the way down the vertebral canal by radicular (radiculomedullary) arteries derived from vessels outside the canal, of which the largest, the artery of Adamkiewicz, is of major surgical importance. Because these channels are of uneven calibre and behave functionally as end-arteries, interruption of a key feeder produces well-defined ischaemic cord syndromes that are frequently tested and clinically important in vascular surgery, anaesthesia and neurology.

1. Longitudinal arterial channels

Artery	Origin	Course	Territory
Anterior spinal artery (single, median)	Formed by union of the anterior spinal branches of the two vertebral arteries, within the skull	Descends in the anterior median fissure for the entire length of the cord to the conus medullaris	Anterior two-thirds of the cord cross-section
Posterior spinal arteries (paired)	Each arises directly from the ipsilateral vertebral artery, or from its posterior inferior cerebellar artery branch	Descend in the posterolateral sulcus , alongside the dorsal nerve roots; each usually divides into two collateral channels flanking the roots	Posterior one-third of the cord (dorsal white columns)
Arterial vasocorona (pial arterial plexus)	Anastomotic network formed where the anterior and posterior channels interconnect over the cord surface, reinforced at each segment	Encircles the cord within the pia mater	Gives short penetrating (peripheral) branches to the superficial white matter

- ▶ With each posterior spinal artery contributing a medial and a lateral collateral channel, the cord is in effect surrounded by **five longitudinal arterial trunks**, all interconnected through the pial plexus.
- ▶ Blood reaching the spinal arteries directly from the vertebral arteries supplies only the **cervical segments**; the rest of the cord is wholly dependent on segmental reinforcement from below.

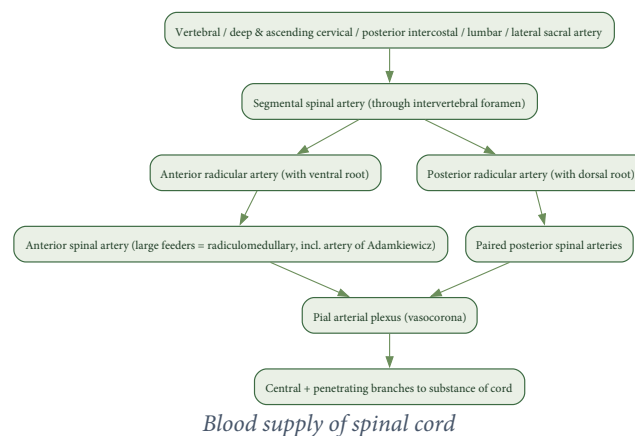
□ Fig 11.1 — Blood supply of spinal cord (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.597)

2. Segmental (radicular) reinforcement

- ▶ At each intervertebral foramen, **segmental spinal arteries** — branches of the vertebral, ascending and deep cervical, posterior intercostal, lumbar and lateral sacral arteries — enter the vertebral

canal and divide into **anterior and posterior radicular arteries** that travel with the corresponding ventral and dorsal nerve roots.

- ▶ Most radicular arteries are small and terminate on the nerve roots (posterior ones also supply the dorsal root ganglia) or in the pial plexus; only some are large enough to reach and reinforce the longitudinal spinal arteries — these are the **radiculomedullary feeder arteries**.
- ▶ **Anterior radiculomedullary feeders:** fewer in number (roughly six to eight, mainly in the lower cervical, lower thoracic and upper lumbar regions) but individually larger; on reaching the anterior median fissure each divides into a slender ascending and a large descending branch.
- ▶ **Posterior radiculomedullary feeders:** more numerous (roughly eight to twelve) but smaller and more evenly distributed than the anterior feeders.
- ▶ The relative sparseness of reinforcing feeders in certain segments is exactly what creates the clinically important **watershed zones** discussed below.



3. Great anterior radiculomedullary artery of Adamkiewicz

- ▶ The largest of the anterior radiculomedullary feeders, also called the **arteria radicularis magna**.
- ▶ Arises from a spinal branch of one of the **lower posterior intercostal arteries (T9–T11)**, or of the **subcostal artery (T12)**, or, less often, of an **upper lumbar artery (L1–L2)**.
- ▶ Arises on the **left side** in the majority of individuals.
- ▶ On reaching the cord it sends a branch to join the anterior spinal artery below, and another branch that anastomoses with a ramus of the posterior spinal artery above.
- ▶ May constitute the **major (sometimes near-sole) blood supply to the lower two-thirds of the spinal cord** — hence its outsized surgical importance (see Applied anatomy).

4. Intramedullary distribution and vascular territories

Zone	Supplying vessel	Structures supplied
Central / anterior two-thirds	Central (sulcal) branches of the anterior spinal artery, entering through the anterior median fissure and alternating right and left	Anterior (ventral) grey columns, base of the posterior grey column (including the dorsal nucleus), and the adjoining anterolateral white columns — corticospinal and spinothalamic tracts

Zone	Supplying vessel	Structures supplied
Peripheral rim + posterior one-third	Penetrating (radial) branches of the pial arterial plexus and of the posterior spinal arteries	Posterior (dorsal) white columns — fasciculus gracilis and cuneatus — the tip of the dorsal grey column, and the peripheral rim of white matter

Diagram to draw

Transverse section of the spinal cord with the following labelled:

- ▶ **Anterior median fissure** carrying the single **anterior spinal artery**
- ▶ Two **posterior spinal arteries** at the posterolateral sulci, each giving medial and lateral collateral channels around the dorsal roots
- ▶ **Pial arterial plexus (vasocorona)** encircling the cord surface
- ▶ **Central (sulcal) branches** entering the anterior fissure, shaded over the anterior two-thirds (ventral grey columns + anterolateral white columns)
- ▶ **Peripheral penetrating branches** shaded over the posterior one-third (dorsal white columns + tip of dorsal grey column)
- ▶ A longitudinal inset showing the vertebral artery giving the anterior/posterior spinal arteries at the foramen magnum, reinforced at intervals by segmental radicular arteries, with the artery of Adamkiewicz entering around the lower thoracic/upper lumbar level

5. Venous drainage

- ▶ Intramedullary veins drain into a circumferential surface network, the **coronal venous plexus**, within which **six tortuous longitudinal channels** are recognised: a midline **anterior spinal (median) vein** and **posterior spinal (median) vein**, plus paired **anterolateral** and **posterolateral** channels flanking the nerve roots.
- ▶ Only the **anterior spinal vein** is consistently complete; it drains the central grey matter through sulcal veins and is of largest calibre in the **lumbosacral region**. The posterior spinal vein is more variable, appearing plexiform in some segments and as a single channel in others.
- ▶ These channels connect superiorly with the **cerebellar veins** and **cranial venous sinuses**, and drain segmentally through **anterior and posterior radiculomedullary/radicular veins** into the **intervertebral veins**.
- ▶ The intervertebral veins open into the **internal (epidural) vertebral venous plexus**, which in turn is drained by the segmental veins into the **external vertebral venous plexus** and thence the **azygos and caval systems**.
- ▶ This whole vertebral venous system is **valveless**, permitting free bidirectional flow with changes in intrathoracic and intra-abdominal pressure.

Applied / Clinical anatomy

- ▶ **Anterior spinal artery syndrome** (infarction of the anterior two-thirds of the cord, from thrombosis or embolism of the anterior spinal artery or its major feeders): bilateral loss of motor function below the lesion (destruction of ventral grey column motor neurons at the level, corticospinal tract involvement below), together with bilateral loss of pain and temperature

sensation from spinothalamic tract ischaemia, and sphincter disturbance from involvement of descending autonomic pathways. **Proprioception, vibration and fine touch are characteristically preserved**, because the posterior white columns are supplied by the posterior spinal arteries, which are usually spared.

- ▶ **Posterior spinal artery occlusion** is rare, because the posterior spinal system is reinforced by more numerous, more evenly spaced radicular feeders; when it does occur it selectively causes loss of proprioception and vibration sense with motor and pain/temperature function preserved.
- ▶ **Watershed (critical) vascular zones**: the mid-thoracic cord is described as the classic critical vascular zone (Gray's Anatomy places this around T4–T9), lying furthest from both the cervical (vertebral-artery-derived) supply above and the artery of Adamkiewicz below. More specifically, the **upper thoracic segments (roughly T1–T3)** are vulnerable because the posterior spinal arteries are small here, while the **fourth thoracic and first lumbar segments** are vulnerable because the anterior spinal artery itself may be extremely small at these levels — all are classic sites of ischaemic infarction during systemic hypotension.
- ▶ **Artery of Adamkiewicz — surgical importance**: because it may be the dominant supply to the lower two-thirds of the cord, this vessel is at risk during **thoraco-abdominal aortic aneurysm repair and aortic cross-clamping**; its origin can also be compromised by **thoracic aortic dissection** (occluding posterior intercostal artery origins) or by a large **abdominal aortic aneurysm** interfering with lumbar artery supply — any of which can produce spinal cord ischaemia and paraplegia. Pre-operative localisation by **CT/MR angiography or spinal digital subtraction angiography**, combined with intra-operative **cerebrospinal fluid drainage** (to raise spinal cord perfusion pressure) and **neurophysiological monitoring** (motor and somatosensory evoked potentials), are used to reduce this risk.
- ▶ Cord ischaemia can also complicate lesser interventions — **paravertebral or intercostal nerve blocks, epidural injections, and severe intra-operative hypotension** — again preferentially injuring the watershed segments.
- ▶ **MRI (T2-weighted and diffusion-weighted imaging)** is the imaging investigation of choice for suspected spinal cord infarction, typically showing signal change confined to the territory of the anterior spinal artery.
- ▶ **Vertebral venous plexus (of Batson)**: being valveless and communicating with the pelvic, prostatic, and breast venous drainage, a rise in intra-abdominal or intrathoracic pressure (coughing, straining) can drive tumour emboli or infection retrogradely into this plexus — the classical route for **vertebral/skip metastases from carcinoma of the prostate or breast**, and for spread of pelvic sepsis to vertebrae, spinal cord, skull and brain without passing through the lungs.
- ▶ A prolapsed intervertebral disc, osteophyte, or vertebral fracture-dislocation compressing a **segmental (radicular) artery** can compound direct neural compression with radiculomedullary ischaemia, worsening the resulting neurological deficit.

High-yield exam pointers

- ▶ **Three longitudinal channels**: one anterior spinal artery (anterior two-thirds) + two posterior spinal arteries (posterior one-third), all arising intracranially from the vertebral artery (posterior

spinal may also come from PICA); together with the paired posterior collaterals they form **five longitudinal trunks**.

- ▶ Longitudinal arteries alone cannot supply the whole cord length — **segmental (radicular) reinforcement is essential**; anterior feeders are fewer but larger, posterior feeders more numerous but smaller.
- ▶ **Artery of Adamkiewicz (arteria radicularis magna)** = largest anterior radiculomedullary feeder; arises from a lower posterior intercostal (T9–T11), subcostal (T12), or upper lumbar (L1–L2) artery, usually on the **left**; may be the dominant supply to the lower two-thirds of the cord.
- ▶ **Anterior spinal artery syndrome** = bilateral motor loss + bilateral loss of pain/temperature + sphincter disturbance, with **preserved posterior column sensation**.
- ▶ Classic watershed zones: **mid-thoracic cord** (~T4–T9) overall, with T1–T3 vulnerable (small posterior spinal arteries) and T4/L1 vulnerable (small anterior spinal artery).
- ▶ Venous drainage: **six longitudinal channels** in the coronal plexus (anterior + posterior median, paired anterolateral, paired posterolateral) → internal (epidural) vertebral venous plexus → azygos/caval systems; system is **valveless**.
- ▶ **Batson's (vertebral) venous plexus** — valveless, clinically important retrograde route for prostate/breast metastasis and septic spread to the vertebral column and cord.
- ▶ Injury to the artery of Adamkiewicz during **thoraco-abdominal aortic aneurysm repair** is a feared cause of iatrogenic paraplegia; pre-operative CT/MR angiographic localisation plus intra-operative CSF drainage and evoked-potential monitoring are now standard protective measures.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e; IB Singh's Textbook of Human Neuroanatomy.



Blood supply to spinal cord and applied aspects

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction The spinal cord, though continuous rostrally with the medulla oblongata, has a comparatively meagre and precarious blood supply. It is nourished by a longitudinal system — one anterior and two posterior spinal arteries — that originates intracranially from the vertebral arteries but is far too small to perfuse the whole length of the cord by itself. Adequate perfusion therefore depends on segmental reinforcement by radicular (radiculomedullary) arteries derived from vessels outside the vertebral column. Because these longitudinal channels are of uneven, sometimes discontinuous calibre and behave functionally as end-artries, interruption of a key segmental feeder — classically the artery of Adamkiewicz — produces well-defined ischaemic cord syndromes that are of major importance in vascular surgery, anaesthesia and neurology.

1. Arterial supply — the three longitudinal channels

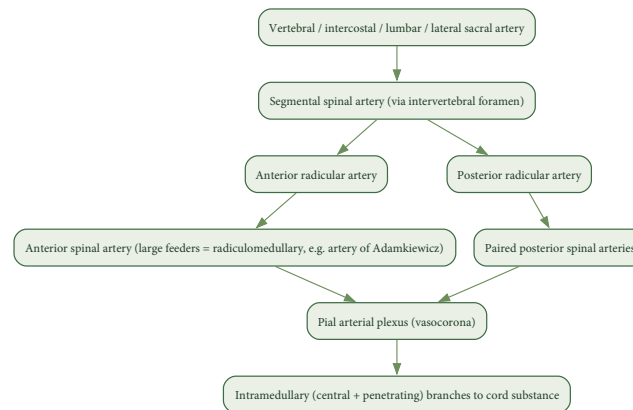
Artery	Origin	Course	Territory
Anterior spinal artery (single)	Union of two small anterior spinal branches, one from each vertebral artery, within the skull	Descends in the anterior median fissure along the whole length of the cord to the conus medullaris	Anterior two-thirds of the cord cross-section
Posterior spinal arteries (paired)	Each arises directly from the ipsilateral vertebral artery or from its posterior inferior cerebellar branch	Descend in the posterolateral sulcus , close to the dorsal nerve roots; each usually divides into two collateral channels flanking the roots	Posterior one-third of the cord (dorsal white columns)
Arterial vasocorona / pial arterial plexus	Anastomotic network formed where the anterior and posterior systems interconnect around the cord surface, reinforced segmentally	Encircles the cord in the pia mater	Sends short penetrating (peripheral) branches to superficial white matter

- ▶ Together the anterior and (doubled) posterior spinal arteries form **five longitudinal arterial trunks** running the length of the cord, all interconnected by the pial plexus.
- ▶ Blood reaching the cord directly from the vertebral arteries supplies only the **cervical segments**; the rest of the cord is dependent on segmental reinforcement (below).

2. Segmental reinforcement — radicular and radiculomedullary arteries

- ▶ At each intervertebral foramen, **segmental spinal arteries** — branches of the vertebral, ascending and deep cervical, posterior intercostal, lumbar and lateral sacral arteries — enter the vertebral canal and divide into **anterior and posterior radicular arteries** that accompany the corresponding nerve roots.
- ▶ Most radicular arteries are small and terminate on the nerve roots or the pial plexus; only some are large enough to reach and reinforce the longitudinal spinal arteries — these are the **radiculomedullary feeder arteries**.

- ▶ **Anterior radicular/medullary feeders:** fewer in number (about six to eight) but larger; mainly situated in the lower cervical, lower thoracic and upper lumbar regions; divide into a slender ascending and a large descending branch on reaching the anterior median fissure.
- ▶ **Posterior radicular/medullary feeders:** more numerous (up to eight) but smaller and more evenly distributed than the anterior feeders; also supply the dorsal root ganglia.
- ▶ **Great anterior radiculomedullary artery of Adamkiewicz** (arteria radicularis magna) — the largest anterior feeder:
 - Arises from a spinal branch of a **lower posterior intercostal artery (T9–T11)**, or the **subcostal artery (T12)**, or occasionally an **upper lumbar artery (L1–L2)**.
 - Most often arises on the **left side**.
 - On reaching the cord it sends a branch to the anterior spinal artery below and another that anastomoses with the posterior spinal artery ramus above.
 - May constitute the **major supply to the lower two-thirds of the cord** — hence its clinical importance.



Blood supply to spinal cord and applied aspects

3. Intramedullary distribution and vascular territories

□ Fig 17.7 — A: Arterial supply of the spinal cord showing the formation of two posterior spinal arteries and one anterior spinal artery. B: Transverse section of the spinal cord showing the segmental spinal arteries and the radicular arteries (Snell — *Clinical Neuroanatomy* — 7e, p.502)

Zone	Supplying vessel	Structures
Central / anterior two-thirds	Central (sulcal) branches of the anterior spinal artery, entering via the anterior median fissure, alternating right and left	Anterior (ventral) grey horns, base of the posterior grey horn (incl. dorsal nucleus), and the adjoining anterolateral white columns (corticospinal and spinothalamic tracts)
Peripheral rim + posterior one-third	Penetrating branches of the pial arterial plexus and the posterior spinal arteries	Posterior (dorsal) white columns — fasciculus gracilis and cuneatus, tip of the dorsal horn, and superficial peripheral white matter

Diagram to draw

Cross-section of the spinal cord with the following labelled:

- ▶ Anterior median fissure with **anterior spinal artery**
- ▶ Two **posterior spinal arteries** at the posterolateral sulci, flanking the dorsal roots
- ▶ **Pial arterial plexus (vasocorona)** encircling the cord
- ▶ **Central (sulcal) branches** entering the anterior fissure and supplying the anterior 2/3 (ventral grey horns + anterolateral white columns)
- ▶ **Peripheral penetrating branches** supplying the posterior 1/3 (dorsal white columns + dorsal horn)
- ▶ A watershed shading over the anterolateral quadrant boundary to show the "anterior 2/3 vs posterior 1/3" split
- ▶ Inset of a longitudinal view showing vertebral artery → anterior/posterior spinal arteries → segmental (radicular) reinforcement at multiple levels, including the artery of Adamkiewicz entering around the lower thoracic/upper lumbar level

4. Venous drainage

- ▶ Intramedullary veins drain into a circumferential **coronal venous plexus** on the cord surface, within which **six tortuous longitudinal channels** are recognised:
 - One **anterior spinal (median) vein** and one **posterior spinal (median) vein**, in the midline.
 - Two **anterolateral** and two **posterolateral** channels, one of each pair on either side.
- ▶ Only the **anterior spinal vein** is consistently complete; it drains the central grey matter via sulcal veins and is largest in calibre in the **lumbosacral region**. The posterior spinal vein is often plexiform rather than a single channel.
- ▶ These channels connect superiorly with the cerebellar veins and cranial venous sinuses, and drain segmentally via **anterior and posterior radiculomedullary/radicular veins** into the **intervertebral veins**.
- ▶ The intervertebral veins open into the **internal (epidural) vertebral venous plexus**, which communicates with the **external vertebral venous plexus** and is itself drained segmentally by the vertebral, posterior intercostal, lumbar and lateral sacral veins into the **azygos and caval systems**; superiorly it communicates with the **basilar venous plexus**.
- ▶ The entire vertebral venous system is **valveless**, permitting bidirectional flow with changes in intrathoracic/intra-abdominal pressure (coughing, straining).

Applied / Clinical anatomy

- ▶ **Anterior spinal artery syndrome** (infarction of the anterior two-thirds of the cord, due to thrombosis/embolism of the anterior spinal artery or its major feeders):
 - Bilateral **spastic paraplegia/quadruplegia** below the lesion from involvement of the corticospinal tracts and destruction of ventral grey horn motor neurons at the level of the lesion (giving LMN signs at that level, UMN signs below).
 - Bilateral **loss of pain and temperature sensation** below the lesion from spinothalamic tract ischaemia.
 - **Bladder and bowel dysfunction** from involvement of descending autonomic pathways.

- **Proprioception, vibration and fine (discriminative) touch are preserved**, because the posterior white columns are supplied by the posterior spinal arteries, which usually escape.
- ▶ **Posterior spinal artery syndrome** is rare because the posterior spinal arteries are reinforced by more numerous, more evenly spaced radicular feeders; when it occurs, it selectively impairs proprioception and vibration sense (posterior column loss) with preserved motor and pain/temperature function.
- ▶ **Critical (watershed) vascular zones**: the **mid-thoracic cord (about T4–T9)**, lying furthest from both the cervical (vertebral-artery-derived) supply above and the great anterior radiculomedullary artery (Adamkiewicz) below, is the classic watershed zone most vulnerable to ischaemic infarction during systemic hypotension. Traditionally, the **fourth thoracic and first lumbar segments** are highlighted as anterior-spinal-artery watershed points, and the **upper 2–3 thoracic segments** as posterior-spinal-artery watershed points, since the reinforcing radicular arteries are relatively sparse there.
- ▶ **Artery of Adamkiewicz — surgical importance**: because it may be the dominant supply to the lower two-thirds of the cord, it is at risk during **thoraco-abdominal aortic aneurysm repair and aortic cross-clamping**, and its ostium may be occluded in **thoracic aortic dissection** (which can block the origins of the posterior intercostal arteries) or compressed by a **leaking abdominal aortic aneurysm** interfering with lumbar-artery supply — all producing spinal cord ischaemia and paraplegia. Pre-operative localisation by **CT/MR angiography or spinal digital subtraction angiography**, along with intra-operative **CSF drainage (to raise spinal cord perfusion pressure)** and **neurophysiological monitoring (motor/somatosensory evoked potentials)**, are used to reduce this risk during aortic surgery.
- ▶ Ischaemia of the cord can also follow **minor procedures** — paravertebral/intercostal nerve blocks, epidural anaesthesia with an inadvertently sclerosing or embolic agent, or any severe intra-operative hypotension — again preferentially affecting the watershed segments.
- ▶ **MRI (T2-weighted/diffusion-weighted)** is the imaging modality of choice for spinal cord infarction, showing signal change in the anterior cord conforming to the distribution of the anterior spinal artery.
- ▶ **Vertebral venous plexus (Batson's plexus)** is valveless and communicates with the pelvic, prostatic and breast venous drainage; a rise in intra-abdominal/intrathoracic pressure can drive tumour cells or infective emboli retrogradely into this plexus, providing a route for **skip metastases from prostate/breast carcinoma** and for spread of pelvic sepsis to the vertebrae, spinal cord, skull and brain without traversing the pulmonary circulation.
- ▶ Compression of a **segmental (radicular) artery** by a prolapsed intervertebral disc, osteophyte or vertebral fracture-dislocation can compound the neural compression with radiculo-medullary ischaemia, worsening the neurological deficit.

High-yield exam pointers

- ▶ Three longitudinal arteries: **one anterior spinal artery (anterior 2/3 of cord) + two posterior spinal arteries (posterior 1/3)** — all arising intracranially from the vertebral artery (posterior spinal may also arise from PICA).

- ▶ Longitudinal arteries alone cannot supply the whole cord length — **segmental/radicular reinforcement is essential**; anterior radicular feeders are fewer but larger, posterior feeders more numerous but smaller.
- ▶ **Artery of Adamkiewicz (arteria radicularis magna)** = largest anterior radiculomedullary feeder; arises from a lower posterior intercostal (T9–T11)/subcostal (T12) or upper lumbar (L1–L2) artery, usually on the **left**; may supply the lower two-thirds of the cord.
- ▶ **Anterior spinal artery syndrome** = bilateral spastic paraplegia + bilateral loss of pain/temperature + sphincter disturbance, with **preserved posterior column (proprioception/vibration) sensation**.
- ▶ **Mid-thoracic cord (T4–T9)** is the classic watershed/critical vascular zone most prone to hypotensive infarction.
- ▶ Venous drainage: **six longitudinal channels** (anterior + posterior median, paired anterolateral, paired posterolateral) → internal (epidural) vertebral venous plexus → azygos/caval systems.
- ▶ Vertebral venous plexus is **valveless (Batson's plexus)** — clinically important route for metastatic spread (prostate, breast) and septic emboli to the vertebral column, cord, and brain.
- ▶ Artery of Adamkiewicz injury during **thoraco-abdominal aortic aneurysm repair/aortic dissection** is a feared cause of iatrogenic paraplegia — pre-op imaging localisation is now standard practice.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e; IB Singh's Textbook of Human Neuroanatomy.



Brown – Sequard syndrome

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction — Brown–Séquard syndrome is the classical clinical syndrome produced by a **hemisection** — a lesion confined to one lateral half — of the spinal cord, eponymously named for the physiologist Charles-Édouard Brown-Séquard. Because the three major long tracts that carry motor and sensory information — the **lateral corticospinal tract**, the **posterior (dorsal) white column**, and the **spinothalamic tracts** — decussate at different levels of the neuraxis, a unilateral cord lesion produces a characteristic *dissociated* pattern: weakness and loss of proprioception on the **same side** as the lesion, but loss of pain and temperature sensation on the **opposite side**, below the level of the lesion. A truly complete hemisection is rare; an incomplete hemisection reproducing the same pattern in a partial or asymmetric form is far more common in clinical practice.

1. Aetiology — causes of spinal cord hemisection

- ▶ **Traumatic**: fracture–dislocation of the vertebral column; a penetrating injury such as a **stab wound or bullet wound** directed to one side of the cord — the classic cause of a clean, near-complete hemisection.

- **Neoplastic:** an expanding intraspinal (extramedullary or intramedullary) **tumour** compressing or infiltrating one half of the cord.
- **Inflammatory/demyelinating:** unilateral cord inflammation (**myelitis**), including as a presenting episode of **multiple sclerosis** — a cause that typically evolves over days rather than occurring acutely.
- **Incomplete hemisection is common; a truly complete hemisection is rare** — most clinical cases are partial, with an asymmetric mixture of the features described below rather than the full textbook picture.

2. Applied neuroanatomical basis — tracts involved and their level of decussation

The clinical picture follows directly from *where* each tract crosses the midline relative to the level of the lesion.

Tract / column	Modality carried	Level of decussation	Effect of hemisection
Lateral corticospinal tract	Voluntary motor (upper motor neurone)	Pyramidal decussation, lower medulla — i.e. above the cord	Ipsilateral spastic (UMN) paralysis below the lesion
Posterior (dorsal) white column — fasciculus gracilis & cuneatus	Proprioception, vibration, fine touch/discrimination	Ascends uncrossed in the cord; crosses as internal arcuate fibres in the medulla (forming the medial lemniscus) — again above the cord	Ipsilateral loss of proprioception, vibration and tactile discrimination below the lesion
Lateral spinothalamic tract	Pain and temperature	Crosses obliquely in the anterior white commissure , one to two segments above its level of entry — i.e. within the cord itself	Contralateral loss of pain and temperature, appearing two to three segments below the level of the lesion
Anterior spinothalamic tract	Crude/light touch	Also crosses in the anterior white commissure	Contralateral but <i>incomplete</i> loss of touch — never fully abolished
Anterior horn cells / ventral (motor) root at the segment	Lower motor neurone outflow	Segmental (no crossing)	Ipsilateral LMN paralysis and muscular atrophy at the level of the lesion
Posterior (dorsal) root at the segment	All sensory modalities of that dermatome	Segmental (no crossing)	Ipsilateral band of cutaneous anaesthesia at the level of the lesion

- Because the corticospinal tract and the posterior columns have **already crossed above the spinal cord** (in the medulla), a hemisection produces **ipsilateral** motor weakness and proprioceptive loss.
- Because the spinothalamic tracts cross **within the cord itself**, close to their segment of entry, the same lesion produces **contralateral** pain and temperature loss.

- ▶ This single asymmetry in the site of decussation of otherwise "parallel" ascending/descending systems is the entire physiological basis of the syndrome and is the point most commonly tested in a viva.

3. Clinical features of hemisection of the spinal cord

At the level of the lesion (segmental signs):

- ▶ Ipsilateral **lower motor neurone paralysis and muscular atrophy** of the muscles of that segment, from damage to the anterior horn cells and/or the emerging ventral (motor) root.
- ▶ Ipsilateral **band (girdle) of cutaneous anaesthesia** corresponding to the damaged dermatome, from destruction of the posterior root at its point of entry into the cord.
- ▶ A narrow zone of ipsilateral **hyperaesthesia** may be found at the upper margin of this anaesthetic band, from irritation of intact dorsal rootlets adjacent to the lesion.

Below the level of the lesion:

- ▶ Ipsilateral **upper motor neurone (spastic) paralysis** — increased tone, exaggerated (brisk) reflexes, an extensor plantar (Babinski) response, and loss of the ipsilateral superficial abdominal and cremasteric reflexes (lateral corticospinal tract).
- ▶ Ipsilateral loss of **proprioception, vibration sense and tactile discrimination** (posterior/dorsal white column).
- ▶ **Contralateral loss of pain and temperature** sensation, typically beginning **two to three segments below** the level of the lesion, because the spinothalamic fibres ascend for a short distance before crossing (lateral spinothalamic tract).
- ▶ **Contralateral but incomplete loss of crude/light touch** — touch is never completely lost because discriminative touch ascending in the intact (contralateral) posterior column is preserved (anterior spinothalamic tract).

Above the level of the lesion: function is normal.

An **incomplete hemisection** (the common clinical form) reproduces this same dissociated ipsilateral-motor/ipsilateral-proprioceptive and contralateral-pain/temperature pattern in a partial or asymmetric degree; the level and side of the lesion can usually still be deduced from this characteristic dissociation even when the picture is incomplete.

4. Distinguishing Brown–Séquard syndrome from other spinal cord syndromes

Syndrome	Structure/territory damaged	Motor findings	Sensory findings
Complete transection	Entire cross-section of the cord	Bilateral paralysis below the level	Total loss of all sensory modalities below the level, bilaterally
Anterior cord syndrome	Anterior spinal artery territory (ventral two-thirds); posterior columns spared	Bilateral paralysis below the level	Bilateral loss of pain/temperature below the level; proprioception and vibration preserved

Syndrome	Structure/territory damaged	Motor findings	Sensory findings
Posterior cord syndrome	Posterior (dorsal) columns	Power usually preserved	Bilateral loss of proprioception/vibration (unsteady gait, positive Romberg's sign); pain/temperature preserved
Central cord syndrome (e.g. syringomyelia)	Central grey matter and decussating spinothalamic fibres	Greater weakness in the upper than the lower limbs when cervical	Bilateral, often "cape-like," dissociated loss of pain/temperature at the affected level; touch/proprioception relatively spared
Brown-Séquard syndrome	One lateral half of the cord (hemisection)	Ipsilateral UMN paralysis below the level	Ipsilateral proprioceptive loss + contralateral pain/temperature loss below the level

□ Fig 7.24 — Brown-Séquard syndrome due to hemisection of spinal cord (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.230)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse (cross) section of the spinal cord at a mid-thoracic level with one (e.g. right) half shaded to show a complete hemisection, and label:

- ▶ Anterior median fissure, posterior median sulcus, central canal
- ▶ Anterior (ventral) grey horn / anterior horn cells — lesioned side, at the level of the lesion
- ▶ Posterior (dorsal) root and posterior grey horn — lesioned side, at the level of the lesion
- ▶ Lateral corticospinal tract — lesioned side (annotate: *ipsilateral spastic paralysis below the lesion*)
- ▶ Fasciculus gracilis / fasciculus cuneatus (posterior white column) — lesioned side (annotate: *ipsilateral loss of proprioception, vibration and discriminative touch below the lesion*)
- ▶ Lateral spinothalamic tract — lesioned side, with an arrow showing fibres crossing to the opposite side in the anterior white commissure a couple of segments below entry (annotate: *contralateral loss of pain and temperature, 2–3 segments below the lesion*)
- ▶ Anterior spinothalamic tract — lesioned side (annotate: *contralateral incomplete loss of touch*)
- ▶ A small body-outline alongside shaded to show the ipsilateral versus contralateral zones of deficit below the level of the lesion

Applied / Clinical anatomy

- ▶ Common real-world causes of the pattern are **penetrating trauma** (stab or gunshot wounds), an **expanding extramedullary spinal tumour**, and **inflammatory/demyelinating cord lesions**

(myelitis, multiple sclerosis); **MRI of the spine** is the investigation of choice to localise the level and side of the lesion and to identify the underlying cause.

- ▶ **Incomplete hemisection is far commoner** than the "textbook-complete" form; even a partial dissociated ipsilateral-motor/contralateral-pain pattern is what localises a lesion to one half of the cord at a specific segmental level.
- ▶ The oblique, delayed crossing of the spinothalamic fibres explains why the clinical **sensory level for pain/temperature loss is found two to three segments below** the true anatomical level of the lesion — a frequently tested applied point that can mislead level-localisation if not appreciated.
- ▶ **Anterolateral cordotomy** — surgical division of the antero-lateral column just anterior to the denticulate ligament (sparing the pyramidal tract lying immediately behind it) — is performed for intractable unilateral pain and deliberately reproduces a controlled, partial "iatrogenic hemisection," understood entirely through the Brown-Séquard crossing principle.
- ▶ Because only one half of the cord is damaged, **bladder, bowel and sexual (autonomic) function are usually relatively preserved** compared with a complete cord transection — an important localising and prognostic distinction.
- ▶ A pure Brown-Séquard picture evolving **sub-acutely over days**, without a history of trauma, should raise suspicion of a demyelinating or inflammatory cause (transverse myelitis/multiple sclerosis) rather than a structural or traumatic one.

High-yield exam pointers

- ▶ Caused by **hemisection** of the spinal cord — trauma (fracture-dislocation, stab/bullet wound), tumour, or demyelinating disease (myelitis/MS); **incomplete hemisection is far commoner than complete**.
- ▶ Classic triad **below** the level of the lesion: **ipsilateral UMN (spastic) paralysis + ipsilateral loss of proprioception/vibration + contralateral loss of pain and temperature**.
- ▶ **At** the level of the lesion: ipsilateral LMN paralysis/atrophy (anterior horn cells/ventral root) + ipsilateral segmental band of cutaneous anaesthesia (posterior root).
- ▶ Mechanistic key: the corticospinal tract and dorsal columns cross **above** the cord (medulla) → ipsilateral deficit; the spinothalamic tracts cross **within** the cord → contralateral deficit.
- ▶ Contralateral pain/temperature loss begins **2–3 segments below** the level of the lesion (oblique intraspinal crossing of spinothalamic fibres).
- ▶ **Touch is never completely lost** on either side, since it travels via both the (crossed) anterior spinothalamic tract and the (uncrossed) posterior column.
- ▶ Must be distinguished from **complete transection, anterior cord syndrome, posterior cord syndrome, and central cord syndrome** — a comparison table is high-yield.
- ▶ **MRI spine** is the investigation of choice to localise the level, side, and cause of the lesion.
- ▶ **Bladder/bowel function relatively preserved** compared with complete transection — a key distinguishing negative finding.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; BD Chaurasia Human Anatomy Vol 3–4 8e.



Central canal of spinal cord

Asked in: Paper IV Apr 2006 — RGUHS MD/MS Anatomy

Definition / Introduction

The central canal is a narrow, ependyma-lined tubular cavity that runs the entire length of the spinal cord in the centre of the grey commissure (Rexed's Lamina X). It is filled with cerebrospinal fluid (CSF) and represents the persistent — though greatly narrowed, "vestigial" — remnant of the lumen of the embryonic neural tube. Rostrally it continues into the central canal of the closed (caudal) part of the medulla oblongata and opens into the fourth ventricle at the obex, so that it forms part of one single, continuous, ependyma-lined CSF pathway that includes the entire cerebral ventricular system.

Embryological development

- ▶ The neural tube possesses a single central cavity enclosed by its neuroepithelial wall; this cavity is the common precursor of the entire adult ventricular system and of the central canal of the spinal cord.
- ▶ In the brain the cavities of the prosencephalic, mesencephalic and rhombencephalic vesicles expand enormously to become the lateral ventricles, third ventricle, cerebral aqueduct and fourth ventricle respectively, whereas the cavity of the spinal part of the tube stays narrow and persists as the central canal.
- ▶ The median dorsal (roof) and ventral (floor) laminae of the neural tube do not take part in the neuroblast proliferation of the lateral walls and remain thin; their cells contribute largely to the ependymal lining. A sulcus limitans develops on each side of the central canal and divides each lateral wall into a basal (motor) and an alar (sensory) lamina.
- ▶ Caudally, the central canal ends as a fusiform dilatation, the terminal ventricle (ventriculus terminalis), at the site corresponding to closure of the posterior neuropore.
- ▶ During the second trimester the vertebral column grows faster than the spinal cord, so the conus medullaris — and with it the terminal ventricle — ascends relative to the vertebral column. The intervening wall of the canal and its covering pia are drawn out to form the filum terminale, while the separated caudal portion of the terminal ventricle usually disappears before birth; its persistence can give rise to a congenital cyst near the coccyx.

Gross anatomy — location, extent and relations

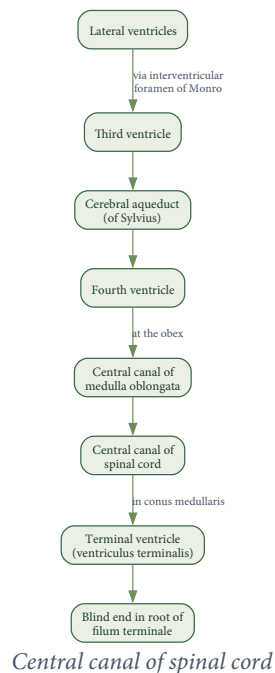
Feature	Description
Position	Centre of the grey commissure, at the crossing point of the "H"/butterfly-shaped grey matter; surrounded by Lamina X
Extent	Runs the entire length of the spinal cord, from its junction with the medulla to the conus medullaris
Calibre	Diminutive and narrow throughout the cord
Rostral continuation	Continuous with the central canal of the closed (caudal) half of the medulla oblongata → opens into the fourth ventricle at the obex
Caudal termination	Expands as the fusiform terminal ventricle within the conus medullaris and ends blindly in the root of the filum terminale — i.e. closed inferiorly, open superiorly
Content	Cerebrospinal fluid
Effect on grey matter	Divides the grey commissure into a dorsal (posterior) grey commissure and a ventral (anterior) grey commissure

Histological structure

- ▶ Lined by a single layer of ciliated, cuboidal-to-columnar ependymal cells (ependymocytes), continuous with the ependyma lining the cerebral ventricles.
- ▶ The apical surface bears cilia, which help circulate CSF, and long microvilli, probably involved in absorption; adjacent ependymal cells are held together by apical junctional complexes similar to those of true epithelium.
- ▶ Unlike a true epithelium, however, the ependyma has no basal lamina — the basal ends of the ependymal cells taper and send branching processes into the adjacent neuropil (in some situations these are the specialised, elongated tanycytes).
- ▶ The ependyma is supported externally by a thin condensation of neuroglial (astrocytic) tissue, the substantia gelatinosa centralis, which forms part of Lamina X of Rexed.
- ▶ With advancing age, ependymal proliferation narrows the lumen further; Gray's Anatomy explicitly describes the adult central canal as "vestigial" in comparison with the greatly expanded cerebral ventricles into which it is continuous.

□ Fig 2.32 — A: Photomicrograph of ependymal cells lining the central canal of the (Snell — Clinical Neuroanatomy — 7e, p.80)

Continuity with the ventricular system



- The entire neuraxis therefore encloses one single, continuous, ependyma-lined, CSF-filled cavity: lateral ventricles → third ventricle → cerebral aqueduct → fourth ventricle → central canal of the medulla → central canal of the spinal cord → terminal ventricle.
- CSF is secreted mainly by the choroid plexuses of the lateral, third and fourth ventricles; most of it leaves the ventricular system through the median aperture (foramen of Magendie) and the paired lateral apertures (foramina of Luschka) of the fourth ventricle into the subarachnoid space, with only a small proportion passing caudally into the narrow central canal.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label a transverse section of the spinal cord (mid-thoracic level) showing:

- Ventral (anterior) median fissure and dorsal (posterior) median septum
- Ventral (anterior) grey column/horn and dorsal (posterior) grey column/horn; lateral grey column
- Dorsal and ventral grey commissures
- **Central canal**, placed centrally within the grey commissure, lined by ependyma
- Lamina X (Rexed) surrounding the central canal
- Ventral, lateral and dorsal white funiculi
- Tract of Lissauer at the tip of the dorsal grey column

Applied / Clinical anatomy

- **Syringomyelia**: a developmental abnormality in the formation of the central canal leads to cavitation and gliosis in the central region of the cord, most often affecting the cervical cord and lower brainstem (syringobulbia). As the cavity enlarges it interrupts the crossing fibres of the lateral spinothalamic tract in the anterior grey/white commissure before the posterior column

pathway is affected, producing the classical dissociated sensory loss — bilateral, "cape/shawl"-distribution loss of pain and temperature sensation with preserved fine touch, joint position and vibration sense. Further enlargement can involve the anterior grey column, producing lower motor neurone wasting and weakness of the small muscles of the hand.

□ Fig 3.19 — Syringomyelia (central spinal cord syndrome) (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.463)

- ▶ **Ependymoma:** the ependymal cells that line the central canal (and the ventricles) are the cell of origin of ependymoma, a glial tumour that in adults classically arises in relation to the central canal of the conus medullaris/filum terminale region.
- ▶ **Persistent terminal ventricle / coccygeal cyst:** failure of complete regression of the separated caudal remnant of the terminal ventricle during ascent of the conus medullaris can leave a small congenital cyst in the region of the coccyx.
- ▶ **Age-related narrowing:** because the canal becomes progressively narrower ("vestigial") with age, a patent central canal is a more conspicuous, and normal, finding on cross-sectional imaging in children and young adults than in older individuals.

High-yield exam pointers

- ▶ Central canal = the persistent lumen of the embryonic neural tube; ependyma-lined; contains CSF; develops from the lumen of the neural tube.
- ▶ Lies in the centre of the grey commissure (Lamina X of Rexed), dividing it into dorsal and ventral grey commissures.
- ▶ Continuous rostrally with the central canal of the closed (caudal) medulla → opens into the fourth ventricle at the obex.
- ▶ Forms one continuous, single CSF-filled cavity with the rest of the ventricular system: lateral ventricles — third ventricle — cerebral aqueduct — fourth ventricle — central canal — terminal ventricle.
- ▶ Caudally expands as the terminal ventricle (ventriculus terminalis) within the conus medullaris and ends blindly in the root of the filum terminale — closed below, open above.
- ▶ Lined by ciliated ependymal cells with apical junctional complexes but no basal lamina; supported by the substantia gelatinosa centralis.
- ▶ Becomes progressively narrow/"vestigial" with advancing age.
- ▶ Cell of origin of ependymoma; a developmental defect in its formation underlies syringomyelia, which classically produces dissociated sensory loss.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; IB Singh's Human Embryology (CBME 2021); IB Singh's Textbook of Human Histology 9e; Junqueira's Basic Histology 17e; BD Chaurasia's Human Anatomy Vol 3–4 8e.



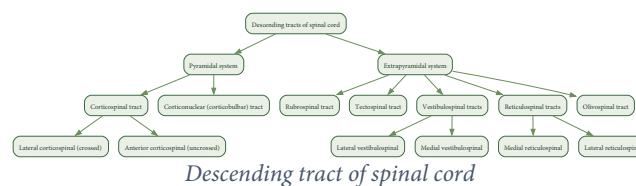
Descending tract of spinal cord

Asked in: Paper IV Nov 2017 — RGUHS MD/MS Anatomy

Definition / Introduction Descending tracts are bundles of nerve fibres in the white matter of the spinal cord that carry impulses from the cerebral cortex and subcortical motor centres (medulla, pons, midbrain, vestibular nuclei, hypothalamus) down to the anterior grey column. Their neurons of origin are collectively called **upper motor neurons (UMNs)**, and they act on the anterior horn cell — the **lower motor neuron (LMN)**, the "final common pathway" to skeletal muscle. Traditionally the descending tracts are divided into the **pyramidal system** (corticospinal + corticonuclear tracts, which traverse the medullary pyramids) and the **extrapyramidal system** (all other descending tracts — rubrospinal, tectospinal, vestibulospinal, reticulospinal and olivospinal). Together they regulate voluntary movement, muscle tone, posture, reflex activity and (through reticulospinal fibres) autonomic outflow.

1. Classification of descending tracts

Feature	Pyramidal tracts	Extrapyramidal tracts
Components	Corticospinal + corticonuclear (corticobulbar)	Rubrospinal, tectospinal, vestibulospinal, reticulospinal, olivospinal
Phylogeny	Recent; present only in mammals	Older
Origin	Predominantly motor cortex (Betz cells, area 4)	Subcortical nuclei — red nucleus, tectum, vestibular nuclei, reticular formation, inferior olive
Connection to LMN	Largely direct/near-direct	Indirect, polysynaptic
Function	Discrete, skilled voluntary movement of distal limb muscles	Gross postural, stereotyped movements of proximal/axial muscles; muscle tone
Lesion	Spastic paralysis, Babinski sign, loss of superficial reflexes	Spasticity, clasp-knife rigidity, exaggerated deep reflexes



An additional working grouping (IB Singh) is functional: the **lateral corticospinal + rubrospinal** tracts form a *lateral pathway* that facilitates flexors and inhibits extensors (controls distal limb muscles); all the remaining descending tracts form a *medial pathway* concerned with postural, axial muscle control.

2. Distribution in the white columns of the cord

White column	Descending tracts present
Anterior (ventral)	Anterior corticospinal, tectospinal, medial reticulospinal, lateral & medial vestibulospinal

White column	Descending tracts present
Lateral	Lateral corticospinal, rubrospinal, lateral reticulospinal, hypothalamospinal, olivospinal

3. Corticospinal (pyramidal) tract

- ▶ **Origin:** ~1 million fibres from pyramidal (Betz) cells, layer V of cerebral cortex — about one-third each from primary motor cortex (area 4), secondary motor/premotor cortex (area 6), and parietal (sensory) cortex (areas 3, 1, 2).
- ▶ **Course:** corona radiata → posterior limb of internal capsule (cervical fibres near the genu, leg fibres more posterior) → middle three-fifths of the crus cerebri/basis pedunculi of the midbrain (cervical fibres medial, leg fibres lateral) → broken into bundles by transverse pontocerebellar fibres in the ventral pons → re-form the **pyramid** on the anterior surface of the medulla (hence "pyramidal tract").
- ▶ **Decussation:** at the lower end of the medulla, about 75–80% of fibres cross at the **decussation of the pyramids** to descend as the **lateral corticospinal tract** in the lateral white column, running the full length of the cord and terminating at all segmental levels.
- ▶ The remaining uncrossed fibres descend in the anterior white column close to the anterior median fissure as the **anterior corticospinal tract**; most of these cross later, segment-by-segment, in the anterior white commissure before terminating (mainly cervical and upper thoracic segments). A small ipsilateral component of the lateral tract also exists.
- ▶ **Termination:** mainly via interneurons in laminae IV–VII, which then relay to alpha/gamma anterior horn cells; only about 2% of the largest fibres synapse directly on motor neurons (lamina IX) — these direct connections subserve the fine, individuated finger movements.
- ▶ **Branches:** given off early to the caudate/lentiform nuclei, red nucleus, inferior olivary nucleus and reticular formation (keeping the extrapyramidal relay centres informed of cortical motor commands), and collaterals back to adjacent cortex.
- ▶ **Function:** speed and skill of voluntary movement, especially of the distal limbs; facilitatory to flexors, inhibitory to extensors; not the sole pathway for voluntary movement — basic movement patterns are mediated through the extrapyramidal tracts it influences via its branches.
- ▶ **Corticonuclear (corticobulbar) tract:** fibres running with the corticospinal tract that cross at various brainstem levels to end on motor cranial-nerve nuclei — functionally the cranial equivalent of the corticospinal tract, together forming the "pyramidal tract" in the broader clinical sense.

4. Extrapyramidal tracts

Tract	Origin	Decussation	Column	Termination (laminae)	Function
Rubrospinal	Red nucleus, midbrain	Immediately, in the ventral tegmental decussation	Lateral, ventral to lateral corticospinal	V–VII	Facilitates flexors, inhibits extensors; rudimentary in man — reaches only upper cervical segments
Tectospinal	Superior colliculus, midbrain	Immediately, dorsal tegmental decussation	Anterior, near anterior median fissure	VI–VIII (cervical segments)	Reflex postural (head/neck) movements in response to visual stimuli
Lateral vestibulospinal	Lateral vestibular nucleus (Deiters')	Uncrossed	Anterior (shifts medially caudally); somatotopic	VII–VIII, all levels	Facilitates extensor (antigravity) tone, inhibits flexors — balance
Medial vestibulospinal	Medial ($\pm$ inferior/lateral) vestibular nucleus	Partly crossed, partly uncrossed	Anterior (sulcomarginal fasciculus)	VII–VIII, cervical only	Inhibits neck and back muscles — head-righting reflexes
Medial reticulospinal	Medial reticular formation of pons + medulla (mainly nucleus gigantocellularis of medulla, and oral/caudal pontine reticular nuclei)	Crossed and uncrossed	Anterior, near median fissure	All levels, laminae VI–VIII mainly	Facilitatory to trunk/limb muscles; some fibres inhibitory to neck muscles; postural adjustment of head, trunk, limbs

Tract	Origin	Decussation	Column	Termination (laminae)	Function
Lateral reticulospinal	Ventrolateral pontine reticular formation (caudal + oral pontine reticular nuclei)	Crosses in the medulla	Lateral	All levels, laminae VI–VIII mainly	Motor control (details less defined); reticulospinal fibres overall also modulate pain transmission in ascending tracts
Olivospinal	Inferior olivary nucleus	—	Lateral/ anterior (variably described)	Anterior horn	Doubtful — recent evidence questions its existence as a distinct tract
Hypothalamospinal	Hypothalamus	Uncrossed	Lateral, medial to lateral corticospinal	Intermediolateral cell column, T1–L2 (sympathetic), S2–S4 (parasympathetic)	Descending autonomic control

- The **reticulospinal fibres** are now considered to carry the descending autonomic pathway, providing the route by which the hypothalamus controls thoracolumbar sympathetic and sacral parasympathetic outflow.
- Naturally occurring lesions rarely respect the pyramidal/extrapyramidal boundary — both sets of tracts are usually affected together in clinical practice, producing a mixed picture.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 7.15 — Transverse section of spinal cord at midcervical region showing main descending (motor) tracts (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.209)

Reproduce as a transverse section of the mid-cervical spinal cord with these exact labels (motor/descending side):

- ▶ Hypothalamospinal tract
- ▶ Lateral corticospinal (crossed pyramidal) tract
- ▶ Rubrospinal tract
- ▶ Lateral reticulospinal tract
- ▶ Medial reticulospinal tract
- ▶ Olivospinal tract
- ▶ Vestibulospinal tract
- ▶ Tectospinal tract
- ▶ Anterior corticospinal (uncrossed pyramidal) tract

Applied / Clinical anatomy

- ▶ **Upper motor neuron (corticospinal) lesion signs:** positive Babinski sign (dorsiflexion of great toe + fanning of other toes on plantar stroking — physiologically present till the corticospinal tract myelinates, ~1 year of age); loss of superficial abdominal and cremasteric reflexes; loss of fine skilled voluntary movement, especially distal limb.
- ▶ **Lesions of extrapyramidal tracts alone:** severe paralysis with little/no muscle atrophy; spasticity/hypertonia (lower limb held in extension, upper limb in flexion); exaggerated deep tendon reflexes with clonus; clasp-knife reaction (sudden give-way on passive stretch, due to Golgi tendon organ-mediated inhibition).
- ▶ **Lower motor neuron lesion signs** (anterior horn cell or its axon): flaccid paralysis, muscle atrophy, loss of reflexes, fasciculation, contracture, and the electrophysiological "reaction of degeneration."
- ▶ **Types of paralysis:** hemiplegia (one side of body), monoplegia (one limb), diplegia (both upper or both lower limbs), paraplegia (both lower limbs), quadriplegia (all four limbs).
- ▶ **Brown-Séquard syndrome** (hemisection of the cord — fracture-dislocation, stab wound, tumour): ipsilateral LMN paralysis at the segmental level; ipsilateral spastic (UMN) paralysis and Babinski sign below the lesion (loss of lateral + anterior corticospinal tracts); ipsilateral loss of tactile discrimination/vibration/proprioception below the lesion (posterior column); ipsilateral band of cutaneous anaesthesia at the segment; contralateral loss of pain and temperature a few segments below the lesion (crossed lateral spinothalamic tract).
- ▶ **Spinal shock:** sudden transection abolishes segmental reflexes and produces flaccid paralysis below the lesion for 1–4 weeks; as reflexes return, tone rises (release of gamma efferents from higher control) to give **paraplegia-in-extension** (extensor tone dominant, attributed to intact vestibulospinal influence) which may progress to **paraplegia-in-flexion** if the vestibulospinal tracts are also destroyed.

- ▶ Interruption of the hypothalamospinal tract above T1 produces an ipsilateral **Horner's syndrome** (miosis, ptosis, anhidrosis) by disrupting descending sympathetic fibres.
- ▶ Rubrospinal tract being rudimentary below the cervical cord in man explains why isolated lesions here contribute little clinically compared to lower mammals, where it is a major locomotor pathway.

High-yield exam pointers

- ▶ Descending tracts = UMN pathways; anterior horn cell = LMN = "final common pathway."
- ▶ Two systems: pyramidal (corticospinal + corticonuclear) and extrapyramidal (rubro-, tecto-, vestibulo-, reticulo-, olivospinal).
- ▶ Corticospinal tract: ~80% cross at the pyramidal decussation (lateral corticospinal tract); remainder descend uncrossed as the anterior corticospinal tract and cross segmentally at the anterior white commissure.
- ▶ Only ~2% of corticospinal fibres synapse directly on anterior horn cells — the substrate for skilled distal (finger) movement.
- ▶ Rubrospinal and tectospinal tracts decussate immediately in the midbrain tegmentum (ventral and dorsal tegmental decussations respectively).
- ▶ Lateral vestibulospinal tract is uncrossed and facilitates extensor/antigravity tone; medial vestibulospinal is confined to cervical cord and inhibits neck muscles.
- ▶ Olivospinal tract existence is doubted in current literature — a favourite "true/false" question.
- ▶ Reticulospinal tracts carry the descending autonomic (sympathetic/parasympathetic) fibres.
- ▶ Babinski sign = hallmark of corticospinal (pyramidal) tract lesion; clasp-knife rigidity and exaggerated reflexes = hallmark of extrapyramidal tract lesion.
- ▶ Brown-Séquard syndrome is the classic applied-anatomy correlate combining descending (corticospinal) and ascending (posterior column, spinothalamic) tract lesions.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Anatomy Vol 3 6e; BD Chaurasia's Human Anatomy Vol 3-4 8e.



Describe the ascending tracts of the spinal cord

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction The ascending (sensory) tracts of the spinal cord are chains of white-matter fibres, usually of three orders of neurons, that carry exteroceptive, proprioceptive and nociceptive impulses from the periphery to the brain. Each tract is named for its origin and termination (e.g. spinothalamic = spinal cord to thalamus) and occupies a constant position in a specific funiculus — posterior, lateral, or anterior white column — throughout the length of the cord. Functionally they fall into three major systems — the dorsal column–medial lemniscus (DCML) system, the antero-lateral (spinothalamic) system, and the spinocerebellar system — supplemented by a few minor tracts (spinotectal, spinoreticular, spino-olivary, spinocervical).

1. General plan and classification

Functional system	Tract(s)	Funiculus	Sensation carried
Dorsal column–medial lemniscus	Fasciculus gracilis, Fasciculus cuneatus	Posterior (dorsal)	Discriminative touch, vibration, conscious muscle-joint (position) sense, two-point discrimination
Antero-lateral (spinothalamic)	Lateral spinothalamic tract; Anterior (ventral) spinothalamic tract	Lateral / Anterior	Pain and temperature (lateral); crude touch and pressure (anterior)
Spinocerebellar	Posterior (dorsal) spinocerebellar; Anterior (ventral) spinocerebellar; Cuneocerebellar; Rostral spinocerebellar	Lateral, at the periphery	Unconscious muscle-joint sense to the cerebellum
Minor ascending tracts	Spinotectal, Spinoreticular, Spino-olivary, Spinocervical	Antero-lateral	Spino-visual reflexes, arousal/pain modulation, proprioceptive relay to inferior olive and lateral cervical nucleus



2. Dorsal column–medial lemniscus (DCML) pathway

- **First-order neuron:** cell body in the posterior (dorsal) root ganglion; peripheral process from Meissner's and Pacinian corpuscles, muscle spindles, tendon organs and joint receptors. The central process enters the posterior white column of the **same side without synapsing** and divides into a long ascending and a short descending branch; the descending branch mediates intersegmental reflexes.
- **Fasciculus gracilis:** present throughout the length of the cord, lying medially against the postero-medial septum; carries fibres from the sacral, lumbar and lower six thoracic segments.

- ▶ **Fasciculus cuneatus:** appears only above the mid-thoracic level, lying lateral to the gracilis and separated from it by a septum; carries fibres from the upper six thoracic and all cervical segments.
- ▶ **Second-order neuron:** fibres of both fasciculi ascend **ipsilaterally, uncrossed**, and terminate by synapsing on second-order neurons in the **nucleus gracilis** and **nucleus cuneatus** in the lower medulla oblongata.
- ▶ **Decussation:** axons of the second-order neurons sweep antero-medially around the central grey matter as the **internal arcuate fibres** and cross the midline high up in the medulla — the **sensory decussation** — then ascend as a single compact bundle, the **medial lemniscus**, through the medulla, pons and midbrain.
- ▶ **Third-order neuron:** medial lemniscus fibres terminate in the **ventral posterolateral (VPL) nucleus of the thalamus**; third-order axons traverse the posterior limb of the internal capsule and corona radiata to reach the **postcentral gyrus**, where the contralateral half of the body is represented inverted.
- ▶ A branch of the fasciculus cuneatus (cervical/upper thoracic levels) relays instead in the **accessory (lateral) cuneate nucleus**; its second-order axons — the posterior external arcuate fibres — form the **cuneocerebellar tract** to the ipsilateral cerebellum via the inferior cerebellar peduncle, the upper-limb equivalent of the posterior spinocerebellar tract.
- ▶ **Function:** fine touch with exact localisation, two-point discrimination, vibratory sense, and conscious muscle-joint (position) sense.

3. Antero-lateral system — spinothalamic tracts

First-order fibres (dorsal root ganglion) entering the posterior grey column ascend or descend one to two segments in the **postero-lateral tract of Lissauer** before synapsing on second-order neurons in the **substantia gelatinosa**.

Lateral spinothalamic tract (pain and temperature)

- ▶ Second-order axons cross very obliquely to the opposite side, within one or two spinal segments, through the anterior grey and white commissures, and ascend in the contralateral lateral funiculus, medial to the ventral spinocerebellar tract.
- ▶ Two functional components: fast, sharp, well-localised pain fibres project directly to the VPL nucleus of thalamus; slow, burning, poorly localised pain fibres are relayed through multiple synapses in the **reticular formation** (spinoreticular component) before reaching higher centres.
- ▶ Third-order neurons project via the posterior limb of the internal capsule to the postcentral gyrus (localisation of pain), with diffuse projections also to the cingulate gyrus (emotional/affective response) and insula (autonomic response to visceral pain).

Anterior (ventral) spinothalamic tract (crude touch and pressure)

- ▶ Second-order neurons cross similarly and ascend in the contralateral anterior funiculus. In the brainstem it joins the lateral spinothalamic and spinotectal tracts to form the **spinal lemniscus**, and terminates in the VPL nucleus of thalamus, relayed onward to the postcentral gyrus.
- ▶ Conveys only crude, poorly localised touch and pressure, with little discrimination of intensity — unlike the fine touch of the DCML system.

4. Spinocerebellar tracts — unconscious proprioception

Posterior (dorsal) spinocerebellar tract (tract of Flechsig)

- ▶ First-order fibres from muscle spindles, tendon organs and joint receptors of the trunk and lower limb synapse on second-order neurons of the **nucleus dorsalis (Clarke's column / posterior thoracic nucleus)**, present only from C8 to L3 segments.
- ▶ Second-order axons remain **uncrossed**, enter the postero-lateral part of the lateral funiculus of the same side, and reach the **cerebellar cortex (vermis) via the inferior cerebellar peduncle**. Fibres entering below L3 ascend first in the posterior white column until they reach Clarke's column.

Anterior (ventral) spinocerebellar tract (tract of Gowers)

- ▶ Second-order neurons (spinal border cells at the base of the posterior grey column) — the **majority cross** to the opposite lateral funiculus, a minority remain uncrossed — ascend through the medulla and pons, and enter the cerebellum via the **superior cerebellar peduncle**; most of the crossed fibres **re-cross within the cerebellum**, so the net destination is predominantly ipsilateral.
- ▶ Carries proprioceptive information from the lower limb as a whole (large receptive fields, used for posture and gait), in contrast to the posterior tract's single-muscle-specific input (used for fine coordination of individual muscles).

Upper-limb equivalents: the **cuneocerebellar tract** (via the accessory cuneate nucleus and inferior cerebellar peduncle) counterparts the posterior spinocerebellar tract; the **rostral spinocerebellar tract** (from the cervical enlargement) is the proposed counterpart of the anterior tract, though unconfirmed in humans. Both principal tracts terminate in the **cerebellar cortex only** — never reaching consciousness — to coordinate muscle tone, posture and movement unconsciously.

5. Minor ascending tracts and somatotopic lamination

- ▶ **Spinotectal tract:** ascends with the spinothalamic tracts to the **superior colliculus** of the midbrain; mediates spino-visual reflexes (turning the head and eyes toward a painful stimulus).
- ▶ **Spinoreticular tract:** fibres terminate in the reticular formation of the brainstem; activates the reticular activating system and modulates pain and arousal — indeed, all ascending pathways send collateral branches to the reticular activating system.
- ▶ **Spino-olivary tract:** crossed fibres from the deeper grey laminae ascend at the junction of the anterior and lateral funiculi to the accessory olivary nuclei, relaying proprioceptive and cutaneous information as climbing-fibre input to the cerebellum; a similar dorsal spino-olivary route relays through the dorsal column nuclei.
- ▶ **Spinocervical tract:** ascends ipsilaterally in the dorsolateral funiculus to the lateral cervical nucleus, which projects onward (crossed) to the VPL thalamus — an accessory touch/pressure pathway.

Somatotopic lamination: within each ascending tract, fibres entering at successively higher segments are added on the medial aspect, pushing earlier (lower-segment) fibres laterally.

- ▶ **Spinothalamic tracts:** cervical fibres lie most medial, sacral fibres most lateral.
- ▶ **Posterior column:** the reverse — sacral fibres lie medially (fasciculus gracilis), cervical fibres laterally (fasciculus cuneatus).

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Real captioned plate — reproduce and label by hand:

embed: ![Fig 3.12 — Location of ascending tracts in spinal cord. Three tracts marked 'X' a (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.457)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/350d6b1f7ddd0559.jpg)

Transverse section of the spinal cord at mid-cervical level — label exactly:

- ▶ **Posterior (dorsal) white column:** fasciculus gracilis (medial), fasciculus cuneatus (lateral, separated by postero-intermediate septum)
- ▶ **Postero-lateral tract of Lissauer** — at the tip of the posterior grey horn
- ▶ **Lateral white column** (from periphery inward): dorsal (posterior) spinocerebellar tract → ventral (anterior) spinocerebellar tract → lateral spinothalamic tract (with intermingled spinotectal/spinoreticular fibres) → spino-olivary tract, closest to the grey matter
- ▶ **Anterior white column:** anterior (ventral) spinothalamic tract, near the anterior median fissure
- ▶ **Grey matter landmarks:** substantia gelatinosa at the tip of the posterior horn; nucleus proprius; nucleus dorsalis (Clarke's column) at the base of the posterior horn — mark "present only C8–L3" since it is absent above and below this range

Applied / Clinical anatomy

- ▶ **Tabes dorsalis** (neurosyphilis): degeneration of the posterior columns → loss of vibration and position sense, sensory ataxia with a positive Romberg's sign, and loss of deep tendon reflexes.
- ▶ **Subacute combined degeneration** (vitamin B12 deficiency): combined posterior-column and lateral corticospinal tract degeneration, producing mixed sensory ataxia and spastic weakness.
- ▶ **Syringomyelia:** an expanding central canal cavity destroys the decussating fibres of the spinothalamic tracts in the anterior white commissure, producing bilateral, segmental ("cape-like") loss of pain and temperature with touch preserved — a classical **dissociated sensory loss**; the posterior columns, lying peripherally, are spared until late.
- ▶ **Brown-Séquard syndrome** (hemisection of the cord): ipsilateral loss of discriminative touch and proprioception (posterior column fibres are uncrossed) and ipsilateral motor paralysis below the lesion, together with **contralateral** loss of pain and temperature beginning one to two segments below the lesion (spinothalamic fibres have already crossed).
- ▶ **Anterior spinal artery occlusion:** bilateral loss of pain, temperature and motor function with preservation of posterior-column modalities (touch, vibration, proprioception), since the posterior columns are supplied by the paired posterior spinal arteries.
- ▶ **Antero-lateral cordotomy:** surgical section of this column for intractable pain must be made a segment or two **rostral** to the level of pain, since spinothalamic fibres have already crossed by the time they ascend.
- ▶ **Bedside tests:** pinprick and hot/cold test-tubes for the lateral spinothalamic tract; Romberg's test, two-point discrimination and stereognosis for the posterior columns; finger-nose and heel-knee-shin tests for the spinocerebellar tracts.

High-yield exam pointers

- ▶ Ascending tracts are three-neuron chains (I order in the dorsal root ganglion → II order relay nucleus → III order in thalamus → cortex), **except** the spinocerebellar tracts, which are two-neuron chains ending in the cerebellar cortex with no thalamic relay.
- ▶ DCML fibres ascend **uncrossed** in the cord and decussate high up in the medulla as internal arcuate fibres (sensory decussation); spinothalamic fibres cross **low**, within one to two segments of entry.
- ▶ Fasciculus gracilis carries sacral-to-lower-thoracic fibres (medial); fasciculus cuneatus carries upper-thoracic-to-cervical fibres (lateral) and appears only above mid-thoracic level.
- ▶ Clarke's column (nucleus dorsalis) exists only from **C8 to L3**; fibres entering below this level ascend in the posterior column first to reach it.
- ▶ Posterior spinocerebellar tract (Flechsig) is uncrossed and uses only the inferior cerebellar peduncle; anterior spinocerebellar tract (Gowers) crosses twice (once in the cord, again in the cerebellum) and uses the superior cerebellar peduncle.
- ▶ Somatotopic lamination is opposite in the two great systems: spinothalamic tracts are sacral-lateral/cervical-medial; posterior columns are sacral-medial/cervical-lateral.
- ▶ Remember the clinical triad: tabes dorsalis (posterior column), syringomyelia (crossing spinothalamic fibres), Brown-Séquard syndrome (dissociated hemisection pattern).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e (embedded figure).



Laminar organization in spinal cord

Asked in: Paper IV May 2011 — RGUHS MD/MS Anatomy

Definition / Introduction — In thick transverse sections of the spinal cord, the grey matter does not simply resolve into the classical anterior, posterior and lateral horns/columns — it also shows a distinct **laminar (layered) cytoarchitectural pattern**. Rexed (1952), working on the cat spinal cord, described **ten such layers**, now universally known as the **laminae of Rexed**, numbered consecutively with **Roman numerals (I–X)** starting at the tip of the posterior (dorsal) horn and running ventrally into the anterior (ventral) horn. The scheme, extended to the human cord, is based on differences in **neuronal size, shape, packing density and myelin content**, and each lamina correlates closely with a specific classical nucleus, a specific afferent input, and a specific efferent tract or function. It is the standard modern framework for describing dorsal-horn sensory processing (including pain) and is of major importance in neurophysiology, pain research and applied neuroanatomy.

1. Basis and general plan of Rexed's lamination

- ▶ The **classical (columnar) description** of spinal grey matter recognises anterior, posterior and (at certain levels) lateral **grey columns/horns**, each containing discrete **nuclear groups** (e.g.

posteromarginal nucleus, substantia gelatinosa, nucleus proprius, Clarke's column, intermediolateral nucleus, motor nuclei).

- ▶ The **laminar (Rexed) description** is an alternative cytoarchitectural subdivision of the *same* grey matter into **10 zones or laminae**, based on neuronal morphology and packing rather than gross nuclear grouping.
- ▶ Laminae are numbered I → X, dorsal to ventral: I at the extreme tip of the dorsal horn, through the intermediate zone, into the ventral horn, ending with X around the central canal.
- ▶ **General functional plan** (dorsal to ventral):
 - **Laminae I–IV** — dorsal horn proper; concerned with **exteroceptive** sensation (pain, temperature, crude touch).
 - **Laminae V–VI** — base of the dorsal horn; concerned mainly with **proprioceptive** relay.
 - **Lamina VII** — the **intermediate zone**; interneurons, propriospinal connections and autonomic (visceral) nuclei.
 - **Laminae VIII–IX** — the ventral horn; **motor** — propriospinal coordination (VIII) and lower motor neurons (IX).
 - **Lamina X** — grey matter surrounding the **central canal**.
- ▶ The relative size and shape of individual laminae vary with the segmental level (cervical/lumbar enlargements versus thoracic cord), reflecting the differing bulk of the limb versus trunk innervation at each level.

2. Lamina-by-lamina correlation with classical nuclei, cytoarchitecture and connections

Lamina	Classical nuclear correlate	Cytoarchitecture / location	Principal connections and function
I (lamina marginalis)	Posteromarginal nucleus	Thin layer at the dorsolateral tip of the dorsal horn, deep to the tract of Lissauer	Receives incoming dorsal-root (mainly nociceptive/thermal) fibres; projection ("T"/tract) neurons give rise to the lateral spinothalamic tract
II	Substantia gelatinosa	Densely packed small neurons (Golgi type II), very few myelinated fibres, found at the tip of the dorsal horn at all cord levels	Receives fine nociceptive and thermal afferents via Lissauer's tract ; key site of intrinsic modulation of pain transmission
III & IV	Nucleus proprius	Lies subjacent to the substantia gelatinosa; larger, more loosely packed neurons	Sensory-associative relay for exteroceptive modalities; axons contribute to spinothalamic tracts

Lamina	Classical nuclear correlate	Cytoarchitecture / location	Principal connections and function
V & VI	Base of the dorsal horn	Lamina VI especially prominent at the cervical and lumbar (limb) enlargements	Relay proprioceptive impulses; give rise to the dorsal and ventral spinocerebellar tracts ; receive descending corticospinal input
VII	Intermediate zone — contains nucleus dorsalis (Clarke's column) , intermediolateral and intermediomedial nuclei	Occupies the territory between dorsal and ventral horns; forms the lateral (grey) horn in the thoracic and upper lumbar cord	Nucleus dorsalis (C8–L3) → dorsal spinocerebellar tract; intermediolateral nucleus → preganglionic sympathetic outflow (T1–L2) and preganglionic parasympathetic outflow (S2–S4); rich interneuronal/propriospinal population
VIII	Commissural/ propriospinal grey	Base of the ventral horn in the thoracic cord; medial part of the ventral horn at the limb enlargements	Propriospinal interneurons coordinating bilateral and intersegmental motor activity
IX	Medial and lateral motor-nuclei groups of the anterior grey column	Discrete columns embedded within laminae VII/VIII throughout the ventral horn	Alpha and gamma lower motor neurons — medial group (axial/trunk muscles, present at all levels) and lateral group (limb muscles, present only at the cervical and lumbar enlargements)
X	Grey matter around the central canal	Surrounds the central canal; composed of the dorsal and ventral grey commissures	Contains decussating (commissural) axons and neuroglia

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 3.9 — *Various laminae in spinal cord* (BD Chaurasia — *Human Anatomy Vol 3-4 — 8e, p.452*)

Reproduce a transverse (cross) section of the spinal cord at a mid-cervical or lumbar level, with the **left half** labelled by classical cell groups and the **right half** by Rexed laminae, and mark:

- ▶ Dorsal (posterior) and ventral (anterior) horns of grey matter, central canal
- ▶ **Lamina I** at the dorsolateral tip of the dorsal horn (deep to tract of Lissauer)
- ▶ **Lamina II** — substantia gelatinosa, immediately beneath lamina I
- ▶ **Laminae III–IV** — nucleus proprius
- ▶ **Laminae V–VI** — base of the dorsal horn
- ▶ **Lamina VII** — intermediate zone, with Clarke's column and intermediolateral nucleus annotated (lateral horn, thoracic level)
- ▶ **Lamina VIII** — medial ventral horn
- ▶ **Lamina IX** — lateral motor-neuron groups within the ventral horn
- ▶ **Lamina X** — around the central canal

3. Functional significance of the laminar scheme

- ▶ Correlates precisely with the **origin of the major ascending sensory tracts**: laminae I–IV give rise to the **spinothalamic tracts** (pain, temperature, crude touch); laminae V–VI give rise to the **spinocerebellar tracts** (unconscious proprioception).
- ▶ Identifies the **autonomic preganglionic outflow** within lamina VII (intermediolateral nucleus) — the anatomical substrate of the sympathetic thoracolumbar and parasympathetic sacral outflows.
- ▶ Identifies the **somatic lower motor neuron pools** of lamina IX, arranged somatotopically (medial group for axial muscles present throughout the cord; lateral group for limb muscles confined to the enlargements) — the basis of the motor homunculus within the ventral horn.
- ▶ Provides the framework for modern **dorsal-horn pain physiology**: superficial laminae I–II are the principal site of primary nociceptive-afferent termination and of intrinsic/descending modulation of pain transmission.

Applied / Clinical anatomy

- ▶ **Gate control theory of pain** (Melzack and Wall, 1965): interneurons of the **substantia gelatinosa (lamina II)** act as the physiological "gate," modulating transmission of nociceptive input from primary afferents to the projection ("T") neurons of **lamina I**, which relay onward via the spinothalamic tract; this concept underlies transcutaneous electrical nerve stimulation (TENS) and dorsal column stimulation for chronic pain.
- ▶ **Superficial dorsal horn (laminae I–II)** is the principal target of neurosurgical **dorsal root entry zone (DREZ) lesioning** and of **spinal (intrathecal/epidural) opioid analgesia**, since these laminae are the first relay for nociceptive input.
- ▶ **Nucleus dorsalis (Clarke's column, lamina VII, C8–L3)** degenerates in **Friedreich's ataxia**, impairing the dorsal spinocerebellar tract and contributing to the ataxic gait.

- ▶ **Intermediolateral nucleus (lamina VII)** carries the preganglionic sympathetic outflow (T1–L2); a lesion at the T1 level interrupting this outflow produces **Horner's syndrome**.
- ▶ **Anterior horn cells (lamina IX)** are selectively destroyed in **poliomyelitis** and in **motor neuron disease/amyotrophic lateral sclerosis**, producing pure lower motor neurone weakness, wasting and fasciculations without sensory loss.
- ▶ **Syringomyelia**: cavitation classically begins around the central canal (lamina X) and expands into the decussating fibres of the anterior white commissure, producing the classical **bilateral, "cape-like," dissociated sensory loss** — pain and temperature lost, touch and proprioception preserved — because laminae I–IV afferents crossing at that level are interrupted while the posterior columns are spared.
- ▶ The laminar concept must be distinguished from the separate, commonly-confused idea of **"lamination of the ascending tracts"** — the somatotopic (segment-wise) layering of fibres *within* a tract (e.g. sacral fibres lying most peripherally in the lateral spinothalamic tract) — which explains **sacral sparing** in extramedullary cord compression, as opposed to the early sacral/central involvement typical of intramedullary (central cord) lesions.
- ▶ The Rexed scheme is primarily an **experimental/research tool**, used to localise degenerating fibre terminals after section of dorsal roots or descending tracts, and to map the origin/termination of individual pathways — of limited direct use to the practising clinician but essential to understanding modern pain and motor physiology.

High-yield exam pointers

- ▶ **Rexed (1952)**, originally in the **cat** spinal cord: **10 laminae**, Roman numerals I–X, numbered dorsal (tip of posterior horn) to ventral (anterior horn), around the central canal at X.
- ▶ **I** = posteromarginal nucleus (spinothalamic origin); **II** = substantia gelatinosa (pain gate); **III–IV** = nucleus proprius.
- ▶ **V–VI** = base of dorsal horn — proprioceptive relay, spinocerebellar tract origin; lamina VI most developed at the limb enlargements.
- ▶ **VII** = intermediate zone — houses **Clarke's column** (C8–L3, dorsal spinocerebellar tract), **intermediolateral nucleus** (sympathetic T1–L2, parasympathetic S2–S4).
- ▶ **VIII–IX** = ventral horn — **VIII** propriospinal, **IX** = alpha/gamma lower motor neurons (medial group = axial, all levels; lateral group = limb, enlargements only).
- ▶ **X** = grey commissure around the central canal.
- ▶ Clinical anchor points: **gate control theory** (lamina II), **Clarke's column loss in Friedreich's ataxia**, **anterior horn (lamina IX) loss in poliomyelitis/ALS**, **syringomyelia** (central canal/lamina X expansion → dissociated sensory loss).
- ▶ Do not confuse with "lamination of ascending tracts" (somatotopic fibre layering within a tract — basis of sacral sparing).

SOURCE & COVERAGE

BD Chaurasia Human Anatomy Vol 3–4 8e; Vishram Singh Clinical Neuroanatomy 4e; Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; IB Singh Textbook of Anatomy Vol 3 6e / Textbook of Human Neuroanatomy.



Brainstem & cranial nerve nuclei



Lateral medullary syndrome

Asked in: Paper IV 20-Jul-2020 · Paper IV Oct 2009 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction — Lateral medullary syndrome, also called **Wallenberg's syndrome** or the **posterior inferior cerebellar artery (PICA) syndrome**, is the classic brainstem vascular (crossed/alternate) syndrome produced by infarction of a wedge-shaped area of the **dorsolateral medulla oblongata**, at the level of the inferior olivary nucleus, following thrombosis of the **posterior inferior cerebellar artery** or, more often, of the **vertebral artery** proximal to the origin of PICA. Because several cranial-nerve nuclei, long ascending/descending tracts and the inferior cerebellar peduncle all pass through this compact dorsolateral segment, occlusion of a single small vessel produces a characteristic constellation of ipsilateral and contralateral deficits without any limb weakness — making it a favourite integrative question linking vascular, gross and clinical neuroanatomy.

1. Arterial territory — origin and course of PICA

- ▶ The **posterior inferior cerebellar artery (PICA)** is usually the **largest branch of the vertebral artery**, arising near the lower end of the olive.
- ▶ **Course:** it ascends behind the roots of the glossopharyngeal and vagus nerves to reach the inferior border of the pons, curves and descends along the inferolateral border of the fourth ventricle, then turns laterally into the cerebellar vallecule and divides into a **medial branch** (to the cerebellar hemisphere and inferior vermis) and a **lateral branch** (to the inferior cerebellar surface, anastomosing with the anterior inferior and superior cerebellar arteries).
- ▶ The **trunk of PICA** supplies the medulla **dorsal to the inferior olivary nucleus and lateral to the hypoglossal nucleus/nerve roots** — i.e., exactly the dorsolateral wedge damaged in this syndrome — together with the choroid plexus of the fourth ventricle and (via a branch passing lateral to the cerebellar tonsil) the dentate nucleus.
- ▶ **PICA is sometimes congenitally absent**, in which case its territory is supplied by the vertebral artery directly — an important variant explaining why occlusion of the vertebral artery itself (rather than PICA) is a common cause of the syndrome.
- ▶ Occlusion may be of PICA itself or of the **vertebral artery proximal to the PICA origin** (thrombosis, atherosclerosis, or dissection); either produces the same dorsolateral medullary infarct.

2. Structures damaged and the resulting clinical features

Six structures crowd the dorsolateral medullary wedge; each is damaged with a predictable, textbook-standard deficit:

Structure damaged	Side of deficit	Clinical feature
Nucleus ambiguus (motor fibres to IX, X, XI)	Ipsilateral	Paralysis of ipsilateral muscles of soft palate, pharynx and larynx → dysphagia, dysarthria/dysphonia , absent gag reflex
Spinal nucleus and tract of the trigeminal nerve	Ipsilateral (face)	Loss of pain and temperature sensation over the ipsilateral half of the face , with retention of light-touch (dissociated sensory loss)
Lateral spinothalamic tract	Contralateral (trunk & limbs)	Loss of pain and temperature sensation over the contralateral half of the body
Vestibular nuclei (medial and inferior)	—	Vertigo, nausea, vomiting and nystagmus
Inferior cerebellar peduncle and cerebellar/spinocerebellar connections	Ipsilateral	Ataxia of gait and of the limbs, loss of equilibrium
Descending (hypothalamospinal) sympathetic fibres in the medullary reticular formation	Ipsilateral	Horner's syndrome — ptosis, miosis, enophthalmos, anhidrosis (± loss of the ciliospinal reflex)

- The combination of **ipsilateral facial** and **contralateral trunk/limb** loss of pain and temperature is the syndrome's signature — a "**crossed**" or "**alternating hemianalgesia**" pattern.
- **Structures characteristically spared** (and hence the key negative findings that distinguish this from other medullary/brainstem strokes): the **pyramid (corticospinal tract)**, the **medial lemniscus**, and the **hypoglossal nucleus/nerve** all lie more medially in the paramedian territory of the anterior spinal artery — so there is **no limb weakness, no loss of proprioception/fine touch, and no tongue paralysis**.

□ Fig 5-31 — Transverse section of the medulla oblongata at the level of the inferior olivary nuclei, showing the extent of the lesion producing the lateral medullary syndrome (Snell — *Clinical Neuroanatomy* — 7e, p.238)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse section of the medulla oblongata at the level of the inferior olivary nucleus and shade the dorsolateral wedge (PICA territory). Label, medial to lateral / dorsal to ventral:

- ▶ Cavity of the fourth ventricle, hypoglossal nucleus, dorsal nucleus of the vagus
- ▶ Medial vestibular nucleus and inferior vestibular nucleus
- ▶ Inferior cerebellar peduncle
- ▶ Spinal tract and spinal nucleus of the trigeminal nerve (dorsolateral rim)
- ▶ Lateral spinothalamic tract and anterior spinocerebellar tract
- ▶ Inferior olivary nucleus, pyramid, and the emerging hypoglossal and vagus nerve rootlets
- ▶ Shade the area supplied by the posterior inferior cerebellar artery over the spinal trigeminal tract/nucleus, vestibular nuclei, inferior cerebellar peduncle and lateral spinothalamic tract — leaving the pyramid, medial lemniscus and hypoglossal nucleus unshaded (spared territory)

3. Lateral vs medial medullary syndrome

The two classic vascular syndromes of the medulla are always contrasted in the same question and are best learned as a pair:

Feature	Lateral medullary syndrome (Wallenberg/PICA syndrome)	Medial medullary syndrome (Dejerine's anterior bulbar syndrome)
Artery occluded	Posterior inferior cerebellar artery (or vertebral artery proximal to it)	Vertebral artery / its medial medullary branches, or anterior spinal artery
Territory	Dorsolateral wedge, behind and lateral to the inferior olivary nucleus	Paramedian region — pyramid, medial lemniscus, hypoglossal nucleus
Motor deficit	None (pyramid spared)	Contralateral hemiplegia (pyramid/corticospinal fibres)
Tongue	Normal	Ipsilateral LMN paralysis of tongue muscles, deviating to the side of the lesion on protrusion (hypoglossal nerve)
Sensory deficit	Ipsilateral facial + contralateral body pain/temperature loss (spinothalamic + spinal trigeminal tract)	Contralateral loss of fine touch, vibration and position sense (medial lemniscus); pain/temperature spared
Other features	Ipsilateral ataxia, vertigo/nystagmus, Horner's syndrome, dysphagia/dysarthria	None of the above

4. Why the deficits are "crossed" — a quick mechanistic note

- ▶ The spinal trigeminal tract and nucleus carry pain/temperature fibres from the face and have not yet crossed at medullary levels — hence facial sensory loss is **ipsilateral** to the lesion.
- ▶ The lateral spinothalamic tract, carrying pain/temperature fibres from the trunk and limbs, has already crossed in the spinal cord before ascending — hence body sensory loss is **contralateral**.
- ▶ This single crossing asymmetry between the two pain/temperature pathways is what produces the pathognomonic "alternating" sensory pattern of the syndrome and is a favourite viva/short-answer trap.

Recent advances

- ▶ **Advanced non-contrast MRI for faster, higher-contrast diagnosis:** accelerated 3D-FLAIR sequences incorporating T2-preparation and magnetisation-transfer contrast pulses have been reported to shorten acquisition time while preserving high lesion contrast, improving visualisation of acute lateral medullary infarction associated with vertebral artery occlusion (Ayabe et al, *Magn Reson Med Sci* 2026) [PMID: 41936453].
- ▶ **Vertebral artery dissection as an increasingly recognised etiology in younger, active adults:** case reports describe Wallenberg syndrome following high-intensity resistance/CrossFit-type exertion and weightlifting, with delayed or missed diagnosis when initial CT is normal — reinforcing that **diffusion-weighted MRI**, not CT, is the investigation of choice (Cho et al, *Cureus* 2025 [PMID: 41278057]; Pereira et al, *Cureus* 2025 [PMID: 41281093]; Remelhe Sá et al, *Cureus* 2025 [PMID: 41613733]).
- ▶ **Hemimedullary syndrome — a rare combined variant:** simultaneous infarction of both the lateral (Wallenberg) and medial (Dejerine) medullary territories has been reported, presenting with mixed features of both syndromes and successfully treated with intravenous thrombolysis plus mechanical thrombectomy (Zhang et al, *Sci Prog* 2026) [PMID: 41983535].
- ▶ **Endovascular mechanical thrombectomy extending to PICA-territory strokes:** case series now describe stent-retriever/aspiration thrombectomy for PICA occlusion (with or without vertebral artery involvement), achieving successful recanalisation in a majority of cases and favourable functional outcome even with incomplete reperfusion, expanding acute treatment options beyond antiplatelet therapy alone (Akpınar & Dogan, *Ann Indian Acad Neurol* 2025 [PMID: 41385203]; Takahashi et al, *Surg Neurol Int* 2026 [PMID: 41660309]).
- ▶ **Structured rehabilitation pathways:** a 2026 scoping review mapping 78 reports on lateral medullary stroke found dysphagia addressed in the large majority, but explicit intervention protocols (versus generic management pathways), dosage and safety-education details remain inconsistently reported — highlighting a gap for standardised post-stroke dysphagia, gait and balance rehabilitation protocols (Izutsu et al, *NeuroRehabilitation* 2026) [PMID: 42330121].

(According to PubMed; DOIs: [10.2463/mrms.ici.2025-0175](https://doi.org/10.2463/mrms.ici.2025-0175), [10.7759/cureus.97420](https://doi.org/10.7759/cureus.97420), [10.7759/cureus.95084](https://doi.org/10.7759/cureus.95084), [10.7759/cureus.100355](https://doi.org/10.7759/cureus.100355), [10.1177/00368504261441414] (https://doi.org/10.1177/00368504261441414), [10.4103/aian.aian_580_25](https://doi.org/10.4103/aian.aian_580_25), [10.25259/SNI_861_2025])

(https://doi.org/10.25259/SNI_861_2025),
[10.1177/10538135261459633](<https://doi.org/10.1177/10538135261459633>).

Applied / Clinical anatomy

- ▶ **Imaging:** CT is frequently normal in the acute phase for small brainstem infarcts; **MRI with diffusion-weighted imaging (DWI)** is the investigation of choice to confirm the dorsolateral medullary lesion, with MR/CT angiography used to identify vertebral artery occlusion or dissection.
- ▶ **Aetiology to remember:** large-vessel atherothrombosis of the vertebral artery/PICA in older, vasculopathic patients; **vertebral artery dissection** in younger patients, classically after neck trauma, chiropractic manipulation or, as increasingly reported, strenuous exercise/heavy lifting.
- ▶ **Bedside localisation:** a patient with crossed sensory loss, ipsilateral Horner's syndrome, ipsilateral ataxia/vertigo and dysphagia/dysarthria **but no limb weakness and no tongue deviation** localises the lesion precisely to the dorsolateral (PICA-territory) medulla, distinguishing it from the medial medullary (Dejerine) syndrome.
- ▶ **Aspiration risk:** nucleus ambiguus involvement causing pharyngeal/laryngeal palsy places the patient at high risk of aspiration — formal swallow assessment is mandatory before oral feeding is resumed.
- ▶ **Lateropulsion:** vestibular and inferior-cerebellar-peduncle involvement can produce a tendency to fall towards the side of the lesion, targeted specifically by vestibular/postural rehabilitation.
- ▶ **Rare complication:** chronic ipsilateral facial hypoaesthesia from spinal trigeminal tract damage can (rarely) lead to self-inflicted skin ulceration in the trigeminal distribution — the **trigeminal trophic syndrome**.
- ▶ **Treatment:** antiplatelet/anticoagulant therapy and vascular risk-factor control remain mainstay management; endovascular thrombectomy is an emerging option in selected PICA/vertebral-artery occlusions with significant deficit.

High-yield exam pointers

- ▶ Caused by occlusion of the **PICA**, or of the **vertebral artery** proximal to it (PICA is occasionally congenitally absent).
- ▶ Infarcts the **dorsolateral medullary wedge** at the level of the **inferior olivary nucleus**.
- ▶ **Crossed/alternating sensory loss:** pain & temperature lost **ipsilaterally on the face** (spinal trigeminal tract/nucleus, uncrossed) and **contralaterally on the trunk/limbs** (lateral spinothalamic tract, already crossed).
- ▶ **Nucleus ambiguus** → ipsilateral palatal/pharyngeal/laryngeal paralysis → dysphagia, dysarthria.
- ▶ **Vestibular nuclei** → vertigo, nystagmus; **inferior cerebellar peduncle** → ipsilateral ataxia.
- ▶ **Descending sympathetic fibres** → ipsilateral **Horner's syndrome**.
- ▶ **No motor weakness** (pyramid spared) and **no tongue palsy** (hypoglossal nucleus spared) — the key negative that distinguishes it from the **medial medullary (Dejerine) syndrome**.
- ▶ MRI-DWI is the investigation of choice; CT is often normal acutely.

- ▶ A recurrently asked RGUHS Paper IV question — always be ready to tabulate it against the medial medullary syndrome.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; BD Chaurasia Human Anatomy Vol 3–4 8e; IB Singh Textbook of Human Neuroanatomy.



Neurobiotaxis

Asked in: Paper IV 13-May-2022 · Paper IV May 2011 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

Neurobiotaxis is the embryological principle that a developing neuron tends to migrate, during morphogenesis, towards the source of its maximum (predominant) afferent stimulation, and that its axon, elongating as the cell body moves, subsequently maps out and retains the pathway travelled during this migration. The concept was propounded by the Dutch neuro-anatomist **C.U. Ariëns Kappers** in 1921 ("On structural laws in the nervous system; the principles of neurobiotaxis," *Brain* 44: 125–149) to explain why the adult positions of several **cranial nerve nuclei** in the brainstem differ so markedly from their primitive embryonic sites. It is best remembered through its classic exemplar — the tortuous migratory course of the **motor nucleus of the facial (VII) nerve** — which also explains the internal genu of the facial nerve and the facial colliculus.

1. Kappers' law of neurobiotaxis

- ▶ **Statement:** a nerve cell body has a tendency to move as near as possible to its predominant source of stimulation during development; to achieve this, it migrates around any intervening structures towards the region of greatest density of afferent impulses.
- ▶ The **axon retains a record of the migration** — the direction and looped course taken by the fibres of a migrated nucleus is assumed to map out the pathway along which the cell bodies travelled.
- ▶ Originally proposed as a general law governing the position of neurons throughout the CNS; in current usage the term is applied specifically and almost exclusively to the **secondary displacement of certain cranial nerve nuclei** in the floor of the fourth ventricle/brainstem, away from their primitive alar/basal-plate positions.
- ▶ The two nuclei most often cited as exemplars of neurobiotaxis are the **motor nucleus of the facial nerve** and the **nucleus ambiguus**.

2. Embryological basis — functional cell columns of the brainstem

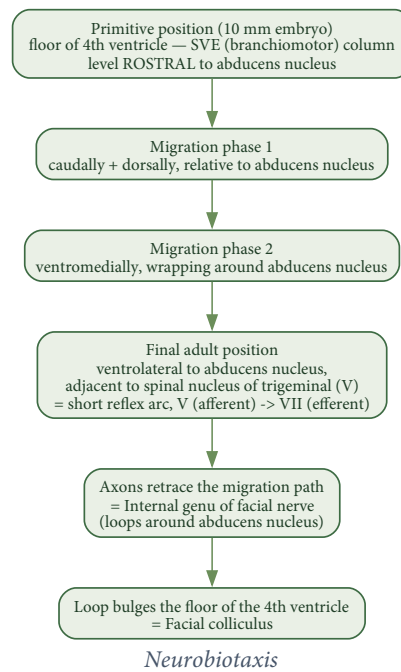
- ▶ The neural tube's alar and basal plates give rise to continuous longitudinal **functional cell columns** flanking the sulcus limitans (from dorsal to ventral): general somatic afferent (GSA), special somatic afferent (SSA), general visceral afferent (GVA), special visceral afferent (SVA) —

all alar-plate derivatives — and general visceral efferent (GVE), special visceral efferent (SVE), general somatic efferent (GSE) — basal-plate derivatives.

- ▶ With growth of the brainstem these continuous columns break up, so that each is no longer represented throughout its whole length but only by one or more **discrete nuclei** at the levels where the corresponding cranial nerves are attached.
- ▶ Some nuclei **retain their primitive position** close to the floor of the fourth ventricle (e.g. hypoglossal nucleus, dorsal nucleus of vagus, abducens nucleus, vestibular and cochlear nuclei).
- ▶ Other nuclei are **secondarily displaced**, migrating deeper into (or across) the substance of the brainstem — by differential growth of surrounding tissue, by the appearance/growth of neighbouring fibre tracts, and by active neurobiotactic migration towards the site of maximal stimulation. The **facial motor nucleus** and the **nucleus ambiguus** are the standard examples of this secondary, neurobiotaxis-driven displacement.

3. Classic exemplar — migration of the facial (VII) nerve nucleus

- ▶ In a **10 mm embryo**, the facial nucleus lies in the floor of the fourth ventricle, occupying the position appropriate to the **special visceral efferent (branchiomotor) column**, at a level **higher (more rostral)** than the abducens nucleus.
- ▶ As growth proceeds, the facial nucleus **migrates caudally and dorsally** relative to the abducens nucleus, and then **ventromedially**, wrapping around it, until it reaches its **permanent adult position ventrolateral to the abducens nucleus**, in close proximity to the **spinal nucleus of the trigeminal nerve** — the site of maximum sensory (proprioceptive) stimulation from the muscles of facial expression, carried centrally by trigeminal afferents.
- ▶ This apposition is functionally purposive: it shortens the reflex arc between the principal **sensory** input to the face (trigeminal) and the principal **motor** output to the face (facial), permitting **quick reflex responses** (e.g. the corneal/blink reflex).
- ▶ Because the nucleus migrates *after* some of its axons have already begun to grow out from its original dorsal position, the intrapontine fibres of the facial nerve are obliged to follow a secondary, looped course to reach their final exit point — this looped intrapontine course is the **internal genu of the facial nerve**.



4. Structural consequences in the adult brainstem

Structure	Relation to neurobiotaxis of the facial nucleus
Internal genu of the facial nerve	The loop of facial-nerve fibres around the dorsomedial aspect of the abducens nucleus, produced because the axons must reach the exit point from a nucleus that has since migrated ventrolaterally
Facial colliculus	The rounded elevation in the floor of the fourth ventricle (medial eminence, caudal pons) produced by the internal genu of VII looping over the abducens nucleus
Abducens (VI) nucleus	Retains its primitive position beneath the facial colliculus, close to the midline, just lateral to the medial longitudinal fasciculus (MLF) — the structure around which the migrating facial fibres loop
Spinal nucleus of trigeminal nerve	The "target" of facial-nucleus migration — final position of VII nucleus lies close to this column, completing a short somatic-sensory–branchiomotor reflex loop

5. Other examples and the broader reflex-arc concept

- **Nucleus ambiguus** (special visceral efferent nucleus of IX, X and the cranial root of XI) is the second classical exemplar: it arises immediately deep to the ventricular floor but, in the adult, lies **much more deeply** placed in the medullary reticular formation; its efferent fibres pass **first dorsally and medially**, then curve **laterally** to emerge at the surface of the medulla — a migratory course again attributed to neurobiotaxis.

- More broadly, neurobiotaxis is invoked to explain why several cranial nerve nuclei come to lie paired for fast **afferent–efferent reflex loops**: the largely sensory trigeminal (V) nucleus with the facial (VII) motor nucleus (corneal/blink reflex); the vestibulocochlear (VIII) afferents with the accessory (XI)/oculomotor group for reflex head-turning and eye movements towards a sound or visual stimulus; and the solitary tract nucleus (taste, IX/X/VII afferents) with the hypoglossal (XII) nucleus for coordinated tongue movements during swallowing.
- The unifying idea in all these examples is the same: **a motor nucleus migrates towards its principal sensory (stimulus) partner**, shortening synaptic delay and sharpening reflex speed — the biological "purpose" ascribed to neurobiotaxis.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 9.2 — Surface projection of cranial nerve nuclei on the dorsal aspect of the (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.298)

Reproduce a schematic transverse section through the **caudal pons** (level of the facial colliculus) and label: **floor of the fourth ventricle**, **facial colliculus**, **abducens (VI) nucleus** (beneath the colliculus, lateral to the MLF), the **internal genu of the facial nerve** looping around the abducens nucleus, the **motor nucleus of the facial nerve** in its final ventrolateral position, the **spinal nucleus and tract of the trigeminal nerve** (the migration "target"), and the **medial longitudinal fasciculus (MLF)**. Beside it, draw two small outline sketches — "primitive (10 mm embryo) position" and "adult position" of the facial nucleus relative to the abducens nucleus — with a curved arrow showing the migratory path (caudal → dorsal → ventromedial), to visually demonstrate the law of neurobiotaxis.

Applied / Clinical anatomy

- **Facial colliculus syndrome** — a small lesion (vascular, demyelinating, or neoplastic) in the dorsal caudal-pontine tegmentum damages the internal genu of the facial nerve together with the underlying abducens nucleus/nerve, producing an **ipsilateral lower motor neurone facial palsy** combined with an **ipsilateral lateral rectus (abducens) palsy** — a direct clinical signature of the neurobiotactic looping relationship between VII and VI.
- **Millard–Gubler syndrome** (ventral pontine lesion, e.g. paramedian branch of basilar artery) — ipsilateral CN VI and VII palsy with **contralateral hemiplegia** (corticospinal tract), because the facial and abducens fibres/nuclei lie close together in the pons as a consequence of this migration.
- **Foville's syndrome** (dorsal pontine tegmental lesion) — ipsilateral CN VI and VII palsy plus an ipsilateral **conjugate horizontal gaze palsy** (paramedian pontine reticular formation) with contralateral hemiparesis; again reflects the tight anatomical grouping of VI, VII and the MLF that results from the migrated facial nucleus looping around the abducens nucleus.
- **Corneal (blink) reflex** — the short reflex arc made possible by neurobiotaxis: afferent limb via the ophthalmic division of the trigeminal nerve to the (spinal) trigeminal nucleus, efferent limb via the facial nerve to orbicularis oculi; its **absence is one of the clinical criteria used in the determination of brainstem death**.

- ▶ **Localising value in neurosurgery/neurology** — because the facial colliculus overlies both the VI and VII intrapontine pathways, its bulge is a key floor-of-fourth-ventricle landmark during posterior fossa surgery, and any lesion here characteristically produces the combined VI + VII picture rather than an isolated cranial-nerve palsy — a strong pointer to an **intrapontine** rather than peripheral or cerebellopontine-angle lesion.

High-yield exam pointers

- ▶ **Definition:** tendency of a developing neuron to migrate towards its predominant source of stimulation; propounded by C.U. Ariëns Kappers (1921).
- ▶ Classic exemplars: **motor nucleus of the facial nerve** and the **nucleus ambiguus**.
- ▶ Facial nucleus: primitive position **rostral/dorsal** to abducens nucleus (10 mm embryo, SVE column) → migrates **caudally, dorsally, then ventromedially** → final position **ventrolateral** to abducens nucleus, next to the **spinal nucleus of trigeminal**.
- ▶ Purpose of migration: to lie close to the trigeminal (sensory) nucleus and shorten the **reflex arc** (e.g. corneal reflex) — motor nucleus moves towards the site of maximum sensory stimulation.
- ▶ Consequence: the facial-nerve axons loop around the abducens nucleus = **internal genu of the facial nerve**, producing the **facial colliculus** in the floor of the fourth ventricle.
- ▶ Nucleus ambiguus: primitively superficial, becomes **deeply placed**; its efferents pass dorsally and medially before curving laterally to the medullary surface — also attributed to neurobiotaxis.
- ▶ Clinical correlate: combined VI + VII nerve palsy (facial colliculus/Millard–Gubler/Foville syndromes) localises a lesion to the **caudal pontine tegmentum**, directly traceable to this migratory relationship.
- ▶ Some cranial nerve nuclei (hypoglossal, dorsal vagal, abducens itself, vestibular/cochlear) **retain** their primitive dorsal position — neurobiotaxis explains the exceptions, not the rule.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Clinical Neuroanatomy 4e; IB Singh — Textbook of Human Neuroanatomy; IB Singh — Textbook of Anatomy Vol 3 6e; BD Chaurasia — Human Anatomy Vol 3-4 8e.



Abducent nerve

Asked in: Paper IV 14-Jul-2023 — RGUHS MD/MS Anatomy

Definition / Introduction. The abducent (abducens) nerve is the sixth cranial nerve — a purely **somatic efferent (motor)** nerve arising from a nucleus in the caudal pons and distributed to a single muscle, the **lateral rectus**, which it enables to abduct the eyeball. Though functionally the simplest of the three ocular motor nerves, it has the **longest and most acutely angulated intracranial course** of any cranial nerve relative to its size, running from the pontomedullary junction, up the clivus, through the cavernous sinus and into the orbit. This long, exposed course makes it exceptionally vulnerable to stretch, compression and raised intracranial pressure, and its isolated palsy is the single most common ocular motor nerve palsy encountered clinically.

1. Functional component, nucleus and central connections

- ▶ **Functional component:** general somatic efferent (GSE) fibres only — no sensory or parasympathetic component.
- ▶ **Abducens nucleus:** a group of about **6500 neurones** lying in the upper floor of the fourth ventricle in the caudal pons, beneath the **facial colliculus**; it is in line with the oculomotor, trochlear and hypoglossal nuclei, forming the paramedian somatic-efferent cell column of the brainstem.
- ▶ **Relations of the nucleus:** ventromedially it is closely related to the **medial longitudinal fasciculus (MLF)**; the looping fibres of the facial nerve (**internal genu**) wind around it, and together they raise the facial colliculus on the ventricular floor — a lesion here damages both nuclei (facial colliculus syndrome).
- ▶ **Two neurone populations** within the nucleus:
- ▶ **Large motor neurones** — axons leave ipsilaterally to supply the lateral rectus.
- ▶ **Small internuclear neurones** — axons cross the midline at the level of the nucleus and ascend in the contralateral MLF to reach the medial rectus subnucleus of the **opposite oculomotor nuclear complex**.
- ▶ This crossed internuclear projection is the anatomical basis of **conjugate lateral gaze** (Hering's law of yoke muscles) — a single command from the **paramedian pontine reticular formation (PPRF)**, the ipsilateral horizontal gaze centre lying close to the nucleus, simultaneously drives the ipsilateral lateral rectus and the contralateral medial rectus so both eyes move together.
- ▶ **Corticonuclear input** to the nucleus is principally crossed (contralateral), consistent with its role in horizontal conjugate gaze rather than isolated single-eye movement.

2. Intracranial (cisternal) course

- ▶ Axons pass ventrally through the trapezoid body, medial lemniscus and basilar pons to emerge at the **lower border of the pons**, in the groove between the pons and the medulla (pontomedullary junction), medial to the facial and vestibulocochlear nerves and in line with the rootlets of the hypoglossal nerve, opposite the upper end of the pyramid.
- ▶ It ascends through the **cisterna pontis** (prepontine subarachnoid cistern), running forwards, upwards and laterally, usually **dorsal to the anterior inferior cerebellar artery**, in close contact

with the clivus within or beneath the dura — this long free intracranial run, out of proportion to the nerve's small size, is the key point of surgical/clinical importance.

- ▶ Near the base of the skull it pierces the dura **lateral to the dorsum sellae**, passing beneath the **petroclinoid (petrosphenoidal) ligament of Gruber**, where it makes a **sharp bend forward over the superior border of the petrous temporal bone** to enter the posterior wall of the cavernous sinus, superior to the apex of the petrous bone.
- ▶ This combination of a long cisternal course plus a sharp angulation over an unyielding bony/ligamentous edge explains why the nerve is so easily stretched or compressed.

3. Relations within the cavernous sinus

- ▶ Unlike the oculomotor, trochlear and the ophthalmic/maxillary divisions of the trigeminal nerve, which are all embedded in the **lateral wall** of the cavernous sinus, the **abducent nerve runs freely within the substance of the sinus itself**, alongside the internal carotid artery and its accompanying carotid sympathetic plexus.
- ▶ Within the sinus it lies close to, and then inferolateral/posterolateral to, the internal carotid artery, running forward to the medial end of the superior orbital fissure.

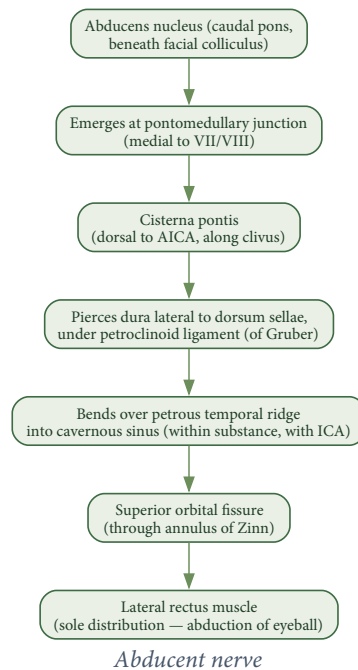
Site	Structures
Lateral wall of sinus (superior to inferior)	Oculomotor (III), Trochlear (IV), Ophthalmic (V1), Maxillary (V2) nerves
Within the sinus	Internal carotid artery, carotid sympathetic plexus, Abducent nerve (VI)

(Mnemonic: "O-TOM-CAT" — Oculomotor, Trochlear, Ophthalmic, Maxillary in the wall; Carotid Artery and Abducens inside.)

- ▶ This exposed intrasinusoidal position is why an isolated VI nerve palsy is often the earliest or most prominent sign of a cavernous sinus lesion (thrombosis, fistula, tumour, aneurysm).

4. Orbital course and distribution

- ▶ The nerve enters the orbit through the **middle part of the superior orbital fissure**, passing through the **common tendinous ring (annulus of Zinn)** together with the oculomotor and nasociliary nerves — within the fissure it lies **inferolateral** to these two nerves.
- ▶ In the orbit it runs forward and enters the **ocular (medial) surface of the lateral rectus muscle**, which it alone supplies.
- ▶ It carries no fibres to any other muscle, gland or area of skin — its entire peripheral distribution is the lateral rectus.



DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 6.8 — Abducent nerve: origin, course and distribution (IB Singh — Textbook of Human Neuroanatomy, p.102)

Reproduce a sagittal/schematic view of the base of the brain and orbit, labelling in sequence:

- ▶ **Abducens nucleus** in the floor of the fourth ventricle, beneath the **facial colliculus**, with the MLF medial to it
- ▶ **Site of emergence** at the pontomedullary junction, medial to VII and VIII, opposite the pyramid
- ▶ **Cisterna pontis**, with the nerve passing close to the **anterior inferior cerebellar artery**
- ▶ The nerve crossing the **clivus**, piercing dura **lateral to the dorsum sellae**, beneath the **petroclinoid ligament**, and bending over the **superior border of the petrous temporal bone**
- ▶ Course **within the cavernous sinus**, alongside the **internal carotid artery** and **carotid sympathetic plexus** (mark III, IV, V1, V2 in the adjacent lateral wall for contrast)
- ▶ Entry into the orbit via the **superior orbital fissure** and **annulus of Zinn**
- ▶ Termination in the **lateral rectus muscle**

Applied / Clinical anatomy

- ▶ **Lateral rectus palsy** — paralysis produces a **medial (convergent) squint** from the unopposed medial rectus, with **horizontal diplopia** that is maximal on attempted gaze towards the side of the lesion and typically worsens with distance fixation.
- ▶ **Sixth nerve palsy as a false localizing sign** — in raised intracranial pressure of any cause, the abducens nerve is the cranial nerve most often paralysed **without local pathology near it**, because its long cisternal course and sharp bend over the petrous ridge make it vulnerable to stretching when the brainstem is displaced caudally towards the foramen magnum; this palsy therefore has no localising value for the site of the primary lesion.

- ▶ **Cavernous sinus syndrome/thrombosis** — septic thrombophlebitis spreading from the "dangerous area" of the face, orbit, or paranasal sinuses via the valveless facial → ophthalmic → cavernous venous route produces painful total ophthalmoplegia (III, IV, VI), with lesser or later involvement of V1/V2 (lateral wall) and proptosis/chemosis from venous congestion.
- ▶ **Gradenigo syndrome** — petrous apicitis/inferior petrosal sinus thrombosis complicating middle-ear or mastoid infection involves the abducens nerve as it bends over the petrous apex, together with the trigeminal nerve, producing ipsilateral VI nerve palsy with facial pain and otorrhoea.
- ▶ **Pontine vascular (crossed brainstem) syndromes:**
 - **Raymond syndrome** — basal pontine infarct involving abducens fibres (ipsilateral lateral rectus palsy) + corticospinal tract (contralateral hemiplegia).
 - **Millard–Gubler syndrome** — basal pontine lesion of facial nerve fibres (ipsilateral facial palsy) + corticospinal tract (contralateral hemiplegia); an extensive lesion also involves abducens fibres.
 - **Foville syndrome** — dorsomedial pontine lesion of the facial nucleus/fibres, abducens nucleus, and the adjacent PPRF, giving ipsilateral facial paralysis with ipsilateral gaze palsy (failure of conjugate gaze towards the side of the lesion).
- ▶ **Internuclear ophthalmoplegia (INO)** — a lesion of the MLF between the abducens and oculomotor nuclei (classically demyelination in multiple sclerosis) causes failure of adduction of the ipsilateral eye on attempted conjugate gaze to the opposite side, with nystagmus of the abducting (contralateral) eye; convergence is preserved as it does not require the MLF pathway.
- ▶ **Duane retraction syndrome** — a congenital anomaly attributed to maldevelopment of the abducens nucleus/nerve; presents with limited abduction (and often limited adduction), narrowing of the palpebral fissure and retraction of the globe on attempted adduction due to co-contraction of the medial and lateral recti.
- ▶ **Iatrogenic/traumatic injury** — the nerve's long free course renders it susceptible to injury in basal skull fractures, during posterior fossa or skull-base surgery, and in lumbar puncture/reduced-CSF-pressure headache (traction on the nerve from downward brain sag).

Recent advances

- ▶ **High-resolution MRI now identifies cisternal-segment avulsion, not just skull-base fracture, as an important and previously underrecognised mechanism of traumatic abducens palsy;** in a retrospective series of 31 patients, strabismus surgery gave the best symptomatic recovery, followed by neurosurgical repair (including trigeminal-motor-branch-to-abducens nerve anastomosis for complete avulsions), while medical management alone gave the least improvement (Zhang et al., *Neurosurgical Review*, 2026) [DOI: 10.1007/s10143-025-04110-y].
- ▶ **Muscle-transposition surgery remains the mainstay for combined oculomotor + abducens palsy with aberrant regeneration,** with transposition performed in the direction of the aberrant movement producing good orthotropic outcomes in reported cases (Kaur et al., *Strabismus*, 2025) [DOI: 10.1080/09273972.2024.2447741].
- ▶ **Isolated abducens nerve palsy is recognised as an early, usually self-limited neurological complication of COVID-19,** occurring at a median of 5–6 days after infection onset, typically

with unremarkable brain MRI, and with complete or near-complete recovery within about a month in most patients even without corticosteroid treatment (Tan & Lin, *Neurology India*, 2025) [DOI: 10.4103/neurol-india.Neurol-India-D-24-00411].

► (According to PubMed.)

High-yield exam pointers

- Purely **somatic efferent (GSE)** nerve — supplies only the **lateral rectus**; no sensory or autonomic component.
- Nucleus in **caudal pons beneath the facial colliculus**, encircled by the internal genu of the facial nerve; internuclear neurones cross and ascend the MLF to the contralateral medial rectus subnucleus of CN III — basis of conjugate lateral gaze.
- Emerges at the **pontomedullary junction**, medial to VII/VIII, opposite the pyramid; has the **longest intracranial course** of any cranial nerve for its size.
- Bends sharply over the **superior border of the petrous temporal bone**, beneath the **petroclinoid ligament (of Gruber)**, before entering the cavernous sinus.
- **Only cranial nerve lying free within the substance of the cavernous sinus** (with the ICA and its sympathetic plexus) — III, IV, V1, V2 are in the lateral wall.
- Enters the orbit through the **superior orbital fissure within the annulus of Zinn**.
- Palsy → **medial squint + horizontal diplopia**; classic **false localizing sign** of raised intracranial pressure.
- Key applied syndromes: **Gradenigo, Raymond, Millard–Gubler, Foville, internuclear ophthalmoplegia, Duane retraction syndrome**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; Vishram Singh's Textbook of Anatomy Vol 3 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e; Snell's Clinical Neuroanatomy 7e; Moore's Clinically Oriented Anatomy 9e; AK Datta's Human Anatomy Vol 2 (Head & Neck); IB Singh's Textbook of Anatomy Vol 3 6e; Larsen's Human Embryology 6e (Duane anomaly). Recent-advances section per PubMed (see DOIs above).



Corpora Quadrigemina

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction The **corpora quadrigemina** ("four bodies") is the collective name for the four rounded eminences — two **superior** and two **inferior colliculi** — that form the **tectum** (roof) of the midbrain, lying dorsal to the cerebral aqueduct. The superior colliculi are the larger, rostral pair and serve as **visual reflex centres**; the inferior colliculi are the smaller, caudal pair and form an important relay station of the **ascending auditory pathway**. Each colliculus is connected to its corresponding thalamic geniculate body by a ridge of white matter, the **brachium**, so that the tectum links the special senses of vision and hearing to reflex motor outflow of the eyes, head and neck. Its relations to the pineal gland and posterior commissure make it a common site of clinically important compressive lesions.

Gross features and relations of the tectum

- ▶ The tectum lies on the **dorsal surface of the midbrain**, rostral to the superior medullary velum, caudal to the posterior commissure, and inferior to the **pineal gland**, which occupies the depression between the two superior colliculi.
- ▶ Below the splenium of the corpus callosum, the colliculi are inferior and medial to the **pulvinar of the thalamus**.
- ▶ The four colliculi are separated from one another by a **cruciform sulcus** — a vertical limb and a horizontal (transverse) limb.
 - The **upper end of the vertical limb** expands into a shallow depression that lodges the pineal gland.
 - The **lower end** continues as the **frenulum veli**, a median ridge on the dorsal surface of the superior medullary velum; the **trochlear nerve** emerges just lateral to the frenulum, caudal to the inferior colliculus — the only cranial nerve to emerge from the dorsal aspect of the brainstem.
 - The **horizontal limb** separates the superior pair from the inferior pair.
- ▶ A thick ridge of white matter, the **brachium**, runs ventrolaterally from the lateral aspect of each colliculus:
 - The **superior (quadrigeminal) brachium** passes below the pulvinar, partly overlapping the medial geniculate body, and carries **optic tract (retinal) fibres** to the superior colliculus.
 - The **inferior (quadrigeminal) brachium** ascends ventrally and carries **lateral-lemniscus/auditory fibres** from the inferior colliculus to the **medial geniculate body**.
- ▶ Functionally, the **superior colliculi** subserve **visual reflexes** (larger of the two) and the **inferior colliculi** subserve **auditory reflexes**.

Position of the tectum within the subdivisions of the midbrain

- ▶ A coronal plane through the **cerebral aqueduct** divides the midbrain into a small **posterior (dorsal) part** — the **tectum** — and a larger **anterior (ventral) part**, further split by a vertical plane into right and left **cerebral peduncles**.
- ▶ Each cerebral peduncle has, from dorsal to ventral: the **tegmentum**, the **substantia nigra**, and the **crus cerebri (basis pedunculi)**.

- The **central (periaqueductal) grey matter** surrounds the aqueduct and separates tectum from tegmentum; it contains cranial nerve nuclei (trochlear and oculomotor ventrally, mesencephalic nucleus of the trigeminal nerve dorsolaterally) at the corresponding levels.
- Because the internal structure of the tectum and tegmentum changes with level, the midbrain is conventionally studied in transverse section at two planes — through the **inferior colliculi** and through the **superior colliculi**.

Superior colliculus — structure and connections

The superior colliculus is a **flattened mass of seven concentric, alternating laminae of white and grey matter** — superficial laminae relaying visual input, deeper laminae integrating auditory/somatosensory input and giving rise to motor outflow.

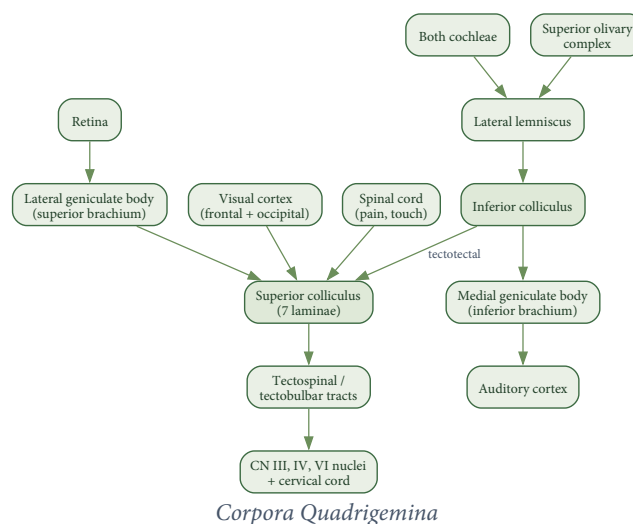
	Source / destination	Pathway	Function
Afferent	Retina (mainly contralateral)	Optic tract → lateral geniculate body → superior brachium	Direct visual input
Afferent	Spinal cord	Spinotectal tract	Pain and tactile impulses
Afferent	Frontal and occipital visual cortex	Corticotectal fibres	Conjugate eye movements
Afferent	Inferior colliculus	Tectotectal fibres	Auditory input for audiovisual orienting
Efferent	Nuclei of CN III, IV, VI + cervical cord	Tectospinal and tectobulbar tracts (decussate as the dorsal tegmental decussation of Meynert)	Reflex movement of eyes, head, neck to visual stimuli
Efferent	Red nucleus, substantia nigra, reticular formation	Tectotegmental tract	Modulation of extrapyramidal centres
Efferent	Cerebellar cortex	Tectocerebellar tract	Coordination of gaze/posture

Closely related to its cranial pole is the **pretectal nucleus**, which receives fibres from the lateral root of the optic tract and projects bilaterally to the **Edinger–Westphal nucleus** — the anatomical basis of the **pupillary light and consensual light reflex**.

Inferior colliculus — structure and connections

The inferior colliculus consists of a large, ovoid **central nucleus** of grey matter lying in the tectum, lateral to the periaqueductal grey matter, surrounded by a lamina of incoming fibres. It is an important **cell station and reflex centre of the auditory pathway**, and each colliculus receives impulses from **both ears**.

	Source / destination	Pathway	Function
Afferent	Lateral lemniscus (ascending auditory fibres)	Terminates directly in the nucleus	Principal auditory input, bilateral
Afferent	Superior olivary complex	Via lateral lemniscus	Binaural input for sound localisation
Efferent	Medial geniculate body	Inferior brachium	Relay to auditory cortex
Efferent	Contralateral inferior colliculus	Commissural fibres	Interaural integration
Efferent	Superior colliculus (same side)	Tectotectal fibres	Superior colliculus then relays auditory signal to spinal cord via tectospinal tract (reflex head/eye turning to sound)



Blood supply

- ▶ The midbrain, and with it the tectum, is supplied chiefly by branches of the **basilar artery**: the **posterior cerebral**, **superior cerebellar**, and direct pontine/mesencephalic branches, supplemented by the **posterior communicating** and **anterior choroidal arteries**.
- ▶ Branches are described as **paramedian** (supplying structures near the midline) or **circumferential** (winding round the midbrain to supply lateral and dorsal parts).
- ▶ One such circumferential vessel, the **quadrigeminal artery** (arising from the posterior cerebral/superior cerebellar territory), is the **main source of blood to the colliculi**.
- ▶ Venous drainage is via the **great cerebral vein** and the **basal vein (of Rosenthal)**.

□ Fig 12.2 — Posterior view of the brainstem showing the thalamus and the tectum of the midbrain (Snell — *Clinical Neuroanatomy* — 7e, p.393)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the dorsal (posterior) aspect of the brainstem and label:

- ▶ **Superior colliculi** (pair, rostral, larger) and **inferior colliculi** (pair, caudal, smaller) — together the **corpora quadrigemina**, separated by the **cruciform sulcus**.
- ▶ **Pineal gland**, lodged in the depression above the superior colliculi; **pulvinar of thalamus** superolateral to the colliculi.
- ▶ **Superior brachium** running from superior colliculus to **lateral geniculate body**; **inferior brachium** running from inferior colliculus to **medial geniculate body**.
- ▶ **Frenulum veli** continuing the cruciform sulcus below the inferior colliculi, with the **trochlear nerve (IV)** emerging just lateral to it.
- ▶ **Superior medullary velum**, superior and middle cerebellar peduncles below, and the **facial colliculus** further caudally in the floor of the fourth ventricle (for orientation).

Applied / Clinical anatomy

- ▶ **Parinaud's syndrome (dorsal midbrain syndrome)** — compression of the tectum at the level of the superior colliculi/posterior commissure, classically by a **pineal gland tumour** (pinealoma/germinoma), produces **paralysis of upward gaze** with light–near dissociation of the pupils; convergence-retraction nystagmus and lid retraction (Collier's sign) may accompany it.
- ▶ **Pretectal nucleus lesions** → **Argyll Robertson pupil** — light reflex lost, accommodation reflex preserved, classically in neurosyphilis.
- ▶ **Unilateral superior colliculus lesion** causes relative neglect of contralateral visual stimuli and defective tracking of moving objects, although basic eye movements remain normal.
- ▶ **Inferior colliculus/brachium lesions** impair tonal discrimination, sound localisation, and reflex (startle) turning of the head/eyes toward sound.
- ▶ **Aqueductal compression by tectal/pineal masses** obstructs CSF flow through the cerebral aqueduct, producing **obstructive (non-communicating) hydrocephalus**.
- ▶ **Radiological correlate** — on midsagittal MRI the corpora quadrigemina are readily identified caudal to the pineal gland and are a key landmark for localising pineal-region masses and assessing aqueductal patency; the "quadrigeminal cistern" (behind the tectum, containing the great cerebral vein) is an important surgical corridor for pineal-region tumours.

High-yield exam pointers

- ▶ Corpora quadrigemina = **tectum of midbrain** = 2 superior + 2 inferior colliculi, separated by the cruciform sulcus.
- ▶ **Superior colliculi (larger, rostral)** = visual reflex centre; **inferior colliculi (smaller, caudal)** = auditory relay/reflex centre.
- ▶ **Superior brachium** → lateral geniculate body (optic fibres); **inferior brachium** → medial geniculate body (auditory fibres).
- ▶ Superior colliculus efferents = **tectospinal/tectobulbar tracts**, decussating at the **dorsal tegmental decussation of Meynert**.

- ▶ Inferior colliculus receives bilateral cochlear input via the **lateral lemniscus**; relays to medial geniculate body → auditory cortex.
- ▶ **Pretectal nucleus** (near superior colliculus) = pupillary light reflex relay; lesion → Argyll Robertson pupil.
- ▶ **Parinaud's syndrome** = paralysis of upward gaze from a pineal-region mass compressing the tectum.
- ▶ Main arterial supply of the colliculi = the **quadrigeminal artery**, a circumferential branch in the basilar-artery territory.
- ▶ Trochlear nerve (IV) is the only cranial nerve emerging from the dorsal brainstem, just caudal to the inferior colliculi.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e; BD Chaurasia Human Anatomy Vol 3–4 8e (figure reference).



Cranial nerve nuclei in the brain stem

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction. Cranial nerve nuclei are collections of neuron cell bodies within the grey matter of the brain stem that constitute either the origin of efferent (motor) cranial nerve fibres or the site of termination of afferent (sensory) cranial nerve fibres. Ten of the twelve cranial nerves (III–XII) are attached to the brain stem — the oculomotor and trochlear to the midbrain; the trigeminal, abducens, facial and (part of) vestibulocochlear to the pons; and the glossopharyngeal, vagus, cranial accessory and hypoglossal to the medulla. These nuclei are organised into longitudinal functional cell columns that mirror the basal (motor) and alar (sensory) plates of the embryonic neural tube, separated throughout development by the **sulcus limitans**.

Embryological basis of the columnar arrangement

- ▶ The **sulcus limitans** divides each half of the floor of the developing fourth ventricle into a medial **basal lamina** (gives rise to efferent/motor nuclei) and a lateral **alar lamina** (gives rise to afferent/sensory nuclei).
- ▶ Within each lamina, **visceral nuclei lie nearer the sulcus limitans** than somatic nuclei, and within each category the **general** nucleus lies nearer the sulcus limitans than the **special** nucleus.
- ▶ Proceeding from medial to lateral, the classical sequence of seven functional columns is:

Order (medial→lateral)	Functional column	Abbreviation	Lamina
1	Somatic efferent (not subdivided into general/special)	SE	Basal (motor)

Order (medial→lateral)	Functional column	Abbreviation	Lamina
2	Special visceral (branchial) efferent	SVE	Basal (motor)
3	General visceral efferent	GVE	Basal (motor)
4	General visceral afferent	GVA	Alar (sensory)
5	Special visceral afferent	SVA	Alar (sensory)
6	General somatic afferent	GSA	Alar (sensory)
7	Special somatic afferent	SSA	Alar (sensory)

- ▶ As development proceeds, each column no longer runs the whole length of the brain stem but is represented by one or more discrete, discontinuous nuclei; some nuclei retain their original subependymal position on the floor of the fourth ventricle (e.g. hypoglossal, dorsal vagal, abducens, facial-colliculus region) while others migrate deep to the surface (e.g. nucleus ambiguus, trigeminal motor nucleus).
- ▶ **Gray's Anatomy** groups the afferent components functionally into three columns rather than four, because the general and special visceral afferents converge on a single nucleus (the nucleus solitarius, with a rostral gustatory part and a caudal cardiorespiratory part) — giving **six discontinuous columns overall (three sensory, three motor)**. The seven-column scheme above is the standard teaching format used to derive the individual nuclei and is followed in the table below.

Functional columns and their nuclei

Functional column	Nuclei (rostral → caudal)	Cranial nerve(s)	Function
SE — somatic efferent	Oculomotor, Trochlear, Abducens, Hypoglossal	III, IV, VI, XII	Motor to extraocular muscles (III, IV, VI) and tongue muscles except palatoglossus (XII)
SVE — branchiomotor	Trigeminal motor nucleus, Facial nucleus, Nucleus ambiguus	V, VII, IX/X/cranial XI	Motor to muscles of pharyngeal-arch origin (mastication, facial expression, pharynx/larynx)
GVE — parasympathetic	Edinger–Westphal nucleus, Superior + inferior salivatory nuclei, Dorsal motor nucleus of vagus	III, VII & IX, X	Preganglionic parasympathetic outflow (pupillary sphincter/ciliary, lacrimal/salivary glands, thoracoabdominal viscera)

Functional column	Nuclei (rostral → caudal)	Cranial nerve(s)	Function
GVA — general visceral afferent	Nucleus solitarius (caudal, cardiorespiratory part)	VII, IX, X	Visceral sensation — cardiovascular, respiratory, gastrointestinal reflex afferents
SVA — special visceral afferent	Nucleus solitarius (rostral, gustatory part)	VII, IX, X	Taste from anterior 2/3 tongue (VII), posterior 1/3 tongue (IX), epiglottis/larynx (X)
GSA — general somatic afferent	Trigeminal sensory complex — mesencephalic, principal (pontine) sensory, and spinal nuclei	V (also touch component of VII, IX, X from external ear/pharynx)	Exteroceptive (touch, pain, temperature) and proprioceptive sensation of the face and jaw muscles
SSA — special somatic afferent	Vestibular nuclear complex (superior, lateral, medial, inferior) and Cochlear nuclei (dorsal, ventral)	VIII	Vestibular (balance) and auditory sensation

Distribution by level of the brain stem

Level	Motor (efferent) nuclei	Sensory (afferent) nuclei
Midbrain	Oculomotor nucleus (III), Edinger–Westphal nucleus (III), Trochlear nucleus (IV)	Mesencephalic nucleus of trigeminal nerve (V)
Pons	Abducens nucleus (VI), Motor nucleus of trigeminal nerve (V), Facial nucleus (VII), Superior salivatory nucleus (VII)	Principal (pontine) sensory nucleus of trigeminal nerve (V), Vestibulocochlear nuclei (VIII)
Medulla	Hypoglossal nucleus (XII), Nucleus ambiguus (IX, X, cranial XI), Inferior salivatory nucleus (IX), Dorsal motor nucleus of vagus (X)	Nucleus solitarius (VII, IX, X), Spinal nucleus of trigeminal nerve (V), caudal Vestibulocochlear nuclei (VIII)
Spinal cord (C1–C5/6)	Nucleus of the spinal root of the accessory nerve	—

Salient features of individual nuclei

- **Oculomotor complex:** midbrain, superior-colliculus level; main (SE) nucleus supplies four extraocular muscles + levator palpebrae superioris; dorsomedial **Edinger–Westphal nucleus** gives preganglionic fibres to the ciliary ganglion (sphincter pupillae, ciliaris).
- **Trochlear nucleus:** inferior-colliculus level, caudal to oculomotor; fibres decussate in the superior medullary velum — the only cranial nerve emerging dorsally.

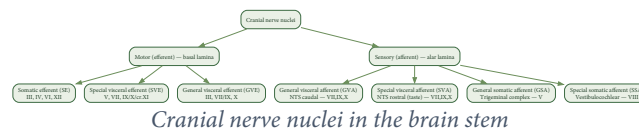
- ▶ **Trigeminal sensory complex:** longest nuclear column (midbrain to C2). **Mesencephalic nucleus** (proprioception, mastication muscles) — midbrain; **principal/pontine sensory nucleus** (touch) — pons; **spinal nucleus** (pain, temperature), continuous with substantia gelatinosa — pons to medulla to C2.
- ▶ **Trigeminal motor nucleus:** pons, medial to principal sensory nucleus; supplies muscles of mastication, mylohyoid, anterior digastric, tensor tympani, tensor veli palatini.
- ▶ **Abducens nucleus:** caudal pons beneath the **facial colliculus**, encircled by the internal genu of the facial nerve — a lesion here gives combined VI + VII palsy.
- ▶ **Facial nucleus:** ventrolateral tegmentum of caudal pons; fibres loop around the abducens nucleus (internal genu) before emerging at the pontomedullary junction. Upper-face part has **bilateral** corticonuclear supply; lower-face part is **only crossed**.
- ▶ **Salivatory nuclei:** diffuse pontomedullary reticular cell groups; superior (via VII) supplies lacrimal, submandibular, sublingual glands; inferior (via IX) supplies the parotid.
- ▶ **Vestibulocochlear nuclei:** vestibular (superior, lateral/Deiters, medial, inferior) beneath the vestibular area of the fourth-ventricle floor; cochlear (dorsal, ventral) cap the inferior cerebellar peduncle.
- ▶ **Nucleus ambiguus:** deep medullary reticular formation, dorsal to the inferior olive; branchiomotor to soft palate, pharynx, larynx via IX, X and the cranial root of XI.
- ▶ **Dorsal motor nucleus of vagus:** medulla, beneath the vagal triangle, lateral to the hypoglossal nucleus; principal parasympathetic outflow to thoracic/abdominal viscera.
- ▶ **Nucleus solitarius:** runs the length of the medulla; rostral **gustatory** part (taste, VII/IX/X) and caudal **cardiorespiratory** part (baroreceptor/chemoreceptor/GI reflex afferents).
- ▶ **Hypoglossal nucleus:** paramedian, beneath the hypoglossal trigone; supplies tongue muscles except palatoglossus; predominantly crossed corticonuclear input.
- ▶ **Nucleus of the spinal accessory nerve:** ventral grey column, upper cervical (C1–C5/6) cord, in line with nucleus ambiguus; supplies sternocleidomastoid and trapezius.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 5.16 — Position of the cranial nerve nuclei within the brainstem (Snell — Clinical Neuroanatomy — 7e, p.225)

Reproduce a dorsal-view schema of the brain stem (posterior aspect, cerebellum removed) with the floor of the fourth ventricle exposed. Label:

- ▶ **Sulcus limitans** running the length of the ventricular floor, dividing it into medial and lateral zones
- ▶ Medial (motor) column, lateral to midline: **Oculomotor nucleus, Trochlear nucleus, Abducens nucleus, Hypoglossal nucleus** (rostral→caudal)
- ▶ Next lateral (branchiomotor): **Trigeminal motor nucleus, Facial nucleus, Nucleus ambiguus**
- ▶ Next lateral (parasympathetic): **Edinger–Westphal nucleus, Salivatory nuclei** (superior/inferior), **Dorsal motor nucleus of vagus**
- ▶ Lateral to sulcus limitans (sensory, medial→lateral): **Nucleus solitarius, Trigeminal sensory nuclei** (mesencephalic, principal, spinal), **Vestibular and cochlear nuclei**
- ▶ Mark **facial colliculus** overlying the abducens nucleus/facial genu, **hypoglossal trigone**, and **vagal (ala cinerea) triangle**
- ▶ Mark levels: midbrain (III, IV), pons (V, VI, VII, VIII), medulla (IX, X, XI, XII)



Connections — medial longitudinal fasciculus and corticonuclear control

- ▶ The **medial longitudinal fasciculus (MLF)** is a compact, heavily myelinated paramedian tract running the length of the brain stem, ventral to the aqueduct/fourth-ventricle floor. It interconnects the nuclei of the oculomotor, trochlear, abducens and vestibular complex (and the nucleus of the spinal accessory), coordinating conjugate eye movements with head/neck movement in response to vestibular input.
- ▶ Motor cranial nerve nuclei receive **corticonuclear (corticobulbar) fibres**, which are **bilateral** for most nuclei (oculomotor, trochlear, abducens, trigeminal motor, nucleus ambiguus, dorsal vagal, spinal accessory) but are **predominantly/exclusively crossed** for the part of the facial nucleus supplying the lower facial muscles and for the hypoglossal nucleus — the anatomical basis for distinguishing an upper motor neurone from a lower motor neurone facial or hypoglossal lesion clinically.

Applied / Clinical anatomy

- ▶ **Lateral medullary (Wallenberg) syndrome** — occlusion of the posterior inferior cerebellar artery (or vertebral artery): ipsilateral dysphagia/dysarthria (nucleus ambiguus), ipsilateral facial analgesia/thermoanaesthesia (spinal nucleus/tract of trigeminal), vertigo/nystagmus (vestibular nuclei), ipsilateral Horner syndrome (descending sympathetic fibres), ipsilateral cerebellar ataxia,

and contralateral loss of pain/temperature over the trunk and limbs (spinothalamic tract) — nuclei themselves are spared, so contralateral face is unaffected.

- ▶ **Medial medullary syndrome** — vertebral artery medullary branch occlusion: contralateral hemiparesis (pyramid), contralateral loss of position/vibration sense (medial lemniscus), and **ipsilateral tongue paralysis with deviation towards the lesion** on protrusion (hypoglossal nucleus/nerve).
- ▶ **Weber syndrome** — vascular lesion of the basal midbrain (posterior cerebral artery branch) involving the emerging oculomotor fibres and crus cerebri: ipsilateral oculomotor palsy (ptosis, lateral squint, dilated pupil) with contralateral hemiplegia.
- ▶ **Benedikt syndrome** — midbrain tegmental ischaemia involving oculomotor fibres, red nucleus, medial and spinal lemnisci: ipsilateral oculomotor palsy with contralateral loss of pain/temperature and position/vibration sense, and contralateral tremor/involuntary movements.
- ▶ **Pontine tumours/haemorrhage** — ipsilateral facial and abducens nerve nucleus involvement (LMN facial weakness plus lateral rectus weakness) with contralateral hemiparesis (corticospinal fibres); involvement of the MLF impairs conjugate gaze.
- ▶ **Internuclear ophthalmoplegia** — a lesion of the MLF (classically in multiple sclerosis) between the abducens and oculomotor nuclei, producing failure of adduction of the ipsilateral eye on attempted conjugate lateral gaze with nystagmus of the abducting eye.
- ▶ **Argyll Robertson pupil** — a small, irregular pupil that accommodates but does not react to light, due to a lesion interrupting the pretectal-to-Edinger-Westphal light-reflex pathway while sparing the near-reflex pathway (classically neurosyphilis).
- ▶ **Bulbar vs pseudobulbar palsy** — direct destruction of the nucleus ambiguus/hypoglossal nucleus (LMN, e.g. motor neurone disease, medullary infarction) gives a wasted, fasciculating tongue with flaccid palatal/pharyngeal weakness; bilateral corticonuclear lesions above the medulla (pseudobulbar palsy) spare the nuclei and give spastic weakness with an exaggerated jaw jerk, since these nuclei have bilateral cortical representation (except lower-face/hypoglossal).
- ▶ **Facial colliculus syndrome** — a caudal pontine tegmental lesion damaging the internal genu of the facial nerve as it loops around the abducens nucleus produces combined ipsilateral facial and lateral rectus palsy.

High-yield exam pointers

- ▶ Cranial nerves III–X and XII relate to brain stem nuclei; III/IV are midbrain, V/VI/VII/VIII(part) are pontine, IX/X/XI(cranial)/XII are medullary.
- ▶ Sulcus limitans divides the floor of the fourth ventricle into medial motor (basal lamina) and lateral sensory (alar lamina) zones.
- ▶ Seven classical functional columns: SE, SVE, GVE (motor) and GVA, SVA, GSA, SSA (sensory); Gray's condenses the afferent side to three (combining GVA/SVA in the nucleus solitarius), giving six columns overall.
- ▶ Nucleus ambiguus is the shared branchiomotor nucleus of IX, X and the cranial root of XI.
- ▶ Nucleus solitarius has a rostral gustatory (taste, SVA) part and a caudal cardiorespiratory (GVA) part.

- ▶ Dorsal motor nucleus of vagus is the principal general visceral efferent (parasympathetic) outflow of the vagus.
- ▶ Facial and hypoglossal nuclei are the key nuclei with predominantly/exclusively crossed corticonuclear supply — basis of UMN vs LMN facial/hypoglossal palsy distinction.
- ▶ MLF links III, IV, VI and vestibular nuclei for conjugate gaze; its lesion causes internuclear ophthalmoplegia.
- ▶ Vascular brain stem syndromes (Wallenberg, medial medullary, Weber, Benedikt) are classic applied-anatomy correlates of specific nuclear columns/tracts and are frequently examined.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Textbook of Anatomy Vol 3 (Neuroanatomy) 4e.



Describe in detail about "Reticular formation of brain stem"

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction

The **reticular formation** is a diffuse, ill-defined mass of intermingled neurons and nerve fibres occupying the entire core of the brainstem — named for its light-microscopic appearance as a vague "network" (*reticulum*) of cells and fibres, distinct from the discretely-named cranial nerve nuclei and long ascending/descending tracts that lie embedded within it. Phylogenetically it is the **oldest part of the brain** and houses the vital cardiac, vasomotor and respiratory centres. It receives afferents from virtually every sensory system and projects, directly or indirectly, to all levels of the neuraxis, making it the single most important **regulatory mechanism** of the CNS — controlling consciousness, muscle tone, vegetative function and pain modulation.

1. Location and anatomical extent

□ Fig 19.1 — Location of reticular formation in the brainstem. (Vishram Singh — Clinical Neuroanatomy — 4e, p.685)

- ▶ Occupies the **central core (tegmentum)** of the medulla, pons and midbrain, lying between the well-defined cranial nerve nuclei/long tracts ventrally and the periaqueductal/periventricular grey dorsally.
- ▶ **Rostral extension:** continuous with the diencephalon — the intralaminar and reticular nuclei of the **thalamus**, the **subthalamus**, and the **hypothalamus** (some authorities also relate it functionally to parts of the cerebrum and cerebellum).
- ▶ **Caudal extension:** continuous with the **proprio-spinal grey matter of the upper cervical spinal cord**.
- ▶ Although described as a diffuse network, discrete, fairly localized **reticular nuclei** are recognised within it and are grouped into three longitudinal columns.

2. Reticular nuclei — the three longitudinal columns

Column	Also called	Neuron size	Representative nuclei	Remarks
Median column	Raphe nuclei	Intermediate	Dorsal raphe nucleus (midbrain); nucleus raphe magnus (medulla)	Serotonergic ; dorsal raphe → spinal cord (pain-control pathway); raphe magnus → caudal spinal nucleus of trigeminal — both inhibit pain transmission when activated
Medial column	Magnocellular column	Large	Ventral reticular nucleus (medulla); gigantocellular nucleus (medulla & pons); oral and caudal pontine reticular nuclei	Chief effluent/effector column — receives from lateral column, gives rise to long ascending/descending (reticulospinal) polysynaptic pathways
Lateral column	Parvocellular column	Small	Parvocellular nuclei (medulla, pons); nucleus locus coeruleus (pons — noradrenergic); pedunculopontine nucleus (midbrain)	Chief "receptor"/association column — receives collaterals from ascending sensory pathways and relays to the medial column; the pedunculopontine and locus coeruleus nuclei are key nodes of the ascending reticular activating system

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a schematic transverse section through the **pons** (mid-level) and repeat for the **medulla** and **midbrain**, and label, from medial to lateral: the **raphe (median) nuclei** in the midline; the **medial (magnocellular) column** — gigantocellular nucleus / oral & caudal pontine reticular nuclei; the **lateral (parvocellular) column** — parvocellular nuclei, **locus coeruleus**, **pedunculopontine nucleus**. Mark the **medial lemniscus (ML)** ventrally and the **spinal lemniscus (SL)** and **trigeminal lemniscus (TL)** laterally as fixed landmarks around which the columns are arranged (after Fig. 19.3 of Vishram Singh).

3. Afferent connections

The reticular formation receives **polysynaptic, ascending and descending, crossed and uncrossed** afferents (hence a unilateral stimulus produces a bilateral response), classified as:

- ▶ **From sensory pathways/systems** — optic and auditory systems (via tectoreticular fibres); olfactory and limbic systems (via descending pathways); gustatory pathway; spinal pathways (via spinoreticular fibres — a large contingent of spinothalamic tract fibres end in the **lateral reticular nucleus of the medulla**, which relays to the cerebellum as the **spinoreticulocerebellar pathway**); trigeminal pathways.
- ▶ **From other CNS parts** — cerebellum (mainly contralateral fastigial nucleus); basal ganglia (corpus striatum); thalamus, hypothalamus, subthalamus; limbic system (septal area, amygdaloid nuclei, hippocampus); cerebral cortex (mainly motor and sensory areas); red nucleus, substantia nigra, habenular nuclei.
- ▶ **Humoral/pharmacological modulation** — adrenaline, acetylcholine and carbon dioxide stimulate it; barbiturates, anaesthetics and tranquillizers depress it.

4. Efferent connections

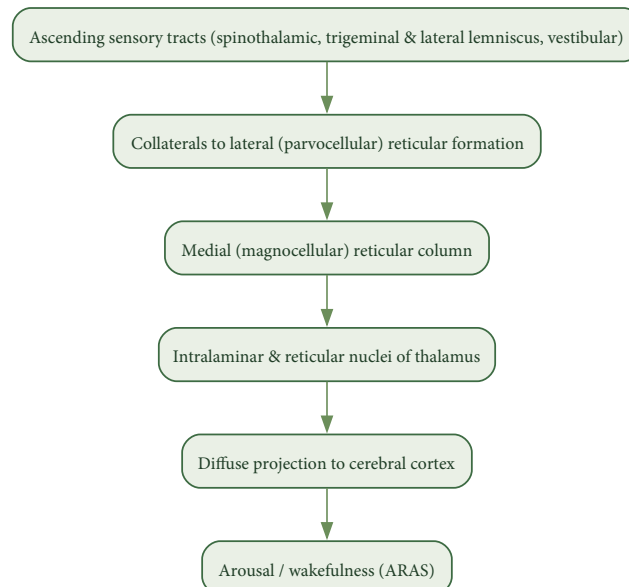
- ▶ **Autonomic and locomotor control centres** of the brainstem and spinal cord (cardiac, vasomotor and respiratory centres).
- ▶ **Cranial nerve nuclei**, e.g. the dorsal (motor) nucleus of the vagus.
- ▶ **Cerebral cortex** — indirectly, via the intralaminar and reticular nuclei of the **thalamus** (the anatomical basis of the ARAS).
- ▶ **Red nucleus, substantia nigra and tectum** of the midbrain.
- ▶ **Spinal cord** — via the reticulospinal tracts (see below).

5. Functional divisions — the ascending reticular activating system and the descending reticular system

Functionally the reticular formation is divided into an **ascending reticular activating system (ARAS)** and a **descending reticular system (DRS)**.

(a) **Ascending reticular activating system (ARAS)** — Collaterals from the major ascending sensory tracts (spinothalamic tract, trigeminal lemniscus, lateral lemniscus, central vestibular pathway) as they pass through the brainstem are relayed through the **lateral (parvocellular) reticular formation** to the **medial column**, which projects to the **intralaminar and reticular nuclei of the thalamus**; these thalamic

nuclei in turn project diffusely to widespread areas of the cerebral cortex. Stimulation of this system produces behavioural **arousal**, so clinicians commonly call it simply the "reticular activating system (RAS)." It is responsible for maintaining the state of **alertness and consciousness**.



Describe in detail about "Reticular formation of brain stem"

(b) **Descending reticular system (DRS)** — descending pathways from the reticular formation to (i) autonomic centres of the brainstem, critical for cardiac and respiratory rhythm, and (ii) the anterior and lateral grey horn cells of the spinal cord, constituting one of the most important **extrapyramidal motor pathways** — the **reticulospinal tracts**.

Tract	Origin	Funiculus	Termination	Crossing	Function
Pontine (medial) reticulospinal	Oral and caudal pontine reticular nuclei	Ventral (anterior) funiculus	Laminae VII–IX	Mostly uncrossed	Facilitates α - and γ -motor neurons of extensor (antigravity) muscles of trunk and limbs; some fibres inhibitory to neck muscles

Tract	Origin	Funiculus	Termination	Crossing	Function
Medullary (lateral) reticulospinal	Gigantocellular nucleus and adjoining medullary reticular nuclei	Lateral funiculus	Wider distribution, laminae IV–X	Crossed and uncrossed (bilateral)	Facilitates flexor motor neurons; also modulates transmission of nociceptive (pain) impulses ascending in the anterolateral system

6. Functions of the reticular formation

- ▶ Maintains **consciousness and wakefulness** through the ARAS and its cortical projections.
- ▶ Regulates **respiration, heart rate, blood pressure** and other vegetative functions via the vital autonomic reflex centres embedded within it.
- ▶ Controls **skeletal muscle tone and posture** directly (reticulospinal tracts) and indirectly (via cerebellum, red nucleus, substantia nigra, corpus striatum and cerebral cortex).
- ▶ Controls **receptivity of sensory end-organs** and the **threshold of central sensory pathways** (sensory gating/habituation).
- ▶ **Modulates pain** transmission through the raphe–spinal and reticulospinal systems.
- ▶ Regulates **endocrine, visceral and emotional functions** through hypothalamic and limbic connections.
- ▶ Regulates the **sleep–wake cycle**.

Applied / Clinical anatomy

- ▶ **Coma and altered consciousness:** bilateral damage to the reticular activating system (trauma, haemorrhage, tumour, herniation) produces progressive loss of consciousness through the graded stages of **lethargy** → **stupor** → **coma**; normal consciousness requires intact, bilaterally-functioning **thalamocortical system + brainstem RAS** together.
- ▶ **Persistent vegetative state:** the RAS may remain intact while the cerebral cortex is non-functional — the patient has sleep–wake cycles and eye opening (wakefulness) but no awareness, illustrating that wakefulness (brainstem) and awareness (cortex) are dissociable.
- ▶ **Effect of stimuli and drugs on the RAS:** sudden sound or bright light arouses consciousness by stimulating the ARAS, while withdrawal of sensory input favours drowsiness/sleep; general anaesthetics and tranquillizers depress the RAS, whereas ammonia and other irritants (used clinically as smelling-salts) stimulate it — the rationale for arousing a fainting or unconscious patient with an ammonia-soaked swab or facial stimulation, which activates trigeminal afferents feeding the RAS.

- ▶ **Stimulation-produced analgesia:** electrical stimulation of the dorsal raphe nucleus/periaqueductal grey or the nucleus raphe magnus produces profound analgesia — a principle exploited clinically for otherwise intractable pain.
- ▶ **Decerebrate rigidity:** the reticular formation normally increases extensor muscle tone but is held in check by descending inhibition from the cerebral cortex; brainstem transection or compression (e.g. transtentorial/uncal herniation) that removes this cortical control releases unopposed reticulospinal (and vestibulospinal) facilitation, producing exaggerated extensor tone of all four limbs — decerebrate rigidity/posturing, often progressing from an initial decorticate posture as herniation worsens.
- ▶ **Vital-centre involvement:** because the cardiac, vasomotor and respiratory centres lie within the medial reticular formation of the medulla and pons, space-occupying or vascular lesions here can produce irregular (Cheyne–Stokes) breathing, blood pressure instability and are potentially fatal.

Recent advances

According to PubMed, the ARAS is now understood not as a single tract but as a distributed, multi-neurotransmitter arousal network whose mapping and modulation are active areas of neuroscience/neurosurgical research:

- ▶ The classical single "reticular activating system" concept has been refined into a **mesocircuit model**: the mesopontine tegmentum (cuneiform/subcuneiform nuclei, nucleus pontis oralis) and brainstem monoaminergic nuclei generate arousal signals that travel via a **medial dorsal tegmental tract** to the thalamic intralaminar (central-thalamic) nuclei and diffusely to cortex, while a parallel **lateral dorsal tegmental tract** engages the thalamic reticular nucleus to gate intrathalamic inhibition — explaining why small paramedian thalamic or brainstem lesions cause disproportionately severe drops in arousal ([DOI](https://doi.org/10.1016/B978-0-443-13408-1.00010-5), *Handbook of Clinical Neurology* 2025).
- ▶ Reviews of brainstem injury–related disorders of consciousness (DOC) now emphasise the specific neurotransmitter systems of the reticular nuclei — **serotonin from the dorsal raphe, norepinephrine from the locus coeruleus, dopamine from the ventral tegmental area** — and use diffusion tensor imaging/functional MRI to correlate disrupted ARAS–cortical connectivity with DOC severity, guiding prognosis after traumatic brain injury ([DOI](https://doi.org/10.1186/s41016-025-00411-9), *Chinese Neurosurgical Journal* 2025).
- ▶ This refined circuit map is being translated into **non-invasive neuromodulation** for vegetative state/unresponsive wakefulness syndrome and minimally conscious state: median nerve stimulation to engage the ARAS directly, low-intensity transcranial focused ultrasound/temporal interference targeting the cortico-thalamocortical circuit, and TMS/tDCS of the frontoparietal network — with combined protocols (e.g. TMS + median nerve stimulation) outperforming monotherapy in early trials ([DOI](https://doi.org/10.3389/fneur.2026.1770928), *Frontiers in Neurology* 2026).
- ▶ A randomized controlled trial of **music therapy** in minimally conscious state patients demonstrated measurable autonomic nervous system activation and diffusion-tensor tractographic reconstruction of ARAS fibre bundles linking the brainstem, thalamus and

temporal cortex, supporting a hypothalamic–brainstem–autonomic axis model for arousal recovery ([DOI](https://doi.org/10.3389/fnins.2023.1182181), *Frontiers in Neuroscience* 2023).

High-yield exam pointers

- ▶ Reticular formation = diffuse core of intermingled neurons/fibres occupying the tegmentum of the whole brainstem; extends from upper cervical cord to the diencephalon.
- ▶ Three longitudinal nuclear columns: **median (raphe, serotonergic)**, **medial (magnocellular, effector)**, **lateral (parvocellular, receptor/association — locus coeruleus, pedunculopontine nucleus)**.
- ▶ Functionally divided into the **ascending reticular activating system (ARAS)** — via thalamic intralaminar/reticular nuclei to cortex, maintains consciousness — and the **descending reticular system**, which forms the reticulospinal tracts.
- ▶ **Pontine (medial) reticulospinal tract** = uncrossed, ventral funiculus, facilitates extensors; **medullary (lateral) reticulospinal tract** = crossed + uncrossed, lateral funiculus, facilitates flexors and modulates pain.
- ▶ Coma is a state of unconsciousness due to inactivity of the RAS; requires bilateral involvement of RAS + thalamocortical system.
- ▶ Persistent vegetative state = intact RAS (wakefulness) but non-functional cortex (no awareness) — wakefulness without awareness is possible; the reverse is not.
- ▶ Raphe nuclei stimulation (dorsal raphe/periaqueductal grey, nucleus raphe magnus) produces analgesia — basis of stimulation-produced pain relief.
- ▶ Decerebrate rigidity follows loss of cortical inhibitory control over the reticular formation, releasing unopposed extensor facilitation via reticulospinal/vestibulospinal tracts.
- ▶ Reticular formation houses the vital cardiac, vasomotor and respiratory centres — its involvement in brainstem lesions is potentially fatal.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy (reticulospinal tract table). Recent-advances section per PubMed (DOIs 10.1016/B978-0-443-13408-1.00010-5, 10.1186/s41016-025-00411-9, 10.3389/fneur.2026.1770928, 10.3389/fnins.2023.1182181).



Describe the clinical features of the lesions of facial nerve at different levels

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — The facial (VIIth cranial) nerve is a **mixed nerve**: special visceral efferent (SVE) to the muscles of facial expression, stapedius, stylohyoid and posterior belly of digastric; general visceral efferent (GVE, parasympathetic secretomotor) to the lacrimal, nasal, palatine, submandibular and sublingual glands; and special/general sensory — taste from the anterior two-thirds of the tongue and cutaneous sensation from a small area of the external ear — carried by its sensory root, the **nervus intermedius (of Wrisberg)**. It has the **longest intraosseous course of any cranial nerve**, passing through the cerebellopontine angle, internal acoustic meatus, and a tortuous **facial canal** within the petrous temporal bone — where it gives off the greater petrosal nerve, nerve to stapedius, and chorda tympani in strict sequence — before emerging at the stylomastoid foramen and dividing within the parotid gland into five terminal branches. Because these branches leave the trunk in a **fixed, well-defined order**, the exact clinical picture — which additional deficits of taste, lacrimation, salivation and hyperacusis accompany the facial weakness — varies characteristically with the **level** of the lesion, making level-wise localisation a classic, high-yield exercise in applied neuroanatomy.

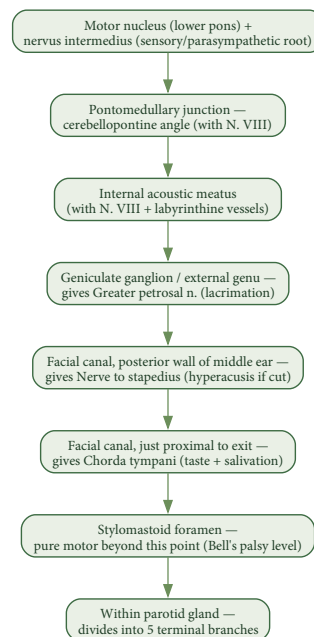
1. Functional components and nuclei

- ▶ **Main motor nucleus (SVE)** — ventrolateral tegmentum of the **lower pons**; supplies muscles of facial expression, auricular muscles, stapedius, posterior belly of digastric and stylohyoid.
 - The part of the nucleus supplying the **upper face** (frontalis, orbicularis oculi) receives **bilateral** corticonuclear fibres.
 - The part supplying the **lower face** receives **predominantly crossed (contralateral)** corticonuclear fibres only.
 - This single asymmetry is the anatomical basis of every UMN-versus-LMN distinction described below.
- ▶ **Parasympathetic nuclei (GVE)** — superior salivatory nucleus (submandibular and sublingual glands, via chorda tympani) and lacrimal nucleus (lacrimal, nasal and palatine glands, via greater petrosal nerve).
- ▶ **Sensory nucleus** — rostral (gustatory) part of the **nucleus of the tractus solitarius** (taste, SVA, via chorda tympani); a few general sensory (GSA) fibres from the geniculate ganglion supply the concha and external acoustic meatus and end in the spinal nucleus of the trigeminal nerve.
- ▶ **Neurobiotaxis**: the motor nucleus migrates in embryonic life to lie close to the spinal nucleus of the trigeminal nerve, which is why its intrapontine fibres take an unusually long, looping course.

2. Course of the facial nerve — the anatomical basis of level-wise localisation

- ▶ Motor fibres leave the nucleus, curve dorsomedially around the **abducens nucleus** (forming the **internal genu**, which raises the **facial colliculus** on the floor of the fourth ventricle), then run ventrolaterally to emerge at the **pontomedullary junction** with the nervus intermedius, in the cerebellopontine angle.

- The nerve and nervus intermedius enter the **internal acoustic meatus** together with the vestibulocochlear nerve and labyrinthine vessels.
- Within the petrous temporal bone the nerve traverses the **facial canal**: it expands at the **geniculate ganglion** (external genu), giving off the **greater petrosal nerve** here; turns backward above the promontory and then sharply downward below the lateral semicircular canal, giving off the **nerve to stapedius** and then the **chorda tympani** in the posterior wall of the middle ear; and finally exits the skull at the **stylomastoid foramen**.
- Extracranially it gives the posterior auricular branch and nerves to the posterior belly of digastric and stylohyoid, then enters the **parotid gland**, within which it divides into its five terminal branches (temporal, zygomatic, buccal, mandibular, cervical — mnemonic "*Ten Zebras Buggered My Car*").



Describe the clinical features of the lesions of facial nerve at different levels

3. Clinical features of facial nerve lesions at different levels

Level of lesion	Representative cause	Clinical features
Supranuclear (UMN)	Internal capsule/cortical lesion, usually part of a hemiplegia	Only the lower quarter of the contralateral face is paralysed — the upper face (frontalis, orbicularis oculi) is spared because it has bilateral cortical representation; voluntary movements are lost but emotional/mimetic expression is relatively preserved (separate extrapyramidal pathway); accompanying limb hemiplegia is on the same side as the facial weakness (both contralateral to the capsular lesion)

Level of lesion	Representative cause	Clinical features
Nuclear	Facial nerve nucleus in lower pons — poliomyelitis, progressive bulbar palsy, pontine glioma, Millard–Gubler syndrome	Complete ipsilateral LMN paralysis of the entire half of the face; in Millard–Gubler syndrome the adjoining abducens fibres are also involved (ipsilateral medial squint) together with the corticospinal tract (contralateral hemiplegia) — a classic "crossed"/alternating hemiplegia
Infranuclear — cerebellopontine angle	Acoustic neuroma (vestibular schwannoma) — "pontocerebellar angle syndrome"	Ipsilateral complete LMN facial palsy + VIIIth nerve signs (tinnitus, progressive deafness, vertigo) + ipsilateral cerebellar ataxia/staggering gait (peduncle compression) + ipsilateral corneal reflex loss and facial anaesthesia (spinal tract/nucleus of trigeminal nerve compressed)
Infranuclear — internal acoustic meatus	Meatal tumour, fracture	As above but without the cerebellar/trigeminal signs — an isolated combined VII + VIII deficit localises the lesion to the meatus rather than the wider angle
Infranuclear — geniculate ganglion	Herpes zoster oticus = Ramsay Hunt syndrome	Complete ipsilateral LMN facial palsy (Bell's-palsy pattern) plus herpetic vesicles on the auricle/external acoustic meatus (GSA fibres of the ganglion) + hyperacusis + loss of taste (anterior two-thirds of tongue) + decreased salivation + decreased lacrimation — every branch given off at or distal to the ganglion is knocked out
Infranuclear — distal facial canal (below nerve to stapedius, above chorda tympani exit)	Facial canal compression distal to the ganglion	LMN facial palsy + loss of taste/decreased salivation (chorda tympani already damaged) but hyperacusis and lacrimation are normal — the greater petrosal and nerve to stapedius were already given off proximal to this point (a direct corollary of the branching sequence above)

Level of lesion	Representative cause	Clinical features
Infranuclear — at/distal to stylomastoid foramen	Bell's palsy (commonest cause of LMN facial paralysis; idiopathic, possibly viral/inflammatory oedema of the nerve in the facial canal)	Pure motor paralysis of the entire half of the face; taste, salivation, lacrimation and hearing/hyperacusis are all normal , since every other branch has already left the trunk proximally
Extracranial (within/beyond the parotid gland)	Parotid malignancy, deep facial lacerations, iatrogenic surgical injury	Pure motor paralysis that may be partial/segmental , limited to only the terminal branch(es) damaged (temporal, zygomatic, buccal, mandibular or cervical), since the five branches have already diverged; a firm parotid swelling with facial weakness strongly suggests malignant infiltration of the nerve

4. Supranuclear (UMN) versus infranuclear/nuclear (LMN) facial palsy

Feature	Supranuclear (UMN) lesion	Infranuclear/nuclear (LMN) lesion
Usual site	Internal capsule / cerebral cortex	Anywhere from the nucleus to the stylomastoid foramen (classically at the stylomastoid foramen)
Part of face affected	Only the lower quarter , contralateral to the lesion	The entire half of the face, ipsilateral to the lesion
Accompanying hemiplegia	Present, on the same side as the facial weakness	Absent in purely infranuclear lesions; if nuclear , hemiplegia is contralateral (crossed brainstem syndrome)
Voluntary vs emotional movement	Voluntary movements lost; emotional/mimetic expression relatively spared (separate pathways)	Both voluntary and emotional movements lost — the LMN is the final common pathway

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 2.14 — Infranuclear lesion of right facial nerve or Bell's palsy (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.92)

□ Fig 2.15 — Supranuclear lesion of left facial nerve (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.92)

Reproduce two half-face panels side by side and label:

- ▶ **Panel 1 (infranuclear/LMN — Bell's palsy, right side):** facial nerve compressed at the stylomastoid foramen; annotate **paralysis of BOTH upper and lower quarters of the face on the same side** — loss of forehead wrinkles, widened palpebral fissure with epiphora (tears flowing out), sagging angle of mouth, loss of nasolabial furrow
- ▶ **Panel 2 (supranuclear/UMN, left side):** cerebral cortex (both hemispheres) → corticonuclear fibres → facial nerve nucleus (upper part with bilateral input, lower part with only crossed input) → **injury to corticonuclear fibres** on one side; annotate **paralysis of only the lower quarter of the face on the contralateral side**, upper quarter (frontalis, orbicularis oculi) spared
- ▶ Draw the **decussating corticonuclear fibres** explicitly to show why the upper-face motoneurons escape a one-sided cortical/capsular lesion

Applied / Clinical anatomy

- ▶ **Testing the nerve:** ask the patient to wrinkle the forehead (frontalis), shut the eyes tightly against resistance (orbicularis oculi), show the teeth/smile (dilators of the mouth), and puff out the cheeks/whistle (buccinator); asymmetry localises a lesion to the LMN pathway.
- ▶ **Corneal/conjunctival reflex:** afferent via the **nasociliary/ophthalmic nerve** (trigeminal), efferent via the **facial nerve to orbicularis oculi** — lost in facial nerve paralysis and used to test the pons.
- ▶ **Crocodile tears syndrome:** paroxysmal lacrimation during eating, seen after **regeneration of a facial nerve injury proximal to the geniculate ganglion** — misdirected preganglionic secretomotor fibres meant for the submandibular/sublingual glands instead grow along the endoneurial sheath destined for the lacrimal gland (via the greater petrosal nerve pathway).
- ▶ **Bell's palsy management points relevant to anatomy:** the widened palpebral fissure and lost blink reflex expose the cornea to drying, so artificial tears are instilled to prevent corneal ulceration until recovery.
- ▶ **Surgical/traumatic vulnerability:** the nerve's petrous course is exposed in mastoid and middle-ear surgery, and its extracranial trunk (identified relative to the tympanomastoid suture and the posterior belly of digastric) is at risk during parotidectomy — a firm parotid mass with new facial weakness should always raise suspicion of malignancy rather than a benign tumour.
- ▶ **Basal skull fracture:** fractures through the petrous temporal bone are a common cause of a combined facial + vestibulocochlear (VII + VIII) deficit, mimicking a cerebellopontine-angle-level lesion.

High-yield exam pointers

- ▶ Facial nerve = mixed (SVE + GVE + SVA + GSA); sensory/parasympathetic fibres travel in the **nervus intermedius**, distinct from the large motor root.

- ▶ **Bilateral cortical representation only for the upper face** → UMN lesions spare forehead wrinkling and eye closure; LMN lesions paralyse the **whole** half of the face.
- ▶ Course/branch order = the localising ladder: nucleus (pons) → cerebellopontine angle → internal acoustic meatus → geniculate ganglion (greater petrosal) → nerve to stapedius → chorda tympani → stylomastoid foramen → parotid (5 terminal branches).
- ▶ **Millard–Gubler syndrome** (nuclear/pontine level) = ipsilateral facial ± abducens palsy + **contralateral** hemiplegia — a classic crossed brainstem syndrome.
- ▶ **Cerebellopontine angle (acoustic neuroma) syndrome** = facial palsy + VIII signs (deafness, tinnitus, vertigo) + cerebellar ataxia + trigeminal/corneal loss.
- ▶ **Ramsay Hunt syndrome** (geniculate ganglion herpes zoster) = Bell's-palsy pattern + auricular vesicles + hyperacusis + taste loss + decreased lacrimation/salivation.
- ▶ **Bell's palsy** (stylomastoid foramen, commonest LMN facial palsy) = pure motor paralysis of the whole half of the face; taste, salivation, lacrimation and hearing all normal.
- ▶ **Extracranial/parotid lesions** can paralyse only some terminal branches (partial, segmental) since the five branches have already diverged.
- ▶ **Crocodile tears syndrome** = aberrant regeneration after a facial nerve injury proximal to the geniculate ganglion.

Recent advances

- ▶ A retrospective cadaveric-adjacent clinical series confirms the **posterior belly of digastric as a reliable intraoperative landmark for the extracranial facial nerve trunk**, locating the trunk approximately 17 ± 0.87 mm superomedial to this muscle during parotidectomy — refining the classical surface-marking teaching for surgical localisation (Singh et al., *Cureus*, 2025) [DOI: 10.7759/cureus.80413].
- ▶ A 2025 comparative study of facial-palsy grading systems found the **House–Brackmann Grading Scale correlates strongly ($r \approx -0.86$ to -0.88) with the Sunnybrook and Modified Portmann scales**, supporting continued use of House–Brackmann as the reference clinical tool for grading the severity of a facial nerve lesion at any level (Lin et al., *PLOS ONE*, 2025) [DOI: 10.1371/journal.pone.0326789].
- ▶ A 2026 systematic review of **diffusion-MRI tractography of the facial nerve** reports at least 87% success in predicting the pre-operative course of CN VII through the cerebellopontine angle/internal acoustic meatus in vestibular schwannoma, allowing the classical "level of lesion" localisation taught anatomically to now be visualised directly on preoperative imaging (Ni et al., *Journal of Neuroimaging*, 2026) [DOI: 10.1111/jon.70131].
- ▶ (According to PubMed.)

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3–4 8e. Recent-advances section per PubMed/journal search (see DOIs above).



Facial nerve nuclear complex and connections

Asked in: Paper IV Apr 2006 — RGUHS MD/MS Anatomy

Definition / Introduction. The facial nerve (cranial nerve VII) is a mixed nerve whose nuclear complex lies in the **caudal pontine tegmentum** and consists of three functionally distinct nuclei — a main (branchio)motor nucleus, two parasympathetic (secretomotor) nuclei, and a sensory (gustatory) nucleus. Together these constitute the "nuclear complex," and their fibres pursue an unusually looped intramedullary course before emerging as the motor root and the nervus intermedius. The complex receives rich **central connections** — corticonuclear, extrapyramidal/reticular, reflex (trigeminal, gustatory) and hypothalamic-autonomic — which explain both its normal reflex physiology and the classical clinico-anatomical distinction between upper and lower motor neurone facial palsy.

1. Components of the facial nerve nuclear complex

Nucleus	Functional component	Location	Chief connection / function
Main (facial) motor nucleus	Special visceral efferent (SVE) — branchiomotor, derived from the 2nd pharyngeal arch	Ventrolateral tegmentum of the caudal pons , anterolateral and caudal to the abducens nucleus, medial to the spinal nucleus/tract of the trigeminal nerve	Supplies muscles of facial expression, stapedius, posterior belly of digastric, stylohyoid and occipito-auricular muscles
Superior salivatory nucleus	General visceral efferent (GVE) — parasympathetic	Posterolateral/medial to the main motor nucleus, near the pontomedullary junction	Preganglionic secretomotor fibres via chorda tympani → submandibular ganglion → submandibular & sublingual glands
Lacrimal nucleus	GVE — parasympathetic	Immediately adjoining the superior salivatory nucleus	Preganglionic fibres via greater petrosal nerve → pterygopalatine ganglion → lacrimal, nasal and palatine glands

Nucleus	Functional component	Location	Chief connection / function
Sensory (gustatory) nucleus — rostral part of the nucleus of the tractus solitarius	Special visceral afferent (SVA)	Close to the motor nucleus, in the dorsal pons/upper medulla	Receives taste from the anterior two-thirds of the tongue via the geniculate ganglion ; relays to the contralateral ventral posteromedial (VPM) thalamic nucleus and thence to the taste area of the postcentral gyrus
(General somatic afferent component)	GSA	Peripheral processes of geniculate ganglion cells end centrally in the spinal nucleus of the trigeminal nerve	Cutaneous sensation from a small area of the external ear/concha

This spread of functional columns (SVE, GVE, SVA, GSA) reflects the general plan of the brainstem cranial-nerve nuclei: the special visceral efferent (branchiomotor) column also contains the trigeminal motor nucleus and nucleus ambiguus; the general visceral efferent column also contains the Edinger–Westphal and dorsal vagal nuclei; and the special/general visceral afferent fibres of the facial, glossopharyngeal and vagus nerves all converge on the nucleus of the tractus solitarius.

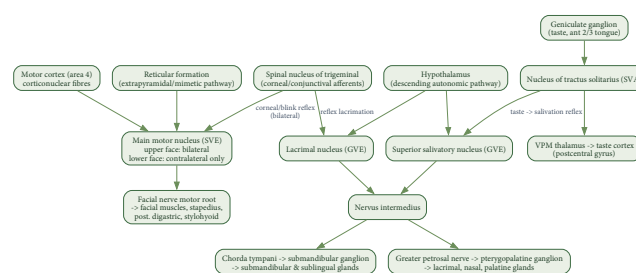
2. Aberrant intramedullary course of the motor fibres

- ▶ Axons of the main motor nucleus first run **dorsomedially** towards the floor of the fourth ventricle and loop around the back of the **abducens nucleus** — this loop is the **internal genu of the facial nerve**, which raises the floor of the fourth ventricle to form the **facial colliculus**.
- ▶ The fibres then turn **ventrolaterally**, passing between their own nucleus (medially) and the spinal nucleus of the trigeminal nerve (laterally), to emerge at the **pontomedullary junction**, in the groove between the olive and the inferior cerebellar peduncle (cerebellopontine angle), lateral to the emerging abducens nerve.
- ▶ This unusual, elongated course is a classic example of **neurobiotaxis** — migration of the developing motor neurones towards the source of their principal afferent input (the trigeminal sensory column).
- ▶ A lesion at the facial colliculus therefore characteristically damages **both** the facial and abducens nuclei/fibres together ("facial colliculus syndrome").
- ▶ The sensory root (**nervus intermedius of Wrisberg**) carries the central processes of geniculate-ganglion cells (taste, cutaneous) together with the preganglionic parasympathetic fibres from the superior salivatory and lacrimal nuclei; it lies between the motor root and the vestibulocochlear nerve as the three structures enter the internal acoustic meatus.

3. Central connections of the nuclear complex

- ▶ **Corticonuclear (corticobulbar) fibres**: arise from the inferior precentral gyrus (area 4), descend through the corona radiata and genu of the internal capsule, and end on the motor nucleus.

- The part of the nucleus supplying the **upper face** (frontalis, orbicularis oculi) receives **bilateral** corticonuclear fibres.
 - The part supplying the **lower face** receives corticonuclear fibres from the **contralateral hemisphere only**.
 - (Together with the genioglossus part of the hypoglossal nucleus, this is one of the two classical exceptions to the rule of bilateral cortical control of cranial motor nuclei.)
- **Reticular formation / extrapyramidal pathway:** mimetic (emotional) facial movements — e.g. spontaneous smiling — travel by a separate pathway through the reticular formation, distinct from the pyramidal corticonuclear route; this is why emotional expression can be preserved even when voluntary facial movement is lost in a supranuclear (pyramidal) lesion, and conversely why extrapyramidal disease can abolish emotional facial movement while voluntary movement is preserved.
- **Trigeminal connections (corneal/blink reflex):** afferents from the cornea and conjunctiva travel in the ophthalmic division of the trigeminal nerve to the spinal nucleus/tract of the trigeminal nerve, which relays (via interneurons in the reticular formation) to the facial motor nucleus of **both sides** — producing bilateral reflex closure of the eyelids (orbicularis oculi) on touching one cornea.
- **Nucleus of the tractus solitarius:** gustatory afferents entering here also connect reflexly with the superior salivatory nucleus, so that taste stimulation triggers reflex salivation.
- **Hypothalamic (descending autonomic) connections:** the superior salivatory nucleus receives descending fibres from the hypothalamus (mediating emotional/psychogenic salivation), and the lacrimal nucleus similarly receives hypothalamic fibres for emotional lacrimation, in addition to its trigeminal sensory input for reflex lacrimation from corneal/conjunctival irritation.
- **Vestibular/abducens relations:** the looping internal genu around the abducens nucleus and the shared facial colliculus mean lesions here commonly involve both nuclei together, and the close relation to the vestibulocochlear nerve at the cerebellopontine angle explains combined VII–VIII involvement in angle tumours.



Facial nerve nuclear complex and connections

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 11.11 — Facial nerve nuclei and their central connections (Snell — Clinical Neuroanatomy — 7e, p.366)

Reproduce this scheme, labelling in sequence:

- ▶ **Cerebral cortex** with corticonuclear fibres descending to the **main motor nucleus**
- ▶ **Descending autonomic pathway** from hypothalamus to the **parasympathetic (superior salivatory and lacrimal) nuclei**
- ▶ **Sensory nucleus (nucleus of tractus solitarius)** receiving the taste fibres, and its ascending connection to the **thalamus and hypothalamic nuclei**
- ▶ The **main motor nucleus** lying in the **pons**, with its efferent fibres forming the **facial nerve**
- ▶ The **facial colliculus** on the floor of the fourth ventricle and the underlying **nucleus of the abducent nerve**, around which the facial fibres loop (internal genu)

Applied / Clinical anatomy

- ▶ **Upper vs lower motor neurone facial palsy** — the single most tested clinical-anatomy point on this topic.

Feature	Supranuclear (UMN) lesion	Nuclear / infranuclear (LMN) lesion
Upper face (frontalis, orbicularis oculi)	Spared — bilateral cortical input	Paralysed on the affected side
Lower face	Paralysed on the contralateral side	Paralysed on the ipsilateral (same) side
Whole face on side of lesion	Not entirely affected	Entirely affected
Associated findings	Usually accompanies hemiplegia	Isolated, or with other cranial nerve signs if brainstem/angle lesion

- ▶ **Bell palsy** — the commonest infranuclear (LMN) facial palsy, due to compression/oedema of the nerve within the bony facial canal (often near the stylomastoid foramen); cause often unknown, sometimes follows cold exposure. Produces complete ipsilateral facial paralysis: unable to close the eye, drooping angle of mouth, loss of the nasolabial fold, food pooling in the cheek (buccinator weakness).
- ▶ **Topognostic (localizing) value of the branches** — since the chorda tympani, nerve to stapedius and greater petrosal nerve leave the nerve at successive points along the facial canal, the level of a lesion can be inferred: loss of taste on the anterior two-thirds of tongue implies a lesion proximal to the chorda tympani; hyperacusis implies involvement of the nerve to stapedius; and loss of lacrimation implies a lesion proximal to the geniculate ganglion/greater petrosal nerve origin.
- ▶ **Nuclear lesion** (true motor nucleus damage) is rare — occurs in poliomyelitis or progressive bulbar palsy; other functional components (taste, salivation, lacrimation) are typically spared because their nuclei are not immediately contiguous with the motor nucleus, though neighbouring abducens/trigeminal nuclei may be co-involved.

- ▶ **Corneal reflex loss** — an infranuclear facial lesion abolishes the efferent (motor) limb of the corneal reflex on the affected side (no blink even though sensation is intact), whereas a trigeminal (ophthalmic division) lesion abolishes the afferent limb bilaterally when testing that eye.
- ▶ **Crossed brainstem (alternating) syndromes** at the facial-nucleus level:
 - **Millard–Gubler syndrome** — caudal pontine (basal) lesion involving the corticospinal tract, and the emerging fibres of the abducens and facial nerves → contralateral hemiplegia with ipsilateral facial (LMN) palsy and ipsilateral medial squint (abducens palsy).
 - **Foville syndrome** — dorsomedial pontine lesion involving the facial nucleus/fibres, the abducens nucleus and the adjacent paramedian pontine reticular formation (horizontal gaze centre) → ipsilateral facial paralysis with ipsilateral conjugate gaze palsy.
 - **Cerebellopontine angle syndrome** — a lesion (classically acoustic neuroma) compressing the VII and VIII nerves together at the angle produces ipsilateral LMN facial palsy with tinnitus, deafness, vertigo, ataxia and loss of the corneal reflex.

High-yield exam pointers

- ▶ Three nuclei of the facial nerve nuclear complex: **main motor (SVE)**, **parasympathetic — superior salivatory + lacrimal (GVE)**, and **sensory/gustatory — rostral nucleus solitarius (SVA)**; a GSA component (external ear) relays through the spinal trigeminal nucleus.
- ▶ Main motor nucleus lies in the **caudal pontine tegmentum**, anterolateral and caudal to the **abducens nucleus**.
- ▶ Fibres loop around the abducens nucleus (**internal genu**) to raise the **facial colliculus** — a textbook example of **neurobiotaxis**.
- ▶ **Upper face = bilateral** corticonuclear supply; **lower face = contralateral only** — the anatomical basis for distinguishing UMN from LMN facial palsy.
- ▶ Reflex connections: **trigeminal spinal nucleus** (corneal/blink reflex, bilateral), **nucleus solitarius** (taste → reflex salivation), **hypothalamus** (emotional lacrimation/salivation via descending autonomic pathway).
- ▶ Mimetic (emotional) facial movement uses a **separate extrapyramidal/reticular pathway**, distinct from the voluntary corticonuclear route.
- ▶ **Bell palsy** = commonest infranuclear (LMN) lesion; site of lesion along the facial canal is localized by loss of taste (chorda tympani), hyperacusis (nerve to stapedius) or lacrimation (greater petrosal nerve).
- ▶ Crossed brainstem syndromes at this level: **Millard–Gubler** (basal, + corticospinal tract) and **Foville** (dorsomedial, + gaze centre).

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Anatomy Vol 3 6e.



Describe the facial nerve under a) Nuclei b) course of motor root c) effects of lesions of motor root at various levels

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction — The facial nerve (7th cranial nerve) is a mixed nerve, predominantly motor, that arises by two roots — a large **motor root** (facial nerve proper, branchial-motor) and a small **sensory root** (nervus intermedius, carrying taste and parasympathetic secretomotor fibres) — from the pontomedullary junction. It is the nerve of the 2nd (hyoid) pharyngeal arch, named for its principal function of supplying the muscles of facial expression, and it is the most frequently paralysed peripheral nerve in the body. Its long, tortuous intrapetrous course makes it uniquely vulnerable, so the level of a lesion can be localised precisely from the pattern of deficit produced.

A. Nuclei of the facial nerve

The facial nerve has three functional nuclear groups, all in the pontine tegmentum:

Nucleus	Location	Fibre type	Function
Main motor nucleus	Deep in the caudal pontine reticular formation, ventromedial to the spinal nucleus/tract of the trigeminal nerve, posterior to the dorsal trapezoid nucleus	Special visceral efferent (SVE) — branchiomotor, 2nd arch	Muscles of facial expression, auricular muscles, stapedius, posterior belly of digastric, stylohyoid
Superior salivatory nucleus	Reticular formation, posterolateral/dorsolateral to the main motor nucleus	General visceral efferent (GVE) — preganglionic parasympathetic	Secretomotor to submandibular & sublingual glands (via chorda tympani → submandibular ganglion) and nasal/palatine glands (via greater petrosal → pterygopalatine ganglion)
Lacrimal nucleus	Closely related to/part of the superior salivatory group	GVE — preganglionic parasympathetic	Secretomotor to lacrimal gland (via greater petrosal → pterygopalatine ganglion); receives hypothalamic (emotional) and trigeminal sensory (reflex lacrimation) afferents

Nucleus	Location	Fibre type	Function
Sensory nucleus (rostral/gustatory part of nucleus of tractus solitarius)	Dorsal to, and close to, the motor nucleus	Special visceral afferent (SVA, taste) + a little general somatic afferent (GSA)	SVA — taste, anterior 2/3 of tongue, floor of mouth, palate; GSA — general sensation from a strip of external ear/meatus (cell bodies of both in the geniculate ganglion)

Key organisational points (high exam value):

- ▶ Within the motor nucleus, neurones are arranged in **columns corresponding to individual muscles/branches**: those supplying the **upper face (frontalis, orbicularis oculi)** lie dorsally and receive **bilateral** corticonuclear (corticobulbar) fibres from both cerebral hemispheres; those supplying the **lower face** lie ventrally and receive only **contralateral** corticonuclear fibres. This asymmetry is the anatomical basis for distinguishing upper- from lower-motor-neurone facial palsy (Section C).
- ▶ A **separate, extrapyramidal pathway** (through the reticular formation) drives involuntary/emotional (mimetic) facial movements, distinct from the direct corticonuclear pathway for voluntary movement — explaining why emotional smiling can be preserved in a supranuclear (UMN) lesion even though voluntary movement is lost.
- ▶ The motor nucleus additionally receives ipsilateral reflex afferents from the nucleus solitarius and the trigeminal sensory nucleus, mediating the corneal, conjunctival and lacrimation reflexes (efferent limb = facial nerve to orbicularis oculi/lacrimal gland; afferent limb = ophthalmic division of trigeminal).

B. Course of the motor root

1. Intrapontine (fascicular) course — the internal genu. Axons of the motor nucleus first run **dorsomedially** toward the floor of the 4th ventricle, then hook **around the rostral pole of the abducent (VI) nucleus**, forming the **internal genu of the facial nerve**; the bulge this produces in the floor of the 4th ventricle is the **facial colliculus**. The fibres then descend ventrolaterally through the pontine tegmentum, passing between their own nucleus (medially) and the spinal trigeminal nucleus (laterally), and emerge at the **cerebellopontine angle**, between the caudal pons and the olive of the medulla.

2. Posterior cranial fossa. The motor root and the sensory root (nervus intermedius) — the latter lying between the motor root of VII (medially) and the vestibulocochlear nerve (laterally) — run laterally through the cerebellopontine angle together with the labyrinthine artery and CN VIII, and enter the **internal acoustic meatus** in the petrous temporal bone.

3. Facial canal (intrapetrous course). At the fundus of the meatus the two roots unite; the nerve then enters the **facial canal**, classically described in three segments:

- ▶ **Labyrinthine segment** — passes above the vestibule to the medial wall of the middle ear near the processus cochleariformis, where it bends sharply backward — the **external genu**, bearing the sensory **geniculate ganglion** (cell bodies of taste/SVA and GSA fibres).

- **Tympanic segment** — runs horizontally backward across the medial wall of the middle ear, above the promontory and below the lateral semicircular canal, to the posterior wall.
- **Mastoid segment** — turns vertically downward in the posterior wall of the middle ear to reach the **stylomastoid foramen**, its exit from the skull.

4. **Extracranial course.** After emerging at the stylomastoid foramen, the nerve gives small branches, then turns forward and enters the **posteromedial surface of the parotid gland**, where it divides (behind the neck of the mandible) into upper (temporofacial) and lower (cervicofacial) divisions — the **pes anserinus** — that ramify within the gland (between its superficial and deep parts) into five terminal branches: **temporal, zygomatic, buccal, marginal mandibular and cervical**, supplying the muscles of facial expression and platysma.

Branches given off along the course:

Origin	Branch	Fibre type	Supplies
Geniculate ganglion (external genu)	Greater petrosal nerve	GVE (preganglionic parasympathetic)	→ pterygopalatine ganglion → lacrimal gland, nasal & palatine glands
Tympanic segment	Nerve to stapedius	SVE	Stapedius (dampens excessive ossicular movement)
Vertical (mastoid) segment, ~6 mm above stylomastoid foramen	Chorda tympani	GVE + SVA	Crosses middle ear, joins lingual nerve → submandibular ganglion (submandibular/sublingual glands secretomotor) + taste, anterior 2/3 tongue
Extracranial, below stylomastoid foramen	Posterior auricular n.; nerve to posterior belly of digastric; nerve to stylohyoid	SVE	Occipitalis/auricular muscles; posterior belly digastric; stylohyoid
Within parotid (pes anserinus)	5 terminal branches	SVE	Muscles of facial expression, platysma

□ Fig 9.11 — The course and distribution of the facial nerve. (Vishram Singh — Clinical Neuroanatomy — 4e, p.333)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

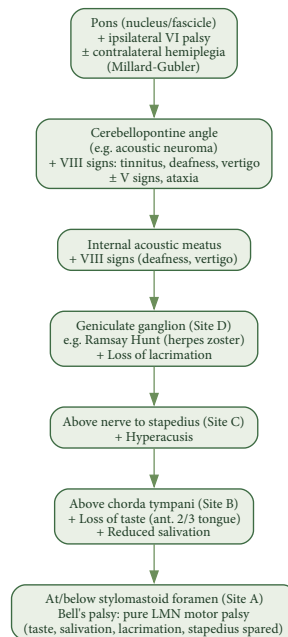
Label, top to bottom: motor root + nervus intermedius at pontomedullary junction → internal genu around abducent nucleus (facial colliculus) → cerebellopontine angle (with CN VIII) → internal acoustic meatus → labyrinthine segment → **external genu + geniculate ganglion** (greater petrosal nerve) → tympanic segment (nerve to stapedius) → mastoid segment (chorda tympani) → stylomastoid foramen → posterior auricular n. / n. to posterior belly of digastric / n. to stylohyoid → parotid gland → pes anserinus → 5 terminal branches (temporal, zygomatic, buccal, marginal mandibular, cervical).

C. Effects of lesions of the motor root at various levels**1. Supranuclear (upper motor neurone) vs nuclear/infranuclear (lower motor neurone) lesion**

Feature	Supranuclear (UMN) lesion	Nuclear / infranuclear (LMN) lesion
Site	Corticofacial fibres anywhere from motor cortex/internal capsule to the facial nucleus (e.g., stroke)	Facial nucleus itself, or the nerve anywhere from nucleus to muscle
Upper face (frontalis, orbicularis oculi)	Spared — bilateral corticofacial supply	Paralysed
Lower face	Paralysed on the side opposite the lesion	Paralysed on the same side as the lesion
Usual association	Often accompanied by hemiplegia	Often isolated; may accompany neighbouring cranial-nerve signs depending on level
Emotional (mimetic) movement	Preserved (separate extrapyramidal pathway)	Lost, along with voluntary movement

2. Nuclear lesion — rare; occurs in poliomyelitis, progressive bulbar palsy, or a pontine glioma/infarct. All facial muscles on the side of the lesion are paralysed (LMN type), but taste and lacrimation/salivation are **spared**, since those nuclei lie apart from the motor nucleus. Because neighbouring nuclei are close, a pontine lesion often also involves the **abducent nucleus/fascicle** (ipsilateral lateral rectus palsy) and, if it extends to involve the corticospinal tract before its decussation, produces a **contralateral hemiplegia** — the combination of ipsilateral facial ± abducent palsy with contralateral hemiplegia is the **Millard–Gubler syndrome**.

3. Infranuclear (peripheral) lesion — **localisation by level**. Because the nerve gives off branches sequentially along its intrapetrous course, the site of a lesion can be read off from the *pattern of added deficits*, proceeding from proximal (brainstem) to distal (stylomastoid foramen):



Describe the facial nerve under a) Nuclei b) course of motor root c) effects of lesions of motor root at various levels

- **Site A — at/below the stylomastoid foramen:** the commonest infranuclear lesion, **Bell's palsy** — pure motor paralysis of all facial muscles on that side; taste, salivation, lacrimation and the stapedius reflex are unaffected.
- **Site B — above the origin of the chorda tympani:** all of Site A **plus** loss of taste over the anterior two-thirds of the tongue and reduced salivary flow from submandibular/sublingual glands.
- **Site C — above the origin of the nerve to stapedius:** all of Site B **plus hyperacusis** (undamped ossicular movement makes normal sounds seem too loud).
- **Site D — at the geniculate ganglion:** all of Site C **plus loss of lacrimation**; involvement of the ganglion by herpes zoster produces **Ramsay Hunt syndrome** (herpetic vesicles on the auricle/external meatus + complete facial palsy + hyperacusis + loss of taste and lacrimation).
- **Cerebellopontine angle / internal acoustic meatus:** facial palsy accompanied by vestibulocochlear signs (deafness, tinnitus, vertigo); a CPA tumour may add trigeminal (lost corneal reflex) and cerebellar (ataxia) signs.
- **Within the parotid gland:** branch-selective weakness (not all five branches equally) with a palpable parotid mass strongly suggests parotid malignancy invading the nerve.

Applied / Clinical anatomy

- **Bell's palsy — clinical picture:** loss of forehead wrinkling, inability to close the eye (lagophthalmos, with Bell's phenomenon — the eyeball rolling up on attempted closure), sagging/drooping of the angle of the mouth, drooling of saliva, loss of the nasolabial fold, and accumulation of food in the vestibule of the mouth due to buccinator paralysis.
- **Bedside testing:** ask the patient to wrinkle the forehead/raise eyebrows (frontalis — distinguishes UMN-sparing from LMN-paralysis of the upper face), show the teeth/blow out the cheeks (orbicularis oris, buccinator), close the eyes tightly against the examiner's resistance (orbicularis oculi), and test taste with sweet/salty/sour/bitter substances on the anterior two-thirds of the tongue.

- ▶ **Corneal and conjunctival reflexes:** afferent limb via the ophthalmic (nasociliary) division of the trigeminal nerve; efferent limb (bilateral blink) via the facial nerve to orbicularis oculi — absent on the paralysed side in a facial nerve lesion.
- ▶ **Crocodile tears syndrome:** paroxysmal lacrimation while eating, following facial nerve injury proximal to the geniculate ganglion — regenerating parasympathetic (secretomotor) fibres destined for the submandibular/sublingual glands are misdirected along endoneurial sheaths meant for the lacrimal gland.
- ▶ **Surgical anatomy (parotidectomy):** the facial nerve trunk is identified as it emerges at the stylomastoid foramen using landmarks such as the tragal pointer and the tympanomastoid suture, just superficial to the posterior belly of digastric, before it enters the gland — essential to preserve the nerve during parotid surgery.
- ▶ **Nerve reanimation:** in established facial paralysis from nerve transection, hypoglossal–facial nerve anastomosis is used clinically to restore tone and voluntary movement to the paralysed face.

High-yield exam pointers

- ▶ Facial nerve = motor root (facial proper) + sensory root (nervus intermedius); three nuclei — main motor, superior salivatory/lacrimal, sensory (nucleus solitarius); all in the pons.
- ▶ Upper-face motor neurones = bilateral corticonuclear supply; lower-face motor neurones = only contralateral supply — the basis of UMN vs LMN facial palsy distinction.
- ▶ Internal genu loops around the abducent nucleus, producing the facial colliculus in the floor of the 4th ventricle.
- ▶ Course: cerebellopontine angle → internal acoustic meatus → facial canal (labyrinthine → external genu/geniculate ganglion → tympanic → mastoid segments) → stylomastoid foramen → parotid gland → pes anserinus → 5 terminal branches.
- ▶ Branches in sequence: greater petrosal (geniculate ganglion) → nerve to stapedius (tympanic segment) → chorda tympani (mastoid segment, ~6 mm above stylomastoid foramen).
- ▶ Site-of-lesion rule: the more proximal the lesion, the more deficits are added — taste/salivation (chorda tympani) < hyperacusis (n. to stapedius) < lacrimation (geniculate ganglion) < VIII/V/cerebellar signs (CPA/IAM) < contralateral hemiplegia ± VI palsy (pons, Millard–Gubler).
- ▶ Bell's palsy = commonest site (at/below stylomastoid foramen) = pure LMN motor palsy only.
- ▶ Ramsay Hunt syndrome = geniculate ganglion herpes zoster; crocodile tears = aberrant regeneration proximal to the geniculate ganglion.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Textbook of Anatomy Vol 3 (4e) and Clinical Neuroanatomy (4e); IB Singh — Textbook of Anatomy Vol 3 (6e); Snell — Clinical Neuroanatomy (7e); BD Chaurasia — Human Anatomy Vol 3–4 (8e).



Describe the reticular formation of the brainstem

Asked in: Paper IV Nov 2016 — RGUHS MD/MS Anatomy

Definition / Introduction

The **reticular formation** is a diffuse, phylogenetically ancient network of intermingled neurons and nerve fibres occupying the central core of the brainstem (medulla, pons and midbrain tegmentum), continuous caudally with the reticular grey of the upper cervical spinal cord and rostrally with the subthalamus, hypothalamus and thalamus. It has no sharp boundaries and is defined by exclusion — it comprises all brainstem grey matter that is *not* one of the named, well-demarcated cranial-nerve nuclei or long fibre tracts. Despite its "reticulated" (net-like) light-microscopic appearance, it contains functionally and chemically distinct nuclear groups that regulate consciousness, muscle tone, respiration, cardiovascular function and pain — making it one of the most clinically important regions of the CNS.

1. Location, extent and general organisation

- Occupies the **core of the brainstem**: dorsal to the inferior olivary nucleus in the medulla, the dorsal tegmentum of the pons, and the tegmentum of the midbrain.
- **Caudal continuity**: with the intermediate (reticular) grey matter of the spinal cord.
- **Rostral continuity**: with the subthalamus, hypothalamus and intralaminar/reticular nuclei of the thalamus (some authorities extend functional connections further, to the limbic system and cerebellum).
- Reticular neurons characteristically have **long, poorly-branched dendrites** oriented along the long axis of the brainstem, intersected by a dense web of ascending and descending fibres — the structural basis for its diffuse, "non-specific" or polymodal action; axons commonly **bifurcate**, sending one branch rostrally and one caudally.
- Pathways through it are **polysynaptic**, both **crossed and uncrossed**, and both **ascending and descending** — so a unilateral stimulus can produce a bilateral response.

2. Cytoarchitecture — three longitudinal columns of reticular nuclei

On cytoarchitectural, chemoarchitectural and functional grounds the reticular nuclei form **three bilateral longitudinal columns**:

Column	Neuron size / type	Alternative name	Representative nuclei (level)
Median column	Intermediate-sized, serotonergic (groups B1–B9)	Raphe nuclei	Dorsal raphe nucleus — midbrain (periaqueductal grey); nucleus raphe pontis / superior central nucleus — pons; nucleus raphe magnus , raphe pallidus (B1), raphe obscurus (B2) — medulla

Column	Neuron size / type	Alternative name	Representative nuclei (level)
Medial column	Large multipolar neurons	Magnocellular column	Cuneiform & subcuneiform nuclei — midbrain; pontine gigantocellular nucleus, oral & caudal pontine tegmental reticular nuclei — pons; medullary gigantocellular nucleus, ventral reticular nucleus — medulla
Lateral column	Small/intermediate neurons	Parvocellular column	Pedunculopontine nucleus (cholinergic, Ch5) — midbrain; nucleus locus coeruleus (noradrenergic) — pons; parvocellular reticular area, lateral reticular nucleus (precerebellar) — medulla

- The **raphe nuclei** produce **serotonin**; the dorsal raphe nucleus projects to the spinal cord and the nucleus raphe magnus projects to the caudal spinal nucleus of the trigeminal nerve, together forming a descending **pain-modulating (analgesic) pathway** — electrical stimulation of either abolishes pain perception, a principle exploited clinically for intractable pain.
- The **medial (magnocellular) column** receives afferents from the lateral column and gives rise to long ascending/descending multisynaptic axons with collaterals to neighbouring reticular cells — the classic polysynaptic "relay chain" of the reticular formation.
- The **lateral (parvocellular) column** receives collaterals from ascending sensory pathways and projects mainly to the medial column; it is regarded as an **association/relay region**. It includes distinct, chemically-defined cell groups: **dopaminergic/noradrenergic (A)**, **serotonergic (B, raphe)**, **adrenergic (C1–C3)** and **cholinergic (Ch)** neurons — e.g. the noradrenergic locus coeruleus and cholinergic pedunculopontine nucleus.
- Three reticular nuclei — the **lateral reticular nucleus**, **paramedian reticular nucleus** and **reticulotegmental nucleus of the pons** — are **precerebellar nuclei**, relaying spinal and cortical information chiefly to the vermis and paravermal cerebellar cortex.

3. Afferent connections

Source	Pathway/fibres
Spinal cord	Spinoreticular fibres; collaterals of the spinothalamic tract (a considerable number terminate in the lateral reticular nucleus, which relays to the cerebellum — spino-reticulo-cerebellar pathway)

Source	Pathway/fibres
Cranial nerve/sensory nuclei	Trigeminal, vestibular and acoustic pathways; tectoreticular fibres from the optic and auditory (tectal) systems
Cerebellum	Mainly from the contralateral fastigial nucleus
Basal ganglia	Corpus striatum, substantia nigra (pars reticularis projects to the reticular formation)
Diencephalon	Thalamus, hypothalamus, subthalamus
Limbic system	Septal area, amygdaloid nuclei, hippocampus
Cerebral cortex	Chiefly the motor and somatosensory areas (corticoreticular fibres, descending with the corticospinal tract)
Chemical/pharmacological	Adrenaline, acetylcholine, CO ₂ (excitatory); barbiturates, anaesthetics, tranquillizers (inhibitory); ammonia and irritants (excitatory)

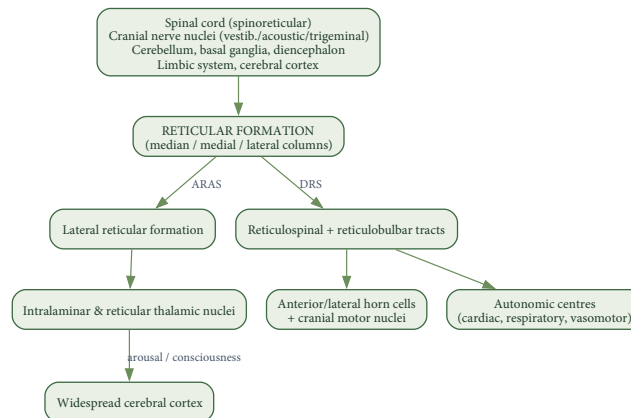
4. Efferent connections

- **Reticulospinal tracts** (medial and lateral) → anterior and lateral horn cells of the spinal cord — the principal **descending motor pathway** of the reticular formation.
- **Reticulobulbar fibres** → motor nuclei of the cranial nerves (branchiomotor nuclei, hypoglossal nucleus, dorsal nucleus of the vagus).
- To **autonomic outflow** — sympathetic and craniosacral parasympathetic centres of brainstem and cord, controlling cardiac, respiratory and vasomotor tone.
- To the **cerebral cortex**, indirectly via the intralaminar and reticular thalamic nuclei.
- To the **red nucleus, substantia nigra and tectum of the midbrain**, and reciprocally to the **cerebellum, corpus striatum, hypothalamus and subthalamus**.

5. Functional divisions

Functionally the reticular formation is divided into an **ascending** and a **descending** system.

- **Ascending Reticular Activating System (ARAS)** — while traversing the brainstem, the major ascending sensory tracts (spinothalamic tract, trigeminal lemniscus, lateral lemniscus, central vestibular pathway) give off collaterals to the **lateral reticular formation**, which in turn projects to the **intralaminar and reticular nuclei of the thalamus**; these relay diffusely to widespread areas of the **cerebral cortex**. Activation of this system produces behavioural **arousal**, and it is regarded as the anatomical substrate for wakefulness and the level of consciousness.
- **Descending Reticular System (DRS)** — descending pathways (reticulospinal, reticulobulbar) from the reticular formation to autonomic centres of the brainstem and to the anterior and lateral horn cells of the spinal cord; it constitutes one of the most important **extrapyramidal motor pathways**, critical for respiratory and cardiac rhythm and for muscle tone.



Describe the reticular formation of the brainstem

6. Functions of the reticular formation

- ▶ **Consciousness and arousal** — via the ARAS; maintains wakefulness and alertness, and its integrity is essential for the state of consciousness.
- ▶ **Somatic motor control** — through reticulospinal projections, modulates alpha and gamma motoneuron activity, muscle tone and reflex activity (including reciprocal inhibition of antagonists); together with the vestibular apparatus and vestibulospinal tract, maintains **antigravity muscle tone** and postural adjustments.
- ▶ **Control of facial expression associated with emotion** — bilateral reticular pathways (distinct from the corticobulbar tract) mediate involuntary emotional facial movements such as spontaneous smiling.
- ▶ **Somatic and visceral sensory modulation** — influences transmission through ascending sensory pathways (facilitation or inhibition), and forms a **pain-"gating"** mechanism via the raphe-spinal serotonergic system.
- ▶ **Autonomic (vegetative) control** — brainstem **cardiac and respiratory "vital centres"** and vasomotor reflex centres are integral parts of the reticular formation.
- ▶ **Neuroendocrine control** — through hypothalamic connections, influences release of hypothalamic releasing/inhibiting factors and hence adenohypophyseal and neurohypophyseal secretion.
- ▶ **Regulation of circadian/biologic rhythms**, including the sleep–wake cycle, through hypothalamic connections.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 19.1 — Location of reticular formation in the brainstem. (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.685)

In addition, draw a transverse-section schematic (one each through midbrain, pons and medulla) and label the **three reticular columns: median column (raphe nuclei)** near the midline, **medial column (magnocellular/gigantocellular nuclei)** just lateral to it, and **lateral column (parvocellular nuclei, including locus coeruleus and pedunculopontine nucleus)** most laterally — with the **medial lemniscus, spinal lemniscus and trigeminal lemniscus** marked as adjoining landmarks.

Applied / Clinical anatomy

- ▶ **Coma** — diffuse or focal damage to the ARAS (traumatic axonal injury, brainstem haemorrhage/infarct, or secondary compression by transtentorial/uncal herniation compromising the thalamic relays of the reticular activating system) produces progressive loss of consciousness, stupor and coma; irreversible destruction of the medullary cardiac/respiratory reticular centres causes cardiorespiratory arrest and is the basis of **brainstem death**.
- ▶ **Unresponsive wakefulness syndrome (persistent vegetative state)** — a classic dissociation: the reticular formation survives (patient shows sleep–wake cycles, spontaneous eye-opening, intact respiration) while the cerebral cortex is destroyed, so the patient is *awake but not aware*.
- ▶ **Arousal manoeuvres** — painful pressure, a slap, splashed water or ammonia held near the nostrils arouses a drowsy/comatose patient because trigeminal (facial/nasal mucosal) afferents excite the ARAS — the physiological basis of bedside arousal testing.
- ▶ **Pharmacology of the RAS** — anaesthetics, barbiturates and tranquillizers depress it (mechanism of induced unconsciousness/sleep); sedative overdose classically produces reticular-formation-mediated coma.
- ▶ **Pain control** — electrical stimulation of the dorsal raphe nucleus (periaqueductal grey) or nucleus raphe magnus produces clinically useful analgesia, exploited in stereotactic pain-relief procedures for otherwise intractable pain.
- ▶ **Locked-in syndrome** (ventral pontine infarction) is an important differential to distinguish from coma/vegetative state at viva: the reticular formation and cortex are both preserved, only the corticospinal/corticobulbar tracts are destroyed, so the patient is conscious but quadriplegic and anarthric, retaining only vertical eye movement/blinking.

Recent advances

- ▶ High-resolution ex vivo (750 μm) and in vivo 7-Tesla diffusion-MRI tractography in humans has mapped previously undescribed brainstem pathways connecting the reticular formation to the thalamus, hypothalamus and basal forebrain that sustain wakefulness, refining the classical ARAS wiring diagram and yielding the publicly released **Harvard Ascending Arousal Network (AAN) Atlas** (Edlow et al., *Science Translational Medicine*, 2024) [DOI: 10.1126/scitranslmed.adj4303].

- ▶ A histology-guided, automated probabilistic MRI segmentation tool now allows in-scanner, patient-specific delineation of the brainstem reticular/arousal nuclei that were previously identifiable only on post-mortem histology, enabling their study in living patients with disorders of consciousness (Olchanyi et al., *Human Brain Mapping*, 2025) [DOI: 10.1002/hbm.70357].
- ▶ An individual-participant-data meta-analysis of **central thalamic deep brain stimulation** (targeting the thalamic relay of the ascending reticular activating system) shows cyclic stimulation acutely improves daytime arousal in patients with severe disorders of consciousness, supporting the reticulo-thalamo-cortical arousal circuit as a therapeutic target (*Journal of Neurosurgery*, 2025) [DOI: 10.3171/2025.3.JNS241092].
- ▶ (According to PubMed.)

High-yield exam pointers

- ▶ Reticular formation = diffuse core of neurons/fibres in medulla, pons and midbrain tegmentum; extends from upper cervical cord to diencephalon.
- ▶ Three longitudinal columns: **median (raphe, serotonergic)**, **medial (magnocellular/gigantocellular)**, **lateral (parvocellular, includes locus coeruleus + pedunculopontine nucleus)**.
- ▶ Functionally divided into **ARAS** (ascending, consciousness/arousal) and **descending reticular system** (motor/autonomic control via reticulospinal & reticulobulbar tracts).
- ▶ ARAS circuit: spinothalamic/trigeminal/lateral lemniscus/vestibular collaterals → lateral reticular formation → intralaminar & reticular thalamic nuclei → diffuse cortex.
- ▶ Coma = ARAS damaged; vegetative state = ARAS intact, cortex dead; locked-in syndrome = both preserved, corticospinal tract destroyed.
- ▶ Dorsal raphe nucleus and nucleus raphe magnus = serotonergic descending pain-control pathway.
- ▶ Precerebellar reticular nuclei: lateral reticular nucleus, paramedian reticular nucleus, reticulotegmental nucleus of pons.
- ▶ Anaesthetics/barbiturates/tranquillizers depress RAS; painful/ammonia/light stimuli activate it — basis of bedside arousal testing.
- ▶ Vital (cardiac and respiratory) centres are reticular-formation nuclei — their destruction is incompatible with life.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy. Recent-advances section per PubMed (see DOIs above).



Discuss about the cranial nerve nuclei in hind brain

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

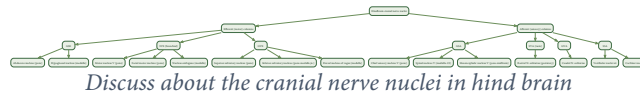
Definition / Introduction The hindbrain (rhombencephalon) comprises the **pons, medulla oblongata and cerebellum**; the cranial nerve nuclei themselves are confined to the pons and medulla — the cerebellum contains no cranial nerve nuclei of its own. These nuclei belong to cranial nerves **V (part), VI, VII, VIII, IX, X, cranial root of XI, and XII** (the olfactory and optic nerves are outgrowths of the forebrain, and the oculomotor and trochlear nuclei belong to the midbrain, not the hindbrain). Embryologically the nuclei develop from **seven functional cell columns** in the alar and basal laminae of the rhombencephalic neural tube, and in the adult they are arranged as a mediolateral series of grey-matter columns in the floor of the fourth ventricle.

1. Embryological basis — the seven functional columns

- ▶ The lateral wall of the developing neural tube is divided by the **sulcus limitans** into a ventral **basal lamina** (motor) and a dorsal **alar lamina** (sensory).
- ▶ In the spinal cord this basal/alar division yields only 4 columns (general somatic efferent, general visceral efferent, general visceral afferent, general somatic afferent), arranged ventrodorsally.
- ▶ During hindbrain development two changes occur: (i) the neural tube widens to form the fourth ventricle, so the alar laminae are splayed apart like "opening a book" and the columns rotate from a ventrodorsal to a **mediolateral** arrangement; (ii) an extra **special visceral (branchial)** column appears between the somatic and general visceral columns (for pharyngeal-arch derivatives), and an extra **special somatic afferent** column appears at the extreme lateral edge of the alar lamina (for the otic placode derivatives — hearing/balance).
- ▶ This yields **seven functional columns**, medial to lateral:

Column	Abbrev.	Lamina	Function	Hindbrain nuclei
General somatic efferent	GSE	Basal (most medial)	Motor to somite-derived striated muscle	Abducens nucleus; Hypoglossal nucleus
Special visceral (branchial) efferent	SVE	Basal	Motor to branchial-arch striated muscle	Motor nucleus of trigeminal; Facial motor nucleus; Nucleus ambiguus
General visceral efferent	GVE	Basal (most lateral motor)	Cranial parasympathetic outflow to glands/smooth muscle	Superior & inferior salivatory nuclei; Dorsal (motor) nucleus of vagus
General visceral afferent	GVA	Alar (most medial sensory)	Visceral sensation (distension, ischaemia)	Caudal nucleus of tractus solitarius
Special visceral afferent	SVA	Alar	Taste	Rostral (gustatory) nucleus of tractus solitarius

Column	Abbrev.	Lamina	Function	Hindbrain nuclei
General somatic afferent	GSA	Alar	Pain, touch, temperature, proprioception of head	Chief sensory, spinal, and mesencephalic nuclei of trigeminal
Special somatic afferent	SSA	Alar (most lateral)	Hearing and equilibrium	Cochlear nuclei; Vestibular nuclei



2. Motor (efferent) nuclei of the hindbrain

Nucleus	Column	Location	Nerve	Chief supply
Abducens nucleus	GSE	Lower pons, beneath the facial colliculus, floor of 4th ventricle; medial longitudinal fasciculus (MLF) applied to its ventromedial aspect	VI	Lateral rectus
Hypoglossal nucleus	GSE	Elongated column through the whole length of medulla, deep to the hypoglossal triangle	XII	Intrinsic and extrinsic tongue muscles
Motor nucleus of trigeminal	SVE	Upper pons, dorsal tegmentum, medial and slightly cranial to the chief sensory nucleus	V	Muscles of mastication, tensor tympani, tensor veli palatini, mylohyoid, anterior belly of digastric
Facial motor nucleus	SVE	Lower pons, ventrolateral tegmentum; its fibres loop dorsomedially around the abducens nucleus (internal genu), raising the facial colliculus	VII	Muscles of facial expression, stapedius, posterior belly of digastric, stylohyoid

Nucleus	Column	Location	Nerve	Chief supply
Nucleus ambiguus	SVE	Medulla (whole length), dorsal to the inferior olivary nucleus, ventromedial to the spinal nucleus of V	IX, X, cranial root of XI	Muscles of pharynx, larynx and soft palate (3rd, 4th, 6th arches)
Superior salivatory & lacrimatory nucleus	GVE	Dorsal pons, medial to the facial motor nucleus	VII (nervus intermedius)	Submandibular/sublingual glands (chorda tympani); lacrimal, nasal, palatine glands (greater petrosal nerve)
Inferior salivatory nucleus	GVE	Dorsolateral pons, just above the pontomedullary junction	IX	Parotid gland (tympanic branch → otic ganglion)
Dorsal (motor) nucleus of vagus	GVE	Medulla, deep to the vagal triangle, dorsal to the hypoglossal nucleus	X	Smooth muscle and glands of thoracic and abdominal viscera up to the right two-thirds of the transverse colon

3. Sensory (afferent) nuclei of the hindbrain

Nucleus	Column	Location	Modality
Chief (principal) sensory nucleus of trigeminal	GSA	Upper pons, dorsolateral tegmentum, lateral to the motor nucleus	Touch (face, oral cavity)
Spinal nucleus of trigeminal (pars rostralis, interpolaris, caudalis)	GSA	Extends from the pons through the medulla to the C2 spinal segment	Pain and temperature — somatotopic "onion-skin" pattern: ophthalmic → pars caudalis, maxillary → pars interpolaris, mandibular → pars rostralis
Mesencephalic nucleus of trigeminal	GSA	From upper pons rostrally into the midbrain, lateral to the cerebral aqueduct	Proprioception from muscles of mastication, TMJ, teeth — the only site of 1st-order sensory (pseudounipolar) cell bodies within the CNS

Nucleus	Column	Location	Modality
Rostral (gustatory) nucleus of tractus solitarius	SVA	Upper medulla	Taste — anterior 2/3 tongue (VII), posterior 1/3 tongue (IX), epiglottis (X)
Caudal nucleus of tractus solitarius	GVA	Medulla, dorsomedial to the dorsal nucleus of vagus; the two sides fuse caudally as the commissural nucleus	General visceral sensation from pharynx, larynx, oesophagus and thoraco-abdominal viscera
Cochlear nuclei (dorsal, ventral)	SSA	Upper medulla, on the dorsal and ventral aspects of the inferior cerebellar peduncle	Hearing
Vestibular nuclei (superior, inferior/spinal, medial, lateral/Deiters')	SSA	Pons and medulla, beneath the vestibular area of the 4th ventricle floor	Equilibrium and balance

4. Surface projection on the floor of the fourth ventricle

- ▶ The **sulcus limitans** divides the floor into a medial **motor** strip and a lateral **sensory** strip (vestibular area), reproducing the embryological mediolateral order.
- ▶ Medial eminence, cranial to caudal: **facial colliculus** (VI nucleus with the looping VII fibres over it), **hypoglossal triangle** (XII nucleus), **vagal triangle** (dorsal nucleus of X); the **area postrema** lies just lateral to the lower vagal triangle.
- ▶ **Striae medullares** cross the floor at the pontomedullary junction (from the arcuate nuclei to the inferior cerebellar peduncle) and mark the boundary between pontine and medullary parts of the floor.
- ▶ The **vestibular area**, lateral to the sulcus limitans, overlies the vestibular and cochlear nuclei.

□ Fig 9.2 — Surface projection of cranial nerve nuclei on the dorsal aspect of the (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.298)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the dorsal (open-book) view of the pons–medulla with the 4th ventricle floor, and label:

- ▶ Median sulcus; sulcus limitans (dividing motor medial eminence from sensory vestibular area)
- ▶ Facial colliculus (VI + looping VII fibres)
- ▶ Hypoglossal triangle (XII nucleus) and vagal triangle (dorsal nucleus of X), with area postrema between the lower vagal triangle and the lateral margin
- ▶ Striae medullares at the pontomedullary junction
- ▶ Vestibular area (vestibular + cochlear nuclei) laterally
- ▶ Motor nuclei labelled on one half (facial motor n., nucleus ambiguus, salivatory nuclei, motor n. of V) and sensory nuclei on the other half (chief/spinal/mesencephalic nuclei of V, nucleus solitarius)

5. Key central connections

- ▶ **Medial longitudinal fasciculus (MLF)** interconnects the vestibular nuclei with the abducens, trochlear and oculomotor nuclei (and the spinal accessory nucleus), coordinating conjugate eye movements with head/neck movement (vestibulo-ocular reflex).
- ▶ **Nucleus solitarius** projects via solitariothalamic/solitariohypothalamic tracts to the thalamus (VPM) and hypothalamus, and locally to the dorsal vagal nucleus and nucleus ambiguus for visceral reflexes (swallowing, gag, cardiorespiratory reflexes).
- ▶ **Vestibular nuclei** give the uncrossed lateral vestibulospinal tract (from the lateral/Deiters' nucleus) and the descending MLF to spinal anterior horn cells, regulating postural tone.
- ▶ **Mesencephalic nucleus of V** forms the afferent limb of the monosynaptic jaw-jerk reflex with the motor nucleus of V.

Applied / Clinical anatomy

- ▶ **Lateral medullary (Wallenberg) syndrome** — thrombosis of the posterior inferior cerebellar artery: dysphagia/dysarthria (nucleus ambiguus), ipsilateral facial analgesia/thermoanaesthesia (spinal nucleus/tract of V), vertigo/nystagmus (vestibular nuclei), ipsilateral Horner syndrome, ipsilateral cerebellar signs, contralateral loss of pain/temperature over trunk and limbs (spinothalamic tract).
- ▶ **Medial medullary syndrome** — vertebral artery/medullary branch occlusion: contralateral hemiparesis (pyramid), contralateral loss of position/vibration sense (medial lemniscus), ipsilateral tongue weakness with deviation to the paralysed side on protrusion (hypoglossal nucleus/nerve).
- ▶ **Millard–Gubler syndrome** (medial inferior pontine syndrome) — ventral pontine lesion involving the pyramidal tract and the emerging fibres of VI and VII: ipsilateral medial squint (abducens), ipsilateral facial palsy (facial nucleus/nerve), contralateral hemiplegia ("abducent alternating hemiplegia").

- ▶ **Pontocerebellar (cerebellopontine) angle syndrome** — acoustic neuroma compressing VII and VIII at the pontomedullary junction: tinnitus, progressive deafness and vertigo (cochlear/vestibular nuclei territory), with later facial weakness.
- ▶ **MLF syndrome (internuclear ophthalmoplegia)** — lesion of the MLF between the abducens and oculomotor nuclei (classically multiple sclerosis): failure of adduction of the ipsilateral eye with monocular nystagmus of the contralateral abducting eye; convergence is preserved.
- ▶ **Bulbar vs pseudobulbar palsy** — a lesion of the hindbrain motor nuclei themselves (nucleus ambiguus, hypoglossal nucleus) gives a **LMN (bulbar)** picture — flaccid, wasted, fasciculating tongue and palate with a nasal/dysarthric voice — whereas bilateral corticobulbar tract lesions above the nuclei give **pseudobulbar palsy** with a spastic tongue and exaggerated jaw jerk.
- ▶ **Facial colliculus** swelling is a useful surface landmark at operation/imaging for the underlying VI nucleus and the looping VII fibres — a lesion here characteristically combines lateral rectus and facial nerve palsy.

High-yield exam pointers

- ▶ Hindbrain cranial nerve nuclei belong to **V (part)–XII**; oculomotor (III) and trochlear (IV) nuclei are **midbrain**, not hindbrain, structures.
- ▶ Seven functional columns (medial→lateral): GSE, SVE, GVE (motor) and GVA, SVA, GSA, SSA (sensory) — the mediolateral order results from "opening of the book" of the alar plates as the 4th ventricle forms.
- ▶ **Facial colliculus** = internal genu of VII looping over the VI nucleus, raising the floor of the 4th ventricle.
- ▶ **Nucleus ambiguus** is shared by IX, X and the cranial root of XI and supplies muscles of the 3rd, 4th and 6th pharyngeal arches.
- ▶ **Mesencephalic nucleus of V** is the only site of primary (1st-order) sensory neuron cell bodies within the CNS.
- ▶ Spinal nucleus of V shows an "onion-skin" somatotopy: ophthalmic → pars caudalis, mandibular → pars rostralis.
- ▶ Dorsal (motor) nucleus of vagus is the largest source of cranial parasympathetic outflow.
- ▶ Vestibular nuclei (4) and cochlear nuclei (2) straddle the pontomedullary junction beneath the vestibular area.
- ▶ MLF links vestibular nuclei with III, IV and VI nuclei — the anatomical basis of internuclear ophthalmoplegia.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e.



Facial nerve

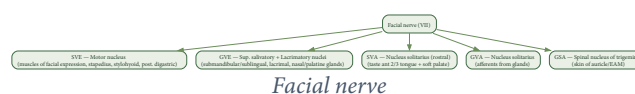
Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction. The facial nerve is the seventh cranial nerve and the nerve of the second (hyoid) pharyngeal arch. It is a mixed nerve with a large motor root supplying all the muscles of facial expression, the stapedius, stylohyoid and posterior belly of digastric, and a smaller sensory/parasympathetic root — the **nervus intermedius** — carrying taste from the anterior two-thirds of the tongue and secretomotor fibres to the lacrimal, submandibular and sublingual glands and to glands of the nose and palate. It has an unusually long and complex course, running successively through the pons, the petrous temporal bone and the parotid gland, and is clinically the most important cranial nerve for the anatomy exam because of the localising value of its lesions.

1. Functional components and nuclei

The nerve has five functional components, related to four nuclei situated in the lower pons.

Functional component	Fibre type	Nucleus	Structures supplied/from
Special visceral (branchial) efferent — SVE	Motor	Motor (branchiomotor) nucleus	Muscles of facial expression, stapedius, stylohyoid, posterior belly of digastric, occipitofrontalis, platysma (all 2nd-arch derivatives)
General visceral efferent — GVE	Parasympathetic secretomotor	Superior salivatory nucleus and Lacrimatory nucleus	Submandibular + sublingual glands (via chorda tympani); lacrimal gland and glands of nose/palate (via greater petrosal nerve)
General visceral afferent — GVA	Sensory	Nucleus of tractus solitarius	Afferents from the glands supplied above
Special visceral afferent — SVA	Taste	Nucleus of tractus solitarius (rostral/gustatory part)	Taste — anterior 2/3 of tongue and soft palate (except vallate papillae)
General somatic afferent — GSA	Cutaneous sensation	Spinal nucleus of trigeminal nerve	A small area of skin of the auricle/external acoustic meatus (via communication with the vagus)



2. Intrapontine course and the internal genu

- ▶ The **motor nucleus** lies deep in the reticular formation of the caudal pons, ventrolateral to the tegmentum, medial to the spinal nucleus/tract of the trigeminal nerve and antero-lateral/caudal to the abducens nucleus.
- ▶ Its axons take an aberrant course: they first run **dorsomedially** towards the floor of the fourth ventricle, hook **around the abducens nucleus** (the **internal genu**), and then descend ventrolaterally through the reticular formation to emerge at the **pontomedullary junction** (**cerebellopontine angle**), medial to the vestibulocochlear nerve.
- ▶ The looping facial fibres together with the underlying abducens nucleus raise the **facial colliculus** on the floor of the fourth ventricle.
- ▶ Two roots are attached to the brainstem — a large **motor root** and a smaller **sensory root** (**nervus intermedius**, of Wrisberg), lying between the motor root and the vestibulocochlear nerve; both roots enter the **internal acoustic meatus** together with CN VIII and the labyrinthine vessels.
- ▶ **Corticonuclear supply**: neurones supplying the upper face receive **bilateral** corticonuclear fibres; those supplying the lower face receive predominantly **crossed** fibres only — the anatomical basis for distinguishing an upper motor neurone lesion (contralateral lower-face paralysis only, forehead spared) from a lower motor neurone lesion (complete ipsilateral paralysis, Bell's palsy).
- ▶ The facial nucleus also receives ipsilateral reflex afferents from the nucleus solitarius and from the trigeminal sensory nucleus, forming the basis of the **corneal (blink) reflex**.

3. Course through the temporal bone (facial/Fallopian canal)

- ▶ At the fundus of the internal acoustic meatus the two roots fuse into a single trunk that enters the **facial canal**, which has three parts separated by two bends:
- ▶ **Labyrinthine segment** — runs laterally above the vestibule to the medial wall of the middle ear.
- ▶ **Tympanic segment** — turns sharply backwards at the **external genu** (thickened here by the **geniculate ganglion**) and runs horizontally above the promontory.
- ▶ **Mastoid (vertical) segment** — bends again at the aditus to the mastoid antrum and descends to the **stylomastoid foramen**, through which the nerve leaves the skull.
- ▶ The **geniculate ganglion** is a sensory ganglion (pseudounipolar cells) at the external genu; it houses the cell bodies for taste and cutaneous sensation carried by the nerve.

□ Fig 4.35 — Course of facial nerve (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.491)

4. Branches — three groups

Site of origin	Branches	Distribution
Within the facial canal	Greater (superficial) petrosal nerve — from geniculate ganglion	Joins deep petrosal nerve (sympathetic) → nerve of pterygoid canal → pterygopalatine ganglion → lacrimal gland, nasal and palatine glands
	Nerve to stapedius	Stapedius muscle (dampens excessive ossicular vibration)

Site of origin	Branches	Distribution
	Chorda tympani — arises ~6 mm above stylomastoid foramen	Crosses tympanic membrane medial to malleus handle, exits via petrotympanic fissure, joins lingual nerve → taste (ant. 2/3 tongue) + secretomotor (via submandibular ganglion) to submandibular/sublingual glands
At exit from stylomastoid foramen	Posterior auricular	Auricularis posterior, occipitalis
	Nerve to posterior belly of digastric	Posterior belly of digastric
	Nerve to stylohyoid	Stylohyoid
Terminal, within the parotid gland ("Two Zebras Bit My Cheek")	Temporal, Zygomatic, Buccal, Marginal mandibular, Cervical	Muscles of facial expression above and below the palpebral fissure, buccinator/orbicularis oris, lower lip/chin muscles, platysma respectively

- The nerve carries only motor fibres to its target muscles; sensory (proprioceptive) supply to the face travels separately in branches of the trigeminal nerve to the mesencephalic nucleus.

5. Extracranial and intraparotid course

- On leaving the stylomastoid foramen the nerve crosses the lateral aspect of the base of the styloid process and enters the **postero-medial surface of the parotid gland**.
- Within the gland it runs forwards, crossing the **retromandibular vein** and the **external carotid artery**, and divides behind the neck of the mandible into its five terminal branches, which emerge along the **anterior border of the gland** — this plane (the nerve and its branches) is used surgically to define the "superficial" and "deep" lobes of the parotid.
- **Communicating branches:** with the auriculotemporal, great auricular, lesser occipital and transverse cervical nerves (for co-ordination and cutaneous overlap), and with the sensory branches of the trigeminal nerve over its motor territory.

6. Ganglia associated with the facial nerve

- **Geniculate ganglion** — sensory; cell bodies for taste (SVA) and cutaneous (GSA) fibres; site of involvement in herpes zoster oticus (Ramsay-Hunt syndrome).
- **Pterygopalatine ganglion** — parasympathetic; receives preganglionic secretomotor fibres via the greater petrosal nerve/nerve of the pterygoid canal; relays to lacrimal gland and nasal/palatine glands.
- **Submandibular ganglion** — parasympathetic; suspended from the lingual nerve; receives preganglionic fibres via the chorda tympani; relays to submandibular and sublingual glands.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce a schematic of the facial nerve from the pons to the periphery, labelling:

- ▶ **Facial nucleus** in the pons, the **internal genu** looped around the **abducens nucleus**, and the **facial colliculus**
- ▶ **Motor root** and **nervus intermedius**, entering the **internal acoustic meatus** with CN VIII
- ▶ The three parts of the **facial (Fallopian) canal** separated by the **external genu/geniculate ganglion** and the second bend near the aditus of the mastoid antrum
- ▶ **Stylomastoid foramen** as the point of exit
- ▶ Branches given off within the canal: **greater petrosal nerve**, **nerve to stapedius**, **chorda tympani**
- ▶ Branches at the stylomastoid exit: **posterior auricular**, **nerve to digastric**, **nerve to stylohyoid**
- ▶ Course through the **parotid gland** (crossing retromandibular vein and external carotid artery) and the five terminal branches — **temporal**, **zygomatic**, **buccal**, **marginal mandibular**, **cervical** — fanning out from the anterior border of the gland
- ▶ **Pterygopalatine** and **submandibular ganglia** with their afferent/efferent connections

Applied / Clinical anatomy

- ▶ **Bell's palsy** — the commonest infranuclear (LMN) facial palsy, classically at/near the stylomastoid foramen; presents with ipsilateral facial asymmetry, loss of forehead wrinkling, inability to close the eye (lagophthalmos with Bell's phenomenon), loss of the nasolabial fold, and drooping of the angle of the mouth accentuated on smiling.
- ▶ **Localising value of lesion level** — proximal-to-distal progression of added deficits: a lesion proximal to the geniculate ganglion adds loss of lacrimation (greater petrosal nerve); proximal to the nerve to stapedius adds **hyperacusis**; proximal to the origin of the chorda tympani adds loss of taste over the anterior two-thirds of the tongue. A lesion distal to the stylomastoid foramen (e.g. in the parotid gland, or classic Bell's palsy) causes pure motor paralysis without these additional deficits.
- ▶ **UMN vs LMN facial palsy** — because the upper-face part of the facial nucleus has bilateral corticonuclear representation, a supranuclear (UMN) lesion (e.g. stroke) spares the forehead/orbicularis oculi and paralyzes only the contralateral lower face; an infranuclear (LMN) lesion paralyzes the entire ipsilateral half of the face, upper and lower.
- ▶ **Ramsay-Hunt syndrome** — herpes zoster infection of the geniculate ganglion; produces facial palsy, hyperacusis, loss of taste and lacrimation, and vesicles on the auricle/external acoustic meatus.
- ▶ **Crocodile tears syndrome** — aberrant regeneration after proximal facial nerve injury, in which regrowing secretomotor fibres destined for the submandibular gland instead enter the endoneurial sheath meant for lacrimal-gland fibres, so the patient lacrimates while eating.

- ▶ **Facial nerve palsy in the newborn** — the mastoid process is undeveloped and the stylomastoid foramen lies superficially, so forceps or manipulation during delivery can injure the nerve, impairing the buccinator action needed for sucking.
- ▶ **Parotid surgery** — the facial nerve trunk is identified deep to the tragal cartilage/pointer and superficial to the posterior belly of digastric before it is followed forward through the gland; deliberate or inadvertent division during parotidectomy for a tumour produces the corresponding branch palsy (most often the marginal mandibular branch, crossing superficial to the mandible).
- ▶ **Surface marking** — the extracranial (pre-parotid) course is marked by a short line from the mid-point of the anterior border of the mastoid process to just in front of the auricular lobule; the intraparotid course/initial buccal branch is marked by a line parallel to, and just below, the parotid duct.
- ▶ **Clinical testing** — asking the patient to wrinkle the forehead, close the eyes tightly (test orbicularis oculi — examiner tries to prise the lids open), smile/show teeth (symmetry of the angles of the mouth), and puff out the cheeks against resistance (buccinator); taste is tested on the anterior two-thirds of the tongue.

Recent advances

- ▶ **Intraoperative facial nerve monitoring (IONM) in parotidectomy** — a 2025 systematic review and meta-analysis of 10 studies (n = 1047) found IONM nearly halves the odds of both immediate (OR 0.49) and permanent (OR 0.49) postoperative facial weakness, supporting its routine use as a nerve-preservation adjunct (Barrameda et al, *Otolaryngol Head Neck Surg* 2025) [PMID: 41353726].
- ▶ **Predictive value of IONM parameters** — a companion systematic review of 8 studies (632 patients) found current evidence does not conclusively validate specific amplitude/threshold cut-offs for predicting postoperative function, though a >50% amplitude drop correlated with severe palsy in some studies (Zhao et al, *J Int Med Res* 2025) [PMID: 41371257].
- ▶ **2026 Korean multidisciplinary clinical practice guideline for facial nerve palsy** — endorses the **House-Brackmann grading system** as the standard assessment tool (Grade A), early oral corticosteroids within 72 hours of Bell's palsy onset (Grade A), and selective addition of antivirals/facial nerve decompression only in severe, atypical cases (Grade B) (Lee et al, *Clin Exp Otorhinolaryngol* 2026) [PMID: 42163702].
- ▶ **Updated Cochrane protocol** registered to formally re-evaluate corticosteroids, antivirals and their combination for Bell's palsy, including equity-related (age) effect modification (Kurotschka et al, *Cochrane Database Syst Rev* 2026) [PMID: 41733053].
- ▶ **Precision-medicine direction in acute peripheral facial palsy** — a 2026 narrative review reaffirms early systemic corticosteroids as the treatment cornerstone, finds antiviral monotherapy unhelpful (combination therapy possibly benefiting older/severe cases), and highlights emerging risk-stratification, electrodiagnostic prognostication and AI-assisted decision tools (Guo & Dong, *Front Neurosci* 2026) [PMID: 42416914].

(According to PubMed; DOIs: [10.1002/ohn.70083](https://doi.org/10.1002/ohn.70083), [10.1177/03000605251403833](https://doi.org/10.1177/03000605251403833), [10.21053/ceo.2026-

00096](<https://doi.org/10.21053/ceo.2026-00096>),
 [10.1002/14651858.CD015563](<https://doi.org/10.1002/14651858.CD015563>),
 [10.3389/fnins.2026.1840400](<https://doi.org/10.3389/fnins.2026.1840400>).)

High-yield exam pointers

- ▶ Facial nerve = nerve of the 2nd pharyngeal arch; motor nucleus lies in the caudal pons, ventrolateral, medial to the spinal trigeminal nucleus.
- ▶ Internal genu = facial fibres looping around the abducens nucleus, raising the facial colliculus in the fourth-ventricle floor.
- ▶ Two roots: large motor root + nervus intermedius (sensory/parasympathetic), entering the internal acoustic meatus with CN VIII.
- ▶ Facial (Falloppian) canal has 3 parts and 2 bends — external genu bears the geniculate ganglion; nerve exits via the stylomastoid foramen.
- ▶ Branches within the canal: greater petrosal nerve, nerve to stapedius, chorda tympani (mnemonic order = proximal to distal).
- ▶ Terminal branches (parotid) — temporal, zygomatic, buccal, marginal mandibular, cervical ("Two Zebras Bit My Cheek").
- ▶ Ganglia: geniculate (sensory), pterygopalatine and submandibular (both parasympathetic relay stations).
- ▶ Lesion-level rule: hyperacusis (stapedius), loss of taste (chorda tympani) and loss of lacrimation (greater petrosal) are added the more proximal the lesion; distal/stylomastoid lesions (Bell's palsy) give pure motor palsy.
- ▶ UMN facial palsy spares the forehead (bilateral cortical supply to upper face); LMN palsy involves the whole ipsilateral half of the face.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3-4 8e; IB Singh's Textbook of Anatomy Vol 3 6e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; Moore's Clinically Oriented Anatomy 9e.



Give a detailed account of medulla oblongata with its applied aspects

Asked in: Paper IV Apr 2008 — RGUHS MD/MS Anatomy

Definition / Introduction — The **medulla oblongata** is the lowest and most caudal part of the brainstem, connecting the pons above to the spinal cord below. It is about **3 cm long and 2 cm broad** at its widest (upper) end, and is divided into a lower **closed part** (surrounding the central canal) and an upper **open part** (forming the caudal half of the floor of the fourth ventricle). It carries the ascending and descending tracts linking spinal cord to higher centres, houses the nuclei of cranial nerves **IX–XII**, and contains the vital **respiratory, cardiac and vasomotor centres** — making it one of the most clinically important parts of the central nervous system.

1. Extent, situation and relations

- ▶ Extends from the **lower border of the pons** (pontomedullary sulcus) to a plane just above the **first cervical nerve**, at the level of the **upper border of the atlas**, where it is continuous with the spinal cord; the precise junction is where the **last hypoglossal rootlet** meets the **first ventral rootlet of C1**.
- ▶ Lies in the **anterior part of the posterior cranial fossa** on the **clivus** (basiocciput), separated from it by the meninges and occipito-axial ligaments; posteriorly related to the **cerebellum** (vallecula) and **cisterna magna**.
- ▶ Divided into a caudal **closed part** (resembles spinal cord, has central canal) and a rostral **open part** (forms the lower half of the fourth-ventricle floor).
- ▶ Connects to the cerebellum via the **inferior cerebellar peduncle**.

2. External features

Ventral (anterior) aspect

- ▶ **Anterior median fissure** — upward continuation of the spinal cord's fissure; ends rostrally at a shallow depression, the **foramen caecum**, at the pontomedullary junction.
- ▶ **Pyramid** — a longitudinal elevation on each side of the fissure, produced by the descending **corticospinal (pyramidal) tract**; in the lower medulla most fibres cross the midline as the **decussation of the pyramids (motor decussation)** to form the lateral corticospinal tract, while uncrossed fibres continue as the ventral corticospinal tract.
- ▶ **Anterolateral sulcus**, lateral to the pyramid, in line with the ventral spinal nerve roots — gives exit to the rootlets of the **hypoglossal nerve (XII)**.
- ▶ **Olive** — an oval elevation lateral to the sulcus, produced by the underlying **inferior olivary nuclear complex**.
- ▶ **Posterolateral sulcus**, behind the olive — gives exit to rootlets of the **glossopharyngeal (IX)**, **vagus (X)** and **cranial root of the accessory (XI)** nerves; the spinal root of XI ascends from C1–C5 cord segments to join it.
- ▶ **Anterior external arcuate fibres** cross the upper pyramid transversely, running to the cerebellum via the inferior cerebellar peduncle.

Dorsal (posterior) aspect

- **Posterior median sulcus** in the midline, continuing the corresponding spinal cord feature.
- **Fasciculus gracilis** (medial) and **fasciculus cuneatus** (lateral), separated by the **posterior intermediate sulcus**, continue the posterior columns and end in the **gracile and cuneate tubercles**, produced by the underlying **nucleus gracilis** and **nucleus cuneatus**.
- **Tuberculum cinereum**, lateral to the cuneate tubercle in the closed part, produced by the underlying **spinal nucleus of the trigeminal nerve** (continuous below with the substantia gelatinosa of the cord).
- The **open (upper) part** forms the caudal half of the floor of the fourth ventricle: medial eminence (hypoglossal + dorsal vagal nuclei), **area postrema (chemoreceptor trigger zone)** at its lower end, sulcus limitans, vestibular area laterally, and striae medullares at its upper limit; bounded laterally by the diverging **inferior cerebellar peduncles**.

Cranial nerve(s)	Site of attachment
III, IV	Midbrain
V	Pons
VI, VII, VIII	Pontomedullary junction
IX, X, XI (cranial), XII	Medulla oblongata

□ Fig 24.1 — ■ External features on the anterior (ventral) (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.1031)

3. Internal structure — transverse sections at three levels

The internal architecture is conventionally studied at three transverse levels, from caudal to rostral:

Level	Grey matter / cranial nerve nuclei	Ascending tracts	Descending tracts	Key feature
Pyramidal (motor) decussation	Nucleus gracilis & cuneatus (continuous with central grey), spinal nucleus of trigeminal + its tract, nucleus of accessory nerve	Anterior & lateral spinothalamic, anterior & posterior spinocerebellar, spino-olivary, spinotectal	Corticospinal (pyramid) fibres decussating here; tectospinal, vestibulospinal, olivospinal, rubrospinal	Central canal with surrounding central grey; ventral horn separated from central grey by the crossing pyramidal fibres — closely resembles a spinal cord section

Level	Grey matter / cranial nerve nuclei	Ascending tracts	Descending tracts	Key feature
Sensory (lemniscal) decussation	Nucleus gracilis & cuneatus (now separate from central grey), accessory cuneate nucleus, hypoglossal nucleus, dorsal nucleus of vagus, nucleus of tractus solitarius, spinal trigeminal nucleus	Anterior/lateral spinothalamic, spinocerebellar, arcuate	Corticospinal (pyramid, ventral), medial longitudinal fasciculus, tectospinal, vestibulospinal, rubrospinal	Internal arcuate fibres from gracile/cuneate nuclei cross the midline as the sensory decussation, then ascend as the medial lemniscus (leg fibres most ventral)
Mid-olivary level (open part, floor of 4th ventricle)	Inferior olivary nuclear complex (largest mass) + medial/dorsal accessory olivary nuclei, hypoglossal, dorsal vagal, nucleus ambiguus , nucleus solitarius, vestibular & cochlear nuclei, spinal trigeminal nucleus, arcuate nuclei/pontobulbar body	Medial lemniscus (now prominent), spinothalamic tracts, spinotectal	Corticospinal (pyramid), medial longitudinal fasciculus, tectospinal, rubrospinal, vestibulospinal	Richest level for cranial-nerve nuclei; prominent inferior cerebellar peduncle laterally; forms floor of 4th ventricle

- **Connections of the inferior olivary complex** — afferents from the cerebral cortex and spinal cord; efferents form **olivocerebellar fibres** to the contralateral cerebellar cortex, constituting the cortico-rubro-olivocerebellar pathway (conveys intention of movement) and the spino-olivocerebellar pathway (feedback on performance of movement).
- **Arcuate nuclei and pontobulbar body** are displaced pontine nuclei; they relay to the cerebellum via anterior external arcuate fibres and the striae medullares (cortico-arcuato-cerebellar / cortico-pontobulbo-cerebellar pathways).

□ Fig 5.15 — Transverse section of the medulla oblongata at the level of the middle (Snell — Clinical Neuroanatomy — 7e, p.224)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Ventral aspect of the medulla** (as above): label the **anterior median fissure**, **foramen caecum**, **pyramid**, **anterior external arcuate fibres**, **anterolateral sulcus**, **olive**, **posterolateral sulcus**, **rootlets of IX, X, XI (cranial)**, **XII**, and the **decussation of the pyramids**.
- ▶ **Dorsal aspect of the medulla**: label the **posterior median sulcus**, **fasciculus gracilis** and **cuneatus**, **gracile and cuneate tubercles**, **tuberculum cinereum**, **inferior cerebellar peduncle**, and the **floor of the fourth ventricle** (**medial eminence**, **sulcus limitans**, **vestibular area**, **area postrema**, **striae medullares**).
- ▶ **Transverse section at the mid-olivary level**: label the **inferior olivary nucleus**, **hypoglossal nucleus**, **dorsal nucleus of vagus**, **nucleus ambiguus**, **nucleus solitarius**, **vestibular nuclei**, **spinal nucleus/tract of trigeminal**, **medial lemniscus**, **pyramid**, **medial longitudinal fasciculus**, and the **inferior cerebellar peduncle**.

4. Functional (vital) centres and connections

- ▶ The **reticular formation**, between the ventral/central grey and the spinal trigeminal nucleus, carries the **vital centres — respiratory, cardiac and vasomotor** — that regulate breathing, heart rate and blood pressure.
- ▶ **Area postrema (CTZ)** at the lower medial eminence — strongest stimulator of the vomiting centre; lacks a blood–brain barrier, so most antiemetics act here (cortical/vestibular vomiting bypasses the CTZ and needs different drugs).
- ▶ **Nucleus ambiguus** — motor to IX, X and cranial XI — supplies pharynx, larynx and soft palate for swallowing and phonation.
- ▶ **Ascending reticular activating system** passes through here to maintain consciousness.
- ▶ **Medial longitudinal fasciculus** links vestibular nuclei to III, IV, VI (vestibulo-ocular reflex), VII/XII (lip-tongue coordination for articulation) and XI/upper cervical nerves (head-righting reflex).

5. Blood supply

- ▶ **Anterior spinal artery** — supplies the paramedian (anteromedial) triangular territory: **pyramid**, **medial lemniscus** and **hypoglossal nucleus**.
- ▶ **Posterior spinal artery** — supplies a small dorsal territory: **gracile and cuneate nuclei**.
- ▶ **Posterior inferior cerebellar artery (PICA)** — supplies the dorsolateral (retro-olivary) territory: **spinothalamic tracts**, **spinal nucleus/tract of trigeminal**, **nucleus ambiguus**, **dorsal vagal nucleus**, **vestibular nuclei**, **descending sympathetic fibres**, and part of the **inferior cerebellar peduncle**.
- ▶ Remaining medulla is supplied by **direct bulbar branches of the vertebral arteries**.

Recent advances

- ▶ **Olivary safe-entry-zone corridors**: a cadaveric + MRI comparative study found the far-lateral approach to the olivary body (anterolateral safe-entry zone) shorter and wider-angled for caudal-

olive lesions, while retrosigmoid suits cranial-olive lesions (Capilla-Guasch et al., *Neurocirugia* 2024) [PMID 38244925] [DOI 10.1016/j.neucie.2023.08.001].

- ▶ **Validated safety of medullary safe-entry zones:** a 154-patient brainstem cavernous-malformation series (18 medullary) showed transgressing an established safe-entry zone gave outcomes equivalent to superficial/exophytic lesions, confirming the anatomical safe-entry-zone concept clinically (Catapano et al., *J Neurosurg* 2022) [PMID 36681989] [DOI 10.3171/2022.9.JNS222012].
- ▶ **GLP-1/amylin drugs act via the medulla:** semaglutide's anorectic and fat-loss effects require **Adcyap1⁺ neurons of the nucleus tractus solitarius**, downstream of area-postrema GLP-1 receptors — mapping anti-obesity pharmacology onto the medulla's "dorsal vagal complex" (Teixidor-Deulofeu et al., *Cell Metab* 2025) [PMID 40409256] [DOI 10.1016/j.cmet.2025.04.018].
- ▶ **Cross-species atlas of the dorsal vagal complex:** single-cell profiling (>530,000 neurons; rat/mouse/macaque) mapped Calcr/Ramp3 area-postrema and Calcr/Prhlh solitary-tract populations as mediators of the amylin agonist cagrilintide (Ludwig et al., *Nat Metab* 2026) [PMID 42260119] [DOI 10.1038/s42255-026-01539-3].

(According to PubMed/journal indexing.)

Applied / Clinical anatomy

- ▶ **Medial medullary (Dejerine) syndrome** — anterior spinal artery occlusion: contralateral hemiplegia (pyramid), contralateral loss of fine touch/vibration/position sense (medial lemniscus), ipsilateral LMN tongue paralysis deviating to the lesion side (hypoglossal nucleus/nerve).
- ▶ **Lateral medullary (Wallenberg/PICA) syndrome** — PICA occlusion: ipsilateral facial pain/temperature loss (spinal trigeminal nucleus/tract), contralateral body pain/temperature loss (lateral spinothalamic), ipsilateral dysphagia/dysarthria (nucleus ambiguus), vertigo/nystagmus/vomiting (vestibular nuclei), ipsilateral ataxia (inferior cerebellar peduncle/spinocerebellar tracts), ipsilateral **Horner's syndrome** (descending sympathetics).
- ▶ **Crossed diplegia** — a lesion at the exact decussation level, where upper-limb fibres have already crossed but lower-limb fibres have not, gives ipsilateral upper-limb + contralateral lower-limb paralysis.
- ▶ **Bulbar vs pseudobulbar palsy** — bulbar palsy is an LMN lesion of IX–XII nuclei/nerves (flaccid palate/pharynx/larynx/tongue weakness); pseudobulbar palsy is bilateral UMN corticobulbar damage (similar dysarthria/dysphagia but spastic tongue, exaggerated jaw jerk).
- ▶ **Vital-centre injury is rapidly fatal** — damage to the open medulla near the 4th-ventricle floor injures the respiratory/cardiac/vasomotor centres; classically the fractured dens strikes these centres in judicial hanging, causing instant death.
- ▶ **Tonsillar herniation (Arnold–Chiari)** through the foramen magnum compresses the lower medulla and obstructs CSF flow; **syringobulbia** damages crossing internal arcuate fibres and cranial nerve nuclei.
- ▶ **Area postrema/CTZ** — no blood–brain barrier, hence the target of most antiemetics and of GLP-1/amylin-receptor anti-obesity agonists (see Recent advances).

High-yield exam pointers

- ▶ Medulla: **3 cm long, 2 cm broad** at its upper end; extends from the pontomedullary junction to the upper border of the atlas (C1).
- ▶ **Closed part** (central canal) caudally; **open part** (floor of 4th ventricle) rostrally.
- ▶ **Pyramid** = corticospinal tract; **pyramidal (motor) decussation** in the lower closed part; **sensory (lemniscal) decussation** slightly rostral to it.
- ▶ **Olive** = inferior olivary nuclear complex — relayed to the contralateral cerebellum via olivocerebellar fibres.
- ▶ Cranial nerves **IX–XII** attach to the medulla proper; **VI–VIII** at the pontomedullary junction.
- ▶ **Vital centres** (respiratory, cardiac, vasomotor) and the **area postrema (CTZ, no BBB)** lie in the open part/floor of the 4th ventricle.
- ▶ Blood supply: **anterior spinal artery** (paramedian) → medial medullary syndrome; **PICA** (dorsolateral) → lateral medullary/Wallenberg syndrome.
- ▶ **Medial medullary syndrome** = contralateral hemiplegia + contralateral loss of fine touch/proprioception + ipsilateral tongue palsy.
- ▶ **Lateral medullary (Wallenberg) syndrome** = ipsilateral facial + contralateral body pain/temperature loss + dysphagia/dysarthria + vertigo + ataxia + Horner's syndrome.
- ▶ Injury to the lower (open) medulla is rapidly fatal — classic in hanging and tonsillar herniation.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3-4 8e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; Snell Clinical Neuroanatomy 7e. Recent-advances citations per PubMed (PMIDs/DOIs as listed above).



Inferior colliculus

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction The inferior colliculus is the caudal (smaller) pair of the four rounded eminences — the corpora quadrigemina — that form the tectum (roof) of the midbrain, lying caudal to the superior colliculus. It is the principal midbrain relay and integrative station of the **ascending auditory pathway**, receiving virtually the entire lateral lemniscus, and also serves as the reflex centre for auditory-evoked movements of the head, eyes and neck. Its grey matter is organised into a tonotopically-mapped central nucleus surrounded by a dorsal cortex and an external (lateral) nucleus, and it relays processed auditory information onward to the medial geniculate body via its own brachium.

Location and external features

- ▶ Lies in the **tectum of the midbrain**, dorsal to the cerebral aqueduct, caudal to the superior colliculi and rostral to the superior medullary velum; the two colliculi of each side are separated

from those of the opposite side, and from the superior colliculi, by a **cruciform sulcus** — its upper limit expands into a pineal-gland depression and its lower limit continues as the **frenulum veli** over the superior medullary velum.

- ▶ Caudal to the pineal gland and posterior commissure, and inferomedial to the pulvinar of the thalamus (below the splenium of the corpus callosum).
- ▶ The **trochlear nerve** emerges from the dorsal brainstem immediately **caudal to the inferior colliculus**, lateral to the frenulum veli, after decussating in the superior medullary velum — an important surgical landmark.
- ▶ A ridge of white matter, the **brachium of the inferior colliculus** (inferior quadrigeminal brachium), passes ventrolaterally from the lateral aspect of the colliculus, partly deep to the medial geniculate body, and carries fibres from the lateral lemniscus and the colliculus itself to the medial geniculate body.
- ▶ Each inferior colliculus receives auditory input from **both ears** (bilateral representation).

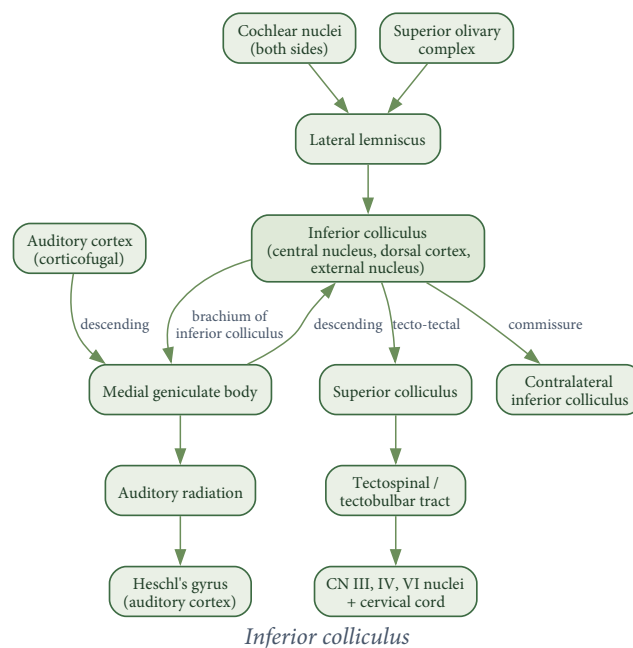
Cytoarchitecture — nuclear subdivisions

Subdivision	Location	Chief input	Functional character
Central nucleus	Large ovoid mass, lateral to the periaqueductal (central) grey matter	Principal termination of the lateral lemniscus (direct + relayed)	Sharply frequency-tuned, laminated — dorsal laminae driven by low frequencies, ventral laminae by high frequencies (tonotopic map); main relay for discriminative hearing
Dorsal cortex	Caps the central nucleus dorsally	Descending corticofugal fibres from auditory cortex (via medial geniculate body)	Broadly frequency-tuned; modulates/gates ascending traffic
External (lateral) nucleus	Lateral and ventral to the central nucleus	Somatosensory and multisensory afferents in addition to auditory	Broadly frequency-tuned; multisensory integration

Connections

	Source / destination	Pathway	Significance
Afferent	Lateral lemniscus (from cochlear nuclei ± superior olivary complex, both sides)	Direct + via nucleus of the lateral lemniscus	Principal auditory input; each colliculus receives impulses from both ears
Afferent	Contralateral inferior colliculus	Commissure of the inferior colliculus	Interaural/binaural integration
Afferent	Auditory cortex	Descending corticofugal fibres via medial geniculate body	Top-down modulation of the ascending pathway

	Source / destination	Pathway	Significance
Efferent	Ipsilateral medial geniculate body	Brachium of the inferior colliculus — central nucleus → ventral (tonotopic) division; dorsal cortex → dorsal division	Onward relay to auditory radiation → transverse temporal gyrus (Heschl's gyrus)
Efferent	Contralateral inferior colliculus	Commissural fibres	Binaural processing
Efferent	Ipsilateral superior colliculus	Tecto-tectal fibres	Superior colliculus then issues tectospinal/tectobulbar tracts
Efferent	Nuclei of cranial nerves + cervical cord (via superior colliculus)	Tectospinal/tectobulbar tracts	Reflex turning of head, eyes and neck toward a sound (auditory-startle/orienting reflex)



Relations at the level of the inferior colliculus (transverse section of midbrain)

Region	Structures cut at this level
Tectum	Paired inferior colliculi, each with central nucleus, dorsal cortex and external nucleus
Central (periaqueductal) grey matter	Trochlear nucleus (ventral part); mesencephalic nucleus of the trigeminal nerve (lateral part)

Region	Structures cut at this level
Tegmentum — lemnisci	Combined medial lemniscus, trigeminal lemniscus and spinal lemniscus (medial to lateral order), dorsal to the substantia nigra; the lateral lemniscus (most lateral/posterior) merges with/terminates in the inferior colliculus
Tegmentum — near midline	Medial longitudinal fasciculus (ventral to trochlear nucleus) → tectospinal tract → decussation of the superior cerebellar peduncle → rubrospinal tract, in that ventrodorsal order
Substantia nigra	Immediately dorsal to the crus cerebri, ventral to the tegmentum
Crus cerebri (base)	Corticospinal/corticonuclear fibres (middle two-thirds), fronto-pontine (medial one-sixth) and parieto-/temporo-/occipito-pontine fibres (lateral one-sixth)
Cerebral aqueduct	Separates tectum from tegmentum, surrounded by the central grey matter

□ Fig 5.15 — Transverse section through the lower part of the midbrain at the level of inferior colliculus (IB Singh — Textbook of Human Neuroanatomy, p.88)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse section through the midbrain at the level of the **inferior colliculi** (caudal midbrain) and label:

- ▶ **Tectum:** paired **inferior colliculus** (central nucleus, dorsal cortex, external nucleus shown schematically), joined across the midline; **cerebral aqueduct** ventral to it surrounded by **central (periaqueductal) grey matter**.
- ▶ **Central grey matter:** **trochlear nucleus** (ventral part); **mesencephalic nucleus of trigeminal nerve** (lateral part).
- ▶ **Tegmentum:** combined **medial + trigeminal + spinal lemnisci** (with the lateral lemniscus merging into the colliculus dorsally); **medial longitudinal fasciculus**, **tectospinal tract**, **decussation of superior cerebellar peduncle** and **rubrospinal tract** near the midline; paired **substantia nigra**.
- ▶ **Base:** paired **crus cerebri**, separated by the interpeduncular fossa.
- ▶ Mark the emerging **trochlear nerve** just caudal to the colliculus on the dorsal surface.

Development

- ▶ The midbrain (mesencephalic) vesicle is the most primitive of the brain vesicles and retains a simple cylindrical form; its narrowed cavity becomes the **cerebral aqueduct**.
- ▶ The **basal lamina** on each side gives rise to the tegmentum and substantia nigra; its marginal layer enlarges to form the **crus cerebri**.

- ▶ The **alar lamina** invades the roof plate to form paired longitudinal elevations; each elevation is later subdivided by a transverse groove into upper and lower parts — the **superior and inferior colliculi** — together constituting the **corpora quadrigemina** of the tectum.

Blood supply

- ▶ The midbrain (including the colliculi) is supplied chiefly by branches of the **basilar artery** — the **posterior cerebral** and **superior cerebellar arteries** give paramedian and circumferential branches.
- ▶ One circumferential branch, the **quadrigeminal artery**, is the **main source of blood to the colliculi** (both superior and inferior).

Applied / Clinical anatomy

- ▶ **Lesions of the inferior colliculus or its brachium** produce defects in appreciation of tones/pitch, sound localisation, and loss of reflex head/eye movements in response to sound; such effects are well documented experimentally but are less clearly characterised in humans because isolated lesions are rare.
- ▶ **Auditory brainstem response (ABR/BAER)**: the lateral lemniscus–inferior colliculus level is classically regarded as a major contributor to wave V of the auditory evoked potential, making the inferior colliculus clinically relevant to neonatal hearing screening, intraoperative auditory monitoring and brainstem-integrity testing.
- ▶ **Surgical landmark**: because the trochlear nerve emerges from the dorsal brainstem immediately caudal to the inferior colliculus, this region is a key hazard zone during the supracerebellar–infratentorial approach to pineal-region and tectal-plate tumours.
- ▶ **Tectal plate (quadrigeminal plate) glioma**: a low-grade glioma at the level of/just rostral to the colliculi can narrow the adjacent cerebral aqueduct, producing obstructive (non-communicating) hydrocephalus.
- ▶ **Auditory midbrain implant (AMI)**: the tonotopically-organised central nucleus of the inferior colliculus is the surgical target for an auditory brainstem/midbrain prosthesis in patients unsuitable for a cochlear implant (e.g. neurofibromatosis type 2 with cochlear nerve destruction, ossified/absent cochleae) — exploiting the same dorsoventral frequency gradient described above.
- ▶ **Reflex pathway to note in the exam**: sound → cochlear nuclei → lateral lemniscus → inferior colliculus → superior colliculus → tectospinal/tectobulbar tracts → reflex turning of head and eyes toward the sound source (the anatomical basis of the auditory-startle/orienting reflex).

Recent advances

- ▶ High-resolution micropillar-based two-photon calcium imaging of the mouse lateral cortex of the inferior colliculus (a region previously inaccessible to in-vivo imaging because it lies within a sulcus) has shown that it is organised into distinct "module" and "matrix" neurochemical subregions with different response properties — modules show offset responses to sound with enhanced bimodal (audio-tactile) responses, while matrix neurons show onset auditory responses that are suppressed by bimodal stimulation — revising the classical view of the

external/lateral nucleus as a functionally uniform multisensory zone (Ibrahim et al., *eLife* 2025;14:e93063) [PMID: 40085494].

- ▶ Extracellular recordings from the inferior colliculus of monkeys performing a sound-duration deviance-detection task have demonstrated a "climbing" rise in firing rate across a sound sequence that reflects **sensory (temporal) prediction** rather than reward expectation, together with distinct reward-prediction-error signals in a separate neuronal subset — showing that the inferior colliculus, long regarded as a purely pre-cortical auditory relay, also contributes to sensory prediction and reward/decision-related processing (Du, Xu et al.; senior author Yu, *eLife* 2025;14:e101142) [PMID: 39879260].
- ▶ In a salicylate-induced rat model of tinnitus, electrical deep brain stimulation of the **external (cortex) nucleus of the inferior colliculus** significantly suppressed the abnormal spontaneous hyperactivity of auditory-cortex neurons that underlies the tinnitus percept, supporting the inferior colliculus as a viable neuromodulation target for tinnitus therapy (Akbarnejad & Asadpour, *Brain and Behavior* 2025;15(9)) [PMID: 40891098].
- ▶ (According to PubMed.)

High-yield exam pointers

- ▶ Inferior colliculus = caudal (smaller) pair of corpora quadrigemina; superior colliculus is the visual reflex centre, inferior colliculus is the **auditory relay + auditory reflex centre**.
- ▶ Three subdivisions: **central nucleus** (tonotopic, principal lateral-lemniscus relay), **dorsal cortex** and **external/lateral nucleus** (both broadly tuned; dorsal cortex receives descending corticofugal fibres).
- ▶ Afferents: **lateral lemniscus** (chief), contralateral IC (commissure), descending auditory cortex fibres via MGB.
- ▶ Efferents: **brachium of inferior colliculus** → **ipsilateral medial geniculate body** (→ auditory radiation → Heschl's gyrus); contralateral IC; ipsilateral superior colliculus → **tectospinal/tectobulbar tracts** for the auditory-startle reflex.
- ▶ **Trochlear nerve emerges just caudal to the inferior colliculus** — key surgical/clinical landmark.
- ▶ TS-of-midbrain spotter at this level: trochlear nucleus, mesencephalic nucleus of V, combined medial/trigeminal/spinal/lateral lemnisci, MLF, tectospinal tract, decussation of superior cerebellar peduncle, rubrospinal tract, substantia nigra, crus cerebri.
- ▶ Blood supply: basilar artery branches — the **quadrigeminal artery** is the main supply to the colliculi.
- ▶ Develops from the **alar lamina of the roof plate** of the mesencephalic vesicle.
- ▶ Clinical relevance: ABR wave V generation, tectal glioma → aqueductal obstruction/hydrocephalus, and target site for the auditory midbrain implant.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh Textbook of Human Neuroanatomy; Vishram Singh Clinical Neuroanatomy 4e; BD Chaurasia Human Anatomy Vol 3–4 8e; IB Singh Textbook of Anatomy Vol 3 6e (figure).



Interpeduncular fossa

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction. The interpeduncular fossa is a **rhomboidal (lozenge-shaped) depression** on the basal (ventral) surface of the brain, situated at the front of the midbrain between the two diverging **crura cerebri** of the cerebral peduncles. It is one of the four features that make up the "base of the brain" seen on gross dissection, and it is clinically pivotal for three reasons: it houses the surface exit of the **oculomotor nerve**, it contains the **posterior perforated substance** through which the deep perforating branches of the posterior circulation enter the brain, and it forms the floor of the **interpeduncular (basal) cistern**, in which the **circle of Willis** completes itself around the basilar bifurcation. Because of this triple relation — nerve, perforating vessels, and CSF cistern — the fossa is a frequent site of localisation in raised-ICP herniation syndromes, posterior-circulation aneurysms, and cross-sectional neuroimaging.

1. Location, shape and boundaries

- ▶ Lies on the **ventral surface of the midbrain**, between the pons behind and the optic chiasma/tuber cinereum in front — part of the interpeduncular (basal) region of the base of the brain.
- ▶ Shape: a rhomboidal (diamond-shaped) space.

Boundary	Structure
On either side	Crus cerebri of the corresponding cerebral peduncle
Anteriorly	Optic chiasma and optic tracts
Posteriorly	Pons (upper border)

- ▶ The floor of the fossa is formed by a thin lamina of grey matter continuous with the hypothalamus — hence several hypothalamic surface features (tuber cinereum, mammillary bodies, infundibulum) are visible within it.

2. Contents of the fossa (floor, front to back)

Structure	Description
Tuber cinereum	A raised area of grey matter lying immediately anterior to the mammillary bodies; part of the hypothalamic floor

Structure	Description
Infundibulum	A narrow grey stalk arising from the tuber cinereum that connects the hypothalamus to the hypophysis cerebri (pituitary gland)
Mammillary bodies	Paired small spherical grey-matter swellings just behind the tuber cinereum; relay nuclei of the mammillothalamic/mammillotegmental tracts (limbic circuit)
Posterior perforated substance	A sheet of grey matter in the angle between the diverging crura cerebri, punctured by numerous small foramina for the central (perforating) branches of the posterior cerebral arteries
Oculomotor nerve rootlets	Emerge from the oculomotor sulcus on the medial aspect of the crus cerebri, in the posterior part of the fossa, between the posterior cerebral and superior cerebellar arteries

- ▶ The **trochlear nerve**, though it does not emerge into the fossa itself, winds around the lateral aspect of the midbrain towards the fossa immediately above the pons, and is encountered here surgically alongside the oculomotor nerve.

3. Relation to the hypothalamus and third ventricle

- ▶ The tuber cinereum, infundibulum and mammillary bodies are the only parts of the **hypothalamus visible on the external surface of the brain**, and all lie within the interpeduncular fossa.
- ▶ These structures also form the **floor of the third ventricle**, so the interpeduncular fossa is effectively the external "window" onto the ventral hypothalamic floor.

4. Vascular relations — the circle of Willis and perforators

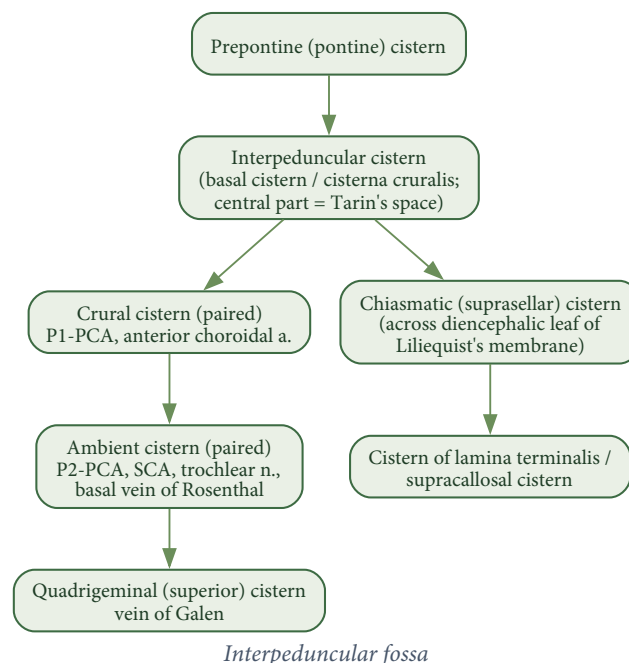
- ▶ The **basilar artery**, ascending in the prepontine cistern, divides within the interpeduncular fossa into the right and left **P1 segments of the posterior cerebral arteries**; the **superior cerebellar arteries** arise from the basilar artery just before this bifurcation.
- ▶ The **posterior communicating artery** runs backward from each internal carotid artery, above the corresponding oculomotor nerve, to join the posterior cerebral artery — completing the **circulus arteriosus (circle of Willis)** around the fossa.
- ▶ **Central (perforating) branches** of the posterior cerebral artery pierce the posterior perforated substance to supply the crus cerebri, subthalamus and thalamus (thalamoperforating vessels).
- ▶ The **basal vein (of Rosenthal)** passes backward alongside the interpeduncular fossa and midbrain to join the great cerebral vein, receiving tributaries from this region.

Cisternal segment around the fossa	Contents
Crural cistern (paired; between uncus and cerebral peduncle)	P1 segment of posterior cerebral artery; postoptic part of anterior choroidal artery

Cisternal segment around the fossa	Contents
Interpeduncular cistern proper (midline, between the two peduncles)	Basilar artery; origins of posterior cerebral and thalamoperforating arteries; proximal oculomotor nerves; proximal anterior pontomesencephalic vein
Ambient cistern (paired; around the midbrain to the quadrigeminal cistern)	P2 segment of posterior cerebral artery; superior cerebellar artery; trochlear nerve; basal vein of Rosenthal

5. The interpeduncular (basal) cistern

- The arachnoid bridging across the two temporal lobes creates a CSF-filled space over the interpeduncular fossa — the **interpeduncular cistern**, also called the **basal cistern**, **cisterna basalis** or **cisterna cruralis**.
- Its central part, lying strictly between the two cerebral peduncles, is named **Tarin's space** (after the 18th-century French anatomist Pierre Tarin).
- **Boundaries:** separated above from the chiasmatic (suprasellar) cistern by the **diencephalic leaf**, and below from the pontine cistern region by the **mesencephalic leaf**, of **Liliequist's membrane**.
- **Communications:** continuous inferiorly with the **prepontine (pontine) cistern**; extends anterosuperiorly to the optic chiasma and communicates with the **chiasmatic (suprasellar) cistern**, whose own extensions are the cistern of the **lamina terminalis** and the **supracallosal cistern**.
- Although not the largest CSF cistern by volume, it is the **widest**, and it lodges the **entire circle of Willis**.



DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 23.22 — *Interpeduncular fossa* (IB Singh — *Textbook of Anatomy Vol 3 — 6e, p.428*)

Reproduce a base-of-brain (ventral) view of the midbrain region, labelling:

- ▶ **Optic nerve and optic chiasma** (anterior boundary)
- ▶ **Optic tract** running back on either side to the **crus cerebri** (lateral boundaries)
- ▶ **Tuber cinereum and infundibulum** in the midline
- ▶ Paired **mammillary bodies** just behind the tuber cinereum
- ▶ **Posterior perforated substance** as a stippled/punctate area behind the mammillary bodies
- ▶ **Oculomotor nerve** rootlets emerging medial to each crus cerebri, and **trochlear nerve** curving around the lateral midbrain just above the pons
- ▶ **Pons** forming the posterior boundary

Applied / Clinical anatomy

- ▶ **Compressive (surgical) third nerve palsy:** the oculomotor nerve's superficial position in the fossa, adjacent to the posterior communicating artery, makes it vulnerable to compression by a **posterior communicating artery (berry) aneurysm** — the pupillomotor parasympathetic fibres run peripherally in the nerve and are affected early, producing a **pupil-involving** third nerve palsy (ptosis, "down-and-out" eye, fixed dilated pupil); this is the classical teaching contrast with medical (microvascular/ischaemic) third nerve palsy, which characteristically spares the pupil.
- ▶ **Transtentorial (uncal) herniation:** a supratentorial mass pushes the uncus and parahippocampal gyrus over the tentorial edge into the region of the interpeduncular fossa, compressing the **ipsilateral oculomotor nerve** (blown pupil, ophthalmoplegia) and the **posterior cerebral artery** (risking occipital lobe infarction and cortical blindness); further pressure compresses the midbrain and can push the contralateral crus cerebri against the opposite free edge of the tentorium, producing a **false-localising ipsilateral hemiparesis** (Kernohan notch phenomenon) alongside the expected contralateral weakness.
- ▶ **Basilar-bifurcation aneurysm / "top of the basilar" lesions:** the basilar artery divides into its P1 segments within the interpeduncular fossa — the single commonest site for a posterior-circulation aneurysm; rupture here bleeds directly into the interpeduncular cistern, producing subarachnoid haemorrhage with early oculomotor involvement.
- ▶ **Suprasellar extension of pituitary/parasellar tumours:** pituitary adenomas and craniopharyngiomas can expand upward through the diaphragma sellae into the **chiasmatic (suprasellar) cistern**, an anterior extension of the interpeduncular cistern, producing chiasmal compression (bitemporal hemianopia) — imaged as effacement of this cistern on CT/MRI.
- ▶ **Cross-sectional/radiological landmark:** at the level of the midbrain, the interpeduncular and ambient cisterns outline the crura cerebri as a CSF-bright "wing" on axial CT/MRI; effacement or asymmetry of this cistern is a key early radiological sign of uncal herniation and raised intracranial pressure.

- ▶ **Neuroendoscopy:** the floor of the third ventricle just superior to the interpeduncular fossa (tuber cinereum) is the site of **endoscopic third ventriculostomy** for obstructive hydrocephalus; fenestration here communicates the third ventricle with the interpeduncular cistern.

High-yield exam pointers

- ▶ **Rhomboidal depression** on the base of the brain, between the two **crura cerebri**; bounded anteriorly by **optic chiasma/tracts**, posteriorly by the **pons**.
- ▶ **Contents (floor, front to back):** tuber cinereum → infundibulum → mammillary bodies → posterior perforated substance; **oculomotor nerve** emerges posteriorly via the oculomotor sulcus.
- ▶ **Posterior perforated substance** = grey matter pierced by **central branches of the posterior cerebral artery**.
- ▶ Tuber cinereum, infundibulum and mammillary bodies are the **only externally visible parts of the hypothalamus**, and form the floor of the **third ventricle**.
- ▶ **Circle of Willis** completes itself around the fossa via the basilar bifurcation (→ P1 PCA) and posterior communicating arteries.
- ▶ Overlying CSF space = **interpeduncular (basal) cistern**; central part between the peduncles = **Tarin's space**; divided from the suprasellar cistern by **Liliequist's membrane**; widest of all cisterns and contains the whole circle of Willis.
- ▶ Clinical triad to remember: **PCoA aneurysm** → **painful pupil-involving CN III palsy**; **uncal herniation** → **CN III + PCA compression**; **basilar-tip aneurysm** → **SAH within the interpeduncular cistern**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; Vishram Singh's Textbook of Anatomy Vol 3 4e; IB Singh's Textbook of Anatomy Vol 3 6e; IB Singh's Textbook of Human Neuroanatomy; Snell's Clinical Neuroanatomy 7e; Moore's Clinically Oriented Anatomy 9e.



Lateral and medial medullary syndrome

Asked in: Paper IV Oct 2008 — RGUHS MD/MS Anatomy

Definition / Introduction — The lateral and medial medullary syndromes are the two classical **vascular (brainstem-stroke) syndromes** of the medulla oblongata, produced respectively by thrombosis of the **posterior inferior cerebellar artery (PICA)** and the **anterior spinal artery (ASA)** — the two principal vessels supplying the medulla. Because each artery supplies an anatomically distinct territory containing a different combination of cranial-nerve nuclei and long ascending/descending tracts, occlusion of each vessel produces a characteristic, reproducible **"crossed" or "alternating" clinical picture** — ipsilateral brainstem/cranial-nerve signs together with contralateral long-tract (sensory or motor) signs — of major localising and examination value. The lateral medullary syndrome is eponymously known as **Wallenberg's syndrome (PICA syndrome)**; the medial medullary syndrome is known as **Dejerine's syndrome (anterior bulbar syndrome)**.

1. Blood supply of the medulla oblongata — the anatomical basis of the two syndromes

Artery	Origin / course	Territory of the medulla	Key structures supplied
Anterior spinal artery (ASA)	A small branch arising near the termination of each vertebral artery; the two unite in the midline at mid-medullary level and descend along the ventral median fissure	Paramedian / ventral territory , on either side of the midline	Pyramid (corticospinal fibres), medial lemniscus, hypoglossal nucleus and its emerging rootlets
Posterior inferior cerebellar artery (PICA)	The largest branch of the vertebral artery; arises near the lower end of the olive, ascends behind the roots of the glossopharyngeal and vagus nerves, and curves around the inferior cerebellar peduncle before reaching the cerebellum (also supplies the inferior cerebellar surface and the choroid plexus of the fourth ventricle)	Dorsolateral (retro-olivary) territory — dorsal to the olive and lateral to the hypoglossal nucleus	Inferior cerebellar peduncle, spinal nucleus and tract of the trigeminal nerve, nucleus ambiguus, lateral spinothalamic tract, vestibular nuclei, descending sympathetic fibres
Vertebral artery (trunk, proximal to the origin of PICA)	Occlusion of the parent vertebral artery reproduces the same dorsolateral picture as isolated PICA thrombosis	Same as the PICA territory	As above — PICA is small and variable, and is sometimes absent altogether, making proximal vertebral occlusion an equally common clinical cause of the lateral syndrome

- The medulla additionally receives twigs from the posterior spinal and basilar arteries entering along the ventral median fissure, the posterior median sulcus, and the rootlets of the IX, X and XII nerves, supplemented by a pial plexus — but the ASA and PICA territories are what account for the two named clinical syndromes.

2. Lateral medullary syndrome (Wallenberg's syndrome / PICA syndrome)

Thrombosis of the PICA (or the vertebral artery proximal to it) infarcts a **wedge-shaped dorsolateral area** of the medulla and often the inferior surface of the cerebellum.

Structure damaged	Function of the structure	Clinical sign produced	Side (relative to the lesion)
Nucleus ambiguus (motor nucleus of IX, X, XI)	Motor supply to palate, pharynx, larynx	Dysphagia and dysarthria/dysphonia; ipsilateral paralysis of the palate, pharynx and larynx	Ipsilateral
Spinal nucleus and tract of the trigeminal nerve	Pain and temperature sensation of the face	Loss of pain and temperature sensation over the face	Ipsilateral
Lateral spinothalamic tract	Pain and temperature sensation of the trunk and limbs	Loss of pain and temperature sensation over the trunk and limbs	Contralateral
Inferior cerebellar peduncle and cerebellum	Coordination	Gait and limb ataxia	Ipsilateral
Vestibular nuclei	Balance/equilibrium	Vertigo, nausea, vomiting, nystagmus	—
Descending sympathetic fibres (in the reticular formation)	Sympathetic outflow to the head	Horner's syndrome — ptosis, miosis, enophthalmos, anhidrosis	Ipsilateral

- Structures that lie in the **spared paramedian (ASA) territory** — the pyramid, medial lemniscus and hypoglossal nucleus — are **not** damaged: hence there is **no limb weakness, no loss of proprioception/vibration, and no tongue paralysis**. This "crossed sensory loss with normal motor power" pattern is the hallmark that distinguishes Wallenberg's syndrome from other brainstem strokes.

3. Medial medullary syndrome (Dejerine's syndrome)

Thrombosis of the ASA (or its medullary branches from the vertebral artery) infarcts the **paramedian, ventral** region of the medulla, on one or occasionally both sides.

Structure damaged	Function of the structure	Clinical sign produced	Side (relative to the lesion)
Pyramid (corticospinal tract)	Upper motor neurone outflow to the limbs	Contralateral hemiplegia of the arm and leg (face spared)	Contralateral
Medial lemniscus	Proprioception, vibration, fine/discriminative touch	Contralateral loss of position and vibration sense	Contralateral
Hypoglossal nucleus and its emerging rootlets	Lower motor neurone supply to the tongue	Ipsilateral tongue paralysis and atrophy; on protrusion the tongue deviates towards the side of the lesion	Ipsilateral

- Structures lying in the **spared dorsolateral (PICA) territory** — the spinothalamic tract, spinal trigeminal nucleus/tract, nucleus ambiguus, vestibular nuclei and inferior cerebellar peduncle — are **not** damaged: hence **pain/temperature sensation, swallowing/phonation, balance and coordination are all normal**.
- The combination of **contralateral hemiplegia** with **ipsilateral lower motor neurone tongue palsy** is a classical example of an "**alternating (crossed) hemiplegia**" of the brainstem, in which the cranial-nerve/nucleus involved localises both the side and the level of the lesion.

4. Cross-sectional correlation at the level of the olive

embed: ![Fig 5.8 — Lesions of medulla oblongata: (1) Medial medullary syndrome; (2) Lateral medullary syndrome (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.518)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/d6739cda20f961aa.jpg)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse (cross) section of the medulla oblongata at the level of the olive (mid-olivary level, through the floor of the fourth ventricle), and label:

- ▶ **Pyramidal tract and medial lemniscus (M)** — paramedian, ventral to the midline (shade this **paramedian wedge** and annotate: *medial medullary/Dejerine's syndrome* — *ASA territory*)
- ▶ **Hypoglossal nucleus and emerging hypoglossal nerve (XII) rootlets** — paramedian, dorsal to the pyramid
- ▶ **Inferior olivary nucleus** — the central landmark of the section
- ▶ **Nucleus ambiguus, spinal nucleus and tract of the trigeminal nerve, lateral spinothalamic tract, descending sympathetic tract, inferior cerebellar peduncle and vestibular nuclei** — dorsolateral (retro-olivary), lateral to the olive (shade this **dorsolateral wedge** and annotate: *lateral medullary/Wallenberg syndrome* — *PICA territory*)
- ▶ **Dorsal nucleus of the vagus and nucleus of the tractus solitarius** — dorsal, near the floor of the fourth ventricle
- ▶ **Arcuate nucleus** — anteromedial to the pyramid

5. Comparative summary — lateral vs medial medullary syndrome

Feature	Lateral medullary syndrome (Wallenberg / PICA syndrome)	Medial medullary syndrome (Dejerine's syndrome)
Artery occluded	Posterior inferior cerebellar artery (or vertebral artery proximal to it)	Anterior spinal artery (or its medullary branches from the vertebral artery)
Region of medulla affected	Dorsolateral (retro-olivary)	Paramedian / ventral
Limb power	Normal (pyramid spared)	Contralateral hemiplegia (pyramid damaged)
Proprioception / vibration	Normal (medial lemniscus spared)	Contralateral loss (medial lemniscus damaged)
Pain / temperature	Ipsilateral face + contralateral trunk/limb loss (spinal V nucleus/tract + spinothalamic tract damaged)	Normal (both spared)
Tongue	Normal (hypoglossal nucleus spared)	Ipsilateral LMN paralysis , deviates to the lesion side
Palate / pharynx / larynx	Ipsilateral paralysis — dysphagia, dysarthria (nucleus ambiguus damaged)	Normal (nucleus ambiguus spared)
Cerebellar signs	Ipsilateral ataxia (inferior cerebellar peduncle damaged)	Normal
Vestibular signs	Vertigo, nystagmus, vomiting	Normal

Feature	Lateral medullary syndrome (Wallenberg / PICA syndrome)	Medial medullary syndrome (Dejerine's syndrome)
Sympathetic	Ipsilateral Horner's syndrome	Normal
Overall clinical pattern	A "crossed sensory" syndrome with no motor weakness	An "alternating hemiplegia" with sensory loss confined to proprioception

Applied / Clinical anatomy

- ▶ Both syndromes are classical examples of a **"crossed" or "alternating" brainstem-stroke syndrome** — ipsilateral cranial-nerve/nucleus signs combined with contralateral long-tract signs — the pattern that localises a vascular lesion to the brainstem, and to a specific side and level, rather than to the cerebral hemisphere or the spinal cord.
- ▶ **Wallenberg's syndrome is the more frequently encountered** of the two lateral brainstem strokes in clinical practice; because PICA is a small, variable branch that is occasionally absent, thrombosis of the parent **vertebral artery** (from atherosclerosis or vertebral artery dissection) is at least as common a cause as isolated PICA occlusion.
- ▶ The bedside combination of **crossed sensory loss, ipsilateral ataxia and Horner's syndrome with entirely normal limb power** is the key clinical clue that localises a stroke to the dorsolateral (PICA) territory of the medulla.
- ▶ **Dysphagia from nucleus ambiguus involvement** in the lateral syndrome carries a real risk of aspiration; nasogastric feeding is often needed in the acute phase until swallowing recovers.
- ▶ The **facial nerve/nucleus is never involved** in either syndrome, since the facial motor nucleus lies in the pons, not the medulla — an important negative finding and a frequent distractor.
- ▶ Because the ASA and PICA territories are adjacent, an **extensive or combined vertebral artery occlusion** can produce a mixed clinical picture with features of both syndromes together — a reminder that "pure" textbook syndromes are the exception rather than the rule at the bedside.
- ▶ **MRI (diffusion-weighted imaging)** is the investigation of choice to confirm a medullary infarct and to distinguish the dorsolateral (Wallenberg) from the paramedian (Dejerine) pattern radiologically, and to guide urgent stroke management.

High-yield exam pointers

- ▶ Lateral medullary syndrome = **Wallenberg's syndrome = PICA syndrome**; caused by thrombosis of the **posterior inferior cerebellar artery or the vertebral artery**, infarcting the **dorsolateral (retro-olivary)** medulla.
- ▶ Medial medullary syndrome = **Dejerine's syndrome (anterior bulbar syndrome)**; caused by thrombosis of the **anterior spinal artery** (or its medullary branches), infarcting the **paramedian/ventral** medulla.
- ▶ Lateral syndrome signs: ipsilateral **palatal/pharyngeal/laryngeal paralysis** (nucleus ambiguus) + ipsilateral **facial pain/temperature loss** (spinal trigeminal nucleus/tract) + contralateral **trunk/limb pain/temperature loss** (spinothalamic tract) + ipsilateral **ataxia** (inferior cerebellar

peduncle) + **vertigo/nystagmus** (vestibular nuclei) + ipsilateral **Horner's syndrome** (descending sympathetics).

- ▶ Medial syndrome signs: contralateral **hemiplegia** (pyramid) + contralateral **loss of position/vibration sense** (medial lemniscus) + ipsilateral **LMN tongue paralysis with deviation towards the lesion side** (hypoglossal nucleus/nerve).
- ▶ **No limb weakness** in the lateral syndrome (pyramid spared) versus **no pain/temperature loss** in the medial syndrome (spinothalamic tract spared) — the key distinguishing negative findings.
- ▶ Both are classical "**crossed**"/"**alternating**" **brainstem syndromes** — ipsilateral cranial-nerve/nucleus palsy + contralateral long-tract signs.
- ▶ The **facial nerve and facial muscles are never involved** in either syndrome, since the facial nucleus lies in the pons, not the medulla.
- ▶ Structures spared define the syndrome as much as structures damaged: know the **paramedian (ASA) vs dorsolateral (PICA) territory boundary** at the level of the olive.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3–4 8e.



Medial longitudinal bundle

Asked in: Paper IV Apr 2008 — RGUHS MD/MS Anatomy

Definition / Introduction. The medial longitudinal bundle (medial longitudinal fasciculus, MLF — the two terms are used interchangeably; "bundle" is BD Chaurasia's usage, "fasciculus" is that of Gray's, Snell and the Singh texts) is a paired, heavily myelinated, paramedian **composite intersegmental tract** that runs the entire length of the brainstem, from the midbrain-diencephalic junction down into the cervical spinal cord. It is chiefly a **vestibulo-ocular and vestibulo-cervical integrating pathway**: its major fibre contingent arises in the vestibular nuclei and interconnects them with the nuclei of the ocular-motor cranial nerves (III, IV, VI) and with the cervical cord, thereby coordinating eye, head and neck movement. It is of high clinical importance because a lesion of the MLF produces the classic **internuclear ophthalmoplegia (INO)**.

1. Location, position and extent

- ▶ Lies in the **paramedian tegmentum**, one on either side of the midline, immediately **ventral to the periaqueductal/periventricular grey matter** and to the floor of the fourth ventricle (rhomboid fossa) at pontomedullary levels.
- ▶ Retains a fixed position close to the central grey matter throughout the **midbrain, pons and upper (closed) medulla**; at the level of the **pyramidal (motor) decussation** it is displaced somewhat ventrally by the crossing corticospinal fibres.
- ▶ **Rostral limit**: ascends to the **interstitial nucleus of Cajal**, which lies in the lateral wall of the third ventricle just above the cerebral aqueduct, at the midbrain–diencephalic junction; fibres also

cross here to the opposite side through the **posterior commissure**, linking the two fasciculi and the two vestibular nuclear complexes.

- ▶ **Caudal limit:** becomes continuous with the **anterior (ventral) intersegmental fasciculus of the spinal cord** and descends as far as the **upper cervical (C1–C6) segments**, ending on ventral horn cells that supply the muscles of the neck.
- ▶ Thus the MLF is one of the longest fibre systems in the central nervous system, spanning diencephalon to cervical cord.

2. Composition — fibres of origin

The fasciculus is a *composite* tract; several groups of fibres run together within it.

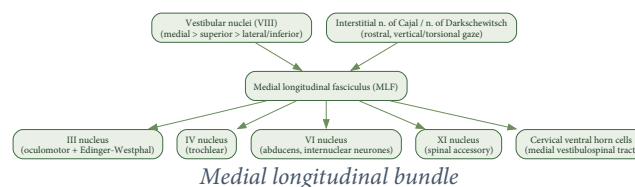
Source	Course / contribution
Medial vestibular nucleus (both sides)	The single largest contributor; sends both ascending and descending fibres, partly crossed and partly uncrossed
Superior vestibular nucleus	Ascending fibres, which remain uncrossed
Lateral and inferior vestibular nuclei	Descending fibres, partly crossed; form the medial vestibulospinal tract , which travels within the MLF into the ventral funiculus of the spinal cord
Interstitial nucleus of Cajal, nucleus of Darkschewitsch, nucleus of the posterior commissure	Rostral (midbrain) nuclei that add fibres concerned with vertical and torsional gaze ; the rostral interstitial nucleus of the MLF (riMLF) here is the principal generator of vertical/torsional saccades
Dorsal trapezoid nucleus / nucleus of the lateral lemniscus, and some cochlear-nucleus fibres	Auditory-linked contributions, allowing sound to reflexly influence eye and head movement
Reticular formation (including the paramedian pontine reticular formation, PPRF)	Functionally integrated with the MLF in generating conjugate horizontal gaze, although its fibres run largely alongside rather than within the fasciculus

3. Nuclei and structures interconnected

This is the crux of any "connections" question — the MLF is essentially an **internuclear cable** linking the following:

Structure	Relationship to the MLF
III — oculomotor nucleus (+ Edinger–Westphal preganglionic nucleus)	Its medial rectus subnucleus receives crossed, ascending internuclear fibres from the contralateral abducens nucleus; the Edinger–Westphal and other oculomotor subnuclei also receive afferents from the riMLF and interstitial nucleus of Cajal for vertical/torsional gaze
IV — trochlear nucleus	Lies close against the MLF; interconnected for coordinated vertical/torsional eye movement

Structure	Relationship to the MLF
VI — abducens nucleus	Contains (i) large motor neurones whose axons supply the ipsilateral lateral rectus and (ii) small internuclear neurones whose axons cross the midline at the nuclear level and ascend in the contralateral MLF to the opposite medial rectus subnucleus of III — the anatomical basis of conjugate horizontal gaze
VII — facial nerve fibres	The internal genu of the facial nerve winds around the abducens nucleus immediately adjacent to the MLF; closely related though not a primary constituent
VIII — vestibular nuclear complex	The chief source of MLF fibres (Table above); both cochlear and vestibular components of the nerve can thereby influence eye and head movement
XI — spinal (nucleus of the) accessory nerve	Descending connection coordinating head-turning (sternocleidomastoid/trapezius) with eye position
XII — hypoglossal nucleus	Lies in the same paramedian somatic-efferent column; some texts describe a functional link that helps coordinate tongue and lip movement with head posture, e.g. during speech
Cervical ventral (anterior) horn cells, C1–C6	Reached via the descending medial vestibulospinal tract running inside the MLF — coordinates neck-muscle tone and posture with head and eye position



4. Functions

- **Coordination of conjugate horizontal eye movements** (Hering's law of equal innervation) — a single PPRF command drives the ipsilateral VI nucleus, whose internuclear neurones cross and ascend the contralateral MLF to fire the opposite medial rectus subnucleus of III, so both eyes move together.
- **Vestibulo-ocular reflex (VOR)** — vestibular nuclear output relayed through the MLF to the III/IV/VI nuclei stabilises gaze on a target during head movement.
- **Vestibulocollic/cervico-ocular coordination** — the medial vestibulospinal component running in the MLF adjusts neck-muscle tone in step with head and eye position.
- **Reflex response to sound** — auditory (cochlear/lateral lemniscal) fibres joining the fasciculus permit reflex turning of the eyes and head towards a sudden noise.
- **Vertical and torsional gaze** — mediated through the rostral (riMLF/interstitial nucleus of Cajal) contribution, largely independent of the crossed horizontal-gaze pathway described above.

- **Maintenance of equilibrium and posture** of the head in relation to eye position, integrating the vestibular, ocular-motor and cervical systems as a single functional unit.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 6.20 — *Medial longitudinal fasciculus* (IB Singh — *Textbook of Human Neuroanatomy*, p.114)

Reproduce a schematic vertical (coronal/paramedian) diagram from midbrain to cervical cord, labelling in sequence from above downward:

- **Posterior commissure and interstitial nucleus of Cajal**, at the top, with the two MLFs crossing here
- **III nerve nucleus, IV nerve nucleus, VI nerve nucleus** — in descending order, close to the midline, each linked to the paired MLF
- **Nucleus of the lateral lemniscus** joining the fasciculus at pontine level
- **Vestibular nucleus** (show its four parts — Superior, Lateral, Medial, Inferior) sending the major contribution into the MLF
- **XI nerve nucleus (spinal accessory)** at the medullary/upper cervical level
- **The medial longitudinal fasciculus itself**, continuing down as a paired paramedian column
- **Ventral (anterior) horn cells in a cervical segment of the spinal cord**, the caudal termination, with arrows indicating outflow to neck muscles

Applied / Clinical anatomy

- **Internuclear ophthalmoplegia (INO)**: caused by a lesion of the MLF, classically in the dorsomedial pontine tegmentum between the abducens and oculomotor nuclei. The lesion interrupts the crossed, ascending internuclear fibres running from the abducens nucleus of one side to the medial rectus subnucleus of the contralateral oculomotor complex.
 - On attempted conjugate horizontal gaze **away from** the side of the lesion: the eye **on the side of the lesion fails to adduct** (weak/paralysed medial rectus), while the **abducting eye on the opposite side** shows dissociated horizontal (jerk) **nystagmus**.
 - **Convergence and vertical gaze are typically preserved**, because these use separate final pathways (the near-response and the riMLF/interstitial-nucleus-of-Cajal vertical-gaze system) that do not depend on the crossed horizontal MLF circuit.
- **Bilateral INO with impaired convergence** is termed **WEBINO (wall-eyed bilateral internuclear ophthalmoplegia)** — bilateral exotropia with bilateral adduction failure; it results from bilateral paramedian MLF lesions.
- **Common causes: multiple sclerosis** (demyelination — the classic cause in younger patients, often bilateral) and **brainstem (pontine) vascular infarcts** in small paramedian branches of the basilar artery (typically unilateral, in older patients); less commonly trauma or brainstem tumour.
- **One-and-a-half syndrome**: a combined lesion of the PPRF/abducens nucleus plus the ipsilateral MLF causes an ipsilateral horizontal gaze palsy ("one") together with an ipsilateral INO ("half"), leaving only abduction of the contralateral eye (with nystagmus) as the sole preserved horizontal movement.

- ▶ The MLF's descending (medial vestibulospinal) fibres explain why vestibular lesions can produce **abnormal head posture and neck stiffness** in addition to eye-movement disturbance; its role in the vestibulo-ocular reflex underlies the head-impulse test used at the bedside to localise vestibular pathway lesions.

Recent advances

(According to PubMed.)

- ▶ **Nomenclature of bilateral adduction-palsy syndromes is being refined:** a 2025 case report of bilateral adduction palsy with impaired convergence from a paramedian midbrain infarct argued that when the lesion actually involves the **medial rectus subnuclei of III** rather than the MLF proper, the term "internuclear" is a misnomer, and proposed **WEBOSO (wall-eyed bilateral oculomotor subnuclear ophthalmoplegia)** as a more anatomically accurate alternative to WEBINO for such cases (Yasuda et al., *International Journal of Neuroscience*, 2025) [DOI: 10.1080/00207454.2025.2534403].
- ▶ **MRI can be falsely negative in genuine INO:** a 2026 paediatric case demonstrated pathognomonic bilateral INO (failure of adduction, dissociated nystagmus, impaired convergence) with normal-appearing MLF on 1.5–3T MRI despite periventricular demyelinating changes elsewhere, reinforcing that the fasciculus is thin enough that small inflammatory lesions can cause clinically obvious internuclear disconnection below current MRI resolution — clinical localisation must take precedence over a negative scan (Mohamed et al., *Cureus*, 2026) [DOI: 10.7759/cureus.108492].
- ▶ **INO of abduction — a rare reversible variant** — was reported in 2026 due to **raised intracranial pressure from cerebral venous sinus thrombosis** without any structural brainstem lesion, presenting as abduction restriction with preserved convergence and contralateral adduction nystagmus, and resolving completely with anticoagulation and acetazolamide; this expands the recognised pathophysiology of MLF-region dysfunction beyond fixed structural lesions to pressure-mediated, reversible causes (Baskar & Maheswarappa, *The Neurologist*, 2026) [DOI: 10.1097/NRL.0000000000000683].

High-yield exam pointers

- ▶ MLF = medial longitudinal **bundle** (BD Chaurasia) = medial longitudinal **fasciculus** (Gray's/Snell/Singh texts) — same structure, synonymous terms.
- ▶ Paramedian, heavily myelinated, runs from the **interstitial nucleus of Cajal** (midbrain–diencephalic junction) to the **upper cervical spinal cord** — one of the longest brainstem intersegmental tracts.
- ▶ **Chief source = vestibular nuclei** (all four contribute); also receives fibres from the interstitial nucleus of Cajal, nucleus of Darkschewitsch, posterior-commissure nucleus, and auditory (lateral lemniscal/trapezoid) nuclei.
- ▶ Interconnects nuclei of **III, IV, VI, VIII and XI** (and is closely related to VII and XII); descending fibres form the **medial vestibulospinal tract** to cervical ventral horn cells.
- ▶ Functionally the anatomical basis of **conjugate horizontal gaze**, the **vestibulo-ocular reflex**, and **head–neck–eye coordination**.

- ▶ Lesion → **internuclear ophthalmoplegia**: failure of adduction on the side of the lesion on gaze away from it, with nystagmus in the contralateral abducting eye; convergence and vertical gaze spared.
- ▶ Classic causes: **multiple sclerosis** (bilateral, young) and **brainstem vascular infarct** (unilateral, elderly).
- ▶ Bilateral INO + impaired convergence = **WEBINO**; combined PPRF + MLF lesion = **one-and-a-half syndrome**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3-4 8e; IB Singh's Textbook of Human Neuroanatomy; IB Singh's Textbook of Anatomy Vol 3 6e; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e. Recent-advances section per PubMed (see DOIs above).



Neuro-biotaxis

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction. Neuro-biotaxis (neurobiotaxis) is the embryological "law" stating that a developing nerve cell body tends to migrate, during morphogenesis, towards the region from which it receives the greatest density of afferent stimuli — and that its axon, elongating as the soma moves, subsequently maps out and permanently retains the pathway travelled during this migration. The principle was propounded by the Dutch neuro-anatomist **C. U. Ariëns Kappers** in 1921 ("On structural laws in the nervous system; the principles of neurobiotaxis," *Brain* 44: 125–149) to explain why the adult positions of certain cranial nerve nuclei in the brainstem differ so strikingly from their primitive embryonic sites. Its textbook proof is the tortuous developmental course of the **motor nucleus of the facial (VII) nerve**, which also accounts for the internal genu of the facial nerve and the facial colliculus.

1. The postulates of neuro-biotaxis

Kappers' concept, as it is taught in the PG curriculum, is really a set of three related postulates about how neuronal cell bodies and their processes come to occupy their adult positions.

Postulate	Statement	Classic example
1. Migration towards maximum stimulus density	A neuron's cell body tends to move as near as possible to its predominant source of afferent stimulation, migrating around any intervening structures to reach the region of greatest impulse density	Facial (VII) motor nucleus migrates to lie beside the spinal nucleus of the trigeminal nerve

Postulate	Statement	Classic example
2. Centralization and encephalization	Through phylogeny, functions originally governed by lower (spinal/brainstem) centres are progressively taken over by higher centres — an evolutionary correlate of the same migratory tendency	Progressive dominance of cortical over brainstem/spinal control of movement in higher vertebrates
3. Grouping of processes with similar function	Fibres/processes serving a common function come to run together in the same territory of the neuraxis	Descending (motor) fibres collect in the basilar part of the pons; ascending (sensory) fibres collect in the tegmentum

- ▶ The first postulate is by far the most clinically and academically important, and is what examiners mean when they simply say "neuro-biotaxis."
- ▶ The axon is assumed to retain a record of the migration — the looped, circuitous course of the fibres of a migrated nucleus is thought to map out the very path along which the cell bodies travelled.
- ▶ In current usage the term is applied almost exclusively to the **secondary displacement of a small number of cranial nerve nuclei** in the floor of the fourth ventricle/brainstem, away from their primitive alar-/basal-plate positions.

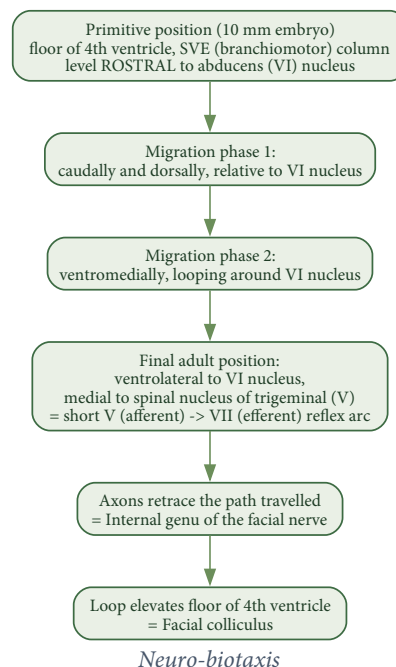
2. Embryological setting — functional cell columns of the brainstem

- ▶ The neural tube's alar and basal plates give rise to continuous longitudinal **functional cell columns** flanking the sulcus limitans: general somatic afferent (GSA), special somatic afferent (SSA), general visceral afferent (GVA) and special visceral afferent (SVA) columns dorsally (alar-plate derivatives), and general visceral efferent (GVE), special visceral efferent (SVE) and general somatic efferent (GSE) columns ventrally (basal-plate derivatives).
- ▶ As the brainstem grows, these once-continuous columns break up so that each is represented only by discrete nuclei at the levels where the corresponding cranial nerves attach.
- ▶ Most nuclei **retain their primitive position** near the floor of the fourth ventricle (e.g. the abducens, hypoglossal, dorsal vagal and vestibulocochlear nuclei).
- ▶ A few nuclei are **secondarily displaced** — by differential growth of surrounding tissue, by the appearance of neighbouring fibre tracts, and (it is proposed) by active neuro-biotactic migration towards their maximal source of stimulation. The **facial motor nucleus** and the **nucleus ambiguus** are the standard cited exemplars of this secondary displacement.

3. The classic proof — migration of the facial (VII) nerve nucleus

- ▶ In a **10 mm embryo**, the facial nucleus lies in the floor of the fourth ventricle, occupying the position proper to the special visceral efferent (branchiomotor) column, at a level **higher (more rostral)** than the abducens nucleus.
- ▶ As growth proceeds, the facial nucleus **migrates caudally and dorsally** relative to the abducens nucleus, and then **ventromedially**, until it reaches its **permanent adult position ventrolateral to the abducens nucleus** — anterolateral and caudal to it, and medial to the spinal nucleus of the trigeminal nerve.

- This final position is deliberate rather than incidental: the spinal trigeminal nucleus is the **site of maximum sensory stimulus** relevant to the facial musculature (it carries proprioceptive afferents from the very muscles of facial expression that the facial nerve supplies), and apposition of the two nuclei shortens the reflex arc between them, permitting quick reflex responses such as the corneal/blink reflex. The facial nucleus also remains applied to the **medial longitudinal fasciculus (MLF)**, which coordinates lip and tongue movements during articulation.
- Because axons had already begun growing out from the nucleus's earlier dorsal position before migration was complete, the intrapontine facial-nerve fibres are obliged to follow the looped course their cell bodies traced — first dorsomedially towards the floor of the fourth ventricle, looping behind (around) the abducens nucleus, and then ventrolaterally between the facial nucleus and the spinal trigeminal nucleus to emerge at the pontomedullary junction. This loop is the **internal genu of the facial nerve**, and it elevates the overlying floor of the fourth ventricle to form the **facial colliculus**.



4. A second exemplar — nucleus ambiguus

- The **nucleus ambiguus** (the motor nucleus of the IXth, Xth and cranial part of the XIth nerves) is the second nucleus classically cited as an example of neuro-biotaxis.
- It arises, in the embryo, immediately deep to the floor of the fourth ventricle, but in the adult it lies **much more deeply placed**, embedded in the medullary reticular formation, dorsal to the inferior olivary nucleus and ventromedial to the spinal nucleus of the trigeminal nerve.
- Its efferent fibres are, correspondingly, first directed **dorsally**, then turn sharply **ventrolaterally** to mingle with the other rootlets of the IXth, Xth and XIth nerves emerging along the posterolateral (retro-olivary) sulcus of the medulla — a curious, indirect course again attributed to the migratory history of the nucleus.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 21.11 — A transverse section through the pons at the level of the facial colli (Gray's Anatomy — Standing — 41e, p.445)

Reproduce a transverse section through the **caudal pons at the level of the facial colliculus** and label: the **floor of the fourth ventricle** with the **facial colliculus** bulging into it; the **abducens (VI) nucleus** lying beneath the colliculus, close to the midline and lateral to the **medial longitudinal fasciculus (MLF)**; the **internal genu of the facial nerve** looping dorsomedially over the abducens nucleus; the **motor nucleus of the facial (VII) nerve** in its final ventrolateral position; the **spinal nucleus and tract of the trigeminal nerve**, immediately adjacent to the facial nucleus (the migration "target"); and, more peripherally, the **superior olivary complex** and **trapezoid body**. Beside this section, sketch two small outline diagrams — the "primitive (10 mm embryo)" and "adult" positions of the facial nucleus relative to the abducens nucleus — joined by a curved arrow tracing caudal → dorsal → ventromedial migration, to visually demonstrate the law.

Applied / Clinical anatomy

- ▶ **Corneal (blink) reflex** — the clinically important short reflex arc made possible by neuro-biotaxis: the afferent limb runs via the ophthalmic division of the trigeminal nerve to the spinal trigeminal nucleus, and the efferent limb via the facial nerve to orbicularis oculi; loss of this reflex is one of the criteria used in the clinical determination of brainstem death.
- ▶ **Facial colliculus lesions** — because the abducens nucleus and the looped internal genu of the facial nerve lie immediately beneath the same small area of the fourth-ventricle floor, a discrete lesion here (vascular, demyelinating, or a pontine glioma in a child) characteristically produces a combined **ipsilateral lower motor neurone facial palsy together with an ipsilateral lateral rectus (abducens) palsy** — a direct clinical signature of the neuro-biotactic relationship between the VIIth and VIth nerves, and an important localising sign of an intrapontine (rather than a peripheral or cerebellopontine-angle) lesion.
- ▶ **Crossed brainstem (pontine) syndromes** exploit the same anatomical juxtaposition: a ventral pontine lesion involving the corticospinal tract together with facial and abducens fibres gives ipsilateral VI + VII palsy with contralateral hemiplegia (**Millard–Gubler syndrome**), while a more dorsal tegmental lesion adds an ipsilateral conjugate gaze palsy (**Foville's syndrome**) — both are direct clinical consequences of how closely the migrated facial nucleus and fibres lie applied to the abducens nucleus.
- ▶ **Not to be confused** with other "curious" nerve courses that are *not* due to neuro-biotaxis — e.g. the recurrent laryngeal nerve's hooking course around the subclavian artery/arch of aorta is a purely mechanical consequence of the caudal migration of the heart and great vessels relative to the fixed pharyngeal-arch origin of the nerve, not neuronal migration towards a stimulus source; examiners frequently test this distinction.

Recent advances

- ▶ Molecular-genetic and live-imaging work in zebrafish and mouse has since given Kappers' century-old descriptive law a mechanistic basis: facial branchiomotor (FBM) neurons are now shown to undergo an active **tangential migration from rhombomere 4 caudally to rhombomere**

6, guided by **planar cell polarity (PCP) signalling** — core PCP components (Vangl2, Frizzled, Prickle1b, Dishevelled, Celsr) acting both within the migrating neurons and in the surrounding hindbrain neuroepithelium to orient and drive their posterior movement (Wanner SJ, Saeger I, Guthrie S, Prince VE. "Facial motor neuron migration advances." *Current Opinion in Neurobiology* 2013; 23(6):943–950 [PMID 24090878]).

- ▶ **Prickle1b**, in particular, has been shown to integrate the multiple migratory cues received by facial branchiomotor neurons into a single polarization instruction, and its loss selectively blocks the posterior (neuro-biotactic) phase of migration without disturbing centrosome positioning (Mapp OM, Wanner SJ, Rohrschneider MR, Prince VE. "Prickle1b mediates interpretation of migratory cues during zebrafish facial branchiomotor neuron migration." *Developmental Dynamics* 2010; 239(6):1596–1608 [DOI: 10.1002/dvdy.22283]).
- ▶ Cadherin-2-mediated cell-to-cell adhesion between migrating neurons has also been shown to be necessary for this migration to proceed collectively and directionally, rather than as isolated cells.
- ▶ *Coverage note:* modern developmental neurobiology therefore reframes Kappers' original "stimulus density" hypothesis in genetic/molecular terms (Hox-gene-patterned rhombomeric origin + PCP-driven tangential migration + cadherin-mediated collective movement) rather than literal chemotaxis towards electrical activity; no major primary research specifically revisiting the classical term "neurobiotaxis" has appeared in the last five years, and the corpus available for this bank covers the classical descriptive law far more richly than this molecular literature.

High-yield exam pointers

- ▶ **Definition:** tendency of a developing neuron to migrate towards its predominant source of afferent stimulation; propounded by **C. U. Ariëns Kappers (1921)**, *Brain* 44:125–149.
- ▶ Three postulates: (1) migration towards maximum stimulus density, (2) centralization/encephalization, (3) grouping of processes with similar function.
- ▶ Classic exemplars: **motor nucleus of the facial nerve** and the **nucleus ambiguus**.
- ▶ Facial nucleus: primitive position rostral to the abducens nucleus (10 mm embryo, SVE column) → migrates caudally, dorsally, then ventromedially → final position ventrolateral to the abducens nucleus, next to the spinal nucleus of the trigeminal nerve.
- ▶ Consequence: looped axons form the **internal genu of the facial nerve**, which raises the floor of the fourth ventricle as the **facial colliculus**.
- ▶ Purpose: shortens the sensorimotor reflex arc (trigeminal afferent → facial efferent), e.g. the corneal reflex.
- ▶ Clinical correlate: combined ipsilateral VI + VII palsy (facial colliculus/Millard–Gubler/Foville syndromes) localises a lesion to the caudal pontine tegmentum.
- ▶ Modern molecular correlate: PCP signalling (Vangl2/Prickle1b/Celsr) and cadherin-2 adhesion drive the actual rhombomere 4→6 tangential migration of facial branchiomotor neurons.
- ▶ Do not confuse with mechanically-determined "curious" nerve courses (e.g. recurrent laryngeal nerve), which are unrelated to neuro-biotaxis.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; Vishram Singh's Textbook of Anatomy Vol 3 4e (index); BD Chaurasia's Human Anatomy Vol 3-4 8e; Snell's Clinical Neuroanatomy 7e (course of facial fibres, corroborative). Recent-advances citations per PubMed (Wanner et al. 2013; Mapp et al. 2010).



Nuclei of trigeminal nerve

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction. The trigeminal nerve (cranial nerve V) is the largest cranial nerve and the principal sensory nerve of the face, and the motor nerve of the first branchial (pharyngeal) arch. It is a mixed nerve carrying a **general somatic afferent (GSA)** component for exteroceptive and proprioceptive sensation from the face, and a **special visceral (branchial) efferent (SVE)** component for the muscles of mastication. Correspondingly it possesses **four nuclei** in the brain stem — three sensory (main/principal sensory, spinal, and mesencephalic) and one motor — which together form the **longest nuclear column of any cranial nerve**, extending from the midbrain down to the upper (C2) segment of the spinal cord.

Functional classification and overview

Nucleus	Functional column	Level in brain stem	Principal modality
Main (principal/chief) sensory nucleus	GSA	Upper pons	Touch and pressure
Spinal nucleus (pars oralis, interpolaris, caudalis)	GSA	Lower pons → medulla → upper cervical cord (C2)	Pain and temperature
Mesencephalic nucleus	GSA (unique — 1st-order neurons within CNS)	Midbrain, extending down to upper pons	Proprioception from muscles of mastication, TMJ, teeth
Motor nucleus	SVE (branchiomotor)	Upper pons	Motor to muscles of mastication and related first-arch muscles

Location and extent of each nucleus

- **Main (principal) sensory nucleus** — lies in the dorsolateral tegmentum of the **upper pons**, lateral to the motor nucleus; it occupies an intermediate position between the mesencephalic nucleus above and the spinal nucleus below, with which it is continuous inferiorly.
- **Spinal nucleus** — continuous superiorly with the main sensory nucleus in the pons; extends caudally through the **whole length of the medulla oblongata** into the upper cervical spinal cord as far as C2, where it becomes continuous with the substantia gelatinosa of the dorsal horn. It lies

medial to the spinal tract of the trigeminal nerve, which embraces it laterally. Based on cytoarchitecture, it is divided (rostral → caudal) into three subnuclei:

Subnucleus (rostral → caudal)	Division of V terminating here	Territory represented	Modality
Pars oralis (rostralis)	Mandibular (V3)	Around the mouth	Pain, temperature
Pars interpolaris	Maxillary (V2)	Cheek	Pain, temperature
Pars caudalis	Ophthalmic (V1)	Forehead/perioral concentric zone; continuous with dorsal horn laminae I, II, V	Pain, temperature (main nociceptive relay); has dorsal-horn-like laminar structure

This rostrocaudal somatotopy — ophthalmic fibres descending furthest caudally to pars caudalis and mandibular fibres remaining most rostral in pars oralis — underlies the clinically important "**onion-skin**" (**Dejerine**) **pattern** of dissociated sensory loss (see Applied anatomy). A small general somatic afferent contribution from the facial, glossopharyngeal and vagus nerves (external ear, posterior tongue, pharynx, larynx) also terminates in the dorsal part of the spinal nucleus/tract.

- ▶ **Mesencephalic nucleus** — a column of unipolar (pseudo-unipolar) cells situated in the lateral periaqueductal grey matter, extending from the midbrain down to the level of the main sensory nucleus in the upper pons. It is unique in being **the only site in the CNS containing the cell bodies of first-order (primary) sensory neurons** — functionally equivalent to a displaced dorsal root ganglion.
- ▶ **Motor nucleus** — situated in the dorsal tegmentum of the **upper pons**, medial to the main sensory nucleus, and separated from it by fibres of the trigeminal nerve. It is ovoid, contains large multipolar motor neurons interspersed with smaller interneurons organised into discrete subnuclei for individual muscles, and forms the rostral end of the branchiomotor (SVE) cell column that continues caudally as the facial and ambiguus nuclei.

Afferent (sensory) pathway

- ▶ Primary sensory neurons (except proprioceptive ones) have their cell bodies in the **trigeminal (semilunar/Gasserian) ganglion**, lying in Meckel's cave on the petrous apex; their central processes form the large sensory root.
- ▶ On entering the pons, about half of these fibres bifurcate into ascending and descending branches; the rest ascend or descend without division.
- ▶ **Ascending fibres** terminate in the **main sensory nucleus** and convey touch/pressure.
- ▶ **Descending fibres** form the **spinal tract of the trigeminal nerve**, which embraces the spinal nucleus, and convey pain and temperature, terminating somatotopically as above. Within the tract itself, fibres of the ophthalmic division lie ventrally, mandibular fibres dorsally, and maxillary fibres between the two.
- ▶ **Proprioceptive fibres** from muscles of mastication, the temporomandibular joint, teeth, and (probably) extraocular and facial muscles bypass the trigeminal ganglion altogether and reach the **mesencephalic nucleus** directly — these are the peripheral processes of its unipolar cells.

- ▶ Second-order axons from the main sensory and spinal nuclei (and central processes of mesencephalic-nucleus cells) **cross the midline** and ascend as the **trigeminal lemniscus**, terminating in the contralateral **ventral posteromedial (VPM) nucleus of the thalamus**; a smaller, more dorsally placed uncrossed component (dorsal trigeminal lemniscus/tract) also exists. Third-order thalamic neurons project via the internal capsule to the **postcentral gyrus** (Brodmann areas 3, 1, 2).

Efferent (motor) pathway and reflex connections

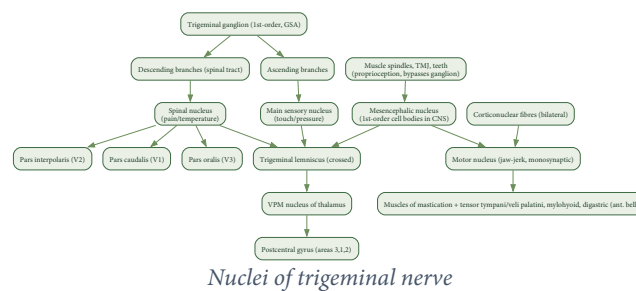
- ▶ The **motor nucleus** receives **bilateral corticonuclear (corticobulbar) fibres** from both cerebral hemispheres, together with fibres from the reticular formation, red nucleus, tectum, and medial longitudinal fasciculus.
- ▶ It also receives **monosynaptic afferents from the mesencephalic nucleus**, forming a proprioceptive reflex arc for control of bite force and jaw position (see jaw-jerk reflex below).
- ▶ Motor axons leave as the **motor root**, join the mandibular division at/beyond the foramen ovale, and supply the four **muscles of mastication** (temporalis, masseter, medial and lateral pterygoid) plus **tensor tympani, tensor veli palatini, mylohyoid, and the anterior belly of digastric**.
- ▶ **Jaw-jerk reflex** — the only clinically significant **supraspinal monosynaptic reflex**: tapping the relaxed, open jaw stretches the masticatory muscles; muscle-spindle afferents (via the mandibular nerve) reach the mesencephalic nucleus directly (cell bodies here, unlike a spinal reflex), and collaterals project monosynaptically onto the motor nucleus, which drives reflex jaw closure.
- ▶ **Corneal (blink) reflex** — light touch on the cornea/conjunctiva is carried by the **ophthalmic division (afferent limb)** to the main sensory nucleus; internuncial neurons relay to the **facial motor nucleus (efferent limb)**, producing bilateral blinking via orbicularis oculi.
- ▶ **Sneeze reflex** — the **maxillary division** carries the afferent limb from the nasal mucosa; the efferent pathway runs via the nucleus ambiguus, medullary respiratory centre, phrenic nucleus, and spinal motor neurons of the intercostal muscles.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 4.26 — Nuclei of trigeminal nerve at level of upper pons (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.487)

Also draw a sagittal/schematic strip of the brain stem (midbrain → pons → medulla → C2 cord) showing the full craniocaudal extent and central connections. Label:

- ▶ **Mesencephalic nucleus** — midbrain, lateral periaqueductal grey, extending to upper pons
- ▶ **Main (principal) sensory nucleus** — upper pons, lateral to motor nucleus
- ▶ **Motor nucleus** — upper pons, medial to main sensory nucleus
- ▶ **Spinal nucleus** with its three subnuclei in sequence — **pars oralis** (upper, pons), **pars interpolaris** (mid, medulla), **pars caudalis** (lower, medulla–C2), each labelled with the division it receives (V3 → oralis, V2 → interpolaris, V1 → caudalis)
- ▶ **Trigeminal ganglion** and **sensory/motor roots** entering the pons
- ▶ **Trigeminal lemniscus** crossing the midline to the **ventral posteromedial nucleus** of thalamus, then to the **postcentral gyrus**



Applied / Clinical anatomy

- ▶ **Dissociated sensory loss** — because touch (main sensory nucleus) and pain/temperature (spinal nucleus) are relayed by anatomically separate nuclei, a low pontine, medullary or high cervical cord lesion (e.g. syringomyelia extending to C1–C2, or a brain-stem infarct) can selectively abolish facial pain/temperature sensation while sparing light touch.
- ▶ **"Onion-skin" (Dejerine) pattern** — because the ophthalmic division terminates most caudally (pars caudalis) and the mandibular division most rostrally (pars oralis), a lesion that progressively ascends the spinal tract/nucleus produces concentric rings of sensory loss centred on the mouth, sparing the perioral ("muzzle") area until last; conversely, surgical section of the spinal tract just below the obex renders the ophthalmic and maxillary territories analgesic while sparing mandibular sensation.
- ▶ **Wallenberg (lateral medullary) syndrome** — occlusion of the posterior inferior cerebellar artery damages the spinal tract and nucleus of the trigeminal nerve, producing **ipsilateral facial analgesia and thermoanaesthesia** together with **contralateral loss of pain/temperature over the trunk and limbs** (spinothalamic tract) — a classic crossed sensory deficit.
- ▶ **Trigeminal neuralgia (tic douloureux)** — paroxysmal, severe, stabbing pain in the distribution of one or more divisions (most often maxillary and mandibular; rarely ophthalmic), usually of

unknown cause; illustrates the clinical relevance of the somatotopic organisation of the sensory root and nuclei.

- ▶ **Corneal reflex testing** — loss of the reflex with an intact contralateral blink on stimulating the affected eye localises a lesion to the **ophthalmic division/main sensory nucleus** (afferent limb); an intact reflex on stimulation but absent blink localises a **facial nerve** (efferent) lesion.
- ▶ **Jaw-jerk reflex** — exaggerated in **upper motor neuron (supranuclear/pseudobulbar)** lesions above the motor nucleus (loss of cortical inhibition), and diminished/absent in lesions of the mandibular nerve, motor nucleus, or mesencephalic nucleus itself.
- ▶ **Herpes zoster ophthalmicus** — reactivation of latent virus within the trigeminal (Gasserian) ganglion, most often affecting the ophthalmic division, with risk of corneal involvement.
- ▶ Sensory examination of the face tests pinprick, temperature and light touch in each of the three divisions; motor examination assesses temporalis/masseter bulk and contraction, and jaw deviation towards the weak side (paralysed pterygoids) on opening the mouth.

High-yield exam pointers

- ▶ Trigeminal nerve = mixed nerve; **4 nuclei** — main sensory, spinal, mesencephalic (all GSA/sensory) + motor (SVE/branchiomotor).
- ▶ Longest cranial nerve nuclear column: **midbrain (mesencephalic) to C2 spinal cord (spinal nucleus)**.
- ▶ Main sensory nucleus (upper pons) = **touch/pressure**; spinal nucleus (pons–medulla–C2) = **pain/temperature**; mesencephalic nucleus (midbrain) = **proprioception**.
- ▶ Spinal nucleus subnuclei rostral→caudal: **pars oralis (V3) → pars interpolaris (V2) → pars caudalis (V1)** — basis of the onion-skin pattern.
- ▶ **Mesencephalic nucleus is the only CNS site with 1st-order sensory neuron cell bodies** — functions like a dorsal root ganglion in the brain stem.
- ▶ Second-order fibres **cross** and ascend as the **trigeminal lemniscus** to the **VPM thalamus**, then to **postcentral gyrus (areas 3, 1, 2)**.
- ▶ **Jaw jerk** = only supraspinal monosynaptic reflex (mesencephalic nucleus → motor nucleus); **corneal reflex** = afferent V1, efferent VII; **sneeze reflex** afferent = maxillary division.
- ▶ Motor nucleus is supplied **bilaterally** by corticonuclear fibres — unlike the lower-face part of the facial nucleus.
- ▶ Applied correlates: dissociated sensory loss, onion-skin sensory loss, Wallenberg syndrome, trigeminal neuralgia, herpes zoster ophthalmicus.

SOURCE & COVERAGE

Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3–4 8e; Gray's Anatomy (Standring) 41e; IB Singh's Textbook of Anatomy Vol 3 (Neuroanatomy) 6e.



Nucleus ambiguus

Asked in: Paper IV Sep 2007 — RGUHS MD/MS Anatomy

Definition / Introduction The nucleus ambiguus is an elongated column of large, typical multipolar motor neurones situated deep within the reticular formation of the medulla oblongata, extending almost throughout its length. It is the **special visceral (branchial) efferent (SVE) motor nucleus common to the glossopharyngeal (IX), vagus (X) and cranial part of the accessory (XI) nerves**, supplying voluntary (striated) muscle derived from the branchial arches — the muscles of the pharynx, larynx and soft palate. Its name reflects the fact that, unlike other brainstem motor nuclei, its boundaries are **not clearly (ambiguously) demarcated** on routine transverse sections of the medulla.

Situation and extent

- ▶ Lies **deep in the reticular formation of the medulla**, dorsal (posterior) to the inferior olivary nucleus and ventromedial (anteromedial) to the spinal nucleus of the trigeminal nerve.
- ▶ Extends as an elongated column through almost the whole length of the medulla:
 - **Rostrally**, it reaches as far as the upper end of the (dorsal) vagal nucleus, where a small **retrofacial nucleus** intervenes between it and the facial motor nucleus.
 - **Caudally**, it lies in line with — but is **not continuous with** — the nucleus of the accessory nerve (spinal accessory nucleus) in the upper cervical cord.
- ▶ At different transverse levels its position shifts: at the level of the sensory (pyramidal) decussation and at the mid-olivary level it lies medial to the spinal nucleus of the trigeminal nerve within the reticular formation; more rostrally (upper medulla/ponto-medullary junction) it lies still more ventrally within the reticular formation, deep to the dorsal vagal nucleus and nucleus of the tractus solitarius.
- ▶ Because it is buried within the diffuse reticular formation rather than forming a discrete, sharply outlined grey mass (as the hypoglossal or dorsal vagal nuclei do), its margins cannot be clearly defined histologically — hence the name "ambiguus."

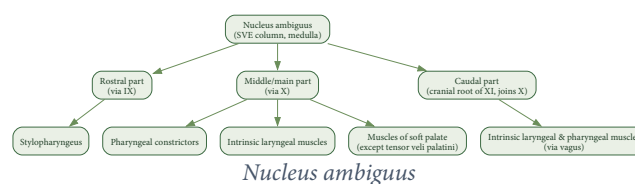
Functional/cytoarchitectural organisation

Feature	Detail
Functional column	Special visceral efferent (SVE) / branchiomotor column
Cell type	Large, typical multipolar somatic-type motor neurones
Topographic order (rostral → caudal)	Neurones supplying soft palate and oesophagus lie rostral; pharyngeal-muscle neurones lie in an intermediate zone; individual laryngeal muscles are supplied by discrete cell groups in the more caudal part
Cortical input	Corticonuclear (corticobulbar) fibres bilaterally, with contralateral preponderance

Feature	Detail
Course of efferent fibres	Fibres first pass dorsomedially, then curve sharply ventrolaterally to emerge on the anterolateral surface of the medulla in the post-olivary (retro-olivary) sulcus, between the olive and the inferior cerebellar peduncle, joining the rootlets of IX, X and cranial XI

Contribution to the individual cranial nerves

- ▶ ordered rostral-to-caudal along the nucleus:
- ▶ **Glossopharyngeal nerve (IX)** — the most rostral part of the nucleus forms its main motor nucleus; supplies only **stylopharyngeus** (muscle of the 3rd pharyngeal arch).
- ▶ **Vagus nerve (X)** — the main (larger) part of the nucleus; supplies the **constrictor muscles of the pharynx** and the **intrinsic muscles of the larynx**, and (via the pharyngeal/palatine branches) the muscles of the soft palate except tensor veli palatini.
- ▶ **Cranial (bulbar) root of accessory nerve (XI)** — arises from the caudal end of the nucleus; its fibres emerge as 4–6 rootlets below those of the vagus, immediately join and are distributed through the vagus (mainly its pharyngeal and recurrent laryngeal branches) to the muscles of the larynx and pharynx.
- ▶ Muscles innervated collectively via the nucleus ambiguus: **all muscles of the palate except tensor veli palatini** (which is supplied by the mandibular nerve), **all muscles of the pharynx except stylopharyngeus**, and **all the intrinsic muscles of the larynx**.
- ▶ **Note on the accessory nerve controversy:** the traditional description of a "cranial root of XI" arising from nucleus ambiguus and joining the vagus is now widely regarded as anatomically and functionally part of the vagus nerve itself; the "spinal root" (from the spinal accessory nucleus, C1–C5) is increasingly regarded as the accessory nerve proper. Cadaveric dissection studies have not reached consensus on constant plexiform connections between the two roots.



Afferent connections and reflex arcs

- ▶ **Swallowing/deglutition:** sensory input from the oropharynx travels via the glossopharyngeal nerve to the **nucleus of the tractus solitarius**, which relays to the nucleus ambiguus; the latter drives the coordinated, programmed motor sequence of pharyngeal, laryngeal and (via vagal branches) oesophageal muscle contraction.
- ▶ **Gag reflex:** afferent limb IX (from oropharyngeal mucosa) → nucleus solitarius; efferent limb X (via nucleus ambiguus) → reflex contraction of pharynx, soft palate and fauces.
- ▶ **Cough reflex:** laryngo-tracheal mechanoreceptors/chemoreceptors → vagal afferents (inferior vagal ganglion) → nucleus of the solitary tract → medullary respiratory centres and nucleus ambiguus, recruiting motor neurones to pharyngeal, laryngeal, diaphragmatic, intercostal and abdominal muscles for the expiratory cough sequence.

- ▶ **Carotid sinus reflex** (baroreceptor reflex): glossopharyngeal afferents from the carotid sinus → nucleus solitarius → connections to the dorsal motor nucleus of the vagus (cardiac slowing) and to the nucleus ambiguus (contributes to reflex adjustments of respiration).
- ▶ The nucleus ambiguus is generally classed as special visceral efferent, but is also a reputed source of general visceral efferent (parasympathetic) fibres running in the vagus to cardiac muscle — a point occasionally tested.

Developmental origin

- ▶ Derived from the **basal (motor) plate of the rhombencephalon**, forming part of the special visceral (branchial) efferent cell column of the brainstem, together with the trigeminal motor nucleus and facial motor nucleus.
- ▶ It supplies muscle derived from the **3rd, 4th and 6th pharyngeal (branchial) arches** (stylopharyngeus from arch 3; pharyngeal constrictors, palatal and laryngeal muscles from arches 4 and 6).
- ▶ The motor neurones destined for sternocleidomastoid and trapezius differentiate close to the cells forming the nucleus ambiguus but **migrate caudally into the cervical spinal cord (C1–C5)** to form the spinal nucleus of the accessory nerve, lying in line with, but not continuous with, the nucleus ambiguus — explaining why the spinal accessory column is also regarded as carrying special visceral (branchial) efferent fibres by lineage even though its adult location is spinal.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Transverse section of the medulla oblongata at the mid-olivary level, showing the position of the cranial nerve nuclear columns (based on BD Chaurasia Fig 4.3 / p.470). Label, from medial to lateral/dorsal to ventral:

- ▶ Fourth ventricle (floor)
- ▶ Hypoglossal nucleus (medial-most, GSE column)
- ▶ Dorsal (motor) nucleus of vagus (GVE column)
- ▶ Nucleus of tractus solitarius (SVA/GVA column)
- ▶ Medial and inferior vestibular nuclei (SSA column)
- ▶ **Nucleus ambiguus** — deep in reticular formation, dorsal to inferior olivary nucleus, ventromedial to spinal nucleus of trigeminal (SVE column)
- ▶ Spinal nucleus and tract of the trigeminal nerve (GSA column)
- ▶ Inferior cerebellar peduncle
- ▶ Inferior olivary nucleus (with medial and dorsal accessory olivary nuclei)
- ▶ Medial longitudinal fasciculus, tectospinal tract, medial lemniscus, pyramid (corticospinal tract) — paramedian, dorsal to ventral
- ▶ Arcuate nucleus (on pyramid, anteromedial)
- ▶ Rootlets of IX, X, cranial XI emerging in the post-olivary (retro-olivary) sulcus

□ Fig 4.3 — Transverse section of medulla oblongata showing the position of cranial nerve nuclear columns (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.470)

Applied / Clinical anatomy

- ▶ **Lateral medullary syndrome (Wallenberg's / PICA syndrome)** — the single most important clinical correlate. Thrombosis of the **posterior inferior cerebellar artery** (usually a branch of the vertebral artery) infarcts the dorsolateral medulla, damaging the nucleus ambiguus along with several neighbouring structures:

Structure damaged	Clinical feature
Nucleus ambiguus	Ipsilateral paralysis of palate, pharynx and larynx → dysphagia (difficulty swallowing) and dysarthria/dysphonia (hoarseness); loss of gag reflex
Spinal nucleus & tract of trigeminal (V)	Ipsilateral loss of pain/temperature over the face
Lateral spinothalamic tract	Contralateral loss of pain/temperature over trunk and limbs
Vestibular nuclei	Vertigo, nausea, vomiting, nystagmus
Inferior cerebellar peduncle/cerebellum	Ipsilateral limb and gait ataxia
Descending sympathetic fibres	Ipsilateral Horner's syndrome (ptosis, miosis, enophthalmos, anhidrosis)

- ▶ On direct laryngoscopy/examination a unilateral nucleus ambiguus (or vagal) lesion produces **ipsilateral vocal cord paralysis**, sagging of the palatal arch with the **uvula deviating to the**

healthy (contralateral) side on phonation ("curtain sign"), and absent gag reflex on the affected side.

- ▶ Because the nucleus is a common motor origin for IX, X and cranial XI, a lesion here (in contradistinction to a peripheral lesion of a single nerve) characteristically produces combined palatal + pharyngeal + laryngeal weakness — an important localising clue distinguishing a **nuclear (medullary)** lesion from an isolated peripheral **jugular foramen syndrome** (which also affects IX, X and XI together but at their exit, and additionally may affect the spinal root of XI supplying sternocleidomastoid/trapezius, unaffected in a pure nucleus ambiguus lesion).
- ▶ Bilateral nucleus ambiguus involvement (e.g. motor neurone disease, bulbar palsy) produces severe dysphagia, dysarthria and aspiration risk — the basis of "bulbar palsy."
- ▶ Surgically relevant during **jugular foramen/skull-base surgery** and **carotid endarterectomy** where the vagus/cranial XI rootlets are at risk, given their close common origin from the nucleus ambiguus and emergence via the post-olivary sulcus.

High-yield exam pointers

- ▶ Nucleus ambiguus = SVE (branchiomotor) nucleus common to **IX, X and cranial (bulbar) root of XI**.
- ▶ Situated **deep in the reticular formation**, dorsal to inferior olivary nucleus, ventromedial to spinal trigeminal nucleus — hence poorly demarcated ("ambiguus").
- ▶ Supplies: stylopharyngeus (IX); pharyngeal constrictors, laryngeal muscles, palatal muscles except tensor veli palatini (X, and via X-XI).
- ▶ Topographic order within the nucleus: **rostral → soft palate/oesophagus; middle → pharynx; caudal → individual laryngeal muscles**.
- ▶ Rostral limit near the retrofacial nucleus/facial nucleus; caudal limit in line with (not continuous with) the spinal accessory nucleus (C1–C5).
- ▶ Receives bilateral corticonuclear fibres (contralateral preponderance) — hence UMN lesions cause only mild bilateral dysarthria/dysphagia, while LMN (nuclear) lesions cause severe ipsilateral deficit.
- ▶ Key reflex relay for swallowing, gag, cough and carotid sinus reflexes (via nucleus solitarius).
- ▶ **Wallenberg/PICA syndrome** is the classic applied-anatomy question — always link nucleus ambiguus damage to dysphagia + dysarthria + loss of gag reflex.
- ▶ Developmentally part of the branchiomotor column (rhombencephalic basal plate), supplying arch 3, 4 and 6 derivatives; spinal accessory neurones migrate away from it into the cervical cord.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3–4 8e; Larsen's Human Embryology 6e (developmental/branchiomotor column).



Red nucleus

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction

The **red nucleus** is a large, ovoid mass of grey matter in the tegmentum of the midbrain, situated mainly at the level of the **superior colliculus**, dorsomedial to the substantia nigra. In fresh specimens it has a pink/reddish tint from its rich vascularity and a ferric-iron pigment in its multipolar neurons — hence the name. It is one of the principal subcortical motor nuclei of the **extrapyramidal system**, acting as an important **integrating and relay centre** linking the cerebral cortex and cerebellum to the spinal cord, cranial nerve motor nuclei and inferior olive. Its close relation to the oculomotor nerve fibres, medial lemniscus and superior cerebellar peduncle gives it major applied importance in midbrain vascular syndromes and, more recently, in stereotactic tremor surgery.

1. Location, extent and gross morphology

Feature	Description
Situation	Tegmentum of midbrain, dorsomedial to the substantia nigra, ventral to the cerebral aqueduct/periaqueductal grey
Level (main mass)	Upper half of the midbrain, at the level of the superior colliculus
Rostral extent	Poorly demarcated rostrally; blends into the reticular formation and the caudal pole of the interstitial nucleus (of Cajal) in the subthalamic region
Caudal extent	Not present as a discrete nucleus at the inferior collicular level — only its efferent (rubrospinal) fibres are found there, ventral to the decussation of the superior cerebellar peduncles
Shape	Cigar-shaped/rounded mass, ovoid in cross-section
Size	About 0.5 cm (~5 mm) in diameter
Colour	Pink/red in the fresh state — high vascularity + ferric-iron pigment in neuronal cytoplasm

2. Relations

- **Medial:** central (periaqueductal) grey matter and the oculomotor nucleus/nerve fibres.
- **Lateral and ventral:** substantia nigra.
- **Fibres traversing it:** the emerging fascicles of the **oculomotor nerve** pass anteriorly through the red nucleus and the medial part of the substantia nigra to emerge on the medial side of the crus cerebri in the interpeduncular fossa — the anatomical basis of Weber's and Benedikt's syndromes.
- **Posterolateral:** the curved band of the medial, trigeminal and spinal lemnisci, pushed further laterally at this level by the bulk of the red nucleus.

- **Dorsal:** cerebral aqueduct and periaqueductal grey; **ventral:** crus cerebri (via the substantia nigra).

3. Histological structure — magnocellular and parvocellular parts

Part	Position	Neurons	Phylogeny/ comparative note
Magnocellular part	Caudal	Large multipolar neurons, as few as ~200 in humans	Phylogenetically older ; predominant in lower mammals
Parvocellular part	Rostral	Small multipolar neurons, numerically predominant	Enlarged reciprocally in primates , including humans

Small multipolar neurons are present throughout both parts. The relative proportion of magnocellular to parvocellular neurons varies markedly between species and correlates directly with the size of the rubrospinal tract those neurons give rise to (see below).

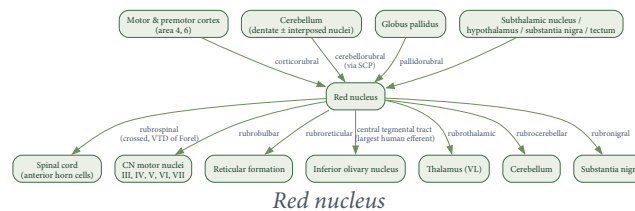
4. Afferent connections

Source	Fibre bundle	Note
Motor and premotor cortex (areas 4 and 6)	Corticorubral fibres	Mostly uncrossed/ipsilateral
Cerebellum — contralateral dentate ($\pm$ interposed) nucleus	Cerebellorubral fibres , via the superior cerebellar peduncle	Crossed
Globus pallidus (same side)	Pallidorubral fibres	—
Subthalamic nucleus (corpus Luysi), hypothalamus, substantia nigra, tectum (superior colliculus)	Additional afferents	Reciprocal with the tectorubral projection

5. Efferent connections

Efferent tract	Destination	Note
Rubrospinal tract	Anterior horn cells of the opposite spinal cord	Decussates immediately as the ventral tegmental decussation (of Forel) ; arises chiefly from the magnocellular part; small/vestigial in humans
Rubrobulbar (rubronuclear) tract	Motor nuclei of cranial nerves V and VII (also III, IV, VI)	—
Central tegmental tract (rubro-olivary fibres)	Ipsilateral inferior olivary nucleus	Arises chiefly from the parvocellular part; the largest group of red-nucleus efferents in humans
Rubroreticular fibres	Reticular formation	—

Efferent tract	Destination	Note
Rubrothalamic fibres	Thalamus (ventral lateral nucleus)	—
Rubrocerebellar and rubronigral fibres	Cerebellum; substantia nigra	Reciprocal to the corresponding afferents



6. Related white-matter decussations

- **Dorsal tegmental decussation (of Meynert)** — tectospinal/tectobulbar fibres arising from the superior colliculus, lying dorsal/rostral in the tegmentum.
- **Ventral tegmental decussation (of Forel)** — rubrospinal fibres arising from the red nuclei, lying ventral to the decussation of the superior cerebellar peduncles.
- The **medial longitudinal fasciculus** lies ventrolateral to the oculomotor nucleus, dorsal to the region of the red nucleus.

7. Functional significance in motor control

- The red nucleus is regarded as an **integrating and relay centre** on three pathways: (a) **cortico-rubro-spinal**, (b) **cortico-rubro-nuclear**, and (c) **cerebello-rubro-spinal** — allowing the cerebral cortex and cerebellum to influence spinal and cranial-nerve motor neurons indirectly.
- In quadrupeds the rubrospinal tract is a major descending motor pathway controlling flexor tone and limb movement; in **humans it is markedly reduced**, and the dominant efferent output instead travels via the **central tegmental tract to the inferior olive** (rubro-olivary projection), which relays onward as climbing fibres to the contralateral cerebellum — a rubro-olivo-cerebellar loop implicated in motor learning.
- Functionally, the corticospinal and rubrospinal systems are complementary rather than redundant: the corticospinal system is most active during **learning** of new movements, while the rubrospinal system is most active during **execution of learned, automated movements**, encoding force, velocity and direction.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 21.16 — A transverse section of the midbrain at the level of the superior colliculi (Gray's Anatomy — Standing — 41e, p.451)

Reproduce a transverse section of the midbrain at the level of the superior colliculus and label: periaqueductal (central) grey matter, cerebral aqueduct, superior colliculus, oculomotor nucleus, medial longitudinal fasciculus, red nucleus, substantia nigra (pars compacta and pars reticularis), decussation of the superior cerebellar peduncles (ventral tegmental decussation), medial/trigeminal/spinal lemnisci, emerging oculomotor nerve rootlets, crus cerebri, and interpeduncular fossa.

Applied / Clinical anatomy

- ▶ **Weber's syndrome** — occlusion of a paramedian branch of the posterior cerebral artery damages the oculomotor nerve fascicles and the crus cerebri, **sparing the red nucleus**: ipsilateral oculomotor palsy (ptosis, dilated fixed pupil, lateral squint) with contralateral hemiplegia and lower facial/tongue weakness.
- ▶ **Benedikt's syndrome** — a more dorsally placed midbrain-tegmental lesion additionally involves the **red nucleus**, medial and spinal lemnisci and the superior cerebellar peduncle fibres entering it: ipsilateral oculomotor palsy with lateral squint and ptosis, contralateral loss of pain and temperature (spinal/trigeminal lemniscus), contralateral loss of tactile, joint and vibration sense (medial lemniscus), and — the red-nucleus-specific sign — **contralateral coarse tremor and involuntary movements** of the limbs.
- ▶ This combination of rest, postural and kinetic tremor produced by a lesion of the red nucleus and its cerebellar (superior cerebellar peduncle) input is clinically termed **rubral (Holmes) tremor**.
- ▶ **Blood supply** — the red nucleus, as part of the midbrain tegmentum, is supplied along with the rest of the midbrain by the **basilar artery, posterior cerebral arteries** (paramedian/interpeduncular perforators), **superior cerebellar arteries, posterior choroidal arteries** and branches of the **anterior choroidal artery**; venous drainage is to the great cerebral and basal veins.
- ▶ **Surgical/imaging relevance** — the red nucleus and the adjacent decussating dentato-rubro-thalamic tract are key intra-operative landmarks for MRI-guided focused-ultrasound thalamotomy and deep brain stimulation used to treat medication-refractory essential and cerebellar outflow tremor (see Recent advances).

Recent advances

According to PubMed-indexed literature (2023–2025):

- ▶ **"Rubral wing" as a stereotactic tremor-surgery target** — a discrete hypointense zone abutting the caudal red nucleus, visible on FGATIR/FLAWS MRI sequences, has been volumetrically and tractographically characterised as the post-decussation segment of the crossed dentato-rubro-thalamic tract (DRTT); it is proposed as a refined single-subject target for MRI-guided focused-ultrasound thalamotomy and DBS for tremor (Coenen et al., *NeuroImage: Clinical*, 2025; [DOI: 10.1016/j.nicl.2025.103849](https://doi.org/10.1016/j.nicl.2025.103849), PMID 40701135).

- **Quantitative susceptibility mapping (QSM) of the red nucleus in atypical parkinsonism** — the iron-rich red nucleus shows a characteristic flattened "rice-grain" shape on coronal QSM in progressive supranuclear palsy, with specificity of 1.00 for distinguishing PSP from Parkinson's disease and healthy controls, proposed as an imaging biomarker (Kawabata et al., *Parkinsonism & Related Disorders*, 2024; [DOI: 10.1016/j.parkreldis.2024.107251](https://doi.org/10.1016/j.parkreldis.2024.107251), PMID 39721339). Susceptibility (iron) values in the red nucleus, substantia nigra and globus pallidus also rise progressively with Parkinson's-disease stage, tracking a midbrain-to-striatum pattern of iron spread (Yan et al., *European Radiology*, 2023; [DOI: 10.1007/s00330-023-10283-1](https://doi.org/10.1007/s00330-023-10283-1), PMID 37853173).
- **Along-tract DRTT diffusion tractography in movement disorders** — probabilistic tractography through the red nucleus/superior cerebellar peduncle decussation shows tract-segment-specific microstructural change: increased fractional anisotropy in the non-decussating DRTT in craniocervical dystonia, correlating with subthalamic-DBS outcome (Liu et al., *Movement Disorders*, 2025; [DOI: 10.1002/mds.70118](https://doi.org/10.1002/mds.70118), PMID 41235506); and segment-specific FA/MD changes along the DRTT in premanifest and manifest Huntington's disease correlating with motor and cognitive decline (Wang et al., *Human Brain Mapping*, 2025; [DOI: 10.1002/hbm.70305](https://doi.org/10.1002/hbm.70305), PMID 40748199).

High-yield exam pointers

- Red nucleus = ovoid grey mass, upper midbrain at level of superior colliculus, dorsomedial to substantia nigra; ~0.5 cm diameter; pink from vascularity + iron pigment.
- Two cytological parts: **magnocellular** (caudal, few large neurons, phylogenetically old) and **parvocellular** (rostral, many small neurons, primate-predominant).
- Oculomotor nerve fibres pass **through** the red nucleus en route to the interpeduncular fossa — the key link to Weber's/Benedikt's syndromes.
- Chief afferents: corticorubral (motor cortex), cerebellorubral (contralateral dentate, via superior cerebellar peduncle), pallidorubral.
- Chief efferents: rubrospinal (crosses at **ventral tegmental decussation of Forel**; vestigial in man), rubrobulbar (CN III–VII motor nuclei), and — largest in humans — the **central tegmental tract to the inferior olive**.
- Integrating/relay centre for cortico-rubro-spinal, cortico-rubro-nuclear and cerebello-rubro-spinal pathways.
- Weber's syndrome spares the red nucleus (crus cerebri + CN III only); **Benedikt's syndrome** additionally involves the red nucleus, producing contralateral tremor/involuntary movements plus sensory loss.
- Dorsal tegmental decussation (Meynert, tectospinal) vs ventral tegmental decussation (Forel, rubrospinal) — a classic "differentiate" question.
- Modern relevance: red-nucleus/DRTT tractography now guides stereotactic tremor surgery (DBS/MRgFUS), and QSM iron-imaging of the red nucleus helps distinguish PSP from Parkinson's disease.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; IB Singh's Textbook of Anatomy Vol 3 (6e); Snell's Clinical Neuroanatomy 7e. Recent-advances section per PubMed-indexed articles (PMID 40701135; PMID 39721339; PMID 37853173; PMID 41235506; PMID 40748199).



Substantia Nigra

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction

The **substantia nigra** ("black substance") is the largest nucleus of the midbrain and, functionally, the largest single component of the **basal ganglia (basal nuclei)** system. It is a curved, plate-like grey-matter band that extends through the entire length of the midbrain, lying between the tegmentum (dorsally) and the crus cerebri (ventrally) in each cerebral peduncle. Grossly visible even to the naked eye as a dark band because its neurons contain the pigment **neuromelanin**, it is the principal source of **dopamine** for the corpus striatum and is the structure whose degeneration underlies **Parkinson's disease**.

1. Location, extent and gross relations

- ▶ Lies in the **cerebral peduncle** of the midbrain, subdividing it (from dorsal to ventral) into **tegmentum**, **substantia nigra**, and **crus cerebri**.
- ▶ Extends throughout the **entire length of the midbrain**, from the pontomesencephalic junction below to the subthalamic/diencephalic junction above, where it becomes continuous with the **zona incerta** and grey matter of the subthalamic region.
- ▶ **Ventrolaterally** related to the crus cerebri, from which spiky (dentate) processes of the nigra project into the crus.
- ▶ **Dorsomedially** related to the ascending lemnisci (medial, spinal and trigeminal) and the **red nucleus**, which lies dorsomedial to it.
- ▶ Its medial part is pierced by the emerging **rootlets of the oculomotor nerve**, which pass through it to exit in the interpeduncular fossa — the anatomical basis of the crossed oculomotor palsies described below.
- ▶ Related anteriorly to the **interpeduncular fossa**, crossed superficially by the posterior cerebral and superior cerebellar arteries.

2. Development

- ▶ The midbrain neural tube differentiates into a dorsal **alar plate** (sensory) and ventral **basal plate** (motor), separated by the sulcus limitans.
- ▶ The **substantia nigra and the red nucleus** are unusual in that they arise from **alar-plate neuroblasts**, which migrate ventrally across the sulcus limitans into the basal-plate territory of the tegmentum — hence both nuclei come to lie among predominantly "motor" (basal-plate-derived) structures despite their alar-plate origin.

- Pigmentation of nigral neurons (neuromelanin) increases with age; it is absent at birth, becomes visible only after several years, and reaches its maximum in adult primates (most in humans) — melanin is present even in albinos, since it is a polymer of dopamine metabolites and not of the tyrosinase/melanocyte pathway.

3. Subdivisions, cytoarchitecture and neurochemistry

Part	Position	Cell type / transmitter	Principal projection
Pars compacta	Dorsal, larger	Densely packed, darkly pigmented (neuromelanin-laden) neurons; dopaminergic (cell group A9); also cholinergic elements	Caudate nucleus + putamen (nigrostriatal/mesostriatal dopamine pathway), topographically organized; smaller projections to globus pallidus and subthalamic nucleus
Pars reticularis	Ventral, intermingled with crus-cerebri fibres	Large multipolar neurons; mostly GABAergic , iron-rich; cytologically and functionally a homologue of the internal (medial) segment of globus pallidus	Ventral anterior & dorsomedial thalamic nuclei; deep layers of superior colliculus (gaze control); pedunculopontine nucleus and brainstem reticular formation
Pars lateralis (small)	Lateral part	Dopaminergic (A9 group)	Ipsilateral superior colliculus — implicated in control of saccadic eye movements

- The **retrotrubral nucleus (A8)** and **ventral tegmental area (A10, "paranigral nucleus")** are contiguous dopaminergic cell groups medial/rostral to the nigra proper; A10 gives rise to the **mesolimbic dopamine system** to the ventral striatum, amygdala and prefrontal/cingulate cortex, distinct from the nigrostriatal (A9) system.
- Functionally the substantia nigra is inseparable from the corpus striatum, and along with the subthalamic nucleus is included in the modern, **restricted/functional definition of the "basal ganglia"** (traditional anatomical definition: corpus striatum + claustrum + amygdaloid body).

□ Fig 23.38 — Transverse section of the midbrain showing substantia nigra (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.437)

4. Connections (afferent and efferent)

Direction	Fibres	Origin / destination
Afferent (to nigra)	Striatonigral fibres	Caudate nucleus (→ rostral third of nigra) and putamen (→ all parts); GABA + substance P/enkephalin

Direction	Fibres	Origin / destination
	Pallidonigral fibres	External (lateral) globus pallidus; GABAergic
	Subthalamonigral fibres	Subthalamic nucleus; glutamatergic (excitatory) — part of the indirect pathway
	Corticonigral fibres	Precentral and postcentral gyri; glutamatergic
Efferent (from nigra)	Nigrostriatal fibres	Pars compacta → caudate nucleus + putamen; dopamine (mesostriatal system)
	Nigrothalamic fibres	Pars reticularis → ventral anterior & dorsomedial thalamic nuclei → frontal/prefrontal cortex
	Nigrotectal fibres	Pars reticularis → deep (polysensory) layers of superior colliculus — gaze control
	Nigroreticular/nigrospinal-relay fibres	Pars reticularis → pedunculopontine nucleus and reticular formation → spinal ventral horn

□ Fig 23.39 — Scheme to show the connections of substantia nigra (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.437)

5. Functional role in basal ganglia circuitry

- The **striatum** is the **principal input structure** of the basal ganglia; the **globus pallidus (internal segment)** together with the **pars reticularis of the substantia nigra** constitutes the **principal output structure**, projecting chiefly to the thalamus and superior colliculus.
- Nigrostriatal **dopamine** has a **dual, receptor-specific action** on striatal medium spiny neurons: it **excites** direct-pathway neurons (bearing **D1** receptors, co-expressing substance P/dynorphin) and **inhibits** indirect-pathway neurons (bearing **D2** receptors, co-expressing enkephalin).
- **Direct pathway** (striatum → internal pallidum/pars reticularis, inhibitory) *disinhibits* the thalamus and **facilitates** intended movement; the **indirect pathway** (striatum → external pallidum → subthalamic nucleus → internal pallidum/pars reticularis) *increases* inhibitory basal-ganglia output and **suppresses** unwanted movement. Loss of nigral dopamine therefore tilts the balance towards net suppression of movement (seen clinically in Parkinson's disease, below).
- The **pars reticularis–superior colliculus** connection additionally regulates gaze, analogous to the pallido-thalamo-cortical circuit for body movement.

6. Blood supply

- **Basilar artery** and its direct branches.
- **Posterior cerebral artery** — including central/perforating branches through the posterior perforated substance.
- **Superior cerebellar artery**.

- ▶ **Posterior choroidal arteries.**
- ▶ Branches of the **anterior choroidal artery** (internal carotid artery).
- ▶ Venous drainage is via the **great cerebral vein** and **basal vein** (of Rosenthal).

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a **transverse section of the midbrain at the level of the superior colliculus** and label: **cerebral aqueduct**, **periaqueductal (central) grey matter**, **oculomotor nucleus** (+ **Edinger–Westphal nucleus**), **medial longitudinal fasciculus**, **red nucleus**, **substantia nigra — pars compacta (dorsal, pigmented)** and **pars reticularis (ventral)**, **crus cerebri** (middle two-thirds: corticospinal/corticonuclear fibres; medial fourth: frontopontine fibres; lateral third: temporo-/parieto-/occipitopontine fibres), **medial lemniscus**, **emerging rootlets of the oculomotor nerve** (piercing the medial substantia nigra and red nucleus to exit via the interpeduncular fossa), and the **interpeduncular fossa/posterior perforated substance**. Shade the crus cerebri region to mark the site of a **Weber's syndrome** lesion and the red-nucleus/tegmental region for a **Benedikt's syndrome** lesion.

Applied / Clinical anatomy

- ▶ **Parkinson's disease (paralysis agitans)** — the most common basal-ganglia disorder; degeneration of dopaminergic neurons of the **pars compacta** (nigrostriatal pathway) severely depletes striatal dopamine while striatal dopamine receptors are spared. Loss of D1-mediated facilitation of the direct pathway and D2-mediated disinhibition of the indirect pathway together produce **net-overactive basal-ganglia output**, over-inhibiting the thalamus. Clinical triad: **resting ("pill-rolling") tremor**, **cogwheel/lead-pipe rigidity**, **bradykinesia/akinesia**, with stooped posture, shuffling gait and mask-like facies. Treatment: **levodopa**, dopamine agonists, and stereotactic **pallidotomy/thalamotomy** or **deep brain stimulation (DBS)** of the subthalamic nucleus/internal globus pallidus.
 - ▶ **Weber's syndrome** — occlusion of a paramedian branch of the posterior cerebral artery supplying the basal peduncle; involves the **crus cerebri** and the **emerging oculomotor nerve fibres**. Produces *ipsilateral* oculomotor palsy (ptosis, dilated fixed pupil from Edinger–Westphal involvement, lateral squint) with *contralateral* hemiplegia and lower facial/tongue weakness (corticospinal and corticobulbar tract involvement) — a classic "crossed" (alternating) hemiplegia.
 - ▶ **Benedikt's syndrome** — ischaemia of the midbrain **tegmentum**, involving the red nucleus, medial and spinal lemnisci, superior cerebellar peduncle fibres and oculomotor nerve fibres. Gives *ipsilateral* oculomotor palsy with *contralateral* loss of pain/temperature and tactile/proprioceptive sensation, plus *contralateral* tremor/involuntary movements from red-nucleus and cerebellar-peduncle involvement.
- Fig 5.17 — Lesion of midbrain: (1) **Weber's syndrome**; (2) **Benedikt's syndrome**; (3) **Parinaud's syndrome** (BD Chaurasia — *Human Anatomy* Vol 3-4 — 8e, p.526)
- ▶ **Neuromelanin** — the pigment responsible for the nigra's naked-eye "black" appearance; it is a byproduct of dopamine oxidation/metabolism, increases with age, and its selective loss (visible as pallor of the nigra at autopsy) is a gross pathological hallmark of Parkinson's disease.

- ▶ **Hemiballismus** and **Huntington's chorea** also involve nigral circuitry indirectly (via subthalamic nucleus and striato-nigral degeneration respectively), underlining the nigra's place in a single functional loop with the rest of the basal ganglia.
- ▶ **Neurosurgical relevance** — the nigra's constant relation to the crus cerebri and red nucleus makes it a stereotactic landmark in approaches to the subthalamic region for DBS electrode placement.

Recent advances

- ▶ **Neuromelanin-sensitive MRI (NM-MRI)** at ultra-high field (7T) achieves markedly superior diagnostic accuracy for Parkinson's disease — 100% sensitivity and 96.8% specificity in distinguishing PD from non-PD subjects by directly visualising loss of pars-compacta neuromelanin signal, substantially outperforming conventional 3T imaging (Lakhani et al., *npj Parkinson's Disease*, 2024) [DOI: 10.1038/s41531-024-00631-3].
- ▶ **Transcranial sonography (TCS)**-detected substantia nigra hyperechogenicity is increasingly validated as a low-cost, non-invasive risk marker for Parkinson's disease and other synucleinopathies, with echogenicity correlating with nigral iron accumulation, neuromelanin depletion and glial activation — supporting its role in early diagnosis and disease-progression monitoring (Zhang et al., *Frontiers in Neurology*, 2024) [DOI: 10.3389/fneur.2024.1407860].
- ▶ The **alpha-synuclein seed amplification assay (SAA)**, which detects pathological alpha-synuclein aggregates (the molecular substrate of nigral pars-compacta cell loss) in CSF, has now been adapted into a standardised, commercially deployable protocol achieving 100% specificity and 72.3% sensitivity for Lewy-body disease, bringing molecular confirmation of nigral synucleinopathy closer to routine clinical practice (Verdurand et al., *Alzheimer's & Dementia: DADM*, 2025) [DOI: 10.1002/dad2.70066].
- ▶ (According to PubMed/journal search.)

High-yield exam pointers

- ▶ Substantia nigra = largest midbrain nucleus, lies between tegmentum (dorsal) and crus cerebri (ventral), extends the whole length of the midbrain.
- ▶ Two main parts: **pars compacta** (dorsal, dopaminergic, A9, pigmented, → striatum) and **pars reticularis** (ventral, GABAergic, homologue of internal globus pallidus, → thalamus/superior colliculus); a smaller **pars lateralis** projects to the superior colliculus.
- ▶ Develops from **alar-plate** neuroblasts that migrate into basal-plate territory (shared origin with the red nucleus).
- ▶ Nigrostriatal dopamine pathway: pars compacta → caudate + putamen; loss of this pathway = **Parkinson's disease**.
- ▶ Output of basal ganglia = internal globus pallidus + pars reticularis → thalamus (VA/dorsomedial) → cortex, and → superior colliculus (gaze).
- ▶ Blood supply: basilar artery, posterior cerebral artery, superior cerebellar artery, posterior choroidal arteries, anterior choroidal artery branches.
- ▶ Oculomotor nerve rootlets pierce the medial substantia nigra — basis of crossed midbrain syndromes.

- ▶ **Weber's syndrome** = crus cerebri + CN III (ipsilateral CN III palsy + contralateral hemiplegia); **Benedikt's syndrome** = tegmentum/red nucleus + CN III (ipsilateral CN III palsy + contralateral sensory loss and tremor).
- ▶ Neuromelanin (dopamine-derived pigment) gives the nigra its black colour; its loss is the gross marker of nigral degeneration in Parkinson's disease.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; IB Singh's Textbook of Anatomy Vol 3 6e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e; Langman's Medical Embryology (Sadler) 14e. Recent-advances section per PubMed/journal search (see DOIs above).



Superior colliculus

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction The superior colliculus is one of the two paired, rounded elevations that make up the corpora quadrigemina (tectum) of the midbrain, lying rostral to the inferior colliculus. It is the primate **visual reflex centre** of the brainstem — a laminated grey-matter structure that receives direct retinal input and integrates it with cortical, auditory and somatosensory signals to generate reflex and voluntary orienting movements of the eyes, head and neck. It also marks the level of the midbrain at which the oculomotor nuclear complex, mesencephalic nucleus of the trigeminal nerve, red nucleus, substantia nigra and pretectal nucleus are cut in transverse section — making it a classic "TS of midbrain" spotter/essay topic.

Location and external features

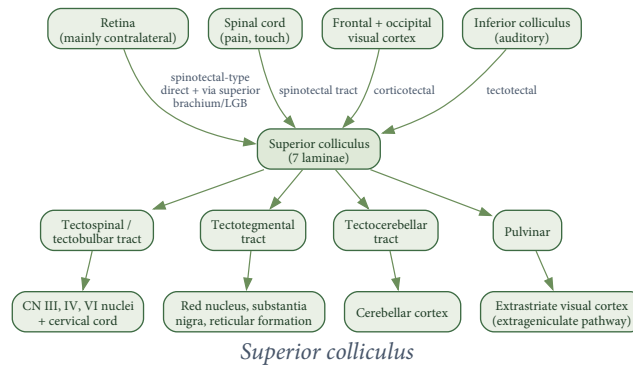
- ▶ Situated in the **tectum (roof) of the midbrain**, dorsal to the cerebral aqueduct, forming the rostral (larger) pair of the four colliculi of the corpora quadrigemina; the inferior colliculi lie caudal to it.
- ▶ Each superior colliculus is connected to the **lateral geniculate body** by a ridge of white matter, the **superior (brachium of the) colliculus**, which carries afferent optic tract fibres to it and lies alongside the medial geniculate body's inferior brachium.
- ▶ The **posterior commissure**, at the junction of the diencephalon and midbrain immediately rostral to the superior colliculi, connects structures of the two sides related to vertical gaze and the pupillary light reflex (its nucleus is the classic site of the lesion producing Parinaud's syndrome — see below).
- ▶ The **pineal gland** lies immediately rostral to the superior colliculi, in the interval between them, which is of surgical/applied importance (see below).
- ▶ The **trochlear nerve** emerges just caudal to the inferior colliculi, and the **oculomotor nerve** emerges ventrally from the interpeduncular fossa at the same level as the superior colliculi.

Structure — lamination of the superior colliculus

- ▶ The superior colliculus is a **flattened mass formed of seven concentric alternating laminae of white matter and grey matter**, arranged from superficial (nearest the pial surface) to deep.
- ▶ The **superficial laminae** are predominantly visual, receiving retinal and visual-cortical input and containing neurones with retinotopically organised receptive fields.
- ▶ The **deeper laminae** are multisensory/motor, receiving auditory and somatosensory input in addition to visual input, and giving rise to the descending efferent tracts (tectospinal, tectobulbar, tectopontine) that drive orienting movements — the SC's characteristic property of a point-to-point **map of visual, auditory and somatosensory space held in common register with a motor map of gaze-shift vectors**.
- ▶ This laminar organisation underlies its role as a **multisensory integration centre** that fuses visual, auditory and somatosensory maps of space to programme coordinated eye, head and neck movements toward a salient stimulus.

Connections of the superior colliculus

	Source / destination	Fibre bundle	Function
Afferent	Retina (mainly contralateral)	Via lateral geniculate body / superior brachium of colliculus	Direct visual input
Afferent	Spinal cord	Spinotectal tract	Pain and tactile (somatosensory) input
Afferent	Frontal and occipital (visual) cortex	Corticotectal fibres	Conjugate eye movements; voluntary/visually-guided saccades
Afferent	Inferior colliculus	Tectotectal fibres	Auditory input for audiovisual orienting
Efferent	Nuclei of cranial nerves III, IV, VI (and cervical cord)	Tectospinal and tectobulbar tracts	Reflex movements of eyes, head and neck to visual stimuli
Efferent	Red nucleus, substantia nigra, reticular formation	Tectotegmental tract	Modulation of extrapyramidal/reticular motor centres
Efferent	Cerebellar cortex	Tectocerebellar tract	Cerebellar coordination of gaze/posture
Efferent	Pulvinar → visual (extrastriate) cortex	Extrageniculate pathway	Non-conscious "second" visual pathway to cortex



Grey matter related to the superior colliculus at this level of the midbrain

- **Oculomotor nucleus** — lies in the ventromedial part of the central (periaqueductal) grey matter; the nuclei of the two sides lie close together and form a single triangular complex bounded laterally by the medial longitudinal fasciculus (MLF).
- **Edinger–Westphal nucleus** — the parasympathetic (accessory oculomotor) component, dorsal to the rostral two-thirds of the main oculomotor nucleus; supplies the sphincter pupillae and ciliaris via the oculomotor nerve and ciliary ganglion.
- **Mesencephalic nucleus of the trigeminal nerve** — occupies the lateral part of the central grey matter, unchanged in position from lower midbrain levels; carries proprioceptive impulses from muscles of mastication and extraocular/facial muscles.
- **Pretectal nucleus** — a small group of neurones lying deep to the superolateral part of the superior colliculus (just rostral to it); receives afferents from the lateral root of the optic tract and projects bilaterally to the Edinger–Westphal nuclei — the key relay of the **pupillary light and consensual light reflex**.
- **Red nucleus** — an ovoid, reddish (iron-pigmented, vascular) mass in the tegmentum dorsomedial to the substantia nigra; connections include afferents from the contralateral dentate nucleus (via superior cerebellar peduncle), ipsilateral motor cortex (areas 4, 6), globus pallidus, subthalamic nucleus and tectum, and efferents forming the rubrospinal, rubro-olivary, rubroreticular, rubrothalamic and rubrocerebellar pathways.
- **Substantia nigra** — lies ventral to the red nucleus throughout the midbrain; its degeneration causes striatal dopamine deficiency and Parkinsonism.

White matter (fibre tracts) at the level of the superior colliculi

- **Medial longitudinal fasciculus (MLF)** — lies ventrolateral to the oculomotor nucleus complex; links vestibular, oculomotor and cervical mechanisms for coordinated eye/head movement.
- **Dorsal tegmental decussation (of Meynert)** — the crossing of fibres arising from the superior colliculi that form the tectospinal and tectobulbar tracts.
- **Ventral tegmental decussation (of Forel)** — the crossing of fibres arising from the red nuclei that form the rubrospinal tracts.
- **Lemnisci** — the medial, trigeminal and spinal lemnisci run together in the tegmentum lateral to the red nucleus (more lateral than at the inferior collicular level); the lateral lemniscus has already terminated in the inferior colliculus and is not present at this level.

- **Cerebral aqueduct** — surrounded by the central (periaqueductal) grey matter, separating tectum from tegmentum.
- **Crus cerebri** — the ventral-most part of the midbrain, carrying corticospinal, corticonuclear and corticopontine fibres; the emerging oculomotor nerve fibres pass ventrally through the tegmentum, intersecting the red nucleus and medial substantia nigra, to emerge in the interpeduncular fossa.

Blood supply

- Chiefly by branches of the **basilar artery**, supplemented by the **posterior cerebral, superior cerebellar, posterior communicating and anterior choroidal arteries** — a rich anastomotic supply that makes isolated infarction of the superior colliculus uncommon.

□ Fig 5.15 — TS of midbrain at the level of superior colliculus (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.524)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse section through the midbrain at the level of the superior colliculi (rostral midbrain) and label:

- **Tectum: superior colliculus** (with its seven alternating laminae shown schematically) on each side, joined across the midline; **cerebral aqueduct** ventral to it, surrounded by **central (periaqueductal) grey matter**.
- **Tegmentum**: paired **red nuclei** (ovoid, central); **substantia nigra** ventral to each red nucleus; **oculomotor nucleus complex** (with **Edinger–Westphal nucleus**) in the ventromedial periaqueductal grey; **mesencephalic nucleus of V** in the lateral periaqueductal grey; **pretectal nucleus** just deep to the superolateral part of the superior colliculus.
- **Fibre tracts**: **medial longitudinal fasciculus** ventrolateral to the oculomotor nucleus; **dorsal tegmental decussation (Meynert)** dorsal to the red nucleus; **ventral tegmental decussation (Forel)** within/around the red nucleus; combined **medial, trigeminal and spinal lemnisci** lateral to the red nucleus; emerging **oculomotor nerve (III)** fibres passing ventrally through the tegmentum and red nucleus to the interpeduncular fossa.
- **Base**: paired **crus cerebri**, separated by the **interpeduncular fossa**.

Applied / Clinical anatomy

- **Parinaud's syndrome (dorsal midbrain syndrome)** — a lesion at the level of the superior colliculi/posterior commissure (classically compression by a **pineal gland tumour**, e.g. pinealoma/germinoma) causes **paralysis of upward gaze**, with light-near dissociation of the pupils; convergence-retraction nystagmus and eyelid retraction (Collier's sign) may accompany it.
- **Pretectal nucleus lesion** → **Argyll Robertson pupil** — the light reflex is lost while the accommodation reflex is preserved, because the pretectal–Edinger–Westphal pathway is interrupted while the closely related but separate near-reflex pathway is spared; classically associated with neurosyphilis and diabetes.

- ▶ **Unilateral superior colliculus lesion** produces relative neglect of contralateral visual stimuli and impaired tracking of moving objects in the contralateral visual field, although basic eye movements remain otherwise normal — reflecting its role in reflex visual orienting rather than primary vision.
- ▶ **Saccade generation:** the frontal eye field (anterior pathway) and posterior (parieto-occipital) eye field both project to the brainstem saccadic generators via the superior colliculus, making it the final common relay for triggering visually-guided saccades — clinically relevant in supranuclear gaze palsies.
- ▶ **Surface/radiological correlate:** the superior colliculi are readily identified on midsagittal MRI as the rostral pair of the corpora quadrigemina immediately caudal to the pineal gland — an important radiological landmark for localising pineal region masses and assessing aqueductal patency.

Recent advances

- ▶ High-density electrophysiology in awake mice (>5000 neurones) shows the superior colliculus encodes **audiovisual temporal (multisensory) integration** through non-linear summation of auditory and visual inputs, with posterior-medial SC populations (representing peripheral space) showing the sharpest temporal discrimination, and multisensory neurones receiving roughly half of their local synaptic input from other multisensory neurones — refining the classical "simple sensory-map overlay" model of collicular multisensory integration (Bianchini et al., *Nature Communications*, 2025;16:9615) [PMID: 41168155].
- ▶ Recordings in primates during free viewing of dynamic scenes show that the **saliency response in the superior colliculus at the future saccade goal predicts fixation duration**, indicating the SC actively computes where and for how long gaze will rest next rather than merely relaying a static visual-saliency map (Heeman et al., *Journal of Neuroscience*, 2025;45(3):e0428242024) [PMID: 39572235].
- ▶ (According to PubMed.)

High-yield exam pointers

- ▶ Superior colliculus = rostral pair of corpora quadrigemina, tectum of midbrain; the **visual reflex centre**, as inferior colliculus is the auditory relay/reflex centre.
- ▶ **Seven alternating laminae** of grey and white matter — superficial laminae visual, deep laminae multisensory/motor.
- ▶ Afferents: **retina, spinotectal tract (spinal cord), visual cortex, inferior colliculus.**
- ▶ Efferents: **tectospinal and tectobulbar tracts** (decussate as the **dorsal tegmental decussation of Meynert**) → CN III/IV/VI nuclei and cervical cord; also tectotegmental and tectocerebellar tracts.
- ▶ **Pretectal nucleus** (just deep/rostral to SC) = relay for pupillary light reflex; its lesion → **Argyll Robertson pupil** (light reflex lost, accommodation preserved).
- ▶ **Parinaud's syndrome** = paralysis of upward gaze from a lesion at the level of superior colliculi/posterior commissure, classically due to a pineal tumour.
- ▶ Blood supply: basilar artery branches + posterior cerebral, superior cerebellar, posterior communicating and anterior choroidal arteries.

- Landmark for a TS-of-midbrain spotter: red nucleus, substantia nigra, oculomotor nucleus/Edinger–Westphal, mesencephalic nucleus of V, MLF, dorsal and ventral tegmental decussations all cut at this level.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3–4 8e; Snell Clinical Neuroanatomy 7e (figure/orientation).



Cerebellum



Cerebellar peduncles

Asked in: Paper IV 14-Jul-2023 · Paper IV 18-Nov-2019 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

The cerebellum is joined to the brainstem by three bilaterally paired, thick bundles of nerve fibres called the **cerebellar peduncles** — the **superior** (brachium conjunctivum), **middle** (brachium pontis) and **inferior** (restiform body) cerebellar peduncles, connecting the cerebellum to the midbrain, pons and medulla oblongata respectively. Together they carry the *entire* afferent and efferent traffic of the cerebellum and also contribute to the lateral walls and roof of the fourth ventricle. Knowledge of their exact fibre composition is the anatomical basis for localising brainstem–cerebellar lesions clinically (e.g. Wallenberg's and cerebellopontine-angle syndromes).

Gross features, position and formation

Peduncle	Synonym	Connects cerebellum to	Salient gross features
Superior cerebellar peduncle (SCP)	Brachium conjunctivum	Midbrain	Emerges from the anterior cerebellar notch/hilus of the dentate nucleus; runs upward, forward and medially along the upper, lateral margin of the rhomboid fossa; enters the midbrain and its fibres decussate in the caudal mesencephalon (decussation of the superior cerebellar peduncles, at the level of the inferior colliculi)

Peduncle	Synonym	Connects cerebellum to	Salient gross features
Middle cerebellar peduncle (MCP)	Brachium pontis	Pons	The most lateral and by far the largest of the three; a lateral continuation of the basal (ventral) pons, externally demarcated by the attachment of the trigeminal nerve; passes laterally and backward to enter the cerebellar white core through the horizontal fissure
Inferior cerebellar peduncle (ICP)	Restiform body (+ juxtarestiform body)	Medulla oblongata	Formed on the posterolateral aspect of the upper medulla; lies medial to the MCP and, near the upper medulla, between the SCP (medially) and MCP (laterally); turns sharply backward (dorsally) to enter the cerebellar white core

Entering the cerebellum, the three peduncles lie in a fixed medio-lateral order: the **superior** peduncle most medial, the **inferior** peduncle intermediate, and the **middle** peduncle most lateral.

Composition of the superior cerebellar peduncle — predominantly EFFERENT

The SCP carries all the efferent fibres arising from the dentate, emboliform and globose nuclei, plus a small fascicle from the fastigial nucleus.

Fibres	Origin → Termination
Dentatothalamic (efferent)	Dentate nucleus → decussates in caudal midbrain → contralateral red nucleus (small relay) and ventrolateral nucleus of thalamus → motor cortex
Globose–emboliform–rubral (efferent)	Globose & emboliform nuclei → decussation of SCP → contralateral red nucleus → rubrospinal tract
Cerebello-olivary, cerebelloreticular, cerebellohypothalamic (efferent)	Dentate/fastigial nuclei → inferior olivary nucleus, reticular formation, hypothalamus
Anterior (ventral) spinocerebellar tract (afferent — the one major afferent of this peduncle)	Contralateral half of spinal cord → loops around the pontine trigeminal-nerve entry to join the SCP
Tectocerebellar (afferent)	Superior/inferior colliculi (visual/auditory reflex input)
Trigemino-cerebellar (afferent)	Mesencephalic nucleus of trigeminal nerve (proprioception)

Fibres	Origin → Termination
Ceruleocerebellar, hypothalamocerebellar (afferent)	Locus ceruleus (noradrenergic), hypothalamus (few, cholinergic)

The **decussation of the superior cerebellar peduncles** in the tegmentum of the caudal midbrain, anterior to the cerebral aqueduct, is the single most important named crossing in this whole topic — it is why one dentate nucleus ultimately controls the **ipsilateral** limb (a "double decussation": once here, and again either in the pyramidal decussation of the corticospinal tract, or at the origin of the rubrospinal tract).

Composition of the middle cerebellar peduncle — PURELY AFFERENT

The MCP is the largest peduncle and consists of **only afferent fibres**, transmitting almost entirely **crossed pontocerebellar fibres** from the contralateral basal pontine nuclei (which in turn receive corticopontine fibres from the frontal, parietal, temporal and occipital lobes — the **corticopontocerebellar pathway**). A small ipsilateral component arises from nuclei of the pontine tegmentum (reticulocerebellar fibres) and a few serotonergic fibres come from the pontine raphe nuclei. No efferent fibres pass through the middle cerebellar peduncle.

Composition of the inferior cerebellar peduncle — restiform body (afferent) + juxtarestiform body (mainly efferent)

Component	Fibres	Function
Restiform body (outer, compact, purely afferent)	Posterior spinocerebellar tract; cuneocerebellar tract (posterior external arcuate fibres); olivocerebellar and para-olivocerebellar (climbing) fibres from the contralateral inferior olivary complex; anterior external arcuate fibres (arcuate nuclei); reticulocerebellar fibres; trigeminocerebellar fibres	Proprioception/exteroception (trunk, lower limb via posterior spinocerebellar; upper limb via cuneocerebellar); climbing-fibre input for motor learning
Juxtarestiform body (medial, mainly efferent)	Primary vestibulocerebellar afferents (vestibular nerve) and secondary afferents (vestibular nuclei) entering; cerebellovestibular efferents — direct Purkinje-cell axons from the flocculonodular lobe plus the crossed uncinate tract from the fastigial nucleus (which loops dorsal to the SCP before entering here); cerebelloreticular efferents	Regulation of equilibrium and muscle tone via vestibulospinal and reticulospinal outflow

Relation to the fourth ventricle

- The **superior cerebellar peduncles**, converging medially with the superior medullary velum stretched between them, form the **upper/roof and superolateral wall** of the fourth ventricle (rhomboid fossa).

- ▶ The **inferior cerebellar peduncles** form the **inferolateral wall** of the fourth ventricle (with the gracile and cuneate tubercles) and are prolonged laterally as the floor of the **lateral recess**, ending near the flocculus at the lateral aperture (foramen of Luschka) — the surgical/anatomical boundary of the **cerebellopontine angle**.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 22.6 — Dissection of the left cerebellar hemisphere and its peduncles. (*Gray's Anatomy — Standing — 41e, p.469*)

A ventral view of the brainstem with the cerebellum reflected, labelling: **superior cerebellar peduncle**, **middle cerebellar peduncle**, **inferior cerebellar peduncle**, cerebral peduncle (crus cerebri), pons (with trigeminal nerve marking the origin of the MCP), olive, pyramid, vermis, and cranial nerves III–XII in sequence from midbrain to medulla (oculomotor, trochlear, trigeminal, abducent, facial, vestibulocochlear, glossopharyngeal, vagus, spinal accessory, hypoglossal) to fix the vertical level of each peduncle.

Applied / Clinical anatomy

- ▶ **Lateral medullary (Wallenberg's) syndrome** — occlusion of the **posterior inferior cerebellar artery (PICA)**: involvement of the **inferior cerebellar peduncle** produces ipsilateral loss of equilibrium and ataxia/gait deviation to the side of the lesion; associated features from adjoining structures include contralateral loss of pain/temperature (spinothalamic tract), ipsilateral facial analgesia (spinal trigeminal tract/nucleus), dysphagia/dysarthria (nucleus ambiguus), vertigo/nystagmus/vomiting (vestibular nuclei) and ipsilateral Horner's syndrome (descending sympathetic fibres).
- ▶ **Cerebellopontine angle (CPA) syndrome** — a **vestibular schwannoma (acoustic neuroma)** arising from the vestibular part of CN VIII in the CPA (the small triangular space between the pons anteromedially and cerebellum posteromedially) compresses in sequence: the **middle cerebellar peduncle** → **ipsilateral ataxia**; the vestibulocochlear nerve → tinnitus, deafness, nystagmus and vertigo; the facial nerve → lower motor neurone facial palsy; and the spinal trigeminal nucleus/tract → facial analgesia.
- ▶ **Superior cerebellar peduncle/decussation lesions** — because the dentatorubrothalamic outflow crosses in the caudal midbrain, a lesion of the peduncle itself (before the decussation) gives **ipsilateral** ataxia and intention tremor, whereas a lesion above the decussation (e.g. red-nucleus level) gives **contralateral** signs — a favourite viva discriminator.
- ▶ **Posterior fossa tumours in children** — a **medulloblastoma** of the vermis presses on the peduncles/fourth ventricle, producing truncal ataxia and obstructive (internal) hydrocephalus.
- ▶ **Radiological correlate** — on axial MRI/CT at the pontine level, the three peduncles are key landmarks for localising infarcts/tumours of the middle and posterior cranial fossa and for planning the retrosigmoid/translabyrinthine surgical approach to the CPA.

High-yield exam pointers

- ▶ Three peduncles: **SCP** (brachium conjunctivum) → midbrain; **MCP** (brachium pontis) → pons; **ICP** (restiform body) → medulla.

- ▶ **MCP = largest of the three, and purely afferent** (crossed pontocerebellar fibres) — no efferents pass through it.
- ▶ **SCP = predominantly efferent** (dentate/emboliform/globose → contralateral red nucleus and thalamus); its only major afferent is the **anterior spinocerebellar tract**.
- ▶ **Decussation of the superior cerebellar peduncles** lies in the tegmentum of the caudal midbrain (level of inferior colliculi) — basis of the "double decussation" that restores ipsilateral cerebellar control of the limbs.
- ▶ **ICP = restiform body** (purely afferent: spino-, cuneo-, olivo-, reticulo-, trigemino-cerebellar) + **juxtarestiform body** (mainly efferent, vestibular connections; carries the crossed **uncinate tract** from the fastigial nucleus).
- ▶ Wallenberg's (PICA/lateral medullary) syndrome = **inferior** peduncle involvement.
- ▶ Cerebellopontine angle syndrome (acoustic neuroma) = **middle** peduncle involvement + CN V, VII, VIII.
- ▶ SCP and ICP together bound the rhomboid fossa (fourth ventricle) superiorly/laterally and inferolaterally respectively.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh — Clinical Neuroanatomy 4e; IB Singh — Textbook of Human Neuroanatomy; BD Chaurasia — Human Anatomy Vol 3-4 8e (figure reference).



Connections of cerebellum

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction — The cerebellum, the largest part of the hindbrain, lies dorsal to the pons and medulla (separated from them by the fourth ventricle) and is linked to the brainstem by three paired **cerebellar peduncles** (superior, middle, inferior) that carry the entire afferent and efferent traffic of the organ. The cerebellum has **no direct connection with lower motor neurons**; it influences movement only indirectly, via the cerebral cortex and brainstem motor centres, and each cerebellar hemisphere controls voluntary muscle tone on the **same (ipsilateral) side** of the body. Its connections are best organised under: (1) the peduncles and their constituent tracts, (2) afferent connections, (3) efferent connections, and (4) the corticonuclear projection pattern.

1. Cerebellar peduncles — gross organisation

Peduncle	Old name	Connects cerebellum to	Predominant traffic
Superior cerebellar peduncle	Brachium conjunctivum	Midbrain	Chiefly efferent (fibres of dentate, emboliform, globose nuclei); decussates in caudal midbrain

Peduncle	Old name	Connects cerebellum to	Predominant traffic
Middle cerebellar peduncle	Brachium pontis	Pons	Purely afferent (pontocerebellar mossy fibres); largest and most lateral of the three
Inferior cerebellar peduncle	Restiform body (+ juxtarestiform body)	Medulla oblongata	Mixed — restiform body is purely afferent; juxtarestiform body (medial part) is mainly efferent

□ Fig 22.6 — Dissection of the left cerebellar hemisphere and its peduncles. (Gray's Anatomy — Standring — 41e, p.469)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Posterior/dissected view of brainstem with the cerebellum removed, labelling: **superior cerebellar peduncle** (→ midbrain), **middle cerebellar peduncle** (→ pons), **inferior cerebellar peduncle** (→ medulla), **cerebral peduncle**, **trigeminal nerve**, **vestibulocochlear nerve**, **olive**, **pyramid**, **fourth ventricle** (floor), **vermis**.

2. Constituents of the three peduncles

Peduncle	Afferent fibres (source)	Efferent fibres (destination)
Superior	Anterior spinocerebellar tract; tectocerebellar fibres (tectum); trigeminocerebellar fibres	Dentatorubral / dentatothalamic (dentate nucleus → contralateral red nucleus / thalamus); cerebellorubral (globose + emboliform → contralateral red nucleus); cerebello-olivary (dentate → opposite inferior olive)
Middle	Pontocerebellar fibres (bulk — corticopontocerebellar pathway); reticulocerebellar fibres	None — no efferent fibres pass through the middle peduncle
Inferior	Posterior spinocerebellar (Clarke's column); cuneocerebellar (accessory cuneate nucleus); olivocerebellar & parolivocerebellar (climbing fibres, contralateral inferior olivary complex); vestibulocerebellar (vestibular nerve + nuclei); reticulocerebellar (lateral/paramedian reticular nuclei); external arcuate fibres	Cerebellovestibular (fastigiovestibular — via juxtarestiform body, to bilateral vestibular nuclei); cerebelloreticular (fastigioreticular); cerebello-olivary

(Table synthesised from BD Chaurasia's classic "constituents of cerebellar peduncles" table and the detailed origin-list in Vishram Singh's Clinical Neuroanatomy; cross-checked against Gray's Anatomy 41e, which confirms the restiform body is purely afferent and the juxtarestiform body mainly efferent.)

3. Afferent connections of the cerebellum

All afferents terminate as either **mossy fibres** (all sources except the olivary) or **climbing fibres** (exclusively from the contralateral inferior olivary nucleus).

Pathway	Origin	Route (peduncle)	Termination
Corticopontocerebellar	Frontal, parietal, temporal, occipital cortex → pontine nuclei	Middle	Contralateral cerebellar cortex (mossy fibres)
Cerebro-olivocerebellar	Same cortical areas → inferior olivary nuclei	Inferior	Contralateral cerebellar cortex (climbing fibres)
Cerebroreticulocerebellar	Sensorimotor cortex → reticular formation	Inferior + Middle	Cerebellar cortex (mossy fibres)
Anterior spinocerebellar	Muscle spindles/tendon organs/joint receptors of trunk & limbs, via nucleus dorsalis (Clarke's column)	Superior	Mossy fibres, cerebellar cortex (crosses twice — net uncrossed effect)
Posterior spinocerebellar	Same receptors, trunk & lower limb, via Clarke's column	Inferior	Mossy fibres, cerebellar cortex
Cuneocerebellar	Muscle/joint receptors of upper limb, via accessory cuneate nucleus	Inferior	Mossy fibres, cerebellar cortex
Vestibulocerebellar	Utricle, saccule, semicircular canals (direct + via vestibular nuclei)	Inferior	Mossy fibres, flocculonodular lobe
Other afferents	Red nucleus, tectum (superior/inferior colliculi), trigeminal nuclei	Superior	Cerebellar cortex

4. Efferent connections of the cerebellum

The **sole output of the cerebellar cortex is the Purkinje cell axon** (inhibitory, GABAergic). Most Purkinje axons synapse on the **deep cerebellar nuclei** (fastigial, globose, emboliform, dentate); a few from the flocculonodular lobe and vermis bypass the nuclei and pass directly to the **vestibular nuclei**. Four named efferent pathways carry the true output:

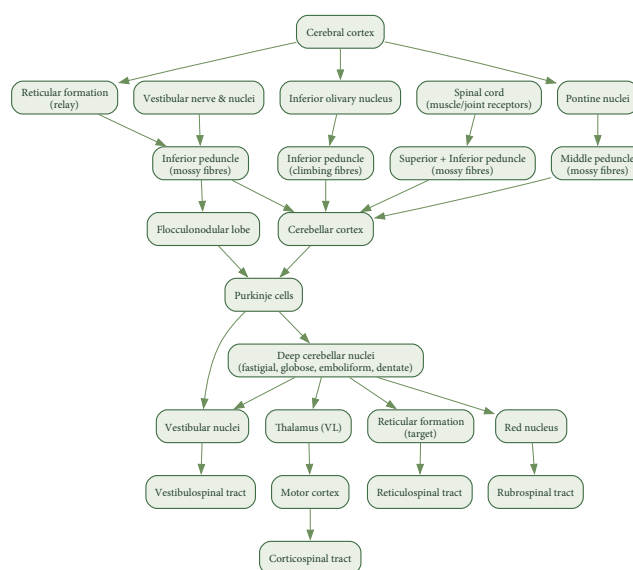
Pathway	Origin	Route	Destination	Function
Globose-emboliform-rubral	Globose + emboliform (interposed) nuclei	Superior peduncle → decussates in midbrain	Contralateral red nucleus → crossed rubrospinal tract	Influences ipsilateral motor activity (crosses twice)

Pathway	Origin	Route	Destination	Function
Dentothalamic	Dentate nucleus	Superior peduncle → decussates	Contralateral ventrolateral (VL) thalamus → motor cortex → crossed corticospinal tract	Influences ipsilateral motor activity (crosses twice)
Fastigiovestibular	Fastigial nucleus (± direct Purkinje fibres)	Inferior peduncle	Bilateral lateral vestibular nuclei → vestibulospinal tract	Facilitates ipsilateral extensor tone
Fastigioreticular	Fastigial nucleus	Inferior peduncle	Reticular formation → reticulospinal tract	Influences ipsilateral muscle tone

5. Corticonuclear projections & functional (phylogenetic) grouping

The cerebellar cortex projects onto the deep nuclei in an orderly medio-lateral map: **vermis** → **fastigial nucleus**; **intermediate (paravermal) zone** → **globose + emboliform (interposed) nuclei**; **lateral hemisphere** → **dentate nucleus**; the **flocculonodular lobe** projects mainly to the vestibular nuclei. This underlies the classic phylogenetic/functional division:

- **Archicerebellum (vestibulocerebellum)** — flocculonodular lobe + fastigial nucleus; afferents from vestibular nerve/nuclei; efferents back to vestibular nuclei — controls equilibrium and eye movements.
- **Paleocerebellum (spinocerebellum)** — anterior lobe + vermis + globose/emboliform nuclei; afferents from spinocerebellar/cuneocerebellar/trigeminocerebellar tracts — controls axial tone, posture and gait.
- **Neocerebellum (pontocerebellum)** — lateral hemispheres + dentate nucleus; afferents via corticopontocerebellar pathway; efferents via dentothalamic pathway — plans and coordinates skilled, distal-limb movements.



Connections of cerebellum

Functional/modern correlate: cerebro-cerebellar loops are not purely motor — the same corticopontocerebellar and dentatothalamocortical circuitry also links prefrontal, posterior parietal and limbic cortex to the posterior lobe/vermis. Lesions here (rather than the classic motor hemisphere) produce the **cerebellar cognitive-affective syndrome** (impaired executive function, visuospatial disorganisation, blunted affect) rather than limb ataxia — a functional-imaging-era addition to the traditional connection scheme.

Applied / Clinical anatomy

- ▶ **Archicerebellar (flocculonodular/vermis) lesions** (e.g., childhood medulloblastoma) → truncal/gait ataxia, wide-based stance, nystagmus, **no limb ataxia** — because connections here are to the vestibular apparatus, not the limbs.
- ▶ **Neocerebellar (hemisphere) lesions** → *ipsilateral* limb signs: hypotonia, intention tremor, dysdiadochokinesia, dysmetria (finger-nose/heel-knee test), rebound phenomenon, scanning speech, nystagmus — ipsilateral because the two chief efferent pathways (dentothalamic and globose-emboliform-rubral) each decussate **twice**, restoring same-side control.
- ▶ **Anterior lobe lesions** (classically chronic alcoholism) → gait ataxia from disruption of spinocerebellar (leg) input.
- ▶ **Superior cerebellar peduncle decussation lesions** in the midbrain tegmentum (e.g., Claude's/Benedikt's syndromes involving the red nucleus) → **contralateral** cerebellar ataxia/tremor, since the lesion lies distal to the crossing.
- ▶ **Middle cerebellar peduncle compression** (cerebellopontine-angle tumour, e.g., acoustic neuroma) → ipsilateral ataxia with VIII/V nerve involvement, because pontocerebellar afferents and the adjacent nerves are compressed together.
- ▶ **Inferior cerebellar peduncle (restiform body) involvement in lateral medullary (Wallenberg) syndrome** (PICA occlusion) → ipsilateral cerebellar ataxia as part of the syndrome.
- ▶ **Chiari malformation** — tonsillar herniation through the foramen magnum distorts the inferior peduncles and fourth ventricular outflow.
- ▶ Pre-operative **diffusion-tensor tractography** of the three peduncles is now used in posterior-fossa (medulloblastoma) surgery to spare the dentatothalamocortical efferent pathway and reduce posterior fossa/cerebellar mutism syndrome.

High-yield exam pointers

- ▶ Three peduncles: **Superior**→midbrain (chiefly efferent), **Middle**→pons (purely afferent, largest), **Inferior**→medulla (restiform body = afferent; juxtarestiform body = efferent).
- ▶ Mossy fibres = all afferents except olivocerebellar; synapse on granule cells → parallel fibres → Purkinje dendrites.
- ▶ Climbing fibres = exclusively from **contralateral inferior olivary nucleus**; 1 olivary fibre : 1 Purkinje cell.
- ▶ Sole cortical output = **Purkinje cell axon** (inhibitory, GABA) → deep nuclei (except direct flocculonodular/vermal fibres to vestibular nuclei).
- ▶ Deep nuclei, medial to lateral: **Fastigial** → **Globose** → **Emboliform** → **Dentate**.

- ▶ Corticonuclear map: vermis→fastigial; intermediate zone→interposed (globose+emboliform); hemisphere→dentate; flocculonodular lobe→vestibular nuclei.
- ▶ Four efferent pathways: globose-emboliform-rubral and dentothalamic (both via superior peduncle, **double decussation** → **ipsilateral** effect); fastigiovestibular and fastigioreticular (both via inferior peduncle).
- ▶ Cerebellum has **no direct connection to lower motor neurons**; acts only through cerebral cortex and brainstem centres.
- ▶ Each cerebellar hemisphere controls voluntary muscle tone on the **same side** of the body.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; BD Chaurasia's Human Anatomy Vol 3–4 8e; Vishram Singh's Clinical Neuroanatomy 4e.



Connections, blood supply and applied anatomy of cerebellum

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction The cerebellum ("little brain") is the largest part of the hindbrain, weighing about 150 g (≈10% of cerebral weight), lying in the posterior cranial fossa beneath the tentorium cerebelli, behind the pons and medulla oblongata, from which it is separated by the cavity of the fourth ventricle. It consists of a median **vermis** and two **cerebellar hemispheres**, each linked to the brainstem by three **cerebellar peduncles** (superior, middle, inferior) that carry all its afferent and efferent connections. Functionally it maintains equilibrium, regulates muscle tone/posture, and coordinates the force, direction and extent of voluntary movement.

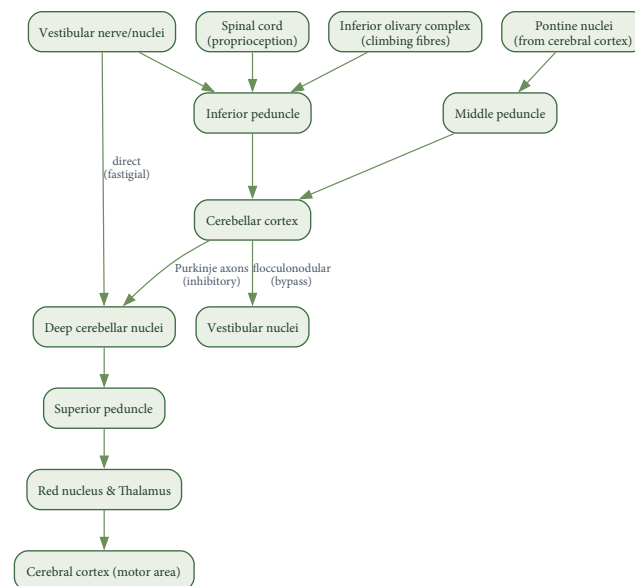
1. Cerebellar peduncles — the pathways of connection

Three paired fibre bundles connect each cerebellar hemisphere to the brainstem.

Peduncle	Old name	Connects cerebellum to	Predominant fibre type
Superior cerebellar peduncle	Brachium conjunctivum	Midbrain	Almost entirely efferent (from dentate, emboliform, globose nuclei)
Middle cerebellar peduncle	Brachium pontis	Pons	Entirely afferent (pontocerebellar fibres, crossed); largest of the three
Inferior cerebellar peduncle	Restiform body (+ juxtarestiform body)	Medulla oblongata	Mixed afferent and efferent

Governing rule of connections: afferent fibres terminate in the cerebellar **cortex**; cortical (Purkinje) efferents terminate in the **cerebellar nuclei**; fibres from the nuclei then project outside the cerebellum.

Exceptions: some vestibular afferents pass directly to the fastigial nucleus, and the flocculonodular-lobe cortex sends efferents that bypass the nuclei to reach the vestibular nuclei directly — hence the vestibular nucleus is regarded as a "displaced cerebellar nucleus."



Connections, blood supply and applied anatomy of cerebellum

2. Afferent connections (peduncle-wise)

Peduncle	Chief afferent tracts	Origin	Information carried
Superior	Ventral spinocerebellar; tectocerebellar; trigeminocerebellar (mesencephalic nucleus)	Spinal cord (lower limb), tectum, trigeminal mesencephalic nucleus	Proprio/exteroception (lower limb), vision, jaw-muscle proprioception
Middle	Pontocerebellar fibres	Pontine nuclei; fibres cross to the opposite cerebellar hemisphere	Cortico-ponto-cerebellar input for motor planning
Inferior	Posterior spinocerebellar; cuneocerebellar (posterior external arcuate); olivocerebellar (climbing fibres); vestibulocerebellar; reticulocerebellar; anterior external arcuate; trigeminocerebellar (main sensory/spinal nuclei)	Spinal cord (lower limb), accessory cuneate nucleus (upper limb), inferior olivary complex, vestibular nerve/nuclei, reticular formation	Proprio/exteroception (upper & lower limb), cerebellar learning signal, head-position information, exteroception from face

All afferents entering the cortex are either **mossy fibres** (from vestibular, pontine and spinal sources; end in glomeruli on granule-cell dendrites) or **climbing fibres** (solely from the inferior olivary complex;

make numerous excitatory synapses on one Purkinje cell each and provide the "teaching signal" for motor learning).

3. Efferent connections and connections of the deep cerebellar nuclei

The sole efferents of the cerebellar cortex are the (inhibitory) axons of **Purkinje cells**, which end in the intracerebellar nuclei — from lateral to medial: **dentate**, **emboliform**, **globose** (emboliform + globose = nucleus interpositus) and **fastigial**.

Nucleus	Afferent from	Efferent to	Function
Fastigial	Vestibular apparatus; vestibulocerebellum (vermis + flocculonodular lobe)	Vestibular nuclei, medullary reticular formation, thalamus, red nucleus/central grey of midbrain, inferior olivary nuclei	Tone of axial and proximal limb muscles in response to labyrinthine stimuli
Emboliform & globose	Paravermal area (spinocerebellum)	Red nucleus, thalamus, reticular formation, pontine nuclei, dorsal accessory olivary nucleus	Control of crude limb movements
Dentate	Neocerebellum (lateral hemisphere)	Thalamus, red nucleus, oculomotor nucleus, inferior olivary nucleus, reticular formation	Highly skilled, precise voluntary movement

Efferents from dentate/emboliform/globose leave via the **superior** peduncle (crossing in the midbrain to the contralateral red nucleus/thalamus); fastigial efferents leave via the **inferior** peduncle. Cerebellar output reaches the spinal cord indirectly — cerebellorubrospinal, cerebellovestibulospinal, cerebelloreticulospinal, and cerebellothalamocorticospinal pathways — and the cerebral cortex via cerebello-thalamo-cortical relay.

4. Functional (phylogenetic) organisation of connections

Subdivision	Anatomical component	Chief connection	Function
Archicerebellum (oldest; = vestibulocerebellum)	Flocculonodular lobe + lingula	Vestibular apparatus	Maintenance of body equilibrium
Paleocerebellum (= spinocerebellum)	Anterior lobe (except lingula), pyramid, uvula	Spinal cord	Muscle tone and posture
Neocerebellum (largest, most recent; = cerebrocerebellum/pontocerebellum)	Posterior (middle) lobe except pyramid and uvula	Pons (relaying cerebral cortex)	Fine coordination of skilled voluntary movement

Longitudinally the cortex is also organised into a **vermal** zone (→ fastigial nucleus → equilibrium/axial tone), a **paravermal** zone (→ interpositus → limb tone), and a **lateral** zone (→ dentate → skilled movement) — the mediolateral position of each nucleus mirrors the cortical zone it drains.

5. Arterial supply of cerebellum

The cerebellum is supplied by three paired cerebellar arteries.

Artery	Origin	Territory on cerebellum	Other structures supplied
Superior cerebellar artery (SCA)	Basilar artery (near its bifurcation)	Superior surface	Pons, pineal body, superior medullary velum, tela choroidea of 3rd ventricle
Anterior inferior cerebellar artery (AICA)	Basilar artery (lower part)	Anterior part of inferior surface	Inferolateral pons; usually gives origin to the labyrinthine artery
Posterior inferior cerebellar artery (PICA)	Vertebral artery (its largest branch)	Posterior part of inferior surface (medial branch → hemisphere + inferior vermis; lateral branch → lateral inferior surface)	Dorsolateral medulla oblongata (dorsal to olive, lateral to hypoglossal nucleus), choroid plexus of 4th ventricle, a branch to dentate nucleus

All three anastomose freely over the cerebellar surface (a rich pial anastomotic network), so occlusion of one is often compensated; PICA is occasionally absent, its territory taken over by AICA.

□ Fig 10.12 — Arterial supply of cerebellum (Vishram Singh — Clinical Neuroanatomy — 4e, p.376)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Sagittal/basal view of brainstem with cerebellum — label: **basilar artery**, **vertebral artery** (both sides), **superior cerebellar artery** (curving onto superior surface, below oculomotor nerve), **anterior inferior cerebellar artery** (looping near internal acoustic meatus, giving off labyrinthine artery), **posterior inferior cerebellar artery** (curving around medulla into the valleculla, medial + lateral branches), **pons**, **medulla oblongata**, **superior surface vs inferior surface** of cerebellum, **vermis**, **cerebellar tonsil**.

Applied / Clinical anatomy

- **Cerebellar syndrome** (unilateral hemisphere lesion, ipsilateral signs): wide-based/staggering gait with hypotonia; **ataxia**; **intention tremor** (worse at the end of a voluntary act); **dysdiadochokinesia/adiadochokinesis** (impaired rapid alternating movements, e.g. pronation-supination); **dysarthria**/scanning speech; **nystagmus**; swaying and falling toward the side of the lesion (positive Romberg-type sign); pendular tendon reflexes and asthenia.
- **Cerebellopontine angle tumour** (e.g. vestibular schwannoma): compresses, in sequence, the trigeminal spinal nucleus (facial pain/temperature loss), facial nerve (facial palsy), middle cerebellar peduncle (ataxia), and vestibulocochlear nerve (vertigo, tinnitus, nystagmus, deafness).
- **Flocculonodular syndrome** — damage to flocculus, nodule and uvula (archicerebellum) produces truncal imbalance without limb ataxia, reflecting its purely vestibular connections; in contrast, a **dentate nucleus/superior peduncle** lesion produces intention tremor and staggering.

- ▶ **Vermian (midline) tumours** (e.g. medulloblastoma in children) cause truncal ataxia with a broad-based gait and a tendency to fall forward/backward (not to one side), and — by invading the roof of the fourth ventricle — obstruct the foramina of Luschka/Magendie, producing non-communicating (obstructive) hydrocephalus with raised intracranial pressure, vomiting and papilledema.
- ▶ **Thrombosis of the posterior inferior cerebellar artery**: because PICA supplies both the cerebellum and the dorsolateral medulla, occlusion produces a combined picture — ipsilateral cerebellar ataxia/hypotonia with a tendency to fall to the same side (via the inferior cerebellar peduncle), together with contralateral loss of pain and temperature over the body and nystagmus (from involvement of medullary structures) — the lateral medullary (Wallenberg-type) presentation.
- ▶ **Arnold–Chiari malformation**: a congenital anomaly with herniation of the cerebellar tonsils (and medulla) through the foramen magnum into the vertebral canal; this blocks CSF egress through the fourth-ventricle foramina, causing hydrocephalus, and is commonly associated with spina bifida.
- ▶ Acute cerebellar lesions (vascular thrombosis, rapidly growing tumour) cause sudden, severe signs because there is no time for other centres (vestibular nuclei, reticular formation, red nucleus, cerebral cortex) to compensate; chronic lesions are better tolerated as compensation develops.

High-yield exam pointers

- ▶ Three peduncles: **superior** (brachium conjunctivum) → midbrain, purely efferent; **middle** (brachium pontis, largest) → pons, purely afferent; **inferior** (restiform body) → medulla, mixed.
- ▶ Rule of connections: afferents → cortex; cortical (Purkinje) efferents → nuclei (inhibitory); nuclear efferents → outside cerebellum. Exception: vestibular fibres and flocculonodular efferents.
- ▶ Deep nuclei, lateral to medial: **dentate** → **emboliform** → **globose** → **fastigial**; dentate = neocerebellum/skilled movement, interpositus = paleocerebellum/limb tone, fastigial = archicerebellum/equilibrium.
- ▶ Only two afferent fibre types to cortex: **mossy fibres** (multiple sources, via granule cells) and **climbing fibres** (inferior olive only, direct to Purkinje dendrites).
- ▶ Purkinje cell axons are the **sole cortical output** and are **inhibitory**.
- ▶ Three cerebellar arteries: **SCA and AICA from basilar**, **PICA from vertebral** (largest branch); each supplies a distinct surface and anastomoses with the others.
- ▶ PICA additionally supplies dorsolateral medulla — thrombosis gives a combined cerebellar + lateral medullary picture.
- ▶ Cerebellar lesions give **ipsilateral** signs (ataxia, hypotonia, intention tremor, nystagmus, dysarthria); vermian lesions give truncal ataxia ± obstructive hydrocephalus.
- ▶ Cerebellopontine angle tumour sequentially involves CN V, VII, middle peduncle, and CN VIII.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; Vishram Singh — Clinical Neuroanatomy 4e; Vishram Singh — Textbook of Anatomy Vol 3 4e; Snell — Clinical Neuroanatomy 7e.



Describe the cerebellum and its functions. What is cerebellar intention tremor?

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

The **cerebellum** ("little brain") is the largest part of the hindbrain and the second-largest part of the brain as a whole, weighing about 150 g. It lies in the posterior cranial fossa, beneath the tentorium cerebelli, dorsal to the pons and medulla oblongata from which it is separated by the cavity of the fourth ventricle. It is connected to the brainstem by three pairs of **cerebellar peduncles** and functions as the "head ganglion of the proprioceptive system" (Sherrington) — it does not initiate movement but continuously compares intended with actual movement to smooth, time and coordinate voluntary activity, maintain muscle tone, and preserve posture and equilibrium. **Cerebellar intention tremor** is a cardinal sign of neocerebellar (cerebellar hemisphere) disease — a purposeful-movement tremor, absent at rest, that appears and worsens as the limb approaches its target.

1. Gross anatomical features

- ▶ **Location:** posterior cranial fossa, roofed by the tentorium cerebelli; anterior cerebellar notch accommodates the pons/medulla, posterior cerebellar notch lodges the falx cerebelli.
- ▶ **Parts:** two lateral **cerebellar hemispheres** united by a narrow median **vermis** (superior vermis continuous with the hemispheres; inferior vermis sunk in the **vallecula cerebelli**).
- ▶ **Surfaces:** convex **superior surface**; **inferior surface** with the median vallecula.
- ▶ **Fissures:** the **horizontal fissure** (most conspicuous, marks the superior/inferior surface junction); the **posterolateral (uvulonodular) fissure** on the inferior surface, separating the flocculonodular lobe from the corpus cerebelli; the V-shaped **primary (fissura prima) fissure** on the superior vermis, dividing the corpus cerebelli into anterior and posterior lobes.
- ▶ **Anatomical lobes:** **anterior lobe** (anterior to the primary fissure), **posterior/middle lobe** (largest — between the primary and posterolateral fissures) and **flocculonodular lobe** (smallest, anterior to the posterolateral fissure, comprising the nodule of the vermis and the flocculus of each hemisphere).
- ▶ **Named lobules** (vermis–hemisphere pairs): lingula–(none), central lobule–alae, culmen–quadrangular lobule, declive–lobulus simplex (anterior lobe); folium–superior semilunar, tuber–inferior semilunar, pyramid–biventral, uvula–tonsil (posterior lobe); nodule–flocculus (flocculonodular lobe).
- ▶ **Surface pattern:** numerous transverse **folia** (cortex over a white-matter core); median sagittal section shows the branching white matter pattern, the **arbor vitae**.

2. Microscopic structure — cortex and intracerebellar nuclei

The cerebellar cortex is **homotypical** (uniform structure throughout) and has three layers:

Layer	Cells	Key features
Molecular (outer)	Stellate cells (superficial), basket cells (deep)	Dendritic arborisations of Purkinje cells + parallel fibres run through it; both cell types are inhibitory
Purkinje cell (middle)	Purkinje cells	Large, flask-shaped, single row; profusely branching dendritic tree in the molecular layer; axon is the sole efferent output of the cortex , relaying (with few exceptions) to the intracerebellar nuclei; Purkinje cells are inhibitory (GABAergic)
Granular (inner)	Granule cells, Golgi cells	Granule cell axons bifurcate as parallel fibres ; granule cells are the only excitatory cortical neurons; the cerebellar glomerulus = mossy-fibre rosette + granule-cell dendrites + Golgi-cell axon terminals

Afferent input reaches Purkinje cells via two excitatory fibre systems: **climbing fibres** (from the contralateral inferior olivary/accessory olivary nuclei — one fibre makes multiple synapses on 1–10 Purkinje cells) and **mossy fibres** (all other afferents — one fibre, via granule cells and parallel fibres, can excite thousands of Purkinje cells).

Intracerebellar (central) nuclei — four masses of grey matter embedded in the white matter of each hemisphere, from **lateral to medial**:

- ▶ **Dentate nucleus** — largest, crumpled-bag shape, hilum facing anteromedially; efferents form the bulk of the superior cerebellar peduncle (dentatorubral, dentatothalamic fibres).
- ▶ **Emboliform nucleus** — ovoid, partly covers the dentate hilum.
- ▶ **Globose nucleus** — rounded; emboliform + globose together = **nucleus interpositus**.
- ▶ **Fastigial nucleus** — near the midline, close to the fourth-ventricle roof; smaller than dentate but larger than globose/emboliform.

White matter = **intrinsic** fibres (intracortical/interhemispheric links), **afferent** fibres (bulk of white matter, enter mainly via the inferior and middle peduncles) and **efferent** fibres (Purkinje-cell axons → nuclei → peduncles).

3. Phylogenetic and functional subdivisions

	Archicerebellum (vestibulocerebellum)	Paleocerebellum (spinocerebellum)	Neocerebellum (cerebrocerebellum/pontocerebellum)
Phylogeny	Oldest (fish, lower amphibians)	Next to appear (reptiles, birds — with limbs)	Most recent (primates, with cerebral expansion)
Components	Flocculonodular lobe + lingula	Anterior lobe (except lingula) + pyramid & uvula	Middle (posterior) lobe, except pyramid/uvula
Related nucleus	Fastigial	Globose + emboliform	Dentate
Chief connections	Vestibular	Spinocerebellar	Corticopontocerebellar
Function	Equilibrium; tone/posture of trunk	Tone, posture, crude limb movement	Smooth, skilled voluntary movement
Lesion effect	Truncal ataxia, staggering gait, nystagmus (Romberg positive)	Hypotonia, pendular knee jerk, gait ataxia	Asynergia — dysmetria, intention tremor, dysdiadochokinesia, dysarthria, rebound phenomenon

4. Afferent connections (via the three cerebellar peduncles)

The **superior cerebellar peduncle** (to midbrain), **middle cerebellar peduncle** (to pons, largest of the three) and **inferior cerebellar peduncle/restiform body** (to medulla) connect the cerebellum to the brainstem.

Source	Pathway	Via peduncle	Fibre type
Cerebral cortex	Corticopontocerebellar (crossed)	Middle	Mossy
Cerebral cortex → inferior olive	Cerebro-olivocerebellar (crossed)	Inferior	Climbing
Sensorimotor cortex → reticular formation	Cerebroreticulocerebellar	Inferior & middle	Mossy
Trunk/lower-limb receptors (Clarke's column)	Posterior spinocerebellar tract	Inferior	Mossy
All-limb receptors	Anterior spinocerebellar tract	Superior	Mossy
Upper-limb/trunk receptors (accessory cuneate nucleus)	Cuneocerebellar tract	Inferior	Mossy
Utricle, saccule, semicircular canals	Vestibulocerebellar fibres (juxtarestiform body)	Inferior	Mossy → flocculonodular lobe

Source	Pathway	Via peduncle	Fibre type
Tectum, red nucleus	Tectocerebellar / other afferents	Superior	Mossy

Rule of thumb: all afferents are mossy fibres except olivocerebellar/parolivocerebellar fibres, which are climbing fibres.

5. Efferent connections

All cortical output is via Purkinje-cell axons, which (with the exception of a few flocculonodular/vermal axons that bypass the nuclei and go straight to the lateral vestibular nucleus) relay in the intracerebellar nuclei before leaving the cerebellum.

Pathway	Origin	Route	Destination	Effect
Dentothalamic	Dentate	Superior peduncle, decussates	Contralateral VL thalamus → motor cortex → corticospinal (crosses again)	Ipsilateral coordination
Globose-emboliform-rubral	Globose + emboliform	Superior peduncle, decussates	Contralateral red nucleus → rubrospinal (crosses again)	Ipsilateral motor activity
Fastigial vestibular	Fastigial	Inferior peduncle	Bilateral lateral vestibular nuclei → vestibulospinal	Ipsilateral extensor tone
Fastigial reticular	Fastigial	Inferior peduncle	Reticular formation → reticulospinal	Ipsilateral muscle tone

Because efferent pathways decussate **twice** (once in the cerebellar peduncle, once again in the rubrospinal/corticospinal tract), each **cerebellar hemisphere controls the ipsilateral side of the body** — the key to lateralising cerebellar hemisphere lesions clinically.

6. Functions of the cerebellum

- **Maintenance of equilibrium and posture** (archicerebellum, via vestibular connections).
- **Regulation of muscle tone** (paleocerebellum; loss produces hypotonia).
- **Coordination of voluntary movement** — smooth, accurately timed, sequenced contraction of agonists with graded relaxation of antagonists (neocerebellum).
- **Comparator function:** the motor cortex informs the cerebellum of the intended movement while proprioceptive afferents report the movement actually occurring; the cerebellum compares the two and, via its efferent pathways to motor cortex and brainstem centres, corrects any discrepancy in rate, range, force, and direction — the anatomical basis of motor learning and skill acquisition.

- Cerebellum has **no direct connection to lower motor neurons** — it always acts indirectly, through the cerebral cortex (corticospinal tract) and brainstem centres (rubrospinal, vestibulospinal, reticulospinal tracts).

7. Arterial supply

Three paired arteries, all from the vertebrobasilar system:

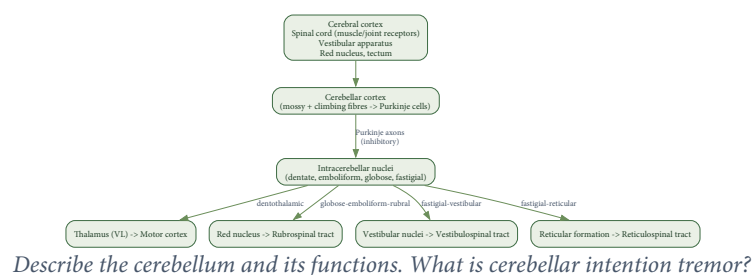
- **Superior cerebellar artery** (from the basilar artery) — superior surface.
- **Anterior inferior cerebellar artery, AICA** (from the basilar artery) — anterior part of the inferior surface.
- **Posterior inferior cerebellar artery, PICA** (from the vertebral artery, its largest branch) — posterior part of the inferior surface.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 6.2 — The cerebellum. A: Superior view. B: Inferior view. (Snell — Clinical Neuroanatomy — 7e, p.252)

Reproduce both views by hand and label:

- **Superior view:** lingula, central lobule, culmen, **primary fissure**, declive (vermis) → quadrangular lobule, superior semilunar lobule (hemisphere); anterior-lobe boundary.
- **Inferior view:** tuber, pyramid, uvula, nodule (vermis) → inferior semilunar lobule, biventral lobule, tonsil, flocculus (hemisphere); **vallecula**, **horizontal fissure**, **posterolateral (uvulonodular) fissure**; middle cerebellar peduncle entering the hemisphere.
- Separate horizontal-section schematic: intracerebellar nuclei, lateral→medial — **dentate**, **emboliform**, **globose**, **fastigial** — above the fourth-ventricle floor.



Applied / Clinical anatomy

- **Cerebellar intention tremor** — a purposeful (target-directed) movement tremor, absent at rest, probably due to **dysmetria** (inability to judge distance): as the finger nears the nose (finger–nose test) or heel nears the shin, oscillation appears and worsens near the target, causing **past-pointing** (overshoot/undershoot). It signs **neocerebellar (hemisphere) disease** and is distinguished from the **resting tremor of Parkinsonism/basal ganglia disease**, which disappears with voluntary movement — cerebellum and basal ganglia give classically opposite tone/tremor findings (hypotonia + intention tremor vs rigidity + resting tremor).
- **Charcot's triad:** nystagmus + dysarthria (scanning speech) + intention tremor. Cardinal signs of cerebellar disease overall: nystagmus, dysarthria, intention tremor, ataxia.

- ▶ **Cerebellar syndrome** — always ipsilateral to the lesion: **vermis syndrome** (e.g. childhood **medulloblastoma**) gives truncal/gait ataxia without limb signs, tendency to fall forward/backward, plus obstructive hydrocephalus (vomiting, papilloedema); **hemisphere syndrome** (e.g. astrocytoma) gives unilateral limb ataxia, dysmetria, dysidiadochokinesia, hypotonia, rebound phenomenon and falling/swaying to the side of the lesion.
- ▶ **Rebound phenomenon**: loss of the antagonist "check" reflex — the limb flies back and may strike the patient when resistance is suddenly released.
- ▶ **Dandy–Walker syndrome**: cystic dilatation at the cerebellomedullary junction with fourth-ventricle enlargement, hydrocephalus and vermal hypoplasia.
- ▶ **Friedreich's ataxia**: hereditary spinocerebellar degeneration — cerebellar signs (intention tremor, ataxia, hypotonia) plus posterior-column loss (impaired vibration/joint-position sense) and corticospinal signs (extensor plantar, absent ankle jerks); a favourite viva vignette linking cerebellar and cord anatomy.
- ▶ **PICA thrombosis** (lateral medullary/Wallenberg syndrome) gives ipsilateral cerebellar signs (ataxia, past-pointing) alongside cranial-nerve/sensory findings — the artery supplies both medulla and cerebellum.

Recent advances

- ▶ Modern diffusion-tractography/connectomic mapping has expanded the classical three-peduncle teaching model, characterising cerebro-cerebellar and cerebello-limbic loops that underlie non-motor (cognitive/affective) cerebellar function, refining the traditional afferent/efferent scheme taught from cadaveric dissection (Boonstra JT, "The cerebellar connectome," *Behavioural Brain Research*, 2025) [DOI: 10.1016/j.bbr.2025.115457].
- ▶ The cerebellum is now recognised to extend well beyond the classical motor-coordination role described here, contributing to executive function, language and affect through cerebro-cerebellar circuits — damage produces the **cerebellar cognitive affective syndrome**, and this cognitive dimension is increasingly implicated in neurodegenerative disease (Xie YY, Zhang XY, Zhu JN, "The cognitive functions of the cerebellum and its role in neurodegenerative diseases," *Ageing and Neurodegenerative Diseases*, 2024;4:18) [DOI: 10.20517/and.2024.27].
- ▶ The classical **dentatothalamic (dentato-rubro-thalamic) pathway** described above is now the direct anatomical target of **MR-guided focused ultrasound (MRgFUS) thalamotomy** for essential/intention tremor: lesioning the ventral intermediate (VIm) thalamic relay of this cerebellar efferent pathway disrupts pathological oscillatory coupling within the cerebello-thalamo-cortical tremor network and produces sustained tremor relief, providing a modern clinical correlate for this classroom pathway (Jiang L et al., "MR-guided focused ultrasound thalamotomy modulates cerebello-thalamo-cortical tremor network in essential tremor patients," *Frontiers in Neurology*, 2025) [DOI: 10.3389/fneur.2025.1526501].
- ▶ (Per literature search of recent cerebellar-connectomics and tremor-network publications.)

High-yield exam pointers

- ▶ Largest part of the hindbrain; ~150 g; three peduncles — superior (midbrain), middle (pons, largest), inferior/restiform body (medulla).

- ▶ Three anatomical lobes (anterior, posterior/middle, flocculonodular) vs three phylogenetic/functional divisions (archi-, paleo-, neocerebellum) — know both classifications and their nucleus/function correlation.
- ▶ Cortex = molecular (stellate, basket — inhibitory) + Purkinje (sole cortical output, inhibitory) + granular (granule cells — only excitatory cortical neurons; Golgi cells) layers.
- ▶ Intracerebellar nuclei, lateral→medial: **dentate, emboliform, globose, fastigial** (mnemonic: "Don't Eat Greasy Food"); dentate = largest, linked to neocerebellum.
- ▶ All afferents are mossy fibres except olivocerebellar/parolivocerebellar (climbing fibres); one climbing fibre excites 1–10 Purkinje cells, one mossy fibre (via granule cells) can excite thousands.
- ▶ Efferent pathways decussate twice → each cerebellar hemisphere controls the **ipsilateral** side of the body.
- ▶ Cerebellar intention tremor = purposeful-movement tremor from dysmetria, absent at rest — opposite of the resting tremor of basal ganglia disease.
- ▶ Charcot's triad: nystagmus + dysarthria + intention tremor. Vermis lesion → truncal ataxia (no limb signs); hemisphere lesion → ipsilateral limb ataxia/dysmetria/dysidiadochokinesia.
- ▶ Arterial supply: SCA (superior surface) and AICA (both from basilar), PICA (posterior inferior surface, from vertebral, its largest branch).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy. Recent-advances section per the cited journal articles (DOIs above).



Inferior cerebellar peduncle

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

The **inferior cerebellar peduncle (ICP)**, also called the **restiform body**, is the smallest and most medially placed of the three paired fibre bundles that connect the cerebellum to the brainstem, linking it specifically to the **medulla oblongata**. It is formed on the posterolateral aspect of the upper half of the medulla, and the two peduncles diverge as they ascend before turning sharply dorsally to enter the white core of their respective cerebellar hemispheres. Structurally it comprises an outer, compact, predominantly **afferent restiform body** and a medial, mainly **efferent juxtarestiform body**, so that the ICP carries the largest variety of fibre systems of any peduncle — spinocerebellar, olivocerebellar, cuneocerebellar, reticulocerebellar and vestibulocerebellar. Clinically it is a high-yield structure because its infarction in **Wallenberg's (lateral medullary) syndrome** produces ipsilateral cerebellar ataxia, and it has recently gained new radiological importance as an imaging marker in cerebellar ataxia work-up.

1. Location, formation and external features

- ▶ Formed on the posterolateral aspect of the upper half of the medulla oblongata; lies medial to the middle cerebellar peduncle at the pontomedullary junction.
- ▶ Near the upper end of the medulla it is sandwiched between the superior cerebellar peduncle (medially) and the middle cerebellar peduncle (laterally).
- ▶ Emerges just posterior to the olive; the rootlets of the glossopharyngeal, vagus and cranial root of the accessory nerve emerge in the groove between the olive and the ICP.
- ▶ The two peduncles diverge as they ascend, then turn sharply backwards (dorsally) to plunge into the white matter of the cerebellum.
- ▶ At their point of entry they are crossed by the striae medullares, which run medial to lateral across the floor of the fourth ventricle.
- ▶ Forms the inferolateral wall of the fourth ventricle, supplemented below by the gracile and cuneate tubercles; the lateral recess of the ventricle runs between the ICP (ventrally) and the peduncle of the flocculus (dorsally), opening into the cerebellopontine angle cistern as the lateral aperture (foramen of Luschka).

2. Structural subdivision — restiform body and juxtarestiform body

Component	Position	Fibre character	Principal content
Restiform body	Outer, compact fibre tract	Purely afferent	Spinocerebellar, trigeminocerebellar, cuneocerebellar, reticulocerebellar and olivocerebellar tracts
Juxtarestiform body	Medial, smaller tract	Mainly efferent (with primary/secondary vestibular afferents also present)	Efferent Purkinje-cell axons to vestibular nuclei, uncrossed fastigial efferents; primary afferents from the vestibular nerve and secondary afferents from vestibular nuclei

3. Afferent fibres of the inferior cerebellar peduncle

Tract	Origin	Course/laterality	Destination in cerebellum
Posterior spinocerebellar	Ipsilateral thoracic nucleus (Clarke's column)	Uncrossed	Vermis and hemisphere — lower-limb/trunk proprioception
Cuneocerebellar (posterior external arcuate fibres)	Ipsilateral accessory cuneate nucleus	Uncrossed; upper-limb equivalent of the dorsal spinocerebellar tract	Anterior lobe/vermis
Olivocerebellar	Contralateral inferior olivary nucleus	Crossed — climbing fibres, major component of the peduncle	Entire cerebellar cortex (1:1 with Purkinje cells)

Tract	Origin	Course/laterality	Destination in cerebellum
Parolivocerebellar	Contralateral medial and dorsal accessory olivary nuclei	Crossed	Cerebellar cortex
Anterior external arcuate fibres	Arcuate nuclei of both sides	Bilateral	Cerebellum via restiform body
Vestibulocerebellar	Vestibular nerve (primary) and medial/inferior vestibular nuclei (secondary)	Via the juxtarestiform body	Flocculonodular lobe (archicerebellum)
Reticulocerebellar	Lateral and paramedian reticular nuclei of medulla	Uncrossed	Vermis and adjacent cortex
Trigeminocerebellar	Trigeminal sensory nuclei	—	Cerebellar cortex

4. Efferent fibres of the inferior cerebellar peduncle

- **Cerebellovestibular fibres** — arise from the ipsilateral flocculonodular lobe and from fastigial nuclei of both sides; pass through the **juxtarestiform body** to the vestibular nuclei.
- **Cerebelloreticular fibres** — arise from the fastigial nuclei of both sides and pass to the pontine and medullary reticular formation.
- **Cerebello-olivary fibres** (of uncertain origin) — connect the cerebellum with the inferior olivary nucleus, closing an olivocerebellar feedback loop.
- A separate small efferent bundle, the **uncinate tract**, carries **crossed fastigial efferents** that arch dorsal to the superior cerebellar peduncle and re-enter the brainstem at the junction of the juxtarestiform and restiform bodies — a classic point of confusion with the ICP proper but worth a mention for completeness.

5. Functional grouping and comparison of the three cerebellar peduncles

Peduncle	Connects cerebellum to	Fibre type	Key content
Superior	Midbrain	Chiefly efferent	Dentate/emboliform/globose → red nucleus, thalamus (dentatorubrothalamic)
Middle	Pons	Purely afferent	Pontocerebellar (crossed) — largest peduncle

Peduncle	Connects cerebellum to	Fibre type	Key content
Inferior (restiform body)	Medulla	Mixed, mainly afferent	Spino-, olivo-, cuneo-, reticulo- and vestibulocerebellar fibres; fastigial efferents

The ICP is thus the principal gateway for both the **spinocerebellum (paleocerebellum)**, via the spino-, cuneo- and olivocerebellar tracts, and the **vestibulocerebellum (archicerebellum)**, via the juxtarestiform body — in contrast to the middle peduncle, which carries only neocerebellar (pontocerebellar) afferents.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 10.11 — Components of the inferior cerebellar peduncle (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.373)

Reproduce a schematic transverse section of the medulla at the level of the olive showing the ICP in the posterolateral corner, and label: **restiform body (outer)**, **juxtarestiform body (medial)**, **inferior olivary nucleus**, **posterior spinocerebellar tract**, **cuneocerebellar tract**, **vestibular nuclei (medial/inferior)**, **reticular formation**, **fourth ventricle floor**, **striae medullares**, and the **middle and superior cerebellar peduncles** for orientation.

Applied / Clinical anatomy

- ▶ **Wallenberg's (lateral medullary) syndrome** — thrombosis of the **posterior inferior cerebellar artery (PICA)** infarcts a wedge-shaped dorsolateral area of the medulla and the inferior cerebellar surface, producing: (1) **contralateral loss of pain/temperature** over the trunk and limbs (spinothalamic tract); (2) **ipsilateral loss of pain/temperature** over the face (spinal trigeminal nucleus/tract); (3) **ipsilateral palatal, pharyngeal and laryngeal paralysis** (nucleus ambiguus); (4) **ipsilateral cerebellar ataxia**, from involvement of the **inferior cerebellar peduncle** and cerebellum itself; and (5) **giddiness/vertigo**, from vestibular nuclear involvement.
- ▶ Contrast with **medial medullary syndrome** (anterior spinal artery territory) — contralateral hemiplegia, ipsilateral tongue paralysis, contralateral loss of position/vibration sense — which spares the ICP, helping distinguish the two clinically.
- ▶ The ICP forms the anterior/rostral boundary of the **lateral recess** of the fourth ventricle at the **cerebellopontine angle**, so tumours in this angle (e.g. vestibular schwannoma) or posterior-fossa tumours near the fourth ventricle can stretch, displace or infiltrate the peduncle, contributing to ipsilateral ataxia and gait disturbance alongside cranial-nerve VII/VIII signs.
- ▶ Because the ICP carries the vestibulocerebellar/juxtarestiform pathway, lesions here can produce **truncal ataxia and nystagmus** resembling primary vestibular disease, an important bedside localising clue.

Recent advances

- ▶ The "**inferior cerebellar peduncle sign**" on **FLAIR MRI** — a 2025 AJNR study (accepted Dec 2024) showed that bilateral ICP signal hyperintensity relative to the medulla, seen on axial

FLAIR, differentiates **multiple system atrophy–cerebellar type (MSA-C)** from **spinocerebellar ataxia (SCA)** with high specificity (~95%) and good diagnostic performance ($AUC \approx 0.82$) — consistent with autopsy evidence that the ICP is among the earliest sites of alpha-synuclein–related demyelination in MSA-C, and offering a marker more specific than the older "hot cross bun" pontine sign [PMID 39674591; AJNR 2025;46(6):1223].

- ▶ **Diffusion-tensor/HARDI tractography of the cerebellar peduncles** is now used for pre- and post-operative surgical planning in posterior fossa tumour resection, directly visualising the restiform body/ICP alongside the middle and superior peduncles to guide tumour-sparing dissection and reduce injury to cerebellar outflow/inflow pathways [Ortug et al., Clinical Anatomy 2022;35(8):1085–1099, PMID 35560729].

High-yield exam pointers

- ▶ ICP = **restiform body**; connects **cerebellum to medulla**; smallest, most medial of the three peduncles.
- ▶ Two parts: **restiform body** (outer, purely afferent) + **juxtarestiform body** (medial, mainly efferent + vestibular afferents).
- ▶ Major afferents: posterior spinocerebellar (Clarke's column), cuneocerebellar (accessory cuneate nucleus), olivocerebellar (contralateral inferior olive — largest component), vestibulocerebellar, reticulocerebellar.
- ▶ Major efferents: cerebellovestibular and cerebelloreticular (from fastigial nuclei, via juxtarestiform body); uncinate tract (crossed fastigial efferents) enters near the ICP but is not part of it.
- ▶ Forms the **inferolateral wall of the fourth ventricle**; bounds the lateral recess/foramen of Luschka.
- ▶ Compare: superior peduncle = efferent (to midbrain); middle peduncle = pure afferent (from pons, largest); inferior peduncle = mixed, mainly afferent (from medulla).
- ▶ **Wallenberg's syndrome (PICA occlusion)** → ipsilateral ataxia (ICP), crossed sensory loss, dysphagia/dysphonia, vertigo — classic applied-anatomy question.
- ▶ New: **ICP hyperintensity on FLAIR** helps separate MSA-C from spinocerebellar ataxia.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3–4 8e (medullary lesion figures). Recent-advances section per AJNR (PMID 39674591) and Clinical Anatomy (PMID 35560729).



Intra cerebellar nuclei

Asked in: Paper IV Nov 2017 — RGUHS MD/MS Anatomy

Definition / Introduction The **intracerebellar (deep/central) nuclei** are four paired masses of grey matter embedded within the white matter core (arbor vitae) of each cerebellar hemisphere. From medial to lateral side these are the **fastigial, globose, emboliform, and dentate** nuclei. They are composed of large multipolar neurons and constitute the **sole output stations of the cerebellar cortex** — every Purkinje cell axon, with the sole exception of those from the flocculonodular lobe and parts of the vermis (which bypass the nuclei and end directly on the vestibular nuclei), terminates on one of these four nuclei. The nuclei therefore relay the entire influence of the cerebellum on descending motor pathways, and — as increasingly recognised — on non-motor (cognitive/affective) circuits as well.

1. Number, position and grouping

- ▶ Four nuclei lie on **each side of the midline**, embedded in the central white matter, arranged (medial → lateral): **fastigial → globose → emboliform → dentate**.
- ▶ The **globose and emboliform nuclei together are called the nucleus interpositus** (globose = *posterior interposed*; emboliform = *anterior interposed* nucleus).
- ▶ The **fastigial nucleus** lies near the midline in the roof of the vermis, close to the roof of the fourth ventricle.
- ▶ The **dentate nucleus** is the most lateral, the largest of the four, and the most prominent — it is the largest cerebellar nucleus in primates, especially humans.
- ▶ A thin bridge of small cholinergic neurones, the **basal interstitial nucleus**, runs from the flocculus to the nodulus, invading the spaces between the nuclei (connections not fully known).

2. Individual nuclei — shape, position and identifying features

Nucleus	Position	Shape / special feature	Relative size
Dentate	Most lateral	Shaped like a crumpled bag/purse ; hilum faces anteromedially ; efferents leave through the hilum. Subdivided into a dorsomedial microgyric and a ventrocaudal macrogyric part	Largest , most prominent
Emboliform	Medial to the dentate, partially covering its hilum	Oval/ovoid	Smaller
Globose	Between the emboliform and fastigial nuclei	One or more rounded cell groups	Smaller

Nucleus	Position	Shape / special feature	Relative size
Fastigial	Nearest the midline, in the vermis, close to the roof of the fourth ventricle	Rounded	Larger than globose/emboliform but smaller than dentate

3. Phylogenetic and functional correlation

Each nucleus is the output nucleus of one of the three phylogenetic/functional divisions of the cerebellum:

Cerebellar division	Cortical component	Corresponding nucleus	Chief afferent connection	Function
Archicerebellum (vestibulocerebellum) — oldest	Flocculonodular lobe + lingula	Fastigial	Vestibular (flocculonodular lobe)	Equilibrium; tone and posture of trunk muscles
Paleocerebellum (spinocerebellum)	Anterior lobe (except lingula) + pyramid and uvula of vermis	Globose + emboliform (nucleus interpositus)	Spinocerebellar	Tone, posture and crude movements of the limbs
Neocerebellum (cerebrocerebellum/pontocerebellum) — newest, largest in humans	Middle lobe (bulk of the hemispheres)	Dentate	Corticopontocerebellar	Planning and smooth execution of skilled voluntary movements

4. Afferent connections of the nuclei

- Each nucleus receives **two kinds of input**: (i) an inhibitory, GABAergic projection from the overlying Purkinje cells of the corresponding cortical zone, and (ii) excitatory **collaterals of the mossy and climbing fibres** passing to that same cortical zone.
- **Cortico-nuclear topography**: the vermis projects to the **fastigial** nucleus; the **intermediate (paravermal)** cortex projects to the **globose and emboliform** nuclei; the **lateral hemisphere** projects to the **dentate** nucleus.
- **Exception**: Purkinje axons of the **flocculonodular lobe** and **parts of the vermis** bypass the nuclei and end directly on the (lateral) vestibular nucleus.

5. Efferent pathways of the nuclei

Pathway	Origin	Course	Destination	Effect
Dentothalamic	Dentate nucleus	Superior cerebellar peduncle → decussates in the SCP decussation	Contralateral ventrolateral (VL) nucleus of thalamus → primary motor cortex	Motor cortex output then re-crosses via the corticospinal tract → net ipsilateral effect

Pathway	Origin	Course	Destination	Effect
Globose–emboliform–rubral	Globose + emboliform (interpositus)	Superior cerebellar peduncle → decussates	Contralateral red nucleus (magnocellular part) → rubrospinal tract (crosses again near its origin)	Crosses twice → net ipsilateral effect; facilitates flexor muscle tone
Fastigial–vestibular	Fastigial nucleus	Fibres form the fastigiobulbar tract via the inferior cerebellar peduncle; some loop around the superior cerebellar peduncle as the crossed uncinate fasciculus (tract of Russell) before joining the main tract	Lateral vestibular nuclei (both sides) → vestibulospinal tract	Facilitates ipsilateral extensor muscle tone
Fastigial–reticular	Fastigial nucleus	Inferior cerebellar peduncle	Reticular formation → reticulospinal tract	Influences ipsilateral muscle tone

- Fibres from the **dentate, emboliform and globose nuclei** leave the cerebellum through the **superior cerebellar peduncle** (forming the **brachium conjunctivum**, the chief cerebellar efferent pathway).
- Fibres from the **fastigial nucleus** leave through the **inferior cerebellar peduncle**.
- All four efferent pathways cross the midline at least once, yet each cerebellar hemisphere ultimately influences muscle tone and movement on the **same side of the body** — a fact used to explain why cerebellar hemisphere lesions produce strictly **ipsilateral** signs.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 10.8 — Horizontal section of the cerebellum showing intracerebellar nuclei (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.365)

Draw a horizontal (transverse) section through the cerebellum at the level of the deep nuclei and label, medial to lateral:

- ▶ **Fastigial nucleus** (nearest the midline/vermis, close to roof of 4th ventricle)
- ▶ **Globose nucleus**
- ▶ **Emboliform nucleus** (partially covering the hilum of the dentate)
- ▶ **Dentate nucleus** (crumpled-bag shape, most lateral, hilum facing anteromedially)
- ▶ Surrounding landmarks: **cerebellar cortex, white matter (arbor vitae), cerebellar hemisphere, cavity of the fourth ventricle, and the superior/middle/inferior cerebellar peduncles** entering the brainstem.

Applied / Clinical anatomy

- ▶ **Cerebellar syndrome** — signs are strictly **ipsilateral** to the lesion (because of the double decussation of the efferent pathways described above) and correlate with which nuclear/phylogenetic division is involved:
 - **Archicerebellar (fastigial) involvement**: truncal ataxia, wide-based staggering gait, nystagmus; positive **Romberg's sign** (falls on closing the eyes).
 - **Paleocerebellar (nucleus interpositus) involvement**: hypotonia, flail joints, **pendular knee jerk**, gait ataxia.
 - **Neocerebellar (dentate) involvement** — **asynergia**: **dysmetria/past-pointing** (finger–nose test), **intention tremor**, **dysdiadochokinesis**, **dysarthria** (scanning speech), **rebound phenomenon**.
- ▶ **Cerebellum vs basal ganglia** — the two great motor-coordinating systems have **opposite** clinical signatures: cerebellar disease gives hypotonia + intention tremor, whereas basal ganglia disease gives hypertonia (rigidity) + resting tremor.
- ▶ **Cerebellar mutism syndrome (posterior fossa syndrome)**: seen after resection of midline posterior-fossa tumours (e.g., medulloblastoma) in children; attributed to bilateral injury of the **dentate nuclei and their efferent (dentato-thalamo-cortical) outflow** through the superior cerebellar peduncles.
- ▶ **Cerebellar cognitive/affective syndrome (Schmahmann's syndrome)**: lesions of the posterior lobe/vermis and their outflow through the fastigial and dentate nuclei to prefrontal, parietal and limbic circuits produce impaired executive function, visuospatial disturbance and affective dysregulation — evidence that the deep nuclei carry non-motor as well as motor output.
- ▶ **Dentate nucleus as a neurosurgical target**: its efferent tract (**dentato-rubro-thalamic tract**) is the tractographic target used for **DBS/thalamotomy in essential tremor** (targeting the ventral intermediate nucleus of thalamus), and the dentate nucleus itself is now a direct **DBS target for post-stroke upper-limb motor rehabilitation** (see Recent advances).

Recent advances

- ▶ **Dentate-nucleus deep brain stimulation for chronic post-stroke motor rehabilitation (EDEN trial):** a first-in-human, open-label phase I trial applied chronic DBS to the cerebellar dentate nucleus, paired with rehabilitation, in 12 patients with persistent moderate-to-severe upper-limb hemiparesis 1–3 years after stroke; it was safe and feasible, with a median 7-point improvement on the Upper-Extremity Fugl-Meyer score, and has led to the ongoing multisite phase II **RESTORE trial** (Baker KB et al., *Nature Medicine* 2023;29:2366–2374, DOI [10.1038/s41591-023-02507-0](https://doi.org/10.1038/s41591-023-02507-0)).
- ▶ **Dentato-rubro-thalamic tract (DRTT) tractography for direct DBS targeting in essential tremor:** proton-density MRI combined with tractography of the DRTT (the dentatothalamic outflow of the dentate nucleus) allows direct, patient-specific "intersectional" localisation of the ventral intermediate thalamic nucleus for DBS lead placement, improving on traditional atlas-based indirect targeting (Morrison MA et al., *J Neurosurg* 2021;135:806–814, DOI [10.3171/2020.8.JNS201378](https://doi.org/10.3171/2020.8.JNS201378)).
- ▶ **Refined in-vivo parcellation of the human dentate nucleus:** diffusion-tractography-based clustering of the dentate nucleus has resolved distinct **motor and higher-order (cognitive/sensory) functional territories**, updating the classical simple "rostral motor / caudal non-motor" bipartite scheme and providing patient-specific atlases for neurosurgical and rehabilitation planning (Palesi F et al., *Human Brain Mapping* 2021;42(13):4348–4361, DOI [10.1002/hbm.25551](https://doi.org/10.1002/hbm.25551)).
- ▶ **A newly identified developmental subset of cerebellar (deep) nuclei neurons:** contrary to the classical model that all deep-cerebellar-nuclei projection neurons arise from either the rhombic lip or the ventricular zone of the cerebellar primordium, an early subset of nuclear-transitory-zone neurons (marked by SNCA, OTX2, MEIS2 and p75NTR/NGFR) has been shown to arise independently of both these classical sources, refining the developmental-origin model of the fastigial/interposed/dentate nuclear complex (Rahimi-Balaei M et al., *eLife* 2024, DOI [10.7554/eLife.93778](https://doi.org/10.7554/eLife.93778)).

High-yield exam pointers

- ▶ Four nuclei each side, medial → lateral: **Fastigial → Globose → Emboliform → Dentate**; globose + emboliform = **nucleus interpositus**.
- ▶ **Dentate** = largest, crumpled-bag shape, hilum anteromedial; nucleus of **neocerebellum**.
- ▶ Phylogenetic pairing: **Archicerebellum** – Fastigial; **Paleocerebellum** – Globose + Emboliform; **Neocerebellum** – Dentate.
- ▶ All cerebellar cortex output (except flocculonodular lobe/vermis, which go straight to the vestibular nucleus) is relayed through these nuclei via **inhibitory Purkinje-cell axons**.
- ▶ **Dentate, emboliform, globose** exit via the **superior cerebellar peduncle** (brachium conjunctivum); **fastigial** exits via the **inferior cerebellar peduncle**.
- ▶ Key efferent circuits: **dentothalamic** (→ VL thalamus → motor cortex), **globose-emboliform-rubral** (→ red nucleus → rubrospinal tract), **fastigial-vestibular** and **fastigial-reticular** pathways.
- ▶ All efferent pathways decussate at least once but net effect on the body is always **ipsilateral** (single vs double crossing).

- ▶ Clinico-anatomical correlation: fastigial/archicerebellar → truncal ataxia + nystagmus; interpositus/paleocerebellar → hypotonia + pendular knee jerk; dentate/neocerebellar → dysmetria, intention tremor, dysdiadochokinesis, scanning speech, rebound phenomenon.
- ▶ Dentate nucleus is the modern neurosurgical target of interest — DBS for essential tremor (via the dentatorubrothalamic tract) and for post-stroke motor rehabilitation.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e (text and Figs 6-7, 6-12, Tables 6-1/6-2); Vishram Singh Clinical Neuroanatomy 4e (text and Fig. 10.8). Recent-advances citations from Nature Medicine, Journal of Neurosurgery, Human Brain Mapping and eLife as linked above.



Middle cerebellar peduncle

Asked in: Paper IV Oct 2008 — RGUHS MD/MS Anatomy

Definition / Introduction

The **middle cerebellar peduncle (MCP)**, classically termed the **brachium pontis**, is the largest of the three paired bundles that connect the cerebellum to the brainstem, linking it exclusively to the **pons**. It is unique among the three peduncles in being a **purely afferent, almost entirely crossed** pathway, carrying the massive **pontocerebellar (cortico-ponto-cerebellar)** projection that relays motor-planning information from the contralateral cerebral cortex to the neocerebellum. Because of its size, superficial position and intimate relationship with the trigeminal, facial and vestibulocochlear nerves at the **cerebellopontine angle**, the MCP is of major applied importance in cerebellopontine-angle tumours, pontine vascular lesions and several imaging signs used in modern neurodegenerative-disease diagnosis.

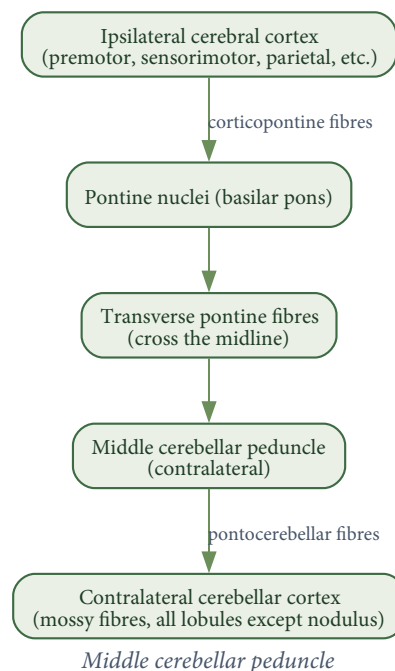
1. Location, extent and external features

- ▶ The MCP begins as the **lateral continuation of the ventral (basilar) part of the pons**; on the surface of the brainstem it is demarcated from the pons proper by the point of attachment of the **trigeminal nerve** — the basilar pons lies inferior to the trigeminal root, the MCP superior and caudal to it.
- ▶ Bundles of **transverse pontine fibres**, arising from the **pontine nuclei** and bridging the midline, converge on each side to form the large MCP, which then passes **laterally and backwards**.
- ▶ It enters the white core (medulla) of the cerebellar hemisphere through the **horizontal fissure**. As the three peduncles converge to enter the cerebellum, the fibres of the MCP lie **lateral** to those of the inferior cerebellar peduncle, the superior cerebellar peduncle being placed still more medially.
- ▶ It is the **largest and most lateral** of the three cerebellar peduncles — a frequently asked "golden fact."

2. Composition and fibre traffic

Feature	Middle cerebellar peduncle
Alternative name	Brachium pontis
Connects cerebellum to	Pons
Size	Largest of the three peduncles
Fibre direction	Afferent only — no efferent fibres pass through it
Laterality	Almost entirely crossed (contralateral)
Chief fibres	Pontocerebellar fibres (from pontine nuclei)
Termination	Mossy fibres, throughout the cerebellar cortex except the nodulus (lobule X)

- ▶ The pontine nuclei receive **corticopontine fibres** from the ipsilateral cerebral cortex (frontal, parietal, temporal and occipital lobes; heaviest from the premotor, somatosensory, posterior parietal, extrastriate visual and cingulate cortices). Their axons cross the midline as the transverse pontine fibres, entering the MCP and are distributed as **pontocerebellar fibres** to the **opposite (contralateral) cerebellar hemisphere**.
- ▶ This two-neuron relay — cerebral cortex → pontine nuclei → contralateral cerebellar cortex — constitutes the **cortico-ponto-cerebellar pathway**, the principal route by which the cerebral cortex influences the neocerebellum for the smooth, coordinated performance of skilled voluntary movement.
- ▶ Smaller afferent contributions to the MCP include **reticulocerebellar fibres** (from the brainstem reticular formation of the same side, projecting mainly to the vermis) and a few **serotonergic fibres** from the pontine raphe nuclei, which modulate the responses of other cerebellar neurotransmitter systems.



3. The middle cerebellar peduncle among the three cerebellar peduncles

Peduncle	Alternative name	Connects cerebellum to	Position on entering cerebellum	Fibre traffic	Chief constituents
Superior cerebellar peduncle (SCP)	Brachium conjunctivum	Midbrain	Most medial	Predominantly efferent	Dentatorubral/dentatothalamic (efferent, chief outflow); anterior spinocerebellar tract (afferent)
Middle cerebellar peduncle (MCP)	Brachium pontis	Pons	Most lateral (largest)	Afferent only	Pontocerebellar fibres (cortico-ponto-cerebellar pathway)
Inferior cerebellar peduncle (ICP)	Restiform body	Medulla oblongata	Intermediate	Predominantly afferent, some efferent	Posterior spinocerebellar, cuneocerebellar, olivocerebellar, vestibulocerebellar fibres (afferent); fastigiovestibular/fastigioreticular fibres (efferent)

The clean division of labour — SCP mainly out, ICP a mix, MCP entirely in — is a favourite viva point: the MCP is the sole peduncle that transmits **no efferent fibres whatsoever**, all its traffic running from the pons into the cerebellum.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 6.8 — *Position of cerebellar peduncles (in posterior view)* (BD Chaurasia — *Human Anatomy Vol 3-4* — 8e, p.535)

In addition to the plate above, reproduce a **transverse section of the pons at the level of the trigeminal (principal sensory and motor) nuclei** and label: **fourth ventricle, superior medullary velum, superior cerebellar peduncle, middle cerebellar peduncle, mesencephalic tract of trigeminal nerve, principal sensory nucleus of trigeminal nerve, motor nucleus of trigeminal nerve, medial longitudinal fasciculus, central tegmental tract, medial lemniscus and trapezoid body, lateral lemniscus, trapezoid nucleus, transverse pontine fibres, and corticospinal/corticopontine fibres.**

4. Relations — the cerebellopontine angle

- ▶ The MCP forms the posterolateral boundary of the small triangular interval called the **cerebellopontine angle (CPA)** — bounded anteromedially by the pons and posteromedially by the cerebellum — through which the **facial and vestibulocochlear nerves** pass, and close to which the **trigeminal nerve** attaches (medial to the MCP).
- ▶ The MCP is separated from the **superior cerebellar peduncle** (still more medial) and lies just superior and lateral to the **inferior cerebellar peduncle**.

5. Blood supply

- ▶ The pontine nuclei and the transverse pontine fibres that form the MCP are supplied chiefly by **pontine perforating branches of the basilar artery**.
- ▶ The MCP itself, together with the anterior and inferior parts of the cerebellum, is supplied mainly by the **anterior inferior cerebellar artery (AICA)**, a branch of the basilar artery that also sends a few twigs to the pons and upper medulla; the labyrinthine artery usually arises from it.

Applied / Clinical anatomy

- ▶ **Cerebellopontine angle tumour** (classically a **vestibular schwannoma/acoustic neuroma** arising from the vestibular part of CN VIII) is the archetypal lesion of this region and produces a characteristic symptom complex as it enlarges: pressure on the **spinal nucleus of the trigeminal nerve** → loss of pain and temperature sensation over the face; pressure on the **facial nerve** → lower motor neurone facial palsy; pressure on the **middle cerebellar peduncle** → ipsilateral cerebellar **ataxia**; and pressure on the **vestibulocochlear nerve** → vertigo, tinnitus, nystagmus and sensorineural deafness.
- ▶ **Infarction of the pons** (thrombosis/embolism of the basilar artery or its branches, including the anterior inferior cerebellar artery): a **paramedian** infarct damages the corticospinal tracts, the pontine nuclei and the fibres passing to the cerebellum through the **middle cerebellar peduncle**; a **laterally-situated** infarct instead damages the trigeminal nerve, the medial lemniscus and the MCP (with the corticospinal fibres to the lower limb also sometimes affected) — in both patterns, MCP involvement contributes the ipsilateral cerebellar (ataxic) component. Involvement of the **corticopontocerebellar tracts** in pontine lesions generally produces marked

ipsilateral cerebellar ataxia, often with an intention tremor that worsens as the movement proceeds.

- ▶ **"Hot cross bun" sign** — a cruciform T2/FLAIR hyperintensity in the basis pontis, often accompanied by **MCP hyperintensity**, is a classical (though not disease-specific) MRI sign seen in **multiple system atrophy, cerebellar type (MSA-C)**, reflecting selective loss of pontocerebellar (transverse pontine) fibres traversing the MCP with relative sparing of the longitudinal corticospinal fibres.
- ▶ Selective involvement of the MCP (sparing the other two peduncles) also underlies the cerebellar-type ataxia of several toxic/metabolic and demyelinating pontine lesions, since it is the only peduncle carrying purely crossed, purely afferent traffic.

Recent advances

(According to PubMed-indexed literature, 2022–2026)

- ▶ A large multicentre, autopsy-confirmed MRI study (97 pathologically-proven MSA cases) has refined the "hot cross bun" sign: **grade-2 (cruciform) HCBS combined with MCP hyperintensity gives 100% specificity for MSA-C over spinocerebellar ataxia** within 3 years of onset, and neuropathological correlation shows the hyperintense MCP corresponds to myelin loss, α -synuclein aggregation and astrocytic reaction in the **transverse (pontocerebellar) fibres**, with relative sparing of the longitudinal corticospinal fasciculi (Sugiyama et al., *J Neurol Neurosurg Psychiatry* 2026; [DOI](https://doi.org/10.1136/jnnp-2025-336869)).
- ▶ A case report documents an **acute bilateral MCP infarct** presenting with the hot-cross-bun pattern, confirming that the sign is not exclusive to neurodegeneration and can mark acute ischaemic pontocerebellar-fibre loss (Nishida & Futamura, *Stroke* 2023; [DOI](https://doi.org/10.1161/STROKEAHA.122.042453)).
- ▶ Combining pontine HCBS with cerebellar MR-spectroscopy (NAA/creatinine ratio) improves early discrimination of MSA-C from genetically-confirmed spinocerebellar ataxias at different disease stages (Chen et al., *Sci Rep* 2022; [DOI](https://doi.org/10.1038/s41598-022-14531-0)).
- ▶ Diffusion-tensor tractography of the three cerebellar peduncles in mild traumatic brain injury with balance impairment found significantly reduced fibre number in the **superior and inferior** peduncles, while MCP fractional anisotropy/ADC/fibre-number were relatively preserved — suggesting differential vulnerability of the three peduncles to concussive injury (Jang & Kwon, *J Integr Neurosci* 2023; [DOI](https://doi.org/10.31083/j.jin2205121)).
- ▶ Probabilistic tractography distinguishing the cerebellar **efferent** (dentato-rubro-thalamic, via SCP) from **afferent** (subthalamo-ponto-cerebellar, running with MCP territory) pathways in craniocervical dystonia patients undergoing subthalamic deep-brain stimulation shows the afferent pathway's structural connectivity best predicts DBS outcome — extending the applied relevance of cerebellar peduncle anatomy into functional neurosurgery (Liu et al., *Mov Disord* 2025; [DOI](https://doi.org/10.1002/mds.70118)).

High-yield exam pointers

- ▶ MCP = brachium pontis; connects cerebellum to the **pons**; largest of the three cerebellar peduncles.

- ▶ **Purely afferent** — the only cerebellar peduncle carrying no efferent fibres at all.
- ▶ Chief content: **pontocerebellar fibres**, almost entirely **crossed**, completing the **cortico-ponto-cerebellar pathway** (cortex → pontine nuclei → contralateral cerebellum).
- ▶ Enters the cerebellum through the **horizontal fissure**; lies lateral to the inferior peduncle, superior peduncle still more medial.
- ▶ Forms the posterolateral boundary of the **cerebellopontine angle**; trigeminal nerve attaches medial to it.
- ▶ Blood supply: pontine branches of the **basilar artery** + **anterior inferior cerebellar artery**.
- ▶ SCP (brachium conjunctivum, efferent, to midbrain) vs MCP (brachium pontis, afferent, to pons) vs ICP (restiform body, mixed, to medulla) — classic comparison table.
- ▶ CPA (vestibular schwannoma) → trigeminal sensory loss + facial palsy + MCP-mediated ataxia + CN VIII symptoms.
- ▶ "Hot cross bun" sign (pons ± MCP hyperintensity) — classical MRI marker of MSA-C, now refined with autopsy-based specificity data.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e and Textbook of Anatomy Vol 3 (4e); IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 (8e). Recent-advances section per PubMed (Sugiyama et al. 2026, PMID 41083252; Nishida & Futamura 2023, PMID 36802764; Chen et al. 2022, PMID 35732792; Jang & Kwon 2023, PMID 37735136; Liu et al. 2025, PMID 41235506).



Nuclei of Cerebellum

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction The deep (intracerebellar) cerebellar nuclei are four paired masses of grey matter embedded in the central core of white matter of each cerebellar hemisphere. From lateral to medial they are the **dentate, emboliform, globose and fastigial** nuclei (first described by Stilling, 1864). They lie close to the roof of the fourth ventricle and are therefore also called the "**roof nuclei**." Purkinje cell axons — the sole output of the cerebellar cortex — synapse on these nuclei, which in turn constitute the entire outflow of the cerebellum to the rest of the CNS; only a few Purkinje axons (from the flocculonodular lobe/vermis) bypass the nuclei to reach the vestibular nuclei directly.

1. Position, gross morphology and phylogenetic correlation

Nucleus	Position (lateral → medial)	Gross description	Phylogenetic division	Cortical zone giving Purkinje input
Dentate	Most lateral; centre of each hemisphere	Largest of the four; a thin, crumpled, folded lamina of grey matter shaped like a crumpled purse/bag with its hilum (opening) facing medially — efferents emerge through this hilum	Neocerebellum (cerebrocerebellum)	Lateral part of cerebellar hemisphere
Emboliform	Medial to dentate, partly covering its hilum	Oval/ovoid	Paleocerebellum; = anterior interposed nucleus	Paravermal (intermediate) zone
Globose	Medial to emboliform, lateral to fastigial	One or more rounded cell groups	Paleocerebellum; = posterior interposed nucleus	Paravermal (intermediate) zone
Fastigial	Nearest the midline, in the vermis, close to the roof of the 4th ventricle	Larger than the globose nucleus	Archicerebellum (vestibulocerebellum)	Vermal cortex + flocculonodular lobe

- Emboliform + globose together = **nucleus interpositus** (anterior interposed + posterior interposed nuclei).
- Functional grouping (Gray's 41e): a **rostromedial group** (emboliform + dentate) and a **caudomedial group** (fastigial + globose).
- A thin strip of small cholinergic neurones — the **basal interstitial nucleus** — extends between the flocculus and nodulus, invading the spaces between the nuclei.

2. Cytoarchitecture and dentate subdivisions

- ▶ The nuclei contain neurones of all sizes: large **glutamatergic relay (projection) neurones** form the main efferent output; small **GABAergic neurones** form a feedback **nucleo-olivary pathway** to the contralateral inferior olive; GABAergic and glycinergic **interneurones** are also present.
- ▶ Every cell type receives an **inhibitory (GABAergic) input from Purkinje cells** and an **excitatory input from mossy- and climbing-fibre collaterals** before these afferents reach the cortex — the nuclei therefore integrate direct excitation with delayed cortical inhibition.
- ▶ The **dentate nucleus** shows a **dorsomedial microgyric** and a **ventrocaudal macrogyric** part on Weigert staining (named by Vicq-d'Azyr). Modern fMRI further parcellates it into a **rostromedial "motor" division** (somatotopic — hindlimb rostrally, face caudally) and a **ventrocaudal "non-motor" division** connected with the ansiform lobule/prefrontal cortex (Küper et al 2012) — the structural basis for the cerebellum's non-motor (cognitive) contributions discussed under Applied anatomy below.

3. Afferent (corticonuclear) connections

The Purkinje cell zones of the cortex project onto the nuclei in a strict **mediolateral topography**:

Purkinje cell zone of cortex	Projects to nucleus
Vermis (+ flocculonodular lobe)	Fastigial nucleus
Paravermal (intermediate) zone	Emboliform + Globose nuclei
Lateral part of cerebellar hemisphere	Dentate nucleus

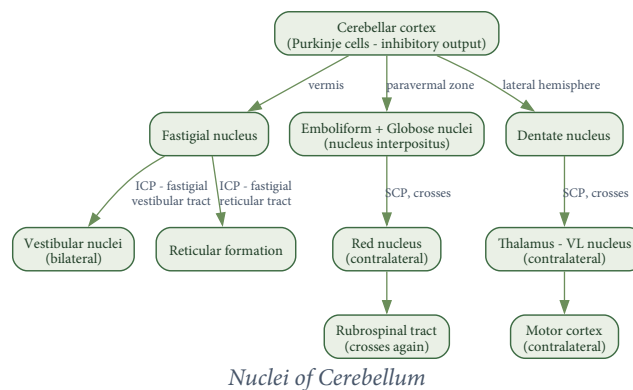
4. Efferent connections — the four outflow pathways

All efferent fibres of the dentate, emboliform and globose nuclei leave through the **superior cerebellar peduncle**; fastigial efferents leave mainly through the **inferior cerebellar peduncle**.

Pathway	Origin	Peduncle of exit	Course	Destination	Function
Dentothalamic	Dentate	Superior cerebellar peduncle	Crosses in the decussation of the superior cerebellar peduncles (midbrain)	Contralateral ventrolateral (VL) nucleus of thalamus → contralateral primary motor cortex	Skilled, precise voluntary movement (neocerebellar function)

Pathway	Origin	Peduncle of exit	Course	Destination	Function
Globose-emboliform-rubral	Emboliform + Globose	Superior cerebellar peduncle	Crosses in the SCP decussation, synapses in contralateral red nucleus , which gives origin to the rubrospinal tract that crosses again near its origin	Ipsilateral spinal motor neurones (via rubrospinal tract)	Tone and crude movement of the limbs (paleocerebellar function)
Fastigial vestibular	Fastigial	Inferior cerebellar peduncle (uncinate tract + direct fastigiobulbar tract)	Largely bilateral/uncrossed	Lateral vestibular nucleus (Deiters') of both sides → vestibulospinal tract	Facilitates ipsilateral extensor tone; equilibrium (archicerebellar function)
Fastigial reticular	Fastigial	Inferior cerebellar peduncle	Uncrossed	Reticular formation → reticulospinal tract	Modulates spinal segmental muscle tone

Because the dentate/interposed outflow **crosses once** in the superior cerebellar peduncle while the corticospinal and rubrospinal tracts **cross again**, each cerebellar hemisphere ultimately controls the **same (ipsilateral) side of the body** — the anatomical basis for ipsilateral cerebellar signs.



5. Functional correlation of the individual nuclei

Nucleus	Chief afferent source	Chief efferent target	Net function
Fastigial	Vestibular nerve/nuclei + vermis (vestibulocerebellum)	Vestibular nuclei, reticular formation (also thalamus, red nucleus, visceral centres)	Equilibrium; tone of axial and proximal limb muscles in response to labyrinthine input

Nucleus	Chief afferent source	Chief efferent target	Net function
Emboliform + Globose	Paravermal cortex (spinocerebellum)	Red nucleus, thalamus, reticular formation	Regulation of muscle tone and crude movement of the limbs
Dentate	Lateral hemisphere (neocerebellum/cerebrocerebellum)	Thalamus (VL) → motor cortex; also red nucleus	Planning and smooth execution of skilled, precise voluntary movements

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label a transverse section through the cerebellum at the level of the deep nuclei showing, from lateral to medial: **dentate nucleus** (crumpled-purse shape, hilum facing medially), **emboliform nucleus**, **globose nucleus**, **fastigial nucleus**; also label the **cerebellar hemisphere**, **vermis**, **cavity/roof of the 4th ventricle**, the **superior cerebellar peduncle** (efferent exit for dentate/emboliform/globose) and the **inferior cerebellar peduncle** (efferent exit for fastigial).

□ Fig 8.11 — Scheme to show the cerebellar nuclei (IB Singh — Textbook of Human Neuroanatomy, p.145)

Applied / Clinical anatomy

- ▶ **Dentate nucleus / superior cerebellar peduncle lesions** — interrupt the dentothalamic pathway, producing **intention tremor**, **dysmetria** and **dysidiadochokinesia**, classically appearing on the **same side** as the lesion because of the double decussation (SCP crossing followed by re-crossing of the corticospinal/rubrospinal tracts).
- ▶ **Flocculonodular (archicerebellar) lesions** — loss of fastigial-vestibular drive causes **truncal ataxia**, a **wide-based staggering gait and disequilibrium**, with a positive Romberg's sign; limb coordination is relatively spared since interposed/dentate circuits are intact.
- ▶ **Paleocerebellar (interposed-nucleus) lesions** — produce **hypotonia and gait/limb ataxia** through loss of the globose-emboliform-rubral pathway's control over crude limb movement and tone.
- ▶ **Posterior fossa tumours** (e.g., medulloblastoma, the commonest posterior fossa tumour of childhood) characteristically arise in the vermis close to the roof of the fourth ventricle and can compress or invade the fastigial/interposed nuclei, producing early truncal ataxia together with obstructive hydrocephalus from fourth-ventricle compression.
- ▶ **Friedreich ataxia** — an inherited spinocerebellar degeneration involving the cerebellum together with the posterior and lateral columns of the spinal cord, giving a mixed cerebellar-plus-sensory ataxia.
- ▶ **Recent structural–functional correlate**: fMRI-based parcellation of the human dentate nucleus into a **rostral, somatotopically-organised "motor" territory** and a **caudal "non-motor" territory** (linked via the thalamus to prefrontal and posterior-parietal cortex) provides the anatomical substrate proposed for the **cerebellar cognitive-affective syndrome** — executive, visuospatial and affective disturbances that can accompany large dentate/vermian lesions in addition to the classical motor signs.

High-yield exam pointers

- ▶ Four deep cerebellar nuclei, **lateral** → **medial**: Dentate – Emboliform – Globose – Fastigial ("Don't Eat Greasy Food").
- ▶ Emboliform + globose = **nucleus interpositus** (anterior + posterior interposed nuclei); all four together = "**roof nuclei**" (close to the roof of the 4th ventricle).
- ▶ Phylogeny–nucleus mapping: **archicerebellum** → **fastigial**; **paleocerebellum** → **emboliform** + **globose**; **neocerebellum** → **dentate**.
- ▶ **Fastigial** efferents leave via the **inferior** cerebellar peduncle; **dentate/emboliform/globose** efferents leave via the **superior** cerebellar peduncle.
- ▶ Superior cerebellar peduncle fibres **decussate in the midbrain** before reaching the red nucleus/thalamus.
- ▶ Dentate nucleus = largest, **crumpled-purse shaped**, subdivided into **microgyric** (rostromedial) and **macrogyric** (ventrocaudal) parts.
- ▶ Purkinje cells are the **sole cortical output** and are **inhibitory** on all four nuclei; the nuclei also receive direct excitatory mossy/climbing-fibre collaterals.
- ▶ **Double decussation** (superior cerebellar peduncle + corticospinal/rubrospinal tracts) explains why cerebellar hemisphere lesions give **ipsilateral** signs.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Textbook of Anatomy Vol 3 (Cerebellum and Fourth Ventricle) 4e; IB Singh Textbook of Human Neuroanatomy.



Signs and symptoms of cerebellar disease

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction The cerebellum coordinates movement by acting as a **comparator**: it compares the intended movement (signalled by the motor cortex) with the actual movement (signalled by proprioceptive feedback from muscles, joints and the vestibular apparatus) and corrects any discrepancy through its efferent projections. Each cerebellar hemisphere is connected principally with the **same side of the body**, so a lesion of one hemisphere produces **ipsilateral** signs. Lesions of the cerebellum — due to trauma, vascular occlusion, tumours, degeneration or toxins — produce a characteristic constellation of motor abnormalities that together constitute the **cerebellar syndrome**; classically summarised by Luciani (1891) as a triad of **atonia, astasia and asthenia**. Crucially, the cerebellum cannot initiate movement, so cerebellar disease never causes paralysis or sensory loss — it purely disrupts the *smoothness, timing, rate, range and force* of movement (competency AN 60.3).

1. General principles of cerebellar dysfunction

- ▶ Signs occur on the **same side** as the lesion (ipsilateral), because each cerebellar hemisphere influences the ipsilateral limbs via the superior cerebellar peduncle/red nucleus/thalamus pathway.
- ▶ There is **no true paralysis and no loss of sensation**; deficits involve *coordination* of otherwise normal muscle power.
- ▶ **Acute lesions** (haemorrhage, infarction, trauma) produce sudden, severe signs; **chronic lesions** (slow-growing tumours, degenerations) produce comparatively mild signs because other CNS areas have time to compensate — patients can recover substantially even after extensive cerebellar destruction.
- ▶ The many manifestations can be reduced to **two basic defects**: (i) **hypotonia**, from loss of cerebellar influence on the stretch reflex, and (ii) **loss of the cerebellum's corrective influence on the motor cortex/brainstem**, producing incoordination.
- ▶ Cerebellar dysfunction is often contrasted with basal ganglia disease: cerebellar lesions give **decreased tone with an intention (kinetic) tremor**, whereas basal ganglia disease gives **increased tone with a resting tremor**.

2. Functional-anatomical correlation of signs

□ Fig 6.5 — Functional subdivisions of cerebellum (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.532)

Functional division	Anatomical part	Chief connection	Signs on lesion
Archicerebellum (vestibulocerebellum)	Flocculonodular lobe ($\pm$ vermis)	Vestibular nerve/nuclei (vestibulocerebellar tract)	Truncal (axial) ataxia , wide-based staggering gait, nystagmus ; instability present even with eyes open (visual input corrects poorly, unlike sensory/dorsal-column ataxia)

Functional division	Anatomical part	Chief connection	Signs on lesion
Paleocerebellum (spinocerebellum)	Anterior lobe + vermis/paravermal (paramedian) zone	Spinocerebellar, cuneocerebellar tracts	Hypotonia, asthenia, flail joints, pendular knee jerk, gait ataxia (classically seen in chronic alcoholics — anterior-lobe/vermian degeneration)
Neocerebellum (cerebrocerebellum)	Posterior/middle lobe, lateral hemisphere	Cortico-ponto-cerebellar tract (via pons)	Asynergia — dysmetria (past-pointing), intention tremor , dysdiadochokinesia, dysarthria/scanning speech , rebound phenomenon

The vermis (midline) controls **axial/proximal** muscles and posture; the paravermal/intermediate zone and hemispheres control **distal limb** movements — hence midline lesions give truncal/gait disturbance without limb ataxia, while hemispheric lesions give limb ataxia on the same side.

3. Individual signs and symptoms — systematic description

- ▶ **Hypotonia**: diminished resistance to passive movement; muscles feel soft and "floppy" on palpation; shaking the limb produces excessive terminal-joint movement (loss of cerebellar influence on the simple stretch reflex).
- ▶ **Asthenia**: muscles tire easily and generate less force; joints may lack normal stability ("flail joints").
- ▶ **Ataxia**: inability to maintain equilibrium of the body while standing or walking. The patient stands on a **wide base**, sways from side to side, and while walking **staggers/lurches toward the side of the lesion**. Unlike sensory (dorsal-column) ataxia — which is markedly worsened by closing the eyes (**Romberg's sign positive**) — cerebellar ataxia is present even with the eyes open and visual input gives little correction; this is a key bedside distinction.
- ▶ **Dysmetria (past-pointing)**: inability to judge distance/range correctly; on the **finger–nose test** the finger overshoots or undershoots the target, and on the **heel–shin test** the heel similarly misjudges the shin. Correction attempts produce further to-and-fro oscillation.
- ▶ **Intention (kinetic) tremor**: a tremor that appears only during a purposeful, target-directed movement and disappears at rest — the opposite of the resting tremor of basal-ganglia disease; probably a consequence of dysmetria.
- ▶ **Dysdiadochokinesia (adiadochokinesia)**: inability to perform rapidly alternating movements evenly, classically tested by asking the patient to rapidly pronate and supinate the forearm, or to tap one hand alternately with the palm and dorsum of the other — the movements become slow, irregular and incomplete.
- ▶ **Dysarthria (scanning/staccato speech)**: incoordination of the laryngeal, lingual and palatal muscles produces jerky, explosive, slurred speech with pauses in the wrong places.

- **Nystagmus:** an involuntary, rhythmic to-and-fro oscillation of the eyeballs on attempting to fixate gaze, especially on lateral gaze; may be **pendular** (equal velocity in both directions) or **jerk** type (slow drift away from the target followed by a fast corrective phase — the direction of nystagmus is named for the fast phase).
- **Disturbance of tendon reflexes — pendular knee jerk:** tapping the patellar tendon produces an oscillating, "pendulum-like" swinging of the leg instead of the normal single, self-limited jerk, because the stretch-reflex check by agonist/antagonist muscles is lost.
- **Rebound phenomenon:** the patient cannot check the contraction of agonist muscles by the corresponding antagonists — if a doctor's hand pushing against the patient's palm is suddenly withdrawn, the patient's limb "rebounds" and may strike the chest.
- **Postural/gait change:** the head is often flexed and rotated, the shoulder on the affected side droops, and the patient adopts a broad-based, stiff-legged stance to compensate for lost tone.

4. Cerebellar syndromes by site of lesion

Syndrome	Site	Classical clinical picture
Vermis (midline) syndrome	Vermis ± flocculonodular lobe	Truncal/gait ataxia with no appendicular (limb) ataxia; tendency to fall forward/backward; titubation (head/trunk tremor); nystagmus and dysarthria may occur. Commonest cause in children is a medulloblastoma of the vermis.
Cerebellar hemisphere syndrome	One lateral hemisphere	Unilateral, ipsilateral limb ataxia (especially the arm), dysmetria, intention tremor, dysdiadochokinesia, nystagmus, dysarthria; swaying/falling toward the side of the lesion. Usually due to a hemisphere tumour, abscess or infarct (e.g., in the territory of the posterior/anterior inferior or superior cerebellar arteries).
Charcot's triad	Diffuse/multifocal (classically multiple sclerosis)	Combination of nystagmus + dysarthria (scanning speech) + intention tremor .
Flocculonodular ("archicerebellar") syndrome	Flocculus, nodule, uvula	Predominantly vestibular — imbalance and nystagmus, minimal limb signs.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a posterior view of the cerebellum (vermis in the midline flanked by the two hemispheres) and overlay the three functional zones:

- ▶ **Vestibulocerebellum (archicerebellum)** — flocculonodular lobe — label its input from the vestibular nerve/nuclei.
- ▶ **Spinocerebellum (paleocerebellum)** — vermis + paravermal (intermediate) zone of the anterior and posterior lobes — label input from the **spinocerebellar tracts**.
- ▶ **Cerebrocerebellum (neocerebellum)** — lateral part of the hemispheres — label input via the **cortico-ponto-cerebellar pathway**.

Alongside, draw three small labelled boxes/arrows connecting each zone to its lesion signs: vestibulocerebellum → truncal ataxia + nystagmus; spinocerebellum → hypotonia + gait ataxia + pendular knee jerk; cerebrocerebellum → dysmetria + intention tremor + dysdiadochokinesia + dysarthria. Mark the deep nuclei (fastigial, globose, emboliform, dentate) medial to lateral beneath the corresponding cortical zone.

Applied / Clinical anatomy

- ▶ **Medulloblastoma** of the vermis is the commonest posterior-fossa tumour of childhood and the classical cause of **vermis syndrome** with truncal ataxia and obstructive hydrocephalus (fourth-ventricle compression).
- ▶ **Dandy-Walker malformation**: a rare congenital posterior-fossa anomaly with a large cyst at the brainstem-cerebellum junction, an enlarged fourth ventricle, hydrocephalus and vermian hypoplasia; presents with congenital hydrocephalus and jerky, uncoordinated movements.
- ▶ **Friedreich's ataxia**: an inherited spinocerebellar degeneration presenting with intention tremor, hypotonia and progressive ataxia — a classic PYQ vignette.
- ▶ **Chronic alcoholism/thiamine deficiency**: selectively degenerates the anterior lobe/vermis, producing a predominantly **gait (truncal) ataxia** with relatively spared upper-limb coordination.
- ▶ **Multiple sclerosis**: a common cause of **Charcot's triad** due to plaques affecting cerebellar white matter/peduncles.
- ▶ **Vascular lesions**: thrombosis of the cerebellar arteries (superior, anterior-inferior or posterior-inferior cerebellar artery) can, besides classical ataxia, produce a **cerebellar cognitive-affective syndrome** — inattention, dysprosodic/agrammatic speech and patchy memory disturbance — reflecting non-motor cerebellar circuitry, especially with vermal involvement (dulled emotional response).
- ▶ **Functional imaging correlation**: fMRI during repetitive right-hand finger movement shows activation of the left precentral gyrus together with the **right cerebellar hemisphere** (anterior quadrangular lobule) — a teaching demonstration of crossed cerebro-cerebellar connections useful for imaging-based questions.
- ▶ Acute cerebellar lesions (haemorrhage/infarct) are surgical emergencies because of the risk of tonsillar/fourth-ventricular compression and acute hydrocephalus, unlike slow-growing chronic lesions which are far better tolerated.

Recent advances

- ▶ **Standardised assessment of non-motor cerebellar signs:** the Cerebellar Cognitive Affective/Schmahmann Syndrome (CCAS) Scale has now been validated in spinocerebellar ataxia cohorts, giving a bedside tool to capture the cognitive/affective signs of cerebellar disease alongside the classical motor signs (Nguyen AT et al., *Cerebellum* 2024, [DOI](https://doi.org/10.1007/s12311-023-01651-0), [PMID 38165578](https://pubmed.ncbi.nlm.nih.gov/38165578/)).
- ▶ **Genomic advances:** long-read sequencing has identified novel repeat-expansion genes — **FGF14** (SCA27B), **ZFHX3** (SCA4) and **THAP11** (SCA51) — broadening the genetic basis of previously "gene-negative" hereditary cerebellar ataxias (*Curr Neurol Neurosci Rep* 2024, [DOI](https://doi.org/10.1007/s11910-024-01400-8)).
- ▶ **Non-invasive cerebellar neuromodulation:** repetitive TMS and transcranial direct current stimulation are being trialled to improve ataxia in degenerative cerebellar disease; a 2024 systematic review/meta-analysis showed modest benefit, possibly via enhanced "**cerebellar reserve**" (Matsugi A et al., *Mov Disord Clin Pract* 2024, [DOI](https://doi.org/10.1002/mdc3.14205)); anatomically-guided electrode placement (accounting for individual cerebellar/peduncle anatomy) is now emphasised to improve targeting accuracy, e.g. in Friedreich's ataxia.

High-yield exam pointers

- ▶ Cerebellar disease → **no paralysis, no sensory loss**; purely a disorder of coordination — signs are **ipsilateral**.
- ▶ Two basic defects (Snell): **hypotonia** + loss of cerebellar corrective influence on the cortex.
- ▶ **Charcot's triad** = nystagmus + scanning (staccato) speech + intention tremor — classic for multiple sclerosis.
- ▶ Vermis lesion → **truncal/gait ataxia only**; hemisphere lesion → **ipsilateral limb ataxia** (dysmetria, intention tremor, dysdiadochokinesia).
- ▶ Archicerebellum = flocculonodular lobe (vestibular); paleocerebellum = anterior lobe + vermis (posture/tone); neocerebellum = posterior lobe/hemisphere (skilled voluntary movement).
- ▶ Tests: finger–nose and heel–shin tests (dysmetria); rapid pronation–supination (dysdiadochokinesia); tandem gait (truncal ataxia).
- ▶ Pendular knee jerk and rebound phenomenon are classic hypotonia-related bedside signs.
- ▶ Commonest childhood posterior-fossa tumour causing vermis syndrome = **medulloblastoma**; classic congenital anomaly = **Dandy–Walker malformation**.
- ▶ Cerebellar (intention) tremor vs basal ganglia (resting) tremor is a favourite "opposite pairs" MCQ.

SOURCE & COVERAGE

Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3–4 8e (text and figure); Gray's Anatomy (Standring) 41e. Recent-advances citations from PubMed/journal sources as linked above.



Vermis of cerebellum

Asked in: Paper IV Apr 2006 — RGUHS MD/MS Anatomy

Definition / Introduction The vermis is the narrow, unpaired, worm-shaped midline strip of the cerebellum that unites the two cerebellar hemispheres, lying in the depth of the vallecule cerebelli on the inferior surface and forming a continuous ridge on the superior surface. Phylogenetically it is the oldest and most medial part of the cerebellum, receiving its name from its resemblance to an earthworm (Latin *vermis*). It is the principal midline structure controlling equilibrium and the tone/posture of axial and proximal (trunk, neck, girdle) musculature, and is of major applied importance because it is the commonest site of childhood medulloblastoma.

1. Location, surfaces and boundaries

- ▶ Lies between the two cerebellar hemispheres, in the posterior cranial fossa, behind the pons and medulla, separated from the occipital lobes above by the tentorium cerebelli.
- ▶ **Superior vermis** — a low, rounded ridge continuous imperceptibly on either side with the superior surface of the hemispheres (no clear sulcus).
- ▶ **Inferior vermis** — sunk in the floor of the **vallecule cerebelli**, a deep median groove between the hemispheres; here it is sharply demarcated from the hemispheres on each side by the **paramedian (sulcus valleculae) sulcus**.
- ▶ Anteriorly related, through the roof of the fourth ventricle, to the pons and medulla; the **nodule** (inferior vermis) lies close to the roof of the fourth ventricle and the **lingula** (superior vermis) lies on the superior medullary velum.
- ▶ Deepest fissures that also define the vermis's lobar divisions: **primary fissure** (superior surface — separates anterior from posterior/middle lobe), **posterolateral fissure** (inferior surface — separates flocculonodular lobe from the rest), and the **horizontal fissure** (separates superior from inferior surface).

2. Subdivisions (lobules) of the vermis

From above downward the vermis is divided by shallower fissures into nine named lobules (Larsell's numbering I–X is used internationally; each vermal lobule is continuous laterally with a named hemispheric lobule, except the lingula):

Lobe	Vermal lobule	Larsell no.	Lateral (hemisphere) counterpart
Anterior lobe	Lingula	I	— (continuous with vinculum lingulae)
Anterior lobe	Central lobule	II–III	Ala of central lobule
Anterior lobe	Culmen	IV–V	Anterior quadrangular lobule
Posterior (middle) lobe	Declive	VI	Posterior quadrangular lobule (lobulus simplex)
Posterior lobe	Folium	VIIA	Superior semilunar lobule
Posterior lobe	Tuber	VIIB	Inferior semilunar lobule
Posterior lobe	Pyramid	VIII	Biventral lobule
Posterior lobe	Uvula	IX	Tonsil
Flocculonodular lobe	Nodule	X	Flocculus (via inferior medullary velum)

□ Fig 8.5 — Subdivisions of the vermis of the cerebellum as seen in a median section (IB Singh — Textbook of Human Neuroanatomy, p.141)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Median sagittal section through the vermis, top to bottom, labelling: **Superior surface:** Lingula (I) → Central lobule (II–III) → Culmen (IV–V) → [primary fissure] → Declive (VI) → Folium (VIIA) → Tuber (VIIB) **Inferior surface:** → Pyramid (VIII) → [prepyramidal fissure] → Uvula (IX) → [posterolateral fissure] → Nodule (X) Also mark: fourth ventricle with its roof (superior and inferior medullary velum), pons, medulla, and the arbor vitae (white matter core).

3. Phylogenetic and functional subdivisions

The vermis contributes to all three phylogenetic divisions of the cerebellum:

Division	Vermal component	Chief connection	Function
Archicerebellum (oldest; vestibulocerebellum)	Lingula (+ flocculonodular lobe)	Vestibular apparatus/nuclei	Equilibrium
Paleocerebellum (spinocerebellum)	Anterior-lobe vermis (except lingula), pyramid, uvula	Spinal cord (spinocerebellar tracts)	Muscle tone and posture

Division	Vermal component	Chief connection	Function
Neocerebellum (cerebrocerebellum/ponocerebellum)	Posterior-lobe vermis except pyramid and uvula (declive, folium, tuber)	Cerebral cortex via pontine nuclei	Fine coordination (mainly a hemisphere function; vermal share is small)

4. Cortex, white matter and connections of the vermis

- **Cerebellar cortex** (uniform throughout, including over the vermis) has 3 layers — outer **molecular** (stellate, basket cells), middle **Purkinje cell** layer, inner **granular** layer (granule cells, Golgi cells); all intrinsic neurons are inhibitory except the excitatory granule cells.
- **White matter of the vermis** is scanty compared with the hemispheres and forms part of the *arbor vitae*.
- **Deep (intracerebellar) nucleus of the vermis — fastigial nucleus**: lies near the midline within the vermis, close to the roof of the fourth ventricle; it is the target of Purkinje cell axons from the vermal cortex (the "vermal/A zone" of longitudinal corticonuclear projection, medial to the paravermal-B-zone → interposed nuclei, and lateral-zone → dentate nucleus projections).
- **Afferents to the vermis**: spinocerebellar fibres (anterior and posterior spinocerebellar tracts, via superior and inferior cerebellar peduncles) terminating chiefly in anterior- and posterior-vermis; primary and secondary vestibulocerebellar (mossy) fibres reaching the vermis bilaterally via the inferior cerebellar peduncle; tecto-/visual afferents reach lobule VII (folium + tuber), hence called the "**visual vermis**" — concerned with long-term adaptation of saccades and other eye movements.
- **Efferents from the vermis**: most vermal Purkinje axons synapse on the **fastigial nucleus**, whose axons run in two pathways through the inferior cerebellar peduncle — (i) the **fastigiovestibular (fastigiobulbar) tract**, projecting bilaterally to the lateral (Deiters') vestibular nucleus → lateral vestibulospinal tract → facilitates ipsilateral extensor tone; (ii) the **fastigiotectal tract**, to the reticular formation → reticulospinal tract. A few Purkinje axons of the flocculonodular lobe/vermis bypass the deep nuclei and project directly onto the lateral vestibular nucleus (the only cerebellar-cortex efferents that do not relay in a deep nucleus).
- **Net function**: the vermis controls movements of the "long axis" of the body — neck, shoulders, thorax, abdomen and hips — i.e. axial/proximal musculature, equilibrium, muscle tone, gait and posture, and (through lobule VII) oculomotor coordination; the nodulus (lobule X) is purely vestibulocerebellar.

5. Blood supply

Three paired arteries, all from the vertebrobasilar system, supply the cerebellum including the vermis:

Artery	Origin	Territory
Superior cerebellar artery (SCA)	Basilar artery	Superior surface of cerebellum, including superior vermis (lingula–culmen–declive)

Artery	Origin	Territory
Anterior inferior cerebellar artery (AICA)	Basilar artery	Anterior part of inferior surface (mainly hemisphere/flocculus)
Posterior inferior cerebellar artery (PICA)	Vertebral artery	Posterior part of inferior surface, including inferior vermis (folium–tuber–pyramid–uvula–nodule) and choroid plexus of the fourth ventricle

□ Fig 10.12 — Arterial supply of cerebellum (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.376)

6. Development

The vermis develops from fusion of the **rhombic lips** — dorsomedially-growing derivatives of the alar plates of the metencephalon — which meet and unite in the midline over the roof of the fourth ventricle and then grow dorsally to form the cerebellum. By about the **12th week** a midline vermis and two lateral cerebellar hemispheres are already distinguishable; fissures begin to appear on the vermis toward the end of the 4th month, producing its characteristic lobulation.

Applied / Clinical anatomy

- ▶ **Vermis (midline cerebellar) syndrome:** the commonest cause is a **medulloblastoma** of the vermis in children — a highly malignant tumour arising from poorly differentiated primitive neuroectodermal cells, typically bulging into the roof of the fourth ventricle. Because the vermis is unpaired and governs midline/axial structures, the syndrome produces **truncal (axial) ataxia** — difficulty holding the head steady and the trunk erect, a broad-based, staggering gait, and a tendency to fall forward or backward (titubation) — **without limb ataxia, dysmetria or intention tremor**, in contrast to a hemisphere lesion (which gives unilateral limb incoordination, dysdiadochokinesia, past-pointing and swaying/falling to the side of the lesion).
- ▶ The medulloblastoma may obstruct the outlets of the fourth ventricle (foramen of Magendie/foramina of Luschka), producing **non-communicating (obstructive) internal hydrocephalus**, and may compress vital centres in the floor of the ventricle causing cardiac irregularity, tachycardia, irregular respiration and vasomotor disturbance.
- ▶ **Dandy–Walker malformation:** a congenital posterior-fossa anomaly with **hypoplasia/agenesis of the cerebellar vermis**, cystic dilatation of the fourth ventricle, and hydrocephalus; presents with congenital hydrocephalus and jerky, uncoordinated movements.
- ▶ General cerebellar signs (from vermal or hemispheric disease) include nystagmus, dysarthria, intention tremor and ataxia — classically remembered as **Charcot's triad** (nystagmus, dysarthria, intention tremor); hypotonia and a positive rebound phenomenon are also seen.
- ▶ Clinically the single most useful localising point is: **truncal/gait ataxia with preserved limb coordination points to the vermis; unilateral limb ataxia points to the ipsilateral hemisphere.**

High-yield exam pointers

- ▶ Vermis = unpaired midline strip joining the two cerebellar hemispheres; lodged in the vallecule cerebelli inferiorly.

- ▶ 9 vermal lobules, superior to inferior: lingula, central lobule, culmen, declive, folium, tuber, pyramid, uvula, nodule (Larsell I–X).
- ▶ Belongs to all three phylogenetic divisions: archi- (lingula + flocculonodular lobe), paleo- (rest of anterior lobe + pyramid + uvula), neo- (declive/folium/tuber).
- ▶ Deep nucleus of the vermis = **fastigial nucleus** (most medial of the four cerebellar nuclei; others are globose, emboliform, dentate — all in the hemisphere).
- ▶ Efferent pathway: vermis → fastigial nucleus → fastigiovestibular + fastigioreticular tracts → vestibulospinal/reticulospinal tracts → axial and proximal muscle tone/equilibrium.
- ▶ Lobule VII (folium + tuber) = "visual vermis" (oculomotor/saccadic control); lobule X (nodule) = purely vestibular.
- ▶ Blood supply: SCA (superior vermis), PICA (inferior vermis), AICA (mainly hemisphere).
- ▶ Commonest tumour of the vermis = **medulloblastoma** (children) → truncal ataxia + obstructive hydrocephalus.
- ▶ Congenital vermian agenesis/hypoplasia = **Dandy–Walker malformation**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy.



Archicerebellum, Paleocerebellum and Neocerebellum — Connections and Blood Supply of the Cerebellum

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — The cerebellum ("little brain") is the largest part of the hindbrain and the second largest part of the brain, weighing about 150 g, occupying the posterior cranial fossa below the tentorium cerebelli. On phylogenetic, developmental and functional grounds it is divided into three parts — **archicerebellum, paleocerebellum and neocerebellum** — each with a characteristic anatomical component, a dominant connection, and a corresponding deep nucleus. The cerebellum communicates with the brainstem through three **cerebellar peduncles**, and is supplied entirely by the vertebrobasilar (posterior circulation) system.

1. Morphological subdivisions of the cerebellum

Two fissures divide the cerebellum into three lobes: the **primary fissure** (fissura prima) separates the anterior lobe from the posterior (middle) lobe on the superior surface, and the **posterolateral fissure** separates the posterior lobe from the flocculonodular lobe on the inferior surface. The **horizontal fissure** merely divides the superior from the inferior surface.

Lobe	Part of vermis	Part of hemisphere
Anterior	Lingula, central lobule, culmen	Ala, anterior quadrangular lobule

Lobe	Part of vermis	Part of hemisphere
Posterior (middle)	Declive, folium, tuber, pyramid, uvula	Posterior quadrangular, superior/inferior semilunar, biventral lobules, tonsil
Flocculonodular	Nodule	Flocculus

2. Archicerebellum, Paleocerebellum and Neocerebellum

Subdivision	Order of phylogenetic appearance	Anatomical component	Chief connection	Functional synonym	Predominant function
Archicerebellum	Oldest — present in aquatic vertebrates	Flocculonodular lobe + lingula	Vestibular apparatus (vestibular nuclei)	Vestibulocerebellum	Maintenance of body equilibrium; control of eye movements
Paleocerebellum	Next to appear, with limbs, in terrestrial vertebrates	Anterior lobe (except lingula) + pyramid and uvula of the vermis	Spinal cord (spino-cerebellar tracts)	Spinocerebellum	Regulation of muscle tone, posture and crude limb movements
Neocerebellum	Newest — mammals only, largest in man	Posterior (middle) lobe except pyramid and uvula	Cerebral cortex, via pontine nuclei (cortico-ponto-cerebellar)	Cerebrocerebellum / pontocerebellum	Fine coordination, planning and smooth execution of skilled voluntary movements

Developmental correlate: the cerebellum develops from the alar-lamina neuroblasts of the rhombic lip of the metencephalon. The archicerebellum is the earliest part to appear; the paleocerebellum develops in its centre, splitting the archicerebellar territory into the lingula and the flocculonodular lobe; later the neocerebellum develops in the centre of the paleocerebellum, splitting it into the anterior lobe (except lingula) and the pyramid-uvula.

□ Fig 6.4 — Lobes and morphological subdivisions of cerebellum. Area above horizontal fissure represents superior surface and area below the fissure shows inferior surface (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.532)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Flattened ("opened-out") scheme of the cerebellum with the superior surface above and inferior surface below the horizontal fissure. Label: **primary fissure**, **posterolateral fissure**, **horizontal fissure**; vermis parts — lingula, central lobule, culmen, declive, folium, tuber, pyramid, uvula, nodule; hemisphere parts — ala, quadrangular lobule, simple lobule, superior/inferior semilunar lobule, biventral lobule, tonsil, flocculus. Shade/ring the three phylogenetic zones — **archicerebellum** (flocculonodular lobe + lingula), **paleocerebellum** (rest of anterior lobe + pyramid + uvula) and **neocerebellum** (remainder of the posterior/middle lobe).

3. Intracerebellar (deep cerebellar) nuclei and their phylogenetic correlation

Four pairs of grey-matter masses lie buried in the central white matter, from medial to lateral: **fastigial**, **globose**, **emboliform** and **dentate**.

Nucleus	Phylogenetic group	Afferents (from)	Efferents (to), via peduncle
Fastigial (nucleus fastigii)	Archicerebellar	Archicerebellar (vestibulo-) cortex; vestibular nerve/nuclei directly	Vestibular and reticular nuclei — inferior cerebellar peduncle (fastigiovestibular, fastigiotreticular)
Globose + Emboliform	Paleocerebellar	Paleocerebellar cortex	Red nucleus (→ rubrospinal tract) — superior cerebellar peduncle (globorubral pathway)
Dentate (largest, most lateral)	Neocerebellar	Neocerebellar cortex	Red nucleus and ventrolateral thalamus (→ motor cortex) — superior cerebellar peduncle (dentatorubral, dentatothalamic)

4. Connections of the cerebellum — the three cerebellar peduncles

Afferent and efferent fibres of the cerebellum are grouped into three large bundles, the **cerebellar peduncles**, connecting the cerebellum to the midbrain, pons and medulla respectively. The middle and inferior peduncles are chiefly **afferent**; the superior peduncle is chiefly **efferent**.

Peduncle	Connects cerebellum to	Chief afferent tracts	Chief efferent tracts
Superior cerebellar peduncle (brachium conjunctivum)	Midbrain	Anterior (ventral) spinocerebellar; tectocerebellar	Globorubral; dentatorubral; dentatothalamic; dentato-olivary; fastigiotreticular

Peduncle	Connects cerebellum to	Chief afferent tracts	Chief efferent tracts
Middle cerebellar peduncle (brachium pontis, the largest peduncle)	Pons	Pontocerebellar fibres (part of the cortico-ponto-cerebellar pathway)	None — purely afferent
Inferior cerebellar peduncle (restiform body)	Medulla oblongata	Posterior (dorsal) spinocerebellar; cuneocerebellar (posterior external arcuate fibres); olivocerebellar and parolivocerebellar (climbing fibres); reticulocerebellar; vestibulocerebellar; trigeminocerebellar; anterior external arcuate fibres; striae medullares	Fastigiovestibular; fastigioreticular; cerebello-olivary

Intrinsic circuitry that completes the "connection": cerebellar afferents reach the cortex as **mossy fibres** (all afferents except the olivocerebellar) or **climbing fibres** (olivocerebellar only, arising from the inferior olivary nucleus). Mossy fibres synapse on granule cells, whose axons form parallel fibres exciting Purkinje cells; climbing fibres wind around Purkinje dendrites and excite them directly (1 fibre : 1 Purkinje cell). The **Purkinje cell axon is the sole efferent of the cerebellar cortex** and is inhibitory — it synapses on the deep cerebellar nuclei (except a few flocculonodular/vermal Purkinje axons that bypass the nuclei and pass directly to the vestibular nuclei). The deep nuclei then relay the outflow through the superior (dentate, globose, emboliform) or inferior (fastigial) peduncle, completing the cerebello-nuclear-peduncular loop that allows the cerebellum to modulate, but never initiate, movement.

□ Fig 6.9 — Three cerebellar peduncles connecting the cerebellum to the rest of the central nervous system (Snell — Clinical Neuroanatomy — 7e, p.257)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Median sagittal/posterior scheme of brainstem with cerebellum removed, showing the three peduncles emerging from the fourth ventricle region. Label: **superior cerebellar peduncle** → **midbrain**, **middle cerebellar peduncle** → **pons**, **inferior cerebellar peduncle (restiform body)** → **medulla**; mark afferent tracts entering (spinocerebellar, pontocerebellar, olivocerebellar, vestibulocerebellar) with inward arrows and efferent tracts leaving (dentatothalamic, dentatorubral, fastigiovestibular) with outward arrows; show the deep nuclei (dentate, emboliform, globose, fastigial, medial to lateral) as the relay station between cortex and peduncle.

5. Blood supply of the cerebellum

The cerebellum is supplied entirely by the **vertebrobasilar (posterior circulation)** system — two posterior inferior, two anterior inferior, and two superior cerebellar arteries; there is no carotid contribution.

Artery	Origin	Territory supplied
Posterior inferior cerebellar artery (PICA)	Largest branch of the vertebral artery	Postero-inferior surface of the cerebellum and inferior vermis; choroid plexus of the fourth ventricle; a branch lateral to the tonsil supplies the dentate nucleus ; also the dorsolateral medulla (lateral medullary territory)
Anterior inferior cerebellar artery (AICA)	Lower part of the basilar artery	Antero-inferior cerebellar surface; inferolateral pons; commonly gives origin to the labyrinthine artery to the internal ear
Superior cerebellar artery (SCA)	Basilar artery, just before its terminal bifurcation into posterior cerebral arteries	Superior surface of the cerebellum; superior medullary velum; tela choroidea of the third ventricle; adjoining pons/midbrain

All three arteries anastomose with each other over the cerebellar surface (pial plexus).

Venous drainage: superior cerebellar veins run either medially across the superior vermis to the **straight sinus/great cerebral vein**, or laterally to the **transverse and superior petrosal sinuses**; inferior cerebellar veins include a small median vessel draining to the **straight or sigmoid sinus**, and laterally-coursing veins draining to the **inferior petrosal and occipital sinuses**.

□ Fig 10.12 — Arterial supply of cerebellum (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.376)

Applied / Clinical anatomy

- **Vermis (archicerebellar) lesions** — truncal/gait ataxia (wide-based, staggering gait), titubation and nystagmus, because vermal connections to the vestibular nuclei are disrupted; classically seen with midline posterior-fossa tumours (e.g., childhood medulloblastoma arising from the roof of the fourth ventricle/vermis).
- **Anterior lobe (paleocerebellar) lesions** — gait ataxia with incoordination of the lower limbs; seen classically in chronic alcoholics (alcoholic cerebellar degeneration).
- **Cerebellar hemisphere (neocerebellar) lesions** — *ipsilateral* signs: intention/action tremor, dysdiadochokinesia (inability to perform rapid alternating movements, e.g. pronation-supination), past-pointing, hypotonia, pendular reflexes, scanning (jerky, explosive) speech, and nystagmus.
- **PICA occlusion** — Wallenberg's lateral medullary syndrome, plus ipsilateral cerebellar ataxia from involvement of the inferior cerebellar peduncle and dentate nucleus territory.
- **AICA occlusion** — lateral pontine syndrome with ipsilateral facial palsy, deafness (via the labyrinthine artery) and limb ataxia.
- **SCA occlusion** — ipsilateral limb and gait ataxia, sometimes with contralateral pain/temperature loss and Horner's syndrome.

- ▶ **Cerebellar (cognitive-affective) syndrome** — thrombosis of any of the six paired cerebellar-supplying arteries can present with hypotonia, intention tremor, adiadochokinesia, nystagmus, scanning speech and ataxic gait; vermal involvement additionally blunts emotional responses.
- ▶ **Tonsillar herniation ("coning")** — a raised posterior-fossa pressure (tumour/haemorrhage) can force the cerebellar tonsils through the foramen magnum, compressing the medulla — a neurosurgical emergency; makes lumbar puncture contraindicated in raised intracranial pressure.
- ▶ Cerebellar structure is uniform (**homotypical**) throughout, unlike the heterotypical cerebral cortex, and cerebellar control of movement is strictly **ipsilateral**.

High-yield exam pointers

- ▶ The cerebellum works on a "**rule of three**": 3 fissures (primary, posterolateral, horizontal), 3 lobes (anterior, posterior/middle, flocculonodular), 3 phylogenetic divisions (archi-, paleo-, neocerebellum), 3 peduncles (superior, middle, inferior), and 3 groups of deep nuclei (fastigial — globose/emboliform — dentate).
- ▶ Archicerebellum = flocculonodular lobe + lingula = vestibulocerebellum = fastigial nucleus.
- ▶ Paleocerebellum = anterior lobe (ex-lingula) + pyramid + uvula = spinocerebellum = globose + emboliform nuclei.
- ▶ Neocerebellum = rest of posterior lobe = cerebrocerebellum/pontocerebellum = dentate nucleus (largest, most lateral).
- ▶ **Middle peduncle** is the largest and is purely **afferent** (pontocerebellar); **superior peduncle** is chiefly **efferent** (dentatothalamic/dentatorubral); **inferior peduncle** (restiform body) carries a mixture, afferent-predominant.
- ▶ The **Purkinje cell** is the sole output neuron of the cerebellar cortex and is always **inhibitory** (GABAergic) on the deep nuclei.
- ▶ **Climbing fibres** = olivocerebellar only (excitatory, 1:1 with Purkinje cells); **all other afferents are mossy fibres**, relaying via granule and parallel fibres.
- ▶ All arterial supply to the cerebellum comes from the **vertebrobasilar system** — PICA (vertebral artery), AICA and SCA (basilar artery); there is no carotid contribution.
- ▶ Cerebellum controls the **ipsilateral** half of the body and does not initiate movement — it only coordinates, times and smooths ongoing motor activity.

SOURCE & COVERAGE

BD Chaurasia's Human Anatomy, Vol 3-4, 8e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy, 4e; Snell's Clinical Neuroanatomy, 7e; Gray's Anatomy (Standring) 41e.



Diencephalon (thalamus & hypothalamus)



Lateral geniculate body

Asked in: Paper IV May 2018 · Paper IV Oct 2008 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction The lateral geniculate body (LGB) is a small, ovoid, laminated nucleus that projects ventrally from the posterior (pulvinar) end of the thalamus; it is the principal thalamic relay nucleus of the visual pathway. Together with the medial geniculate body it constitutes the **metathalamus**, traditionally described separately but now classed functionally as part of the dorsal thalamus. Every retinal ganglion-cell axon destined for conscious vision (except a minority diverted to the pretectum/superior colliculus for reflexes) synapses here before continuing as the optic radiation to the striate cortex.

Location, gross features and relations

- ▶ Situated on the **postero-inferior aspect of the thalamus**, immediately antero-lateral to the medial geniculate body, from which it is separated by the point of entry of the **brachium of the superior colliculus (superior quadrigeminal brachium)**.
- ▶ Lies **inferior to the pulvinar**, which overhangs it, and lateral to the crus cerebri/cerebral peduncle of the midbrain.
- ▶ It is the visible terminal swelling of the **optic tract** — most optic tract fibres end here.
- ▶ Shape: a small, flattened, **inverted, somewhat U-shaped (horseshoe-shaped)** nucleus with its hilum directed postero-medially, where the brachium of the superior colliculus enters carrying afferent retinal fibres and where efferent geniculocalcarine fibres leave.
- ▶ Related structures: pulvinar (superior), medial geniculate body (postero-medial), crus cerebri (medial), and the temporal horn of the lateral ventricle/choroidal fissure (postero-lateral), via which the posterior choroidal vessels reach it.

Structure — the six laminae

- ▶ The grey matter is organised into **six cellular laminae** separated by intervening fibre layers (interlaminar zones), numbered **1 to 6 from the ventral-most to the dorsal-most** layer (occasionally a seventh/eighth lamina or an additional ventral "S" lamina is described).
- ▶ **Laminae 1 and 2** — large neurones — the **magnocellular** layers.
- ▶ **Laminae 3, 4, 5 and 6** — smaller, more numerous neurones — the **parvocellular** layers.
- ▶ Crossed and uncrossed retinal input alternate strictly, layer by layer:

Lamina	Cell type	Retinal input received
1	Magnocellular	Contralateral (crossed) nasal hemiretina
2	Magnocellular	Ipsilateral (uncrossed) temporal hemiretina
3	Parvocellular	Ipsilateral (uncrossed) temporal hemiretina
4	Parvocellular	Contralateral (crossed) nasal hemiretina

Lamina	Cell type	Retinal input received
5	Parvocellular	Ipsilateral (uncrossed) temporal hemiretina
6	Parvocellular	Contralateral (crossed) nasal hemiretina

- ▶ Mnemonic: laminae 1, 4 and 6 = **crossed (opposite eye)**; laminae 2, 3 and 5 = **uncrossed (same eye)**.
- ▶ Functional streams: the **parvocellular (P) laminae** receive slowly-conducting, sustained-response **X-type** ganglion-cell axons and subserve fine detail/colour vision; the **magnocellular (M) laminae** receive fast-conducting, transient-response **Y-type** axons concerned with movement and depth; **W-type** ganglion cells (large receptive fields) project diffusely to the interlaminar zones and the ventral-most **S lamina**, as well as to the superior colliculus.

□ Fig 7.10 — Laminae of lateral geniculate body (IB Singh — Textbook of Human Neuroanatomy, p.129)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a coronal/oblique section through the LGB as an inverted, curved (U-shaped) stack of six laminae and label:

- ▶ Laminae 1–6, numbered ventral (1) to dorsal (6); mark 1, 2 = **magnocellular** and 3–6 = **parvocellular**.
- ▶ Incoming **optic tract** fibres entering at the hilum (postero-medial aspect), splitting to laminae 1, 4, 6 labelled "**crossed — contralateral nasal retina**" and to laminae 2, 3, 5 labelled "**uncrossed — ipsilateral temporal retina**".
- ▶ **Brachium of superior colliculus** entering the hilum dorsally.
- ▶ Outgoing **geniculocalcarine fibres (optic radiation)** leaving the hilum toward the retrolentiform limb of the internal capsule.
- ▶ Adjacent labels for orientation: **pulvinar** (above), **medial geniculate body** (postero-medial), **crus cerebri** (medial).

Retinotopic (visuotopic) organisation

- ▶ The LGB contains a precise, point-to-point map of the **contralateral half of the visual field** (visuotopic/retinotopic organisation), preserved through all six laminae — a radially-arranged column ("inverted pyramid") of neurones through all laminae responds to one small area of visual field and projects to one circumscribed cortical locus.
- ▶ Within the map: the **vertical meridian** is represented posteriorly, the **peripheral field** anteriorly, the **upper visual field** laterally, and the **lower visual field** medially.
- ▶ This precise topography is preserved in the geniculocalcarine projection to the primary visual cortex, permitting exact localisation of field defects to a lesion site along the pathway.

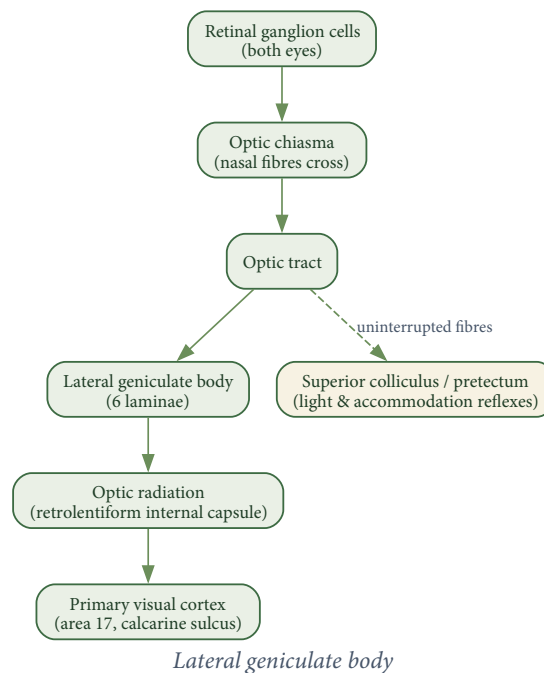
Connections

Afferents

- ▶ Chief input: the **lateral root of the optic tract**, carrying axons of retinal ganglion cells of both eyes — crossed fibres from the contralateral nasal hemiretina and uncrossed fibres from the ipsilateral temporal hemiretina — terminating in the laminar pattern described above.
- ▶ **Cortico-fugal (cortico-geniculate) feedback** from the primary visual cortex (area 17) and extrastriate visual areas, terminating chiefly in the interlaminar zones — a large "descending" projection that modulates/gates the ascending retinal signal.
- ▶ Afferents from the **superior colliculus** and the **reticular formation** of pons and medulla.
- ▶ Modulatory monoaminergic afferents: **noradrenergic** fibres from the locus coeruleus and **serotonergic** fibres from the raphe nuclei of the midbrain, regulating the gain of transmission (e.g. with arousal/sleep state).

Efferents

- ▶ Geniculocalcarine fibres constitute the **optic radiation**, which passes through the **retrolentiform (sublentiform) part of the internal capsule** to reach the **primary visual cortex (area 17/striate cortex)** in the banks of the calcarine sulcus of the occipital lobe; small collaterals may also reach extrastriate visual areas (18, 19), possibly arising from the interlaminar zones.



Blood supply

- ▶ Chiefly by **posterior choroidal branches of the posterior cerebral artery**, which pass over the lateral geniculate body and supply it before continuing into the choroidal fissure to reach the choroid plexus of the temporal horn of the lateral ventricle.
- ▶ The adjoining **optic tract and optic radiation** are supplied by the **anterior choroidal artery** (a branch of the internal carotid) and by deep branches of the middle and posterior cerebral arteries respectively — vessels running in close proximity to the LGB and clinically important because vascular lesions here can produce homonymous field defects.

Comparison with the medial geniculate body

Feature	Lateral geniculate body	Medial geniculate body
Pathway	Visual	Auditory
Position	Antero-lateral to medial geniculate body, below pulvinar	More prominent; postero-lateral, below pulvinar, lateral to superior colliculus
Brachium	Superior (quadrigeminal) brachium	Inferior (quadrigeminal) brachium
Structure	6 laminae (magno/parvocellular)	3 subnuclei — medial (magnocellular), ventral, dorsal
Afferents	Optic tract (retina, both eyes)	Lateral lemniscus / inferior colliculus (± direct)
Efferents	Optic radiation → area 17	Auditory radiation → sublentiform internal capsule → areas 41, 42
Organisation	Retinotopic (visuotopic)	Tonotopic (ventral nucleus only)

Applied / Clinical anatomy

- ▶ The LGB is the obligatory relay for **conscious vision**; a small proportion of optic tract fibres bypass it to reach the **pretectal nucleus and superior colliculus**, mediating the pupillary light reflex and visual (ocular) reflexes — these survive even if the LGB itself is destroyed.
- ▶ Because every fibre at and beyond the LGB is already segregated by hemifield, a lesion of the **optic tract, LGB, optic radiation, or visual cortex** on one side produces a **contralateral homonymous hemianopia** (same-sided field loss in both eyes) — in contrast to a chiasmal lesion, which produces **bitemporal hemianopia**, or a lesion anterior to the chiasma/optic nerve, which produces monocular blindness.
- ▶ Vascular infarction along the **thalamogeniculate branches of the posterior cerebral artery** is a recognised cause of an isolated LGB lesion, producing dense contralateral homonymous field loss.
- ▶ The LGB's precise retinotopic lamination is the anatomical basis for **localising field defects** clinically (e.g. quadrantanopia vs complete hemianopia) to a level along the visual pathway.
- ▶ Surgically/radiologically, the LGB and optic radiation lie close to the **temporal horn of the lateral ventricle and choroidal fissure**, relevant during temporal lobectomy (risk of a contralateral superior quadrantanopia from Meyer's loop injury more distally in the radiation).

Recent advances

- ▶ Functional imaging (fMRI) and electrophysiological recordings in primates have confirmed that the LGB is not a passive relay: the large **corticofugal feedback projection** from V1 actively modulates gain and attention-related gating of ascending retinal signals, refining the classical "simple relay" concept taught in gross texts.
- ▶ Refined parcellation recognises **koniocellular (K) interlaminar zones**, in addition to the magnocellular and parvocellular laminae, forming a third parallel channel implicated in colour

and low-acuity/blue-yellow visual processing — an extension of the classical six-lamina scheme worth noting for completeness.

High-yield exam pointers

- ▶ LGB = metathalamic relay nucleus of the **visual pathway**; MGB = auditory pathway relay — do not confuse.
- ▶ **6 laminae**, numbered ventral (1) → dorsal (6); 1, 2 = **magnocellular**; 3–6 = **parvocellular**.
- ▶ **Laminae 1, 4, 6 = crossed (contralateral nasal retina); laminae 2, 3, 5 = uncrossed (ipsilateral temporal retina).**
- ▶ Afferents = optic tract (lateral root); efferents = optic radiation → area 17 via retrolentiform internal capsule.
- ▶ Retinotopic map: vertical meridian posterior, periphery anterior, upper field lateral, lower field medial.
- ▶ A lesion at/behind the LGB → **contralateral homonymous hemianopia**; light-reflex fibres bypass LGB to superior colliculus/pretectum and are spared.
- ▶ Blood supply mainly via posterior choroidal branches of PCA.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e; BD Chaurasia Human Anatomy Vol 3–4 8e (figure).



Classify thalamic nuclei, connections and functions

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction The thalamus (dorsal thalamus) is a paired, egg-shaped mass of grey matter, about 3.5–4 cm long and 1.5 cm broad, forming the bulk of the diencephalon and lying on each side of the third ventricle; the two thalami are usually joined across the midline by the **interthalamic adhesion (connexus)**. It is the great sensory gateway of the brain — the principal relay and integrating station through which almost every sensory modality (all except olfaction), together with cerebellar and basal ganglia motor information, reaches the cerebral cortex. A Y-shaped sheet of white matter, the **internal medullary lamina**, subdivides its grey matter into anterior, medial and lateral nuclear masses, and this structural division is the basis for classifying the numerous thalamic nuclei, each with its own characteristic connections and function.

Gross subdivision (basis of classification)

- ▶ **Ends** — anterior end (tubercle of thalamus) narrow, forms the posterior boundary of the interventricular foramen; posterior end expanded as the **pulvinar**, overhanging the superior colliculus and separated from the medial geniculate body by the brachium of the superior colliculus.

- **Coverings of white matter** — superior surface covered by the **stratum zonale**; lateral surface covered by the **external medullary lamina**, external to which lies a thin sheet of grey matter, the **reticular nucleus**, before the posterior limb of the internal capsule intervenes between thalamus and lentiform nucleus.
- **Internal medullary lamina** — a vertical, Y-shaped sheet of fibres passing between thalamic nuclei; it bifurcates anterosuperiorly, enclosing the **anterior nuclear mass** between the limbs of the Y, with the **medial** and **lateral** nuclear masses lying on either side of the stem. **Intralaminar nuclei** are embedded within this lamina, and **midline (paraventricular) nuclei** lie against the ependyma of the third ventricle.

Classification of thalamic nuclei

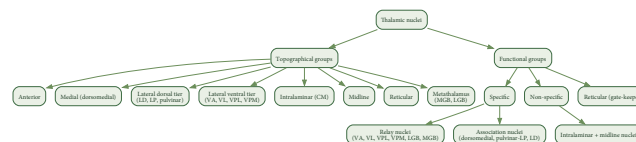
Thalamic nuclei are classified on two complementary bases — a **topographical (anatomical)** basis, using the divisions created by the internal/external medullary laminae, and a **functional** basis, using the nature of their connections.

A. Topographical classification

Group	Nuclei	Chief connections
Anterior	Anteroventral (largest), anteromedial, anterodorsal — together often called "anterior nucleus"	Mammillothalamic tract; cingulate gyrus
Medial	Dorsomedial (mediodorsal) nucleus — magnocellular + parvocellular parts; small medial ventral nucleus	Prefrontal cortex, amygdala, hypothalamus
Lateral — dorsal tier	Lateral dorsal (LD), lateral posterior (LP), pulvinar (largest thalamic nucleus)	Parietal, occipital, temporal association cortex
Lateral — ventral tier	Ventral anterior (VA), ventral lateral (VL/ventral intermediate), ventral posterior — subdivided into ventral posterolateral (VPL) and ventral posteromedial (VPM)	Basal ganglia/cerebellum (VA, VL); ascending sensory lemnisci (VP)
Intralaminar	Several small nuclei within the internal medullary lamina; largest is the centromedian (CM) nucleus	Reticular formation, spinothalamic and trigeminothalamic tracts
Midline	Paraventricular, rhomboid, reuniens nuclei, against the third ventricle ependyma	Reticular formation
Reticular	Thin curved sheet external to the external medullary lamina	Cerebral cortex and other thalamic nuclei (no cortical efferents)
Metathalamus	Medial geniculate body (MGB), lateral geniculate body (LGB)	Auditory and visual pathways respectively

B. Functional classification (Vishram Singh; Gray's Anatomy 41e)

- ▶ **Specific nuclei** — receive a well-defined ascending tract and relay it topographically to a discrete cortical area.
 - *Relay*: VA, VL, VPL, VPM, LGB, MGB.
 - *Association*: dorsomedial, pulvinar-LP, LD — connect with cortical "association areas" rather than primary sensory cortex, and receive their chief subcortical input from structures such as the amygdala or superior colliculus rather than a discrete ascending tract.
- ▶ **Non-specific nuclei** — no defined ascending tract; diffuse reticular-formation input, widely projected to association cortex and other thalamic nuclei. Group: **intralaminar** and **midline** nuclei (and, by some schemes, the anterior nucleus).
- ▶ **Reticular nucleus** — a distinct third category: a thin GABAergic shell receiving corticothalamic/thalamocortical collaterals and projecting back only to other thalamic nuclei — **no direct cortical projection**; thought to "gate" thalamocortical traffic.



Classify thalamic nuclei, connections and functions

□ Fig 9.5 — Nuclei of thalamus (IB Singh — Textbook of Human Neuroanatomy, p.157)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Two schematic sections of the right thalamus, side by side (as above):

- ▶ **Lateral (horizontal) view** — label, from anterior to posterior: **ventral anterior (VA)**, **ventral lateral (VL)**, **ventral posterior (VP)** with its **lateral (VPL)** and **medial (VPM)** parts, **lateral posterior (LP)**, **pulvinar**; along the top, **anterior nucleus**; centrally, **medial dorsal nucleus**, **intralaminar nuclei**, **midline nuclei**; peripherally, **external medullary lamina** with the **reticular nucleus** just internal to it, and the **internal medullary lamina** separating the masses.
- ▶ **Medial (coronal-type) view** — label **anterior**, **medial dorsal**, **lateral dorsal**, **centromedian**, **midline**, and **ventral posterolateral / ventral posteromedial / ventral lateral nuclei**.

Then, alongside, a connections scheme with afferents drawn entering on the left and efferents leaving on the right (Snell Fig. 12-4 / Vishram Singh Fig. 11.4 pattern).

Connections and functions of individual nuclei

Nucleus	Afferents	Efferents	Function
Anterior	Mammillothalamic tract; hippocampus via fornix; cingulate gyrus	Cingulate + parahippocampal gyrus (reciprocal)	Limbic relay — emotional tone, recent memory (Papez circuit), attention

Nucleus	Afferents	Efferents	Function
Dorsomedial (medial)	Prefrontal cortex, hypothalamus, amygdala, piriform cortex, other thalamic nuclei	Whole prefrontal cortex (reciprocal); hypothalamus	Integrates somatic, visceral, olfactory information with mood/emotional state
LD, LP, pulvinar	Other thalamic nuclei, superior colliculus, pretectum, spinothalamic tract	Parietal, occipital, temporal association cortex; cingulate gyrus	Association — multimodal sensory integration (connections incompletely known)
Ventral anterior (VA)	Reticular formation, substantia nigra, globus pallidus, premotor cortex, other thalamic nuclei	Premotor cortex, frontal eye field	Influences motor cortex activity; basal-ganglia motor loop
Ventral lateral (VL)	As VA, plus major input from contralateral cerebellum (dentate), minor input from red nucleus	Motor and premotor cortex (areas 4, 6)	Influences motor cortex; cerebellar relay for coordinated movement; "tremor cells"
Ventral posteromedial (VPM)	Trigeminal lemniscus (face); gustatory fibres	Somatosensory cortex (areas 3,1,2) + insula	Relays facial sensation and taste
Ventral posterolateral (VPL)	Medial + spinal (spinothalamic) lemnisci	Somatosensory cortex (areas 3,1,2) via posterior limb of internal capsule	Relays touch, pain, temperature, proprioception — trunk/limbs
Medial geniculate body	Inferior colliculus via inferior brachium, both ears (mainly contralateral)	Auditory radiation → superior temporal gyrus	Hearing
Lateral geniculate body	Optic tract (6-layered nucleus), opposite visual field	Optic radiation → occipital visual cortex	Vision
Intralaminar (incl. centromedian)	Reticular formation; spinothalamic/trigeminothalamic tracts; corpus striatum	Other thalamic nuclei → cortex; corpus striatum	Levels of consciousness and alertness; pain relay
Midline	Reticular formation	Uncertain / limbic structures	Poorly defined; probably arousal-related
Reticular nucleus	Cerebral cortex (corticothalamic collaterals), reticular formation	Other thalamic nuclei only — no cortex	Postulated "gate" regulating thalamocortical traffic

Two loops summarise overall thalamic connectivity: (1) every nucleus except the reticular nucleus exchanges reciprocal fibres with a cortical area — thalamus and cortex continually modify each other;

(2) the **cerebello-rubro-thalamo-cortico-ponto-cerebellar** and **cortico-striato-pallido-thalamo-cortical** loops, both essential for voluntary movement.

Functions of the thalamus (overall)

- ▶ Acts as the **sensory relay/gateway** to the cerebral cortex for all modalities except smell (olfactory information reaches the thalamus only indirectly, via the amygdala/hippocampus and mammillothalamic tract, after first being integrated at a lower level with taste and other sensations).
- ▶ Permits **crude appreciation** of pain, touch and temperature at its own level, even without the cortex; the cortex is needed only for fine discrimination (localisation, two-point discrimination, exact intensity/quality).
- ▶ **Motor integration** — relays basal ganglia and cerebellar output (VA, VL) to the motor/premotor cortex, influencing voluntary movement.
- ▶ **Arousal and consciousness** — the intralaminar and reticular nuclei, as part of the ascending reticular activating system, regulate the level of alertness and consciousness, and influence synchronisation/desynchronisation of cortical EEG rhythms.
- ▶ **Emotional/limbic function** — anterior nucleus (Papez circuit, recent memory) and dorsomedial nucleus (mood, emotional tone) link sensory experience to subjective/affective states.
- ▶ **Special sensory relay** — medial and lateral geniculate bodies relay hearing and vision respectively.

Applied / Clinical anatomy

- ▶ **Arterial supply** — mainly perforating branches of the **posterior cerebral artery**: the **posteromedial group** (thalamoperforating) supplies the medial and anterior parts; the **posterolateral group** (thalamogeniculate arteries) supplies the posterior and lateral parts; minor contributions from the posterior communicating, anterior/posterior choroidal and middle cerebral arteries.
- ▶ **Thalamic (Dejerine–Roussy) syndrome** — follows infarction of the lateral thalamic nuclei, classically from thalamogeniculate artery occlusion in a hypertensive patient: contralateral pansensory loss (VPL/VPM); **thalamic overreaction/pain** — raised threshold but, once reached, exaggerated, perverted, disagreeable burning pain that may outlast the stimulus and resist analgesics; emotional instability (spontaneous laughing/crying); choreoathetosis with ataxia may co-exist (adjacent caudate/lentiform or dentatothalamic involvement).
- ▶ **Thalamic hand** — contralateral wrist pronated and flexed, metacarpophalangeal joints flexed, interphalangeal joints extended; finger movement possible but slow, from altered muscle tone rather than paralysis.
- ▶ **Surgical relief of pain** — stereotactic lesioning of the intralaminar nuclei relieves intractable pain of terminal malignancy.
- ▶ **Deep brain stimulation (DBS)** — clinical application of nuclear topography: **VL (Vim)** for essential tremor/tremor-dominant Parkinsonism; **anterior nucleus** for refractory epilepsy; **centromedian nucleus** for Tourette's syndrome and disorders of consciousness; **VPL/VPM + periventricular grey** for chronic pain.

- ▶ Because the thalamus is centrally placed, a vascular lesion here often involves neighbouring structures — midbrain extension can cause coma; internal-capsule extension adds motor deficits that may overshadow pure thalamic signs.

High-yield exam pointers

- ▶ **Two bases of classification:** topographical (anterior / medial / lateral — with dorsal and ventral tiers of the lateral mass — plus intralaminar, midline, reticular, and metathalamic groups) and functional (specific-relay, specific-association, non-specific, reticular/gate-keeper).
- ▶ **Internal medullary lamina** (Y-shaped) creates the anterior, medial and lateral masses and houses the intralaminar nuclei; **external medullary lamina** separates the main thalamic mass from the **reticular nucleus**.
- ▶ **VPL** = body sensation (spinothalamic tract + medial lemniscus); **VPM** = face sensation + taste (trigeminal lemniscus + solitariothalamic tract) — both project to postcentral gyrus areas 3, 1, 2.
- ▶ **VA and VL** relay basal ganglia/cerebellar output to motor and premotor cortex — key to voluntary movement and DBS for tremor.
- ▶ **Anterior nucleus** = thalamic link in the **Papez circuit** — recent memory and emotional tone.
- ▶ Thalamus relays **all sensory modalities except olfaction**; the reticular nucleus is the only thalamic nucleus with **no cortical projection**.
- ▶ **Dejerine-Roussy thalamic syndrome:** thalamogeniculate artery occlusion → contralateral pansensory loss + thalamic pain + emotional lability ± choreoathetosis.
- ▶ **Pulvinar** is the largest thalamic nucleus (association type); **metathalamus** (MGB, LGB) relays hearing and vision respectively.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy.



Describe the hypothalamus and its nuclear subdivisions

Asked in: Paper IV Sep 2007 — RGUHS MD/MS Anatomy

Definition / Introduction

The **hypothalamus** is the ventral part of the diencephalon that forms the floor and the lower part of the lateral walls of the **third ventricle**. Although it constitutes only about 4 cm^3 (0.3% of total brain volume), it is the chief integrating centre for the **autonomic nervous system**, the **neuroendocrine (hypophyseal) system**, and **homeostatic/emotional behaviour** — through its rich vascular and neural connections it continuously samples the internal milieu and mounts appropriate corrective responses. It is composed of small, often poorly-demarcated groups of neurons — the **hypothalamic nuclei** — classified both by their **mediolateral position (zones)** and by their **anteroposterior position (regions)**.

1. Extent, boundaries and relations

Boundary	Structure
Anterior	Lamina terminalis ; continuous rostrally with the preoptic area (extends to the anterior commissure)
Posterior	Vertical plane behind the mammillary bodies ; continuous with the midbrain tegmentum and subthalamus
Superior	Hypothalamic sulcus , running from the interventricular foramen to the cerebral aqueduct, separating it from the thalamus
Inferior	Floor of the third ventricle — pierced by the optic chiasma , tuber cinereum/infundibulum , and mammillary bodies
Lateral	Internal capsule and optic tract anteriorly, subthalamus posteriorly

The **preoptic area**, though developmentally a telencephalic derivative (like the lamina terminalis), is functionally grouped with the hypothalamus and is included in most nuclear classifications.

2. External (basal) features

Viewed from the base of the brain, from before backwards: the **optic chiasma** → **tuber cinereum**, from which the hollow **infundibulum** (**pituitary stalk**) descends (its base encircled by the **median eminence**) → paired, pea-sized **mammillary bodies** → the **posterior perforated substance** in the interpeduncular fossa (pierced by central branches of the posterior cerebral arteries, and containing the small interpeduncular nucleus).

3. Nuclear subdivisions

Two complementary classical schemes are used, both taking the **column of the fornix** and the **mammillothalamic tract** (which run in a parasagittal plane) as the dividing landmark between medial and lateral nuclear groups.

(a) **Mediolateral zones** (nuclei listed anterior → posterior):

Medial zone	Lateral zone
Part of preoptic nucleus	Part of preoptic nucleus
Anterior nucleus	Part of suprachiasmatic nucleus
Part of suprachiasmatic nucleus	Supraoptic nucleus
Paraventricular nucleus	Lateral nucleus
Dorsomedial nucleus	Tuberomammillary nucleus
Ventromedial nucleus	Lateral tuberal nuclei
Infundibular (arcuate) nucleus	
Posterior nucleus	

The preoptic, suprachiasmatic and mammillary nuclei straddle both zones and are not confined to one side of the fornix/mammillothalamic plane.

(b) Anteroposterior regions, each further divided into medial/intermediate and lateral parts:

Region	Zone	Principal nucleus	Secretion / hallmark	Function
Chiasmatic (supraoptic)	Medial	Median preoptic	GnRH	Gonadotrophin control
	Medial	Periventricular	GnRH, somatostatin, CRH, TRH	Multiple releasing/inhibiting hormones
	Medial	Suprachiasmatic	—	"Master" circadian clock
	Intermediate	Supraoptic	Vasopressin	Osmoreceptor; ADH release
	Intermediate	Paraventricular	Vasopressin, oxytocin	Magnocellular + parvocellular parts
Tuberal (infundibulotuberal)	Medial	Dorsomedial	TRH, atrial natriuretic peptide	—
	Medial	Ventromedial	TRH	Satiety centre
	Medial	Arcuate (infundibular)	GHRH, dopamine	Secretes into hypophyseal portal system
	Lateral	Lateral hypothalamic area	—	Feeding ("hunger") centre
Posterior (mammillary)	Medial	Mammillary body	—	Memory (relay in Papez circuit)

The narrow periventricular zone continues posteriorly as the **posterior hypothalamic area**, which blends behind with the midbrain **periaqueductal grey**.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 11.10 — Different nuclei of hypothalamus in sagittal section (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.416)

Reproduce a **median sagittal section** and label, anterior to posterior: **lamina terminalis**, **preoptic nucleus**, **anterior nucleus**, **suprachiasmatic nucleus**, **paraventricular nucleus**, **supraoptic nucleus**, **dorsomedial nucleus**, **ventromedial nucleus**, **lateral hypothalamic area**, **tuberomammillary nucleus**, **infundibular (arcuate) nucleus**, **posterior nucleus**, **mammillary body**; mark the **fornix column/mammillothalamic tract** as the zone divider and the **hypothalamic sulcus** superiorly.

4. Functional correlation of the nuclei

- ▶ **Preoptic and anterior nuclei** → predominantly **parasympathetic** effects (bradycardia, hypotension, increased gut motility) and the **heat-loss response** (cutaneous vasodilation, sweating).
- ▶ **Posterior and lateral nuclei** → predominantly **sympathetic** effects (tachycardia, hypertension, pupillary dilation, hyperglycaemia) and the **heat-conservation/production response** (vasoconstriction, shivering — circuitry located in the dorsomedial posterior hypothalamus).
- ▶ **Lateral hypothalamic area** = hunger and thirst centre; **ventromedial nucleus** = satiety centre — the two act reciprocally on food intake and on intermediary metabolism (ventromedial stimulation favours glucagon release/glycogenolysis; lateral stimulation favours insulin release).
- ▶ **Suprachiasmatic nucleus** = the "master" circadian pacemaker; it is the only hypothalamic nucleus with a direct retinal (retinohypothalamic) input and entrains sleep-wake, temperature, and hormonal rhythms to the light-dark cycle.
- ▶ **Supraoptic and paraventricular nuclei** = magnocellular neurosecretory nuclei (vasopressin and oxytocin respectively); **periventricular and arcuate nuclei** = parvocellular neurosecretory nuclei controlling the anterior pituitary.

5. Connections of the hypothalamus

Afferent pathway	Origin → destination
Somatic/visceral/gustatory	Medial and spinal lemnisci, tractus solitarius, reticular formation → hypothalamic nuclei generally
Visual	Retina → optic chiasma → suprachiasmatic nucleus
Olfactory	Olfactory mucosa, via medial forebrain bundle → lateral hypothalamic nuclei
Corticohypothalamic	Frontal lobe cortex → hypothalamic nuclei (direct)
Hippocampohypothalamic	Hippocampal formation, via fornix → mammillary body (main limbic output route)
Amygdalohypothalamic	Amygdaloid complex, via stria terminalis (long route) and ventral amygdalofugal tract (short route) → hypothalamic nuclei

Afferent pathway	Origin → destination
Thalamohypothalamic	Dorsomedial and midline thalamic nuclei → hypothalamic nuclei
Tegmental	Midbrain tegmentum → hypothalamic nuclei

Efferent pathway	Course
Descending autonomic fibres	Reticular formation → brainstem parasympathetic nuclei (III, VII, IX, X) and, via reticulospinal fibres, sympathetic (T1–L2) and sacral parasympathetic (S2–S4) preganglionic neurons
Mammillothalamic tract	Mammillary body → anterior nucleus of thalamus → relayed to cingulate gyrus (limbic/Papez pathway)
Mammillotegmental tract	Mammillary body → reticular formation of midbrain tegmentum
Multiple pathways	Reciprocal connections to the limbic system (septal area, amygdala)

6. Hypothalamo-hypophyseal relationship

The hypothalamus controls the pituitary through **two distinct routes**:

- **Neural (hypothalamohypophyseal) tract** — magnocellular axons of the **supraoptic** and **paraventricular nuclei**, carrying hormone bound to the carrier protein **neurophysin**, descend through the infundibulum to terminate on fenestrated capillaries of the **posterior pituitary (pars nervosa)**, releasing **vasopressin** (mainly supraoptic — antidiuretic action, osmoreceptor-driven) and **oxytocin** (mainly paraventricular — uterine contraction/milk ejection).
- **Hypophyseal portal (vascular) system** — parvocellular neurosecretory axons end in the **median eminence/infundibular stem**, discharging releasing/inhibiting hormones onto the **superior hypophyseal artery capillary plexus**; long and short portal vessels carry these to sinusoids of the **anterior pituitary**.

Hypothalamic hormone	Nuclear origin	Anterior pituitary hormone
GnRH	Periventricular + arcuate nuclei (also median preoptic area)	LH, FSH
CRH	Parvocellular paraventricular/periventricular neurons	ACTH
TRH	Periventricular, ventromedial, dorsomedial nuclei	TSH
GHRH	Arcuate (infundibular) nucleus	Growth hormone (stimulates)
Somatostatin (GHIH)	Periventricular nucleus	Growth hormone (inhibits); also inhibits TSH

Hypothalamic hormone	Nuclear origin	Anterior pituitary hormone
Dopamine (PIH)	Arcuate nucleus	Prolactin (inhibits)

Applied / Clinical anatomy

- ▶ **Diabetes insipidus** — lesion of the supraoptic nucleus or the supraopticohypophyseal tract (e.g. head injury, pituitary stalk section) abolishes vasopressin release, causing polyuria of low specific gravity with polydipsia.
- ▶ **Fröhlich (adiposogenital) syndrome** — a suprasellar tumour (classically **craniopharyngioma**) damaging the **ventromedial nucleus** produces uncontrolled hyperphagia and truncal obesity, combined with genital hypoplasia from associated gonadotrophin deficiency.
- ▶ **Hyperthermia** — damage to the **anterior hypothalamus** (e.g. during surgery for suprasellar pituitary extensions) abolishes heat-loss mechanisms and can cause uncontrollable fever without the malaise of infective pyrexia.
- ▶ **Sexual disorders** — hypothalamic lesions in children may cause sexual precocity or retardation; in adults, impotence or amenorrhoea. **Kallmann syndrome** (failure of embryonic migration of GnRH neurons together with the olfactory placode) classically presents with anosmia and hypogonadotropic hypogonadism.
- ▶ **Emotional disturbance** — lesions/stimulation of the **ventromedial** and **lateral** nuclei can produce passivity or rage respectively; hypothalamic disease is also linked to disordered sleep-wake cycles (anterior/suprachiasmatic damage) and emotional lability.
- ▶ **Vascular supply** — anterior hypothalamus via central (anteromedial) branches of the **anterior cerebral artery**; posterior hypothalamus via central (posteromedial) branches of the **posterior cerebral/posterior communicating arteries**; at risk during anterior communicating artery aneurysm rupture or clipping, producing electrolyte disturbance or diabetes insipidus.

Recent advances

According to PubMed, the arcuate nucleus's classical role as source of hypophysiotrophic hormones is being refined at cellular level:

- ▶ **KNDy neurons** (co-expressing kisspeptin, neurokinin B and dynorphin) within the arcuate nucleus are now established as the anatomical "**GnRH pulse generator**." Recent work shows they are directly hyperpolarised by brainstem noradrenergic input from the locus coeruleus, pausing pulsatile GnRH/LH secretion ([DOI](https://doi.org/10.1038/s41467-025-60837-8), *Nature Communications* 2025), and that they excite preoptic (surge-generator) Kiss1 neurons via glutamatergic transmission to drive the ovulatory LH surge ([DOI](https://doi.org/10.1210/endocr/bqaf015), *Endocrinology* 2025).
- ▶ **Metabolic and immune/inflammatory stress** act directly on arcuate KNDy neurons: prostaglandin-dependent suppression of Kiss1 activity during systemic inflammation ([DOI](https://doi.org/10.1111/jne.70004), *J Neuroendocrinology* 2025), and a paraventricular-nucleus urocortin-2/CRHR2 pathway that likewise inhibits pulsatile LH secretion ([DOI](https://doi.org/10.1210/endocr/bqaf042), *Endocrinology* 2025) — refining the mechanism of classical "stress-anovulation."

- ▶ **Insulin-like growth factor-1** has been identified as a novel metabolic signal that depolarises and modulates KNDy neuron excitability, linking nutritional status directly to the arcuate pulse generator ([DOI](https://doi.org/10.1111/jne.70130), *J Neuroendocrinology* 2026).
- ▶ **GLP-1 receptor agonists** (the liraglutide/semaglutide anti-obesity drug class) act directly on arcuate POMC and NPY/AgRP neurons — the classical "satiety" and "feeding-centre" populations — reducing obesity-induced neuronal apoptosis via the PI3K/AKT/Foxo1 pathway, giving a mechanistic anatomical basis for how this drug class engages the hypothalamic feeding nuclei ([DOI](https://doi.org/10.1007/s00221-026-07274-1), *Experimental Brain Research* 2026).

High-yield exam pointers

- ▶ Hypothalamus = floor + lower lateral wall of the third ventricle; extends from the lamina terminalis to a plane behind the mammillary bodies; only ~4 cm³ (0.3% of brain) yet controls ANS, endocrine system and behaviour.
- ▶ Bounded above by the **hypothalamic sulcus** (separates it from thalamus), laterally by the **internal capsule**; the **preoptic area** is telencephalic in origin but functionally grouped with it.
- ▶ Two classifications of nuclei: **mediolateral zones** (medial vs lateral, divided by the plane of the fornix column + mammillothalamic tract) and **anteroposterior regions** (chiasmatic/supraoptic → tuberal → posterior/mammillary).
- ▶ **Supraoptic + paraventricular** = magnocellular → posterior pituitary (vasopressin, oxytocin); **arcuate + periventricular** = parvocellular → median eminence → hypophyseal portal system → anterior pituitary.
- ▶ **Suprachiasmatic nucleus** = master circadian clock; sole nucleus receiving direct retinal input.
- ▶ **Ventromedial nucleus** = satiety centre; **lateral hypothalamic area** = feeding/hunger and thirst centre; bilateral ventromedial destruction → hyperphagia/obesity (Fröhlich syndrome).
- ▶ **Anterior/preoptic nuclei** → parasympathetic + heat-loss; **posterior/lateral nuclei** → sympathetic + heat-conservation.
- ▶ **Mammillary body** → **mammillothalamic tract** → **anterior thalamic nucleus** → **cingulate gyrus** = a limb of the Papez memory circuit.
- ▶ Blood supply: **anterior medial (ACA)** branches to the anterior hypothalamus, **posterior medial (PCA/posterior communicating)** branches to the posterior hypothalamus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy. Recent-advances section per PubMed (DOIs 10.1038/s41467-025-60837-8, 10.1210/endocr/bqaf015, 10.1111/jne.70004, 10.1210/endocr/bqaf042, 10.1111/jne.70130, 10.1007/s00221-026-07274-1).



Describe the various nuclei of the thalamus. Mention its connections

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

The **thalamus** is the largest, dorsal part of the diencephalon — a pair of egg-shaped grey-matter masses, one on each side of the slit-like third ventricle, joined across the midline by the **interthalamic adhesion** (*massa intermedia*). It is the great **sensory relay and integrating station** of the brain: every sensory modality except olfaction is relayed through a specific thalamic nucleus to the cerebral cortex, and the thalamus additionally relays motor, limbic and associative information via reciprocal, topographically organised **thalamocortical–corticothalamic loops**. Internally, a Y-shaped sheet of white matter, the **internal medullary lamina**, splits the grey matter into anterior, medial and lateral nuclear masses, around and within which several smaller nuclear groups are described.

1. Gross internal architecture — the medullary laminae

- ▶ **Stratum zonale** — thin layer of white matter capping the superior surface.
- ▶ **External medullary lamina** — thin sheet on the lateral surface, separating the main nuclear mass from the **reticular nucleus** and, more laterally, the internal capsule.
- ▶ **Internal medullary lamina (IML)** — a Y-shaped bundle that splits anterosuperiorly into three limbs; the **anterior nuclear group** lies between the limbs of the Y, the **medial nuclear group** medial to the stem, and the **lateral nuclear mass** lateral to the stem. Small **intralaminar nuclei** are embedded within the IML itself.

2. Classification of the thalamic nuclei

Group	Principal nuclei	Chief feature
Anterior	Anteroventral, anteromedial, anterodorsal (together = "anterior nucleus")	Lies between the limbs of the Y; part of the Papez (limbic) circuit
Medial	Dorsomedial (mediodorsal) nucleus — magnocellular (anteromedial) + parvocellular (posterolateral) parts	Largest nucleus of this group; linked to the whole prefrontal cortex
Lateral — ventral tier	Ventral anterior (VA), ventral lateral (VL), ventral posterior (VP) = ventral posterolateral (VPL) + ventral posteromedial (VPM)	VA/VL = motor relay; VPL/VPM = principal somatosensory relay
Lateral — dorsal tier	Lateral dorsal (LD), lateral posterior (LP), pulvinar	Association/"sensory-modulator" nuclei; pulvinar is the largest single nucleus, overhangs the superior colliculus

Group	Principal nuclei	Chief feature
Intralaminar	Anterior subgroup — central medial, paracentral, central lateral; posterior subgroup — centromedian (largest) and parafascicular	Embedded in the IML; related to the reticular activating system
Midline	Reuniens, rhomboid, parataenial nuclei	Lie against the third-ventricular ependyma/interthalamic adhesion; limbic connections
Reticular	Reticular nucleus	Thin curved lamella between external medullary lamina and internal capsule; the only thalamic nucleus that does <i>not</i> project to the cortex
Metathalamus (now classed with thalamus)	Medial geniculate body (MGB), lateral geniculate body (LGB)	MGB = auditory relay; LGB = visual relay (6-layered)

Functional classification (a favourite exam grouping):

Functional group	Nuclei
Motor relay	Ventral anterior, ventral lateral
Sensory relay	Ventral posterolateral, ventral posteromedial, medial geniculate body, lateral geniculate body
Sensory modulator / association	Lateral dorsal, lateral posterior, pulvinar
Limbic	Anterior nucleus, dorsomedial nucleus
Non-specific (reticular-activating)	Intralaminar nuclei, midline nuclei, reticular nucleus

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 9.5 — Nuclei of thalamus (IB Singh — *Textbook of Human Neuroanatomy*, p.157)

Reproduce a horizontal (schematic) section of the thalamus and label: **anterior nucleus**, **medial nuclei**, **internal medullary lamina**, **interthalamic adhesion**, **centromedian nucleus**, then the lateral mass subdivided into **LD (lateral dorsal)**, **LP (lateral posterior)**, **pulvinar**, **VA (ventral anterior)**, **VL (ventral lateral)**, **VP** split into **VPL** and **VPM**, and finally the **medial and lateral geniculate bodies** at the postero-inferior pole.

3. Connections — general principles

- ▶ Every thalamic nucleus **except the reticular nucleus** sends axons to a defined cortical area, and every cortical area returns reciprocal corticothalamic fibres — information reaching the thalamus is always shared with, and modifiable by, the cortex.
- ▶ **Afferents** converge from: the ascending sensory pathways (medial lemniscus, spinothalamic tract, trigeminothalamic/trigeminal lemniscus, solitariothalamic fibres for taste), the optic tract (to LGB) and auditory pathway/inferior brachium (to MGB), the cerebellum (dentate nucleus →

VL), the basal nuclei (globus pallidus, substantia nigra → VA/VL), the hypothalamus and mammillary bodies (→ anterior nucleus via mammillothalamic tract), the amygdala/piriform cortex (→ dorsomedial nucleus), and the reticular formation (→ intralaminar/midline nuclei).

- **Efferents** leave as four **thalamic radiations (peduncles)** — anterior/frontal, superior/dorsal, posterior/caudal, and inferior/ventral — carrying thalamocortical fibres through the internal capsule and corona radiata to virtually the whole cerebral cortex; additional efferents pass to the corpus striatum, hypothalamus and reticular formation.
- Two clinically important sensorimotor loops run **through** the thalamus: the **cerebello-rubro-thalamo-cortical-ponto-cerebellar loop** and the **cortico-striato-pallido-thalamo-cortical loop** — both essential for normal voluntary movement.

4. Connections of individual nuclei

Nucleus	Major afferents	Major efferents (cortex)	Function
Anterior	Mammillary body (mammillothalamic tract), hippocampal formation via fornix	Cingulate gyrus, parahippocampal gyrus	Papez circuit — emotion, recent memory
Dorsomedial (medial)	Amygdala, piriform cortex, hypothalamus, other thalamic nuclei	Whole prefrontal cortex	Integrates somatic/visceral/olfactory information with emotional/subjective states
Ventral anterior (VA)	Globus pallidus, substantia nigra pars reticularis, reticular formation	Premotor and supplementary motor cortex	Motor relay — influences motor cortex activity
Ventral lateral (VL)	Contralateral dentate nucleus (cerebellum), globus pallidus	Primary motor and supplementary motor cortex	Motor relay — target for thalamotomy in tremor
Ventral posterolateral (VPL)	Medial lemniscus, spinothalamic tract (body/limbs)	Primary somatosensory cortex (areas 3, 1, 2)	Relays touch, pain, temperature, proprioception from trunk/limbs
Ventral posteromedial (VPM)	Trigeminal lemniscus, solitariothalamic (taste) fibres	Primary somatosensory cortex (face area)	Relays facial sensation and taste
Lateral geniculate body	Optic tract (contralateral visual field)	Visual cortex (area 17) via optic radiation	Vision
Medial geniculate body	Inferior colliculus via inferior brachium	Auditory cortex (superior temporal gyrus) via auditory radiation	Hearing

Nucleus	Major afferents	Major efferents (cortex)	Function
LD / LP / Pulvinar	Other thalamic nuclei, superior colliculus, pretectum	Parietal, cingulate, occipital, temporal association cortex	Sensory integration/association; pulvinar = "lower visual centre"
Intralaminar (centromedian and others)	Reticular formation, spinothalamic/trigeminothalamic collaterals, globus pallidus, cerebellar nuclei	Widespread cortex + corpus striatum	Levels of consciousness, alertness, sensorimotor integration, pain relay
Midline nuclei	Reticular formation, hypothalamus, periaqueductal grey	Hippocampus, amygdala, cingulate cortex	Limbic — memory and arousal
Reticular nucleus	Cerebral cortex, reticular formation	Other thalamic nuclei only (not cortex)	Gates/regulates thalamocortical traffic

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 11.5 — Scheme to show connections of ventral and lateral groups of thalamic nuclei (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.401)

Reproduce a simple flow scheme showing: **medial/spinal lemniscus** and **trigeminal lemniscus/solitariothalamic tract** entering VPL/VPM and projecting to the **sensory cortex** (areas 3, 1, 2); **globus pallidus** and **contralateral cerebellum** entering VA/VL and projecting to the **premotor** (area 6) and **motor cortex** (area 4); reciprocal dashed arrows from LD/LP/pulvinar to the **cingulate gyrus** and **superior parietal lobule**.

Applied / Clinical anatomy

- **Arterial supply** — chiefly perforating branches of the **posterior cerebral artery**: the **posteromedial (thalamoperforating) group** supplies the anterior and medial parts, and the **posterolateral group (thalamogeniculate arteries)** supplies the posterior and lateral parts; additional twigs come from the posterior communicating, anterior choroidal, posterior choroidal and middle cerebral arteries.
- **Thalamic syndrome of Dejerine–Roussy** — follows vascular occlusion of a thalamogeniculate branch of the posterior cerebral artery (posterolateral thalamus): **contralateral pansensory loss** (ventral posterior nuclei), severe **thalamic pain/"anaesthesia dolorosa"** (intralaminar and other non-specific nuclei), **transient hemiparesis** (adjoining internal capsule), and **hemiataxia with choreiform movements** (pallidofugal fibres traversing the region).
- **Thalamic hand** — contralateral wrist pronated/flexed with flexed metacarpophalangeal and extended interphalangeal joints, due to altered muscle tone after a thalamic lesion.
- **Korsakoff syndrome** — damage to the anterior nucleus (a limb of the Papez circuit) causes loss of recent memory and inability to form new memories.
- **Stereotactic thalamotomy** of the posterior part of the **ventral lateral nucleus** (which receives cerebellar/pallidal input) historically relieved parkinsonian and essential tremor; it is now largely

superseded by **deep brain stimulation** and **MR-guided focused ultrasound (MRgFUS)** **thalamotomy** of the ventral intermediate (Vim) nucleus.

- ▶ A thalamic vascular lesion, because the thalamus is centrally placed, commonly produces signs from **neighbouring structures** (midbrain — coma; internal capsule — extensive motor/sensory deficit) that overshadow the pure thalamic signs.

Recent advances

- ▶ **Bilateral, staged MRgFUS thalamotomy** of the Vim nucleus (FDA-approved for staged bilateral treatment of medication-refractory essential tremor) continues to accrue 2025 outcome data — patient-reported tremor control and quality-of-life outcomes comparable to bilateral deep brain stimulation, with probabilistic lesion-location mapping refining the optimal Vim target (PubMed PMID 41159306, 2025; *Movement Disorders* 2025).
- ▶ **7-Tesla MRI-based connectivity targeting** of thalamic/subthalamic nuclei for deep brain stimulation now has multi-institutional consensus recommendations, reflecting improved in-vivo visualisation of individual thalamic nuclei beyond classical stereotactic atlases (*Journal of Neurosurgery* 143(5), 2025).
- ▶ **Diffusion-MRI structural-connectivity-based parcellation** of the thalamus is being benchmarked against classical cyto-architectural nuclear maps, refining in-vivo, patient-specific nuclear boundaries for neurosurgical planning (medRxiv 2025.09.16.25335779).
- ▶ **Central-thalamic (intralaminar) deep brain stimulation** for disorders of consciousness — a 2025 individual-participant-data meta-analysis found cyclic stimulation of the central thalamus acutely improves daytime arousal in severely brain-injured patients, extending the classical concept of intralaminar nuclei as part of the ascending reticular activating system into a clinical restorative tool (PubMed PMID 40680302, 2025, *Journal of Neurosurgery*).

High-yield exam pointers

- ▶ Y-shaped internal medullary lamina divides the thalamus into **anterior, medial and lateral** nuclear masses; intralaminar nuclei lie within it, reticular nucleus lies outside the external medullary lamina.
- ▶ **VPL** relays body/limb sensation (medial lemniscus + spinothalamic tract); **VPM** relays face sensation and taste (trigeminal lemniscus + solitariothalamic fibres) — both project to areas 3, 1, 2.
- ▶ **VA/VL** = motor relay nuclei (globus pallidus, substantia nigra, contralateral cerebellum → premotor/motor cortex).
- ▶ **MGB** = auditory relay, **LGB** = visual relay; both now classed as thalamic (metathalamic) nuclei.
- ▶ **Anterior nucleus** = limbic/Papez circuit — mammillothalamic tract in, cingulate gyrus out; lesion → Korsakoff-type memory loss.
- ▶ **Centromedian** is the largest intralaminar nucleus; intralaminar + midline + reticular nuclei form the "non-specific" thalamic group linked to the reticular activating system.
- ▶ **Reticular nucleus is the sole thalamic nucleus that does NOT project to the cerebral cortex** — it projects only to other thalamic nuclei.

- ▶ **Dejerine–Roussy thalamic syndrome** = thalamogeniculate artery (branch of posterior cerebral artery) occlusion → contralateral sensory loss + thalamic pain + transient hemiparesis + hemiataxia.
- ▶ Thalamus receives every sensory modality **except smell** directly; olfactory information reaches it indirectly via the amygdaloid complex.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e. Recent-advances section per PubMed (PMID 41159306; PMID 40680302) and Journal of Neurosurgery 2025 (143(5)) reporting on 7T MRI-guided DBS targeting.



Epithalamus

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction The epithalamus is the smallest and most dorsally-placed of the four subdivisions of the diencephalon (the others being the thalamus, subthalamus and hypothalamus), lying posterosuperior to the thalamus. It forms part of the roof and posterior wall of the third ventricle and comprises the habenular nuclei with their connecting fibre tracts (stria medullaris thalami, habenular commissure), the posterior commissure and the pineal gland. Functionally it is a phylogenetically old relay linking the limbic system to the midbrain reticular formation (via the habenular nuclei), and an endocrine transducer of the light–dark cycle to the reproductive and circadian axes (via the pineal gland).

Location and extent

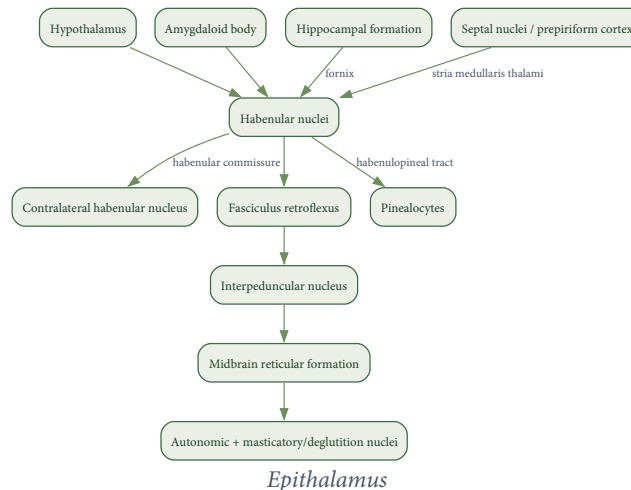
- ▶ Occupies the caudal part of the roof of the diencephalon, immediately posterosuperior to the thalamus.
- ▶ Contributes to the **posterior wall of the third ventricle**, formed (from above down) by the pineal body, the habenular commissure and the posterior commissure.
- ▶ Contributes to part of the **roof** of the third ventricle, continuous anteriorly with the tela choroidea and the ependyma stretched between the two thalami.
- ▶ Bounded laterally by the **habenular trigone** — a small triangular depression above the superior colliculus and medial to the pulvinar, limited medially by the stria medullaris thalami and the stalk of the pineal body.
- ▶ The **suprapineal recess** of the third ventricle lies above the pineal stalk in relation to the epithalamus; the **pineal recess** lies between the two laminae of the pineal stalk.

Components of the epithalamus

Component	Salient feature
Habenular nuclei (medial + lateral)	Grey matter beneath the floor of each habenular trigone; medial nucleus densely packed and cholinergic, lateral nucleus more dispersed
Stria medullaris thalami (habenular stria)	Afferent bundle running along the junction of the medial and superior thalamic surfaces to reach the habenular nucleus
Habenular commissure	Connects the two habenular nuclei; crosses in the superior (anterior) lamina of the pineal stalk
Posterior commissure	Connects midbrain/pretectal nuclei of the two sides; crosses in the inferior (posterior) lamina of the pineal stalk
Pineal gland (epiphysis cerebri)	Neuroendocrine gland attached by the stalk between the two laminae
Paraventricular nuclei (anterior + posterior)	Included in the epithalamus by Gray's Anatomy, in addition to the habenular complex

Habenular nuclei, stria medullaris thalami and connections

- ▶ The habenular nucleus is a small nodal group of neurones on the dorsomedial aspect of the thalamus, forming part of the **limbic system**.
- ▶ **Afferents** reach it chiefly through the stria medullaris thalami: from the hypothalamus, the amygdaloid body (via the stria terminalis route), the hippocampal formation (via the fornix), the septal nuclei and prepiriform cortex, the nucleus basalis of Meynert, the pars compacta of the substantia nigra, the midbrain raphe nuclei and the lateral dorsal tegmental nucleus. Some stria medullaris fibres decussate to reach the contralateral habenular nucleus as the **habenular commissure**.
- ▶ **Efferents** leave the ventral margin of the nuclei as the **fasciculus retroflexus** (habenulo-interpeduncular tract), which skirts the mediodorsal thalamic nucleus and the red nucleus to end in the **interpeduncular nucleus** of the midbrain; this in turn relays to the midbrain reticular formation, from which tectotegmentospinal fibres and the dorsal longitudinal fasciculus reach autonomic preganglionic neurones (salivary, gastric and intestinal secretomotor) and the motor nuclei of mastication/deglutition. Additional habenular efferents pass to the raphe nuclei, substantia nigra, ventral tegmental area, hypothalamus and basal forebrain.
- ▶ The medial habenular nucleus also gives the **habenulopineal tract**, by which serotonergic and noradrenergic afferents relayed through the habenula influence pinealocyte activity.
- ▶ **Function:** the habenular complex is the principal point of convergence of olfactory, visceral and somatic (basic emotional) inputs, relaying them onto autonomic and viscerosendocrine effector pathways; it has also been implicated in the control of sleep, thermoregulation and neuroendocrine regulation.



Posterior commissure

- ▶ A fasciculus that decussates in the **inferior lamina** of the pineal stalk; its exact fibre constitution in humans is not fully established.
- ▶ Associated nuclei include the interstitial nucleus of the posterior commissure and the nucleus of Darkschewitsch.
- ▶ Carries fibres connecting the two superior colliculi, pretectal nuclei and posterior thalamic nuclei, and fibres linking the tectal and habenular nuclei; it is functionally linked to convergence and vertical-gaze mechanisms of the dorsal midbrain.

Pineal gland (epiphysis cerebri)

- ▶ A small, reddish-grey, conical body about **8 mm long**, occupying the groove between the two superior colliculi, inferior to the splenium of the corpus callosum from which it is separated by the tela choroidea of the third ventricle.
- ▶ Its base is attached by a **stalk (peduncle)** that divides into superior and inferior laminae, separated by the pineal recess; the superior lamina carries the habenular commissure, the inferior lamina the posterior commissure.
- ▶ **Structure:** composed of **pinealocytes** (highly modified neurones with multiple synaptic ribbons and gap junctions, but no true synapses onto other neurones) and **astrocyte-like neuroglial cells**; pial septa carrying blood vessels and unmyelinated sympathetic fibres divide the gland into lobules. The pineal contains **no neural (ganglion cell) tissue** of its own.
- ▶ **Blood supply:** pineal arteries, branches of the medial posterior choroidal arteries (from the posterior cerebral artery); drainage is via pineal veins into the internal cerebral veins and great cerebral vein of Galen.
- ▶ **Nerve supply:** the **nervus conarii** — postganglionic sympathetic fibres from the superior cervical ganglion — making the pineal the only part of the brain innervated by a nerve arising outside the central nervous system; a ganglion conarii is sometimes described at its apex.
- ▶ **Comparative anatomy:** in some reptiles the epiphysis cerebri is double — an anterior parapineal organ forming the parietal ("third") eye, and a posterior glandular part; the human pineal represents only the persistent posterior glandular component.

- **Development:** the epithalamus (pineal gland + habenular nuclei) develops from the roof plate of the diencephalon, the pineal outgrowing posteriorly at the diencephalon–midbrain junction.

□ Fig 11.8 — (A) The pineal gland in relation to the third ventricle and habenular and posterior commissures (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.409)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A midsagittal section through the posterior diencephalon showing:

- Splenium of corpus callosum
- Tela choroidea of the third ventricle
- Suprapineal recess
- Pineal body with its stalk
- Superior lamina of stalk → **habenular commissure**
- Inferior lamina of stalk → **posterior commissure**
- Pineal recess (between the two laminae)
- Superior colliculi (paired, below the pineal)
- Habenular trigone / habenular nucleus and stria medullaris thalami
- Posterior end (pulvinar) of thalamus
- Third ventricle cavity, continuing into the cerebral aqueduct

Functions of the epithalamus

- **Habenular complex** — integrates olfactory, limbic and hypothalamic input and routes it to brainstem autonomic and reticular effectors via the fasciculus retroflexus; implicated in sleep, thermoregulatory and visceral control.
- **Pineal gland** — an endocrine organ that synthesises **serotonin and, from it, melatonin** (via N-acetyltransferase), with a circadian rhythm driven by the suprachiasmatic nucleus and suppressed by light. Melatonin is largely **inhibitory** on the adenohypophysis, neurohypophysis, endocrine pancreas, parathyroids, adrenal cortex/medulla and gonads, and in particular suppresses hypothalamic GnRH — thereby holding back gonadal maturation until an appropriate age (regulation of onset of puberty). It also functions as the body's principal **biological clock/photoneuroendocrine transducer**.

Applied / Clinical anatomy

- **Pineal calcification:** from the second decade onward, calcareous corpora arenacea ("brain sand") deposit in the gland; together with the choroid plexus this is the commonest site of physiological intracranial calcification, visible on plain skull radiograph (classically ~5 cm above the external auditory meatus on a lateral view) and on CT/MRI — a useful **midline landmark**; lateral shift of the calcified shadow suggests a space-occupying lesion displacing the brain.
- **Pineal region tumours** (germinoma is the commonest) compress the tectal plate/superior colliculi and pretectal area to produce **Parinaud (dorsal midbrain) syndrome** — paralysis of upward gaze with convergence–retraction nystagmus — and may obstruct the cerebral aqueduct, causing **non-communicating hydrocephalus**.

- ▶ **Precocious puberty:** destructive/non-secretory pineal lesions reduce melatonin's inhibitory brake on GnRH release and classically precipitate precocious puberty; conversely a hormonally active pineal tumour can delay puberty.
- ▶ **Melatonin therapeutics:** exogenous melatonin, mimicking the pineal's normal secretion, is used to reset circadian rhythm in jet lag and shift-work sleep disorders.
- ▶ **Surgical approach** to pineal region masses (supracerebellar-infratentorial or occipital transtentorial) must respect the intimate relations of the gland to the great cerebral vein of Galen, internal cerebral veins and straight sinus.
- ▶ **Habenular lesions/ablation** cause disturbances of visceral, endocrine and thermal regulation, underscoring its role as a limbic-autonomic relay.

High-yield exam pointers

- ▶ Epithalamus = habenular nuclei + stria medullaris thalami + habenular commissure + posterior commissure + pineal gland (Gray's Anatomy adds the paraventricular nuclei).
- ▶ Lies posterosuperior to thalamus; forms part of the roof and the whole of the posterior wall of the third ventricle.
- ▶ Habenular nucleus: limbic relay — afferents from hypothalamus/amygdala/hippocampus/septal nuclei via stria medullaris thalami; efferents via fasciculus retroflexus to the interpeduncular nucleus.
- ▶ Pineal gland ≈ 8 mm long, conical, between the superior colliculi below the splenium; stalk has two laminae (superior = habenular commissure, inferior = posterior commissure) separated by the pineal recess.
- ▶ Made of pinealocytes + glial cells, has no neurones of its own, and is the only brain structure supplied by a nerve of extracranial (sympathetic, nervus conarii) origin.
- ▶ Secretes melatonin, largely inhibitory on other endocrine glands; regulates onset of puberty and circadian rhythm.
- ▶ Commonest site of intracranial calcification (with choroid plexus) — a radiological midline marker; lateral shift indicates a mass lesion.
- ▶ Pineal region tumour → Parinaud syndrome + obstructive hydrocephalus; destructive lesion → precocious puberty.
- ▶ Develops from the roof plate of the diencephalon at its junction with the midbrain; represents the vestigial posterior (glandular) part of the reptilian double epiphysis, the parietal-eye component having disappeared in humans.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3-4 8e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy.



Hypothalamic nuclei

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction The **hypothalamus** is the part of the diencephalon lying below the thalamus, forming the floor and lower part of the lateral wall of the **third ventricle**; anatomically it weighs only about 4 g ($\approx 4 \text{ cm}^3$), just 0.3% of total brain mass, yet it is the master integrator of the **autonomic nervous system, the endocrine system, and the limbic system**, earning it Sherrington's description as the "**head ganglion of the autonomic nervous system**." Microscopically it is built of numerous, often ill-defined, aggregations of small nerve cells — the **hypothalamic nuclei** — arranged around the third ventricle and best understood by a combined zonal and regional classification. The nuclei act as the neural substrate for temperature regulation, food and water intake, circadian rhythm, emotional behaviour, and — via the pituitary — the entire neuroendocrine axis.

1. Location, boundaries and gross subdivision

- ▶ Extends anteroposteriorly from the **lamina terminalis/optic chiasma** to a vertical plane just behind the **mammillary bodies**, merging caudally with the midbrain tegmentum.
- ▶ **Boundaries**: anteriorly the lamina terminalis; posteriorly the subthalamus/midbrain tegmentum; superiorly the hypothalamic sulcus separating it from the thalamus; laterally the internal capsule; medially the cavity of the third ventricle; inferiorly the floor structures — **optic chiasma, tuber cinereum with infundibulum, and mammillary bodies** — seen from the base of the brain.
- ▶ The **preoptic area**, though developmentally telencephalic, is included functionally with the hypothalamus in most descriptions.
- ▶ A parasagittal plane containing the **column of the fornix and the mamillothalamic tract** divides each half of the hypothalamus into a **medial zone** and a **lateral zone**; the medial zone is further split into an inner, thin **periventricular (subependymal) zone** and a thicker **intermediate zone** (some authors combine these two as a single medial zone).

2. Classification of the hypothalamic nuclei — zones and regions

The nuclei are conventionally named by combining the mediolateral **zone** with an anteroposterior **region**.

Region (antero → posterior)	Medial zone nuclei	Lateral zone nuclei
Preoptic region (adjoining lamina terminalis)	Medial preoptic nucleus	Lateral preoptic nucleus
Supraoptic (chiasmatic) region (above optic chiasma)	Anterior nucleus; part of the suprachiasmatic nucleus ; paraventricular nucleus	Part of the suprachiasmatic nucleus; supraoptic nucleus ; (rostral) lateral nucleus
Tuberal region (tuber cinereum, infundibulum, median eminence)	Dorsomedial nucleus ; ventromedial nucleus ; infundibular (arcuate) nucleus	Lateral tuberal nuclei ; lateral nucleus (continued)
Mammillary (posterior) region (mammillary bodies)	Posterior nucleus ; nuclei of the mammillary body	Tuberomammillary nucleus ; lateral nucleus (continued)

- ▶ The **preoptic, suprachiasmatic, and mammillary nuclei** overlap both zones and are exceptions to the strict medial/lateral division; the **lateral nucleus** runs the full anteroposterior length of the hypothalamus and cannot be assigned to a single region.
- ▶ Most boundaries between nuclei are histologically indistinct; modern tracer, immunohistochemical, and (more recently) transcriptomic techniques continue to refine and rename subgroups, so only the well-established major nuclei are examined.

3. Individual nuclei and their principal functions

Nucleus	Principal function
Supraoptic nucleus	Synthesizes vasopressin (ADH) ; acts as an osmoreceptor for blood osmotic pressure
Paraventricular nucleus	Synthesizes oxytocin ; parvocellular neurones secrete CRH and TRH
Preoptic and anterior nuclei	Control the parasympathetic system; anterior nucleus mediates heat-loss responses (cutaneous vasodilatation, sweating)
Posterior and lateral nuclei	Control the sympathetic system; posterior nucleus mediates heat-conservation/production (vasoconstriction, shivering)
Lateral nucleus	" Hunger centre " — stimulation increases feeding; also the " thirst centre "
Ventromedial nucleus	" Satiety centre " — bilateral destruction causes uncontrolled hyperphagia and obesity
Suprachiasmatic nucleus	Master circadian pacemaker ; receives direct retinal (retinohypothalamic) afferents
Arcuate (infundibular) nucleus	Neurosecretory cells producing GHRH , dopamine (PIH) and GnRH , released into the hypophyseal portal system at the median eminence
Dorsomedial nucleus	Influences gastrointestinal motility and blood pressure; contributes TRH-secreting neurones

4. Afferent and efferent connections

Afferent pathway	Origin → destination
Somatic/visceral afferents	Medial and spinal lemnisci, tractus solitarius, reticular formation → hypothalamic nuclei
Visual afferents	Retina → suprachiasmatic nucleus
Olfactory afferents	Olfactory mucosa, via medial forebrain bundle → hypothalamic nuclei
Corticohypothalamic fibres	Frontal lobe cortex → hypothalamic nuclei
Hippocampohypothalamic fibres	Hippocampus, via fornix → mammillary body (chief limbic output pathway)

Afferent pathway	Origin → destination
Amygdalohypothalamic fibres	Amygdaloid complex, via stria terminalis and ventral amygdalofugal pathway → hypothalamic nuclei
Thalamohypothalamic fibres	Dorsomedial and midline thalamic nuclei → hypothalamic nuclei
Tegmental fibres	Midbrain tegmentum → hypothalamic nuclei

Efferent pathway	Origin → destination
Descending reticular fibres	Preoptic, anterior, posterior and lateral nuclei → craniosacral parasympathetic (III, VII, IX, X nuclei; S2–S4) and thoracolumbar sympathetic (T1–L2) outflow
Mammillothalamic tract (bundle of Vicq d'Azyr)	Mammillary body → anterior thalamic nucleus → relayed to cingulate gyrus
Mammillotegmental tract	Mammillary body → reticular formation of midbrain tegmentum
Multiple diffuse pathways	Hypothalamic nuclei ↔ limbic system

5. Hypothalamo-hypophyseal connections and neurosecretion

- **Hypothalamohypophyseal tract:** unmyelinated axons of the **supraoptic** (mainly vasopressin) and **paraventricular** (mainly oxytocin) nuclei carry hormone bound to carrier proteins (**neurophysins**) down to the posterior lobe (neurohypophysis), where they are released into fenestrated capillaries.
- **Hypophyseal portal system:** the **superior hypophyseal artery** (branch of the internal carotid) forms a capillary plexus in the **median eminence/infundibulum**; long and short portal veins carry this blood to a second sinusoidal plexus among the secretory cells of the **anterior lobe**, delivering releasing/inhibiting hormones secreted by parvocellular neurosecretory neurones (mainly of the arcuate, periventricular and paraventricular nuclei).

Hypothalamic hormone	Principal nuclear origin	Anterior pituitary hormone affected
GHRH	Arcuate (infundibular) nucleus	Growth hormone ↑
GHIH (somatostatin)	Periventricular nucleus	Growth hormone ↓; also inhibits TSH
CRH	Paraventricular nucleus	ACTH ↑
TRH	Paraventricular and dorsomedial nuclei	TSH ↑
GnRH (LHRH)	Preoptic/anterior nuclei and arcuate/periventricular nuclei	LH and FSH ↑

Hypothalamic hormone	Principal nuclear origin	Anterior pituitary hormone affected
Dopamine (PIH)	Arcuate nucleus (tuberoinfundibular neurones)	Prolactin ↓

□ Fig 11.10 — Different nuclei of the hypothalamus in sagittal section (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.416)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a medial (sagittal) section through the third ventricle wall and label:

- ▶ **Landmarks:** fornix, mammillothalamic tract, lamina terminalis, anterior commissure, hypothalamic sulcus, interventricular foramen, aqueduct of Sylvius.
- ▶ **Medial-zone nuclei** (anterior → posterior): preoptic nucleus, anterior nucleus, paraventricular nucleus, dorsomedial nucleus, ventromedial nucleus, arcuate (infundibular) nucleus, posterior nucleus.
- ▶ **Lateral-zone nuclei:** supraoptic nucleus, lateral nucleus, tuberomammillary nucleus.
- ▶ **Mammillary nucleus** at the mammillary body; **optic chiasma**, **tuber cinereum** and **infundibular stalk** in the floor.

Applied / Clinical anatomy

- ▶ **Diabetes insipidus:** a lesion of the **supraoptic nucleus** or of the hypothalamohypophyseal tract abolishes vasopressin secretion, producing large volumes of low-specific-gravity urine and marked thirst — distinguished from diabetes mellitus by absence of glucosuria.
- ▶ **Fröhlich (adiposogenital) syndrome:** a hypothalamic tumour (classically a **craniopharyngioma**) near the tuber cinereum compresses the ventromedial/arcuate region and adjacent optic chiasma, producing truncal obesity, genital hypoplasia and **bitemporal hemianopia**.
- ▶ **Ventromedial nucleus** destruction → hyperphagia and obesity; **lateral nucleus** destruction → anorexia and weight loss; **anorexia nervosa** itself is regarded as a disorder of hypothalamic feeding control with psychogenic overlay.
- ▶ **Suprachiasmatic nucleus** lesions disrupt the sleep–wake cycle and other circadian rhythms (body temperature, adrenocortical activity, eosinophil count).
- ▶ **Hyperthermia or hypothermia** can follow head injury or hypothalamic surgery, reflecting loss of anterior (heat-loss) or posterior (heat-conservation) nuclear function.
- ▶ **Emotional disturbance:** stimulation of the lateral nuclei produces rage, and of the ventromedial nucleus produces passivity; lesions produce the reverse — clinically seen as unexplained weeping, laughter or rage in hypothalamic disease.
- ▶ Because the hypothalamus is small and centrally placed, it is easily compressed by suprasellar tumours or internal hydrocephalus, so an **acute** lesion produces florid signs while a slow-growing tumour may be silent for long periods.

Recent advances

- ▶ **Automated MRI segmentation of hypothalamic nuclei:** a deep convolutional-neural-network tool segments the whole hypothalamus and its subunits on routine T1-weighted MRI in seconds, approaching intra-rater precision, now enabling in-vivo volumetric study of individual nuclei in obesity and neurodegenerative disease (Billot B et al., *NeuroImage* 2020, DOI [10.1016/j.neuroimage.2020.117287](https://doi.org/10.1016/j.neuroimage.2020.117287)).
- ▶ **Human HYPOMAP — a spatio-cellular atlas of the hypothalamus:** single-nucleus RNA sequencing of 433,369 human hypothalamic cells combined with spatial transcriptomics has resolved spatially and molecularly distinct **arcuate POMC and AgRP neuron** subpopulations and their MC3R/MC4R and incretin-receptor (GLP1R/GIPR) profiles, refining the classical nuclear map at a molecular level and informing anti-obesity drug targets (Tadross JA et al., *Nature* 2025, DOI [10.1038/s41586-024-08504-8](https://doi.org/10.1038/s41586-024-08504-8)).
- ▶ **Arcuate KNDy (kisspeptin/neurokinin-B/dynorphin) neurons as the GnRH pulse generator:** this small arcuate-nucleus population has been confirmed as the anatomical "pulse generator" driving pulsatile GnRH/gonadotrophin secretion, with recent work clarifying the glutamatergic network mechanism of neuronal synchronization (Han SY et al., *Cell Reports* 2023, DOI [10.1016/j.celrep.2022.111914](https://doi.org/10.1016/j.celrep.2022.111914)).
- ▶ **AgRP/POMC arcuate melanocortin circuit:** optogenetic and chemogenetic dissection has clarified opposing AgRP (orexigenic) and POMC (anorexigenic) projections to the paraventricular and lateral hypothalamic nuclei, providing the anatomical basis for current incretin-based anti-obesity therapy (Deem JD et al., *FEBS J* 2022, DOI [10.1111/febs.16176](https://doi.org/10.1111/febs.16176)).
- ▶ **Posterior-hypothalamic deep brain stimulation for chronic cluster headache:** stereotactic targeting near the posterior hypothalamic nucleus/mammillothalamic-tract region, originally based on PET evidence of regional activation during attacks, has been reviewed across systematic case series confirming its role as a functional-anatomy-guided neurosurgical target (systematic review, *BMC Neurol* 2025, DOI [10.1186/s12883-025-04373-4](https://doi.org/10.1186/s12883-025-04373-4)).

High-yield exam pointers

- ▶ Hypothalamus = 4 g / 0.3% of brain mass; bounded by lamina terminalis, subthalamus, hypothalamic sulcus, internal capsule and third-ventricle cavity.
- ▶ Fornix + mammillothalamic tract mark the plane dividing **medial** and **lateral** zones; four anteroposterior regions — preoptic, supraoptic, tuberal, mammillary.
- ▶ **Supraoptic** → **vasopressin**; **paraventricular** → **oxytocin**; both reach the posterior pituitary via the hypothalamohypophyseal tract with neurophysin carrier proteins.
- ▶ **Arcuate nucleus** = origin of hypophysiotropic releasing/inhibiting hormones delivered via the **hypophyseal portal system** (superior hypophyseal artery branch of ICA).
- ▶ **Suprachiasmatic nucleus** = circadian pacemaker (retinal input); **ventromedial** = satiety; **lateral** = hunger/thirst; **anterior** = heat loss (parasympathetic); **posterior** = heat conservation (sympathetic).

- ▶ Mammillothalamic tract → anterior thalamic nucleus → cingulate gyrus (Papez circuit link); mammillotegmental tract → midbrain reticular formation.
- ▶ Diabetes insipidus (supraoptic lesion); Fröhlich syndrome (adiposogenital dystrophy with bitemporal hemianopia); ventromedial destruction → obesity; lateral destruction → anorexia.
- ▶ Preoptic area is developmentally telencephalic but functionally grouped with the hypothalamus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e (text and Fig. 11.10). Recent-advances citations from PubMed/Nature/Cell Reports as linked above.



Hypothalamohypophyseal tract

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction — The hypothalamohypophyseal tract (also called the supraopticohypophyseal tract) is the direct neurosecretory nerve pathway by which magnocellular neurons of the supraoptic and paraventricular nuclei of the hypothalamus discharge vasopressin and oxytocin into the posterior lobe of the hypophysis cerebri (neurohypophysis). It is one of the two anatomical routes by which the hypothalamus controls the pituitary gland, the other being the parvocellular tuberoinfundibular tract and hypophyseal portal system that regulates the anterior lobe (adenohypophysis). Together these pathways make the hypothalamo-hypophyseal axis the master neuroendocrine link between the nervous and endocrine systems.

1. Hypothalamic nuclei of origin

- ▶ **Supraoptic nucleus (SON)** — a compact group of large (magnocellular) neurons curved over the lateral part of the optic chiasma, with a thin retrochiasmatic extension behind it; virtually all its neurons project to the neurohypophysis and synthesize mainly **vasopressin**.
- ▶ **Paraventricular nucleus (PVN)** — extends from the hypothalamic sulcus down across the medial aspect of the column of the fornix; contains a mixed neuronal population:
 - **Magnocellular neurons** (lie laterally) — project to the neurohypophysis; synthesize mainly **oxytocin**, with vasopressin-producing cells clustering ventrolaterally and oxytocin cells around them.
 - **Parvocellular neurons** (lie medially) — project instead to the median eminence and infundibulum as part of the tuberoinfundibular tract (see below), producing releasing/inhibiting hormones, not vasopressin or oxytocin.
- ▶ Isolated clusters of magnocellular neurosecretory cells also occur between the SON and PVN and contribute a small number of axons to the tract.

Feature	Magnocellular neurons	Parvocellular neurons
Location	Supraoptic nucleus; lateral part of paraventricular nucleus	Medial paraventricular nucleus; arcuate (infundibular) and periventricular nuclei
Hormone produced	Vasopressin (SON) / Oxytocin (PVN)	Hypophysiotropic releasing and release-inhibiting hormones
Axonal tract	Hypothalamohypophyseal (supraopticohypophyseal) tract	Tuberoinfundibular tract
Destination	Pars nervosa (posterior lobe) — direct systemic release	Median eminence — hypophyseal portal veins — pars anterior
Storage form	Herring bodies (dilated axon terminals)	No comparable storage; act promptly on portal capillaries

2. Course and termination of the tract

- ▶ Axons of the paraventricular magnocellular neurons first pass towards the supraoptic nucleus as the **paraventriculohypophysial tract**, where they join the axons of the supraoptic neurons.
- ▶ Together they form the **supraopticohypophysial (hypothalamohypophyseal) tract**, which runs down superficially through the infundibulum (pituitary stalk) and enters the neural lobe (pars nervosa).
- ▶ Within the pars nervosa the unmyelinated axons become distended and branch repeatedly around the fenestrated capillaries of the posterior lobe, where the neurosecretion is released directly into the bloodstream — there is **no synapse and no intervening portal system** for this pathway, unlike the anterior-lobe route.
- ▶ The thin axons are ensheathed by astrocytes within the infundibulum; near the posterior lobe these are replaced by **pituicytes**, dendritic glial cells whose processes end on capillary/sinusoidal walls between the nerve terminals and provide structural, non-secretory support.

3. Neurosecretory transport and storage

- ▶ Vasopressin and oxytocin are synthesized in the cell bodies of the supraoptic and paraventricular neurons, each bound to a specific carrier protein called a **neurophysin**, and packaged into membrane-bound secretory granules.
- ▶ The hormone-neurophysin granules are transported down the axons by **axoplasmic flow** and accumulate at intervals along the terminal axon as swollen dilatations called **Herring bodies**, which act as short-term storage depots.
- ▶ On appropriate stimulation, the granules are released by exocytosis at the axon terminals directly onto the fenestrated capillaries of the neurohypophysis, and the hormone (dissociating from its neurophysin) enters the systemic circulation.
- ▶ This is anatomically distinct from the parvocellular pathway: releasing/inhibiting hormones from the tuberoinfundibular tract are released onto the **primary capillary plexus of the median eminence**, drain via long and short **hypophyseal portal veins**, and act on secretory cells of the pars anterior — they never reach the systemic circulation directly at this level.

Feature	Hypothalamohypophyseal tract	Tuberoinfundibular tract + hypophyseal portal system
Neurons of origin	Magnocellular (SON + lateral PVN)	Parvocellular (arcuate/periventricular + medial PVN)
Cargo	Vasopressin, oxytocin (with neurophysins)	Releasing hormones (GHRH, TRH, CRH, GnRH) and release-inhibiting hormones (somatostatin, dopamine)
Termination	Fenestrated capillaries of the pars nervosa	Primary capillary plexus of the median eminence → portal veins → sinusoids of pars anterior
Target gland regulated	Neurohypophysis (direct systemic release)	Adenohypophysis (ACTH, TSH, FSH, LH, GH, prolactin secretion)
Storage	Herring bodies	None comparable — acts promptly through the portal blood

4. Hormones carried and their actions

Hormone	Principal nucleus of synthesis	Carrier	Chief actions
Vasopressin (antidiuretic hormone, ADH)	Supraoptic nucleus	Neurophysin	Vasoconstriction; increases water reabsorption in the distal convoluted tubules and collecting tubules of the kidney (antidiuretic action). The supraoptic nucleus itself acts as an osmoreceptor , detecting as little as a 1% rise in plasma osmotic pressure, and also responds to a fall of >5–10% in blood volume/pressure (via vagal and glossopharyngeal afferents relaying through the nucleus tractus solitarius), triggering both ADH release and the urge to drink.

Hormone	Principal nucleus of synthesis	Carrier	Chief actions
Oxytocin	Paraventricular nucleus	Neurophysin	Stimulates contraction of uterine smooth muscle during labour — a positive-feedback loop (the Ferguson reflex) initiated by cervical/uterine stretch afferents relayed via the pelvic plexus and anterolateral spinal pathways to the magnocellular oxytocin neurons; also contracts the myoepithelial cells around mammary alveoli and ducts, producing the milk-ejection reflex evoked by suckling (this reflex can be conditioned to a baby's cry and inhibited by maternal stress).

5. Blood supply of the neurohypophysis

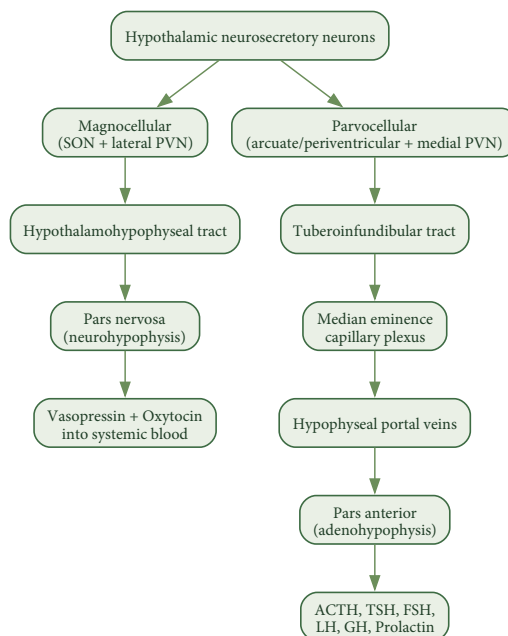
- ▶ **Superior hypophyseal arteries** (branches of the supraclinoid internal carotid artery and the anterior/posterior cerebral arteries) supply the median eminence and upper infundibulum, feeding the primary portal capillary plexus.
- ▶ **Inferior hypophyseal arteries** (branches of the cavernous part of the internal carotid artery) divide into medial and lateral branches that anastomose across the midline, forming an **arterial ring around the infundibulum**; fine branches from this ring enter the neurohypophysis directly to supply its capillary bed.
- ▶ A confluent capillary network runs through the whole neurohypophysis, fed by both sets of vessels, so that flow can be shared between the two supplies; hypophyseal veins drain the gland into the adjacent venous (cavernous) sinus.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 13.7 — A: Hypothalamohypophyseal tract. B: Hypophyseal portal system. (Snell — *Clinical Neuroanatomy* — 7e, p.409)

Reproduce by hand with these exact labels (Panel A — the tract itself; Panel B alongside for contrast):

- Panel A (Hypothalamohypophyseal tract): **Supraoptic nucleus, Paraventricular nucleus**, axons converging into the **Hypothalamohypophyseal tract**, running through the infundibulum into the **Posterior lobe of hypophysis cerebri**, shown alongside the **Anterior lobe of hypophysis cerebri**.
- Panel B (Hypophyseal portal system, for comparison): **Superior hypophyseal artery** (branch of internal carotid artery), **Median eminence**, **Capillary network**, **Hypophyseal portal vein**, **Vascular sinusoids**, **Inferior hypophyseal artery**, **Anterior lobe of hypophysis cerebri**, **Veins draining into venous sinus**.



Hypothalamohypophyseal tract

Applied / Clinical anatomy

- **Cranial (central) diabetes insipidus** — results from a lesion of the supraoptic/paraventricular nuclei or of the hypothalamohypophyseal tract itself (head injury, hypothalamic tumour, pituitary/stalk surgery), interrupting vasopressin delivery. Features: **polyuria** (large volume, low specific-gravity urine) and **polydipsia**; the absence of glycosuria differentiates it from diabetes mellitus. It is the best-known clinical hypothalamic syndrome.
- **SIADH** (syndrome of inappropriate ADH secretion) is the physiological converse — persistent, non-osmotic vasopressin release (e.g. from CNS injury or paraneoplastic sources) causing water retention and dilutional hyponatraemia.
- **Posterior pituitary "bright spot"** — the pars nervosa shows a characteristic T1-weighted MRI hyperintensity that reflects normally stored vasopressin-neurophysin granules travelling down

an intact tract; its loss or an ectopic bright spot along the stalk is an important radiological sign of tract/stalk pathology, relevant to the cross-sectional/radiological anatomy component of Paper IV.

- ▶ **Pituitary stalk section** (surgical or traumatic) interrupts the hypothalamohypophyseal tract, typically producing a transient (often triphasic) diabetes insipidus, and may separately compromise the portal vessels running alongside it, affecting anterior-lobe function as well.
- ▶ **Oxytocin** is used clinically to induce/augment labour and to control postpartum haemorrhage, exploiting the Ferguson-reflex pathway; conversely, maternal stress can inhibit the milk-ejection reflex by suppressing hypothalamic oxytocin release.

Recent advances

- ▶ **Whole-brain viral tracing has reconstructed the three-dimensional architecture of the hypothalamo-neurohypophyseal system**, showing that magnocellular oxytocin neurons send axon collaterals well beyond the classical single route to the posterior lobe — projecting to more than 50 additional brain regions and shaping fear-related behaviour, revising the older view of a purely "single-tract" neurosecretory pathway (Zhang et al., *Neuron*, 2021) [DOI: 10.1016/j.neuron.2020.10.032].
- ▶ **A dedicated imaging review confirms the posterior-pituitary "bright spot" as the direct in-vivo correlate of intact vasopressin-neurophysin granules traversing the hypothalamohypophyseal tract**, cementing its role as a key MRI landmark in the work-up of stalk and pituitary pathology (Báñez-López et al., *Neuroendocrinology*, 2023) [PMID: 34438401].
- ▶ **An imaging series in malignant germ-cell tumours involving the hypothalamo-neurohypophyseal axis found bright-spot loss in over 90% of cases**, correlating closely with clinical diabetes insipidus and helping localise small neurohypophyseal-axis tumours even before overt mass effect (*Neuroradiology*, 2024) [DOI: 10.1007/s00234-024-03384-1].
- ▶ **A 2025 review re-frames the oxytocin arm of the tract as part of a far more anatomically and functionally complex signalling system**, with paraventricular oxytocin neurons projecting widely across the brain and being implicated in several neuropsychiatric and metabolic disorders, extending the classical "neurohypophyseal endocrine output only" concept (*Neuroscience Bulletin*, 2025) [DOI: 10.1007/s12264-025-01424-1].
- ▶ (*According to PubMed and recent journal literature.*)

High-yield exam pointers

- ▶ Two nuclei of origin: **supraoptic** (mainly vasopressin) and **paraventricular** (mainly oxytocin) — both magnocellular.
- ▶ Also called the **supraopticohypophyseal tract**; runs superficially down the infundibulum to end on capillaries of the pars nervosa — **no synapse, no portal vessel involved**.
- ▶ Hormones travel bound to **neurophysins** by axoplasmic flow and are stored transiently in **Herring bodies** before exocytotic release.
- ▶ Must be distinguished from the **tuberoinfundibular tract** (parvocellular, arcuate/periventricular nuclei) which ends on the **hypophyseal portal system** supplying the anterior lobe — a favourite "compare and contrast" examiner trap.

- ▶ Neurohypophysis = pars nervosa + infundibular stem + median eminence, a **diencephalic (neuroectodermal) downgrowth**, unlike the adenohypophysis, which arises from Rathke's pouch (oral ectoderm).
- ▶ Blood supply: superior hypophyseal arteries (median eminence/upper infundibulum) and inferior hypophyseal arteries (arterial ring around infundibulum, direct neurohypophyseal supply) — both from the internal carotid artery.
- ▶ Classic lesion syndrome: **cranial diabetes insipidus** — polyuria + polydipsia with no glycosuria.
- ▶ Oxytocin reflexes are both **positive-feedback neuroendocrine loops**: the Ferguson reflex (parturition) and the milk-ejection reflex (suckling).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e.



Metathalamus

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction The metathalamus is the paired posteroinferior subdivision of the diencephalon consisting of the **medial geniculate body (MGB)** and the **lateral geniculate body (LGB)**, one pair on each side flanking the midbrain below the pulvinar of the thalamus. The MGB is the obligatory thalamic relay for the auditory pathway and the LGB the obligatory thalamic relay for the visual pathway. Traditionally described as a separate subdivision alongside the thalamus, epithalamus and subthalamus, both geniculate bodies are now regarded functionally and developmentally as part of the dorsal thalamus, though the term "metathalamus" is retained for descriptive convenience and remains examinable (competency code AN62.5).

1. Subdivisions of the diencephalon — where the metathalamus fits

Subdivision	Location	Principal contents
Thalamus	Bulk of the lateral wall of the third ventricle	Anterior, medial, lateral (dorsal + ventral tiers), intralaminar, midline and reticular nuclear groups
Metathalamus	Posteroinferior to the thalamus, lateral to the midbrain	Medial geniculate body (auditory relay), lateral geniculate body (visual relay)
Epithalamus	Roof of the third ventricle, posterior end	Pineal body, habenular trigone/nuclei, habenular and posterior commissures, stria medullaris thalami
Subthalamus	Between thalamus (above) and midbrain tegmentum (below)	Subthalamic nucleus, zona incerta, fields of Forel, prerubral field

Subdivision	Location	Principal contents
Hypothalamus	Below the hypothalamic sulcus, floor/lower wall of third ventricle	Preoptic, supraoptic, tuberal and mamillary nuclear groups

2. Gross location and relations of the metathalamus

- ▶ The medial and lateral geniculate bodies are small, rounded/oval elevations on the inferior aspect of the posterior thalamus, one lateral to each side of the midbrain; the name "geniculate" (Latin *geniculum*, little knee) reflects the bent-on-itself shape of the enclosed grey matter.
- ▶ **Medial geniculate body (MGB)** — an oval elevation lying just below the pulvinar and lateral to the superior colliculus; connected to the inferior colliculus by the **inferior (quadrigenal) brachium**.
- ▶ **Lateral geniculate body (LGB)** — a smaller, ovoid elevation anterolateral to the MGB, at the posterior end of the optic tract; overlapped by the medial part of the temporal lobe; connected to the superior colliculus by the **superior (quadrigenal) brachium**, which runs between the LGB and the pulvinar.
- ▶ Both bodies thus lie in series with the tectal colliculi of the midbrain — MGB with the inferior colliculus (auditory midbrain station), LGB with the superior colliculus (visual/oculomotor reflex station) — an arrangement that is a favourite exam diagram.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Posterolateral schematic of the thalamus/midbrain junction, labelling: **Pulvinar of thalamus** • **Medial geniculate body** • **Lateral geniculate body** • **Superior colliculus** • **Inferior colliculus** • **Superior (quadrigenal) brachium** • **Inferior (quadrigenal) brachium** • **Optic tract** • **Brachium conjunctivum/midbrain outline**. Show the superior brachium passing between LGB and pulvinar, and the inferior brachium passing between MGB and inferior colliculus.

3. Medial geniculate body (MGB) — auditory relay

- ▶ **Structure:** three subnuclei — a **ventral nucleus** (tonotopically organised; densely packed, medium-sized cells; projects to the primary auditory cortex), a **dorsal nucleus** (overlies the ventral nucleus, not tonotopically organised, projects to auditory belt areas around the primary cortex), and a **medial (magnocellular) nucleus** (sparse, deeply staining, multimodal neurones responding to a broad range of frequencies and to non-auditory stimuli; projects diffusely to auditory, insular and opercular cortex).

Details	
Afferents	Lateral lemniscus (direct, or after relay in the inferior colliculus) via the inferior brachium; fibres from both inferior colliculi (bilateral cochlear input); descending corticothalamic fibres from the auditory cortex; ascending reticular/spinothalamic-type fibres carrying nociceptive input to the magnocellular nucleus

Details	
Efferents	Geniculotemporal (auditory) radiation through the sublentiform part of the internal capsule to the primary auditory area (Brodmann areas 41, 42) of the superior temporal gyrus; a smaller projection to the secondary somatosensory area
Function	Last subcortical relay of the auditory pathway; because each MGB receives input from both cochleae, a unilateral lesion does not cause significant deafness

4. Lateral geniculate body (LGB) — visual relay

- **Structure:** a laminated, inverted U-shaped nucleus with **six cellular layers (laminae)** numbered 1–6 from the innermost ventral to the outermost dorsal surface, separated by thin interlaminar zones (an additional superficial "S" lamina lies most ventrally).
 - **Laminae 1 and 2** are large-celled (**magnocellular**) — receive fast-conducting Y-type retinal ganglion-cell axons (motion/low-resolution pathway) and also give branches to the superior colliculus.
 - **Laminae 3–6** are small-celled (**parvocellular**) — receive slower X-type ganglion-cell axons (fine-detail/colour pathway).
 - **Laminae 1, 4 and 6** receive the crossed fibres of the **contralateral nasal hemiretina**; **laminae 2, 3 and 5** receive the uncrossed fibres of the **ipsilateral temporal hemiretina** — i.e. each LGB receives both eyes but represents only the contralateral visual field.
 - The W-type ganglion cells (large receptive fields, slow) terminate diffusely in the interlaminar zones/S lamina and also project to the superior colliculus.
 - The nucleus is retinotopically organised: the vertical meridian is represented posteriorly, the periphery anteriorly, the upper visual field laterally and the lower field medially, with a precise point-to-point map preserved in the geniculocalcarine projection.

Details	
Afferents	Lateral root of the optic tract (temporal retinal fibres of the same side + nasal retinal fibres of the opposite side); corticothalamic feedback from the primary and extrastriate visual cortex; a smaller input from the superior colliculus and brainstem reticular formation
Efferents	Optic radiation (geniculocalcarine tract) through the retrolentiform part of the internal capsule to the primary visual cortex (Brodmann area 17) in the banks of the calcarine sulcus
Function	Final relay of the conscious visual pathway; retinal fibres subserving pupillary light reflexes bypass the LGB and end directly in the pretectal area and superior colliculus

□ Fig 8.16 — Six layers of the lateral geniculate body: laminae 1–6, showing crossed input from the opposite side to laminae 1, 4, 6 (blue) and uncrossed input from the same side to laminae 2, 3, 5 (pink) (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.565)

□ Fig 9.11 — Connections of the medial geniculate body: lateral lemniscus and inferior colliculus (afferent) to auditory radiation and primary auditory area (efferent) (IB Singh — Textbook of Human Neuroanatomy, p.164)

5. Comparison: medial vs lateral geniculate body

Feature	Medial geniculate body	Lateral geniculate body
Pathway relayed	Auditory	Visual
Position	Below pulvinar, lateral to superior colliculus	Anterolateral to MGB, at end of optic tract
Connected to colliculus by	Inferior (quadrigenal) brachium — to inferior colliculus	Superior (quadrigenal) brachium — to superior colliculus
Internal structure	3 subnuclei (ventral, dorsal, medial/magnocellular)	6 laminae (magnocellular 1–2, parvocellular 3–6)
Chief afferent	Lateral lemniscus (bilateral cochlear representation)	Optic tract (contralateral visual field only)
Internal capsule route of efferents	Sublenticular part	Retrolenticular part
Cortical destination	Areas 41, 42 (superior temporal gyrus)	Area 17 (calcarine cortex)
Effect of unilateral lesion	No significant deafness (bilateral input)	Complete contralateral homonymous hemianopia

6. Development

The medial and lateral geniculate bodies develop, along with the rest of the thalamus, from a proliferating thickening of the **alar plate** of the embryonic diencephalon; they arise as paired solid buds projecting posterior to the developing thalamus as the thalami enlarge and narrow the third-ventricular cavity. Their internal lamination (LGB) and subnuclear organisation (MGB) are established by selective, activity-dependent segregation of retinal/auditory afferents during later fetal life.

7. Arterial supply

- ▶ **Lateral geniculate body** — the **anterior choroidal artery** (a branch of the internal carotid artery, running close to the optic tract) supplies the LGB along with the optic tract, crus cerebri and internal capsule; a supplementary supply comes from the **lateral posterior choroidal artery**, a branch of the posterior cerebral artery.
- ▶ **Medial geniculate body** — supplied by thalamogeniculate/posterior choroidal branches of the **posterior cerebral artery**, which also supply the thalamus and pineal region.
- ▶ This dual-artery territory (anterior choroidal + posterior cerebral) explains why geniculate infarcts are often partial and why the resulting visual field defect can be incomplete or patchy rather than a clean, dense hemianopia.

Applied / Clinical anatomy

- ▶ **Thalamic (Dejerine–Roussy) syndrome:** due to a vascular lesion of the thalamogeniculate branch of the posterior cerebral artery (thalamic infarction). Features include contralateral hemianaesthesia followed by severe, paroxysmal spontaneous pain (thalamic pain/anaesthesia dolorosa), transient hemiparesis (adjacent internal capsule involvement), hemiataxia/choreoathetoid movements (pallidofugal fibres), and **contralateral homonymous hemianopia** when the lesion extends to involve the lateral geniculate body.
- ▶ **Isolated LGB lesion** (e.g. anterior choroidal artery occlusion): produces a dense, **complete contralateral homonymous hemianopia** without macular sparing, because — unlike the occipital cortex — the LGB has no dual (collateral) cortical blood supply to spare the macular representation.
- ▶ **Isolated unilateral MGB or auditory radiation lesion:** does *not* produce clinically significant deafness, because each MGB (and each auditory cortex) receives input from both cochleae; bilateral lesions are needed for cortical deafness.
- ▶ **Pupillary light reflex is preserved** even after LGB destruction, because the reflex afferents leave the optic tract before the LGB and terminate directly in the pretectal nucleus and superior colliculus — a useful bedside/exam discriminator between a geniculate and a pretectal lesion.
- ▶ **Surgical/radiological relevance:** the geniculate bodies lie close to the optic tract and temporal horn and can be affected by mesial temporal lobe surgery, posterior thalamic tumours, or be visualised as distinct grey-matter nodules on high-resolution MRI at the level of the crus cerebri/pulvinar.

High-yield exam pointers

- ▶ Metathalamus = medial + lateral geniculate bodies; now grouped functionally with the dorsal thalamus.
- ▶ MGB → auditory relay → areas 41, 42 via sublentiform internal capsule; connected to inferior colliculus by inferior brachium.
- ▶ LGB → visual relay → area 17 via retrolentiform internal capsule; connected to superior colliculus by superior brachium.
- ▶ LGB is 6-laminated: 1, 2 magnocellular; 3–6 parvocellular; laminae 1, 4, 6 crossed (contralateral nasal retina), 2, 3, 5 uncrossed (ipsilateral temporal retina).
- ▶ Each MGB gets bilateral cochlear input → unilateral lesion does not cause deafness; each LGB gets only the contralateral visual field → unilateral lesion causes complete contralateral homonymous hemianopia.
- ▶ Pupillary light reflex fibres bypass the LGB (end in pretectal area/superior colliculus) — light reflex survives LGB lesions.
- ▶ Thalamic (Dejerine–Roussy) syndrome follows thalamogeniculate branch (PCA) infarction; hemianopia occurs only if the LGB is co-involved.
- ▶ Arterial supply: LGB — anterior choroidal artery (+ lateral posterior choroidal); MGB — posterior cerebral artery branches.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 3-4 8e; Vishram Singh — Clinical Neuroanatomy 4e; IB Singh — Textbook of Human Neuroanatomy; Snell — Clinical Neuroanatomy 7e.



Subthalamus

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction

The **subthalamus** (also called the **ventral thalamus**) is a small, wedge-shaped region of the diencephalon that lies between the **dorsal thalamus** above and the **midbrain tegmentum** below, with which it is directly continuous. It is a functional and structural crossroads: a mosaic of grey-matter nuclei (chief among them the **subthalamic nucleus of Luys**) embedded in a dense network of fibre bundles — the ansa lenticularis, fasciculus lenticularis, subthalamic fasciculus and thalamic fasciculus — that carry outflow of the corpus striatum to the thalamus. Though topographically part of the diencephalon, the subthalamic nucleus is functionally and clinically inseparable from the **basal nuclei**, and its damage produces one of the most dramatic movement disorders in clinical neurology, **hemiballismus**; today it is also the single most important stereotactic target for **deep brain stimulation (DBS)** in Parkinson's disease.

1. Location, extent and boundaries

- Lies in the **ventral part of the diencephalon**, caudal to the lateral half of the (dorsal) thalamus and inferomedial to the globus pallidus.

Boundary	Relation
Superior	Dorsal thalamus (separated from it by the zona incerta)
Inferior	Continuous with the tegmentum of the midbrain ; rostral poles of the red nucleus and substantia nigra extend up into it
Medial	Hypothalamus (posterior part — behind the mammillary bodies) and third ventricle
Lateral	Lowest part of the internal capsule , separating it from the globus pallidus

- Developmentally it is one of the four subdivisions of the diencephalic wall — **epithalamus** (most superior), **thalamus** (central), and **subthalamus** and **hypothalamus** (both inferior) — the subthalamus forming the inferior part of the lateral diencephalic wall together with the hypothalamus.

2. Grey matter of the subthalamic region

Nucleus/grey mass	Description
Subthalamic nucleus (of Luys)	Biconvex, lens-shaped nucleus; the principal grey mass of the region; traditionally described here but functionally grouped with the basal nuclei
Zona incerta	Thin lamina of grey matter continuous with the reticular nucleus of the thalamus; intervenes between the subthalamic nucleus and the thalamus; function largely unknown
Reticular nucleus (ventral thalamic)	Thin sheet of neurons covering the lateral aspect of the dorsal thalamus, separated from it by the external medullary lamina; becomes continuous inferiorly with the zona incerta
Fields of Forel (H, H1, H2)	Regions of intermingled fibres and scattered cells along the trajectory of the pallidofugal bundles (detailed below); the prerubral nucleus lies along the lower edge of the zona incerta, near the upper pole of the red nucleus
Rostral extensions	The rostral poles of the red nucleus and substantia nigra project into the caudal subthalamus

3. Fibre bundles traversing the subthalamic region

Two families of fibres pass through the subthalamus: (a) **ascending sensory tracts** en route to the thalamus, and (b) **pallidofugal (pallido-thalamic) bundles** carrying globus pallidus outflow.

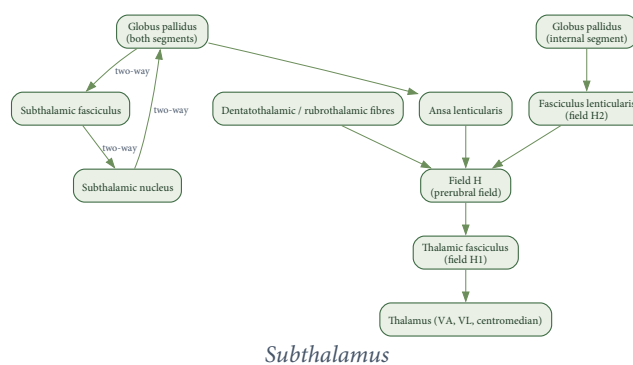
- **Passing through only:** medial lemniscus, spinal lemniscus and trigeminal lemniscus (with the dentatohalamic and rubrothalamic fibres from the contralateral superior cerebellar peduncle and red nucleus respectively) — all en route to thalamic relay nuclei.
- **Pallidofugal outflow bundles**, summarised below:

Bundle	Course	Connects
Ansa lenticularis	Arises from both segments of the globus pallidus; loops around the ventral/posterior border of the internal capsule to reach the subthalamic region, lying ventromedial to the subthalamic nucleus	Globus pallidus → prerubral field
Fasciculus lenticularis	Fibres from the internal (medial) pallidal segment pierce directly through the internal capsule (do not loop); pass medially, above the subthalamic nucleus and below the zona incerta (= field H2 of Forel)	Globus pallidus (internal segment) → prerubral field

Bundle	Course	Connects
Subthalamic fasciculus	A two-way bundle that traverses the internal capsule at right angles, connecting the subthalamic nucleus with both pallidal segments	Subthalamic nucleus $\rightleftharpoons$ globus pallidus
Thalamic fasciculus	Formed medial to the subthalamic nucleus (field H of Forel) by the union of ansa lenticularis + fasciculus lenticularis + dentatothalamic/rubrothalamic fibres; passes dorsal to the zona incerta (field H1) to reach the thalamus	Prerubral field $\rightarrow$ ventral anterior (VA), ventral lateral (VL) and centromedian thalamic nuclei

Fields of Forel at a glance:

Field	Position	Chief content
H (prerubral field)	Medial to the subthalamic nucleus, dorsal to the red nucleus	Convergence point where ansa + fasciculus lenticularis unite with dentatothalamic/rubrothalamic fibres to form the thalamic fasciculus; site of the prerubral nucleus
H1	Dorsal to the zona incerta	Thalamic fasciculus
H2	Between the zona incerta and the subthalamic nucleus	Fasciculus lenticularis



4. Subthalamic nucleus — structure and connections

- ▶ A small, **biconvex, lens-shaped** nucleus lying medial to the internal capsule and immediately rostral to the level where the capsule becomes continuous with the crus cerebri; separated from the dorsal thalamus by the zona incerta.
- ▶ **Afferents:** a dense GABAergic projection from the **external segment of the globus pallidus**, arriving via the subthalamic fasciculus (part of the **indirect pathway**); direct glutamatergic afferents also arrive from the **cerebral cortex** (the fast cortico-subthalamic, i.e. "**hyperdirect**", projection that can brake movement without first passing through the striatum).

- ▶ **Efferents:** unique among basal-nuclear structures, its neurons are **glutamatergic (excitatory)** and project to **both segments of the globus pallidus and to the pars reticularis of the substantia nigra** — chiefly to the internal (medial) pallidal segment.
- ▶ Functionally, the subthalamic nucleus is the key relay of the **indirect pathway** (striatum → external pallidum → subthalamic nucleus → internal pallidum/substantia nigra pars reticularis → thalamus), where its excitatory output normally **increases** basal-nuclear inhibitory outflow on the thalamus, thereby suppressing unwanted movement.

5. Functions of the subthalamus

- ▶ Relay station for **pallidal (basal-nuclear) outflow** to the thalamus via the ansa/fasciculus lenticularis and thalamic fasciculus.
- ▶ The subthalamic nucleus itself provides the principal **excitatory drive** within basal-nuclear circuitry, balancing the inhibitory striato-pallidal output and fine-tuning the **amplitude, speed and initiation of voluntary movement**.
- ▶ Through the hyperdirect cortical projection, it allows rapid "braking" of an already-initiated motor programme.
- ▶ The zona incerta and fields of Forel receive somatic afferents from the sensorimotor cortex, deep cerebellar nuclei, trigeminal nuclear complex and spinal cord, and project back to the spinal cord — though their precise physiological role remains poorly defined.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 23.3 — *The main nuclear aggregations of cell bodies in the diencephalon, coronal sections (Gray's Anatomy — Standring — 41e, p.488)*

Reproduce a coronal section through the caudal diencephalon at the diencephalic–mesencephalic junction and label: **dorsal thalamus, internal capsule, globus pallidus (external + internal segments), zona incerta, subthalamic nucleus, red nucleus, substantia nigra, third ventricle, hypothalamus, and the fibre bundles ansa lenticularis, fasciculus lenticularis and fields of Forel (H, H1, H2).**

Applied / Clinical anatomy

- ▶ **Hemiballismus** — a discrete vascular lesion (small stroke/haemorrhage) of the subthalamic nucleus, or its connections, produces sudden, violent, flinging (choreiform/ballistic) involuntary movements of the proximal limb musculature on the **contralateral** side. Removing the excitatory drive of the subthalamic nucleus disinhibits the thalamocortical projection, producing excessive, uncontrolled movement; the disorder is characteristically abolished by ablation of the globus pallidus or its efferent tracts, the anterior ventral nucleus of the thalamus, area 4 of the cerebral cortex, or the corticospinal tract — evidence that the abnormal signal must reach the motor cortex to produce the clinical picture.
- ▶ **Parkinson's disease** — the subthalamic nucleus (along with the internal globus pallidus) is now the preferred **neurosurgical/stereotactic target** for both lesioning and **deep brain stimulation (DBS)**; DBS of the subthalamic nucleus is particularly effective for relieving akinesia and rigidity and allows reduction of anti-parkinsonian medication, though it carries a small risk of

precipitating dyskinesias or affective/behavioural side-effects from spread of current to adjacent limbic-related fibres.

- ▶ **Essential tremor** — contralateral stimulation of either the ventral intermediate thalamic nucleus or the **zona incerta** is used to relieve tremor, reflecting the subthalamic region's role in this alternative surgical target.
- ▶ **Imaging** — the small size and variable shape of the subthalamic nucleus make direct visualisation difficult on conventional MRI; high-field (e.g. 7–9.4 T) MRI with histological validation has been used to map its precise boundaries and improve preoperative DBS-electrode targeting.
- ▶ Pathophysiological model: dopaminergic loss in Parkinson's disease renders the indirect pathway overactive → excessive pallidosubthalamic inhibition of the subthalamic nucleus paradoxically explains how *underactivity* of the nucleus removes excitatory drive on internal pallidal neurons in levodopa-induced dyskinesia and in Huntington's chorea — both conditions producing movements resembling ballism.

Recent advances

- ▶ Intra-operative high-density electrophysiological recording during subthalamic-nucleus DBS shows that the **evoked resonant neural activity (ERNA)** waveform is a direct electrophysiological signature of engagement of the external-pallidum–subthalamic-nucleus (indirect-pathway) mesocircuit, refining anatomical lead placement for optimal stimulation (Steiner et al., *Nature Communications*, 2024).
- ▶ Combined on/off-medication and on/off-DBS recordings demonstrate that **levodopa and subthalamic-nucleus DBS act through a shared, pathway-specific mechanism** — both suppress excessive cortico-subthalamic beta-band synchrony carried by the hyperdirect pathway — unifying the pharmacological and surgical models of Parkinson's disease treatment (Binns et al., *Nature Communications*, 2025).
- ▶ Patient-specific diffusion-MRI **tractography** of the subthalamic region is increasingly used to explain variable DBS outcomes, showing that cortical fibres traversing the subthalamic/ventral-tegmental territory connect predominantly with the supplementary motor area (Loução et al., *Stereotactic and Functional Neurosurgery*, 2025).
- ▶ (According to PubMed.)

High-yield exam pointers

- ▶ Subthalamus = ventral thalamus; lies between dorsal thalamus (above) and midbrain tegmentum (below, continuous with it); medial to hypothalamus, lateral to internal capsule.
- ▶ Grey matter = subthalamic nucleus (of Luys), zona incerta, reticular nucleus, prerubral nucleus, fields of Forel; rostral poles of red nucleus and substantia nigra extend into it.
- ▶ Pallidofugal bundles: **ansa lenticularis** (loops round internal capsule) + **fasciculus lenticularis** (pierces internal capsule directly, field H2) unite in **field H** to form the **thalamic fasciculus** (field H1) → VA/VL/centromedian thalamus.
- ▶ **Subthalamic fasciculus** = two-way GABA/glutamate link between subthalamic nucleus and globus pallidus.

- ▶ Subthalamic nucleus is the **only glutamatergic (excitatory)** nucleus in basal-nuclear circuitry — key node of the **indirect pathway**; also receives a direct cortical **hyperdirect** input.
- ▶ **Hemiballismus** = contralateral subthalamic nucleus lesion → violent proximal flinging movements.
- ▶ Subthalamic nucleus = commonest modern **DBS target** for Parkinson's disease (akinesia + rigidity); zona incerta/Vim thalamus targeted for tremor.
- ▶ Subthalamic nucleus, though anatomically diencephalic, is described functionally with the **basal nuclei**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e (clinical correlation). Recent-advances section per PubMed (see citations above).



Thalamic nuclei and connections

Asked in: Paper IV 14-Jul-2023 — RGUHS MD/MS Anatomy

Definition / Introduction The thalamus is the largest, dorsal-most part of the diencephalon — a paired, egg-shaped mass of grey matter about 3.5 cm long and 1.5 cm broad, one lying on each side of the third ventricle and joined across the midline by the interthalamic adhesion. It is the principal relay and integrating station through which almost all sensory modalities (except olfaction), as well as basal ganglia and cerebellar motor information, reach the cerebral cortex. Internally it is subdivided by a Y-shaped internal medullary lamina into anterior, medial and lateral nuclear masses, together with intralaminar, midline and reticular nuclei and the metathalamus (medial and lateral geniculate bodies). Almost every thalamic nucleus (the reticular nucleus is the exception) sends fibres to, and receives fibres from, the cerebral cortex — the thalamus is therefore a two-way gateway, not a passive relay.

Gross anatomy (orientation)

- ▶ **Ends** — anterior end narrow, forms the posterior boundary of the interventricular foramen; posterior end expanded as the **pulvinar**, which overhangs the superior colliculus and is separated from the medial geniculate body below it by the (superior) quadrigeminal brachium.
- ▶ **Surfaces** — superior surface covered by the thin **stratum zonale**, forms part of the floor of the lateral ventricle laterally and is separated from the body of the fornix by the choroid fissure/tela choroidea medially; its lateral edge is marked by the stria terminalis and thalamostriate vein. Inferior surface is continuous with the midbrain tegmentum and subthalamus. Medial surface forms the dorsal part of the lateral wall of the third ventricle. Lateral surface is covered by the **external medullary lamina**, beyond which lies the **reticular nucleus** and then the posterior limb of the internal capsule separating the thalamus from the lentiform nucleus.

- **Internal medullary lamina** — a vertical, Y-shaped sheet of white matter that bifurcates anterosuperiorly, dividing the thalamic grey matter into **anterior, medial and lateral** nuclear masses; **intralaminar nuclei** lie embedded within it.

Classification of thalamic nuclei

Group	Nuclei	Functional class
Anterior	Anteroventral (largest), anteromedial, anterodorsal	Relay — limbic
Medial	Dorsomedial (mediodorsal) nucleus — magnocellular + parvocellular parts	Association
Lateral — dorsal tier	Lateral dorsal (LD), lateral posterior (LP), pulvinar	Association
Lateral — ventral tier	Ventral anterior (VA), ventral lateral (VL), ventral posterolateral (VPL), ventral posteromedial (VPM)	Relay — motor / sensory
Metathalamus	Medial geniculate body (MGB), lateral geniculate body (LGB)	Relay — auditory / visual
Intralaminar	Anterior: central medial, paracentral, central lateral; Posterior: centromedian (CM, largest), parafascicular	Non-specific
Midline	Rhomboid, reuniens, parataenial nuclei	Non-specific
Reticular	Thin shell external to the external medullary lamina	Reticular — gate-keeper (distinct third functional category, alongside specific and non-specific nuclei)

□ Fig 9.5 — Nuclei of thalamus (IB Singh — Textbook of Human Neuroanatomy, p.157)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Schematic horizontal section of the right thalamus (as above), labelling:

- ▶ Y-shaped **internal medullary lamina** dividing anterior / medial / lateral masses
- ▶ **Anterior nucleus** (in the limb of the Y)
- ▶ **Dorsomedial nucleus** (medial mass)
- ▶ Dorsal tier: **LD, LP, pulvinar**; Ventral tier: **VA, VL, VPL, VPM** (lateral mass)
- ▶ **Centromedian nucleus** (within the lamina)
- ▶ **Interthalamic adhesion, medial and lateral geniculate bodies**

Then, alongside, a connections scheme (afferents on the left, efferents on the right — as in Snell Fig. 12-4 / Vishram Singh Fig. 11.4): draw the thalamus centrally; on the left, arrows in from mammillary body, hypothalamus, globus pallidus/substantia nigra, cerebellum (dentate nucleus), spinothalamic + medial + trigeminal lemnisci, optic tract, inferior colliculus, and reticular formation; on the right, arrows out to cingulate/parahippocampal gyrus, prefrontal cortex, motor/premotor/supplementary motor cortex, postcentral gyrus, visual cortex and auditory cortex.

Afferent and efferent connections of the major nuclei

Nucleus	Major subcortical afferent	Major cortical efferent	System / function
Anterior	Mammillary body via mammillothalamic tract ; hippocampus via fornix	Cingulate and parahippocampal gyrus (reciprocal)	Limbic relay — recent memory, alertness (Papez circuit)
Dorsomedial	Amygdala, piriform (olfactory) cortex, ventral pallidum, hypothalamus, other thalamic nuclei	Prefrontal cortex (reciprocal)	Association — mood, emotional tone; integrates somatic, visceral and olfactory information
Ventral anterior (VA)	Ipsilateral globus pallidus interna (GPi), substantia nigra pars reticularis (SNr)	Premotor cortex (area 6), frontal eye field (area 8)	Relay motor — basal ganglia loop
Ventral lateral (VL)	Pars oralis: ipsilateral GPi; pars caudalis: contralateral deep cerebellar (dentate) nuclei	Supplementary motor area and primary motor cortex (area 4)	Relay motor — voluntary movement; "tremor cells"; DBS target for essential tremor
Ventral posterolateral (VPL)	Spinothalamic tract + medial lemniscus (trunk and limbs)	Primary somatosensory cortex (areas 3, 1, 2) via posterior limb of internal capsule	Relay sensory — touch, pain, temperature, proprioception

Nucleus	Major subcortical afferent	Major cortical efferent	System / function
Ventral posteromedial (VPM)	Trigeminothalamic tract (trigeminal lemniscus) + solitariothalamic (taste) fibres	Somatosensory cortex + insula	Relay sensory — face and taste
Lateral geniculate body	Optic tract (6-layered nucleus)	Optic radiation to visual cortex (areas 17, 18, 19)	Vision
Medial geniculate body	Inferior colliculus via inferior (quadrigeminal) brachium	Auditory radiation to superior temporal gyrus (areas 41, 42)	Hearing
LD, LP, pulvinar	Superior colliculus, pretectum, spinothalamic tract	Parietal, occipital and temporal association cortex, cingulate gyrus	Association — multimodal sensory integration
Intralaminar (CM–parafascicular)	GPI, substantia nigra, deep cerebellar nuclei, spinothalamic tract	Striatum; motor, premotor and supplementary motor cortex	Non-specific — arousal (ascending reticular activating system), sensorimotor integration
Midline	Hypothalamus, periaqueductal grey, spinothalamic tract, brainstem reticular formation	Hippocampus, amygdala, nucleus accumbens, cingulate cortex	Non-specific — memory, arousal
Reticular	Collaterals from cerebral cortex (corticothalamic) and from other thalamic nuclei	GABAergic fibres back to other thalamic nuclei only — no cortical projection	Gate-keeper — regulates thalamocortical traffic

Applied / Clinical anatomy

- **Arterial supply** — the thalamus is supplied mainly by perforating branches of the **posterior cerebral artery**: the **posteromedial group** ("**thalamoperforators**"), arising from the posterior communicating artery and proximal posterior cerebral artery, enters the posterior perforated substance and supplies the hypophysis, hypothalamus, anterior and medial thalamic nuclei, subthalamus and midbrain tegmentum; the **posterolateral group** ("**thalamogeniculate arteries**"), arising from the posterior cerebral artery as it winds round the cerebral peduncle, supplies the caudal half of the thalamus, pulvinar, geniculate bodies and the lateral/ventral nuclear groups. Additional twigs come from the posterior communicating, anterior choroidal, posterior choroidal and middle cerebral arteries.
- **Thalamic (Dejerine–Roussy) syndrome** — follows occlusion of the thalamogeniculate branch of the posterior cerebral artery (classically in a hypertensive patient), producing:
 - **Contralateral pansensory loss** (VPL/VPM involvement)

- **Thalamic pain** — severe, persistent, paroxysmal, intolerable burning pain evoked by trivial stimuli and unresponsive to analgesics (also called *anaesthesia dolorosa*), from involvement of intralaminar/non-specific nuclei
- **Transient hemiparesis** (adjacent internal capsule oedema/involvement)
- **Hemiataxia and choreoathetoid movements** (pallidofugal fibres crossing the internal capsule/subthalamus)
- **Contralateral homonymous hemianopia** (lateral geniculate body involvement)
- ▶ **Thalamic hand** — in some thalamic lesions the contralateral forearm is pronated, the wrist flexed, metacarpophalangeal joints flexed and interphalangeal joints extended; finger movements remain possible but slow, due to altered muscle tone rather than paralysis.
- ▶ **Intralaminar lesions** — unilateral damage to the centromedian–parafascicular complex can cause **thalamic neglect** (unilateral sensory neglect) or **motor neglect** (paucity of contralateral spontaneous movement); bilateral damage produces kinetic mutism with apathy.
- ▶ **Deep brain stimulation (DBS) targets** — a direct clinical application of nuclear topography: **VL (Vim)** for essential tremor and tremor-dominant Parkinson's disease; **anterior thalamic nucleus** for refractory epilepsy; **centromedian nucleus** for Tourette's syndrome and minimally conscious states; **VPL/VPM + periventricular grey** for chronic pain; **inferior thalamic peduncle** for obsessive–compulsive disorder.
- ▶ **Functional note** — after ablation of the sensory cortex, the thalamus alone can still appreciate crude sensations (touch, pain, temperature), but discriminative aspects (localisation, two-point discrimination, exact intensity) require the cortex — the basis for using thalamotomy/DBS rather than cortical ablation to control pain.

High-yield exam pointers

- ▶ Y-shaped **internal medullary lamina** divides the thalamus into anterior, medial and lateral nuclear masses, and houses the **intralaminar nuclei**; the **reticular nucleus** forms an external shell and is the only thalamic nucleus with no cortical projection.
- ▶ **VPL** relays body sensation (spinothalamic + medial lemniscus) and **VPM** relays face/taste (trigeminal lemniscus + solitariothalamic tract) — both project to the postcentral gyrus (areas 3, 1, 2) via the posterior limb of the internal capsule.
- ▶ **Anterior nucleus** is the thalamic link in the **Papez circuit** (mammillothalamic tract → anterior nucleus → cingulate gyrus) — key to recent memory.
- ▶ **VA and VL** are the motor relay nuclei of the basal ganglia–cerebellar loops to the premotor/motor cortex; VL (Vim) is a classic tremor-surgery/DBS target.
- ▶ Thalamus relays **all sensory modalities except olfaction**.
- ▶ **Dejerine–Roussy thalamic syndrome** = thalamogeniculate artery infarct → contralateral pansensory loss + thalamic pain + transient hemiparesis + hemiataxia/choreoathetosis + homonymous hemianopia.
- ▶ **Pulvinar** is the largest nucleus (association type), connecting with parieto-temporo-occipital association cortex.
- ▶ Metathalamus (**LGB, MGB**) are dedicated relay nuclei for vision and hearing respectively.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy.



Thalamic nuclei

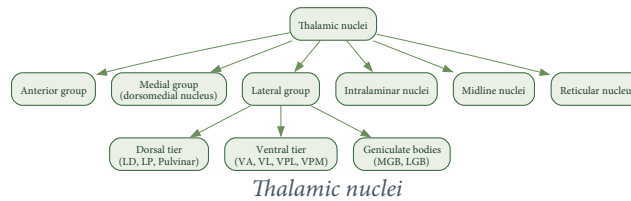
Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction The **thalamus** is the largest paired ovoid grey-matter mass of the diencephalon, about 4 cm long, lying on either side of the third ventricle and continuous posteriorly with the midbrain tegmentum. It is the principal subcortical relay station of the brain — every sensory modality except olfaction, and major motor, limbic and reticular-activating pathways, synapse here before reaching the cerebral cortex. A **Y-shaped internal medullary lamina** of myelinated fibres splits its grey matter into anterior, medial and lateral nuclear masses, with additional intralaminar, midline and reticular nuclei — the basis of both the anatomical and functional classification asked below.

1. Gross subdivision — the internal medullary lamina and nuclear groups

- ▶ The thalamus borders the third ventricle medially; its anterior pole forms the posterior boundary of the interventricular foramen, and its posterior expansion, the **pulvinar**, overhangs the superior colliculus.
- ▶ Superior surface — covered by the **stratum zonale**, floors part of the lateral ventricle; its lateral edge is marked by the **stria terminalis** and thalamostriate vein (border with caudate nucleus).
- ▶ Lateral surface — separated from the reticular nucleus by the **external medullary lamina**, and from the lentiform complex by the posterior limb of the internal capsule.
- ▶ Medial surface — forms the upper part of the lateral wall of the third ventricle; the two thalami are usually joined across the ventricle by the **interthalamic adhesion (massa intermedia)**.
- ▶ Internally, the **internal medullary lamina** (a vertical Y of white matter) divides each thalamus into:
 - ▶ **Anterior nuclear group** — cradled between the arms of the Y.
 - ▶ **Medial nuclear group** — the dorsomedial nucleus, medial to the lamina.
 - ▶ **Lateral nuclear group** — the largest mass, lateral to the lamina, itself split into a **dorsal tier** and a **ventral tier**.
 - ▶ **Intralaminar nuclei** — embedded within the lamina itself.
 - ▶ **Midline nuclei** — abutting the third-ventricle wall.
 - ▶ **Reticular nucleus** — a thin shell lateral to the external medullary lamina, separating the main nuclear mass from the internal capsule.

□ Fig 9.5 — Nuclei of thalamus (IB Singh — Textbook of Human Neuroanatomy, p.157)



DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Coronal/schematic outline of the thalamus (as in Fig. 9.5) labelled with: **interthalamic adhesion**, **internal medullary lamina**, **pulvinar**, **medial geniculate body**, **lateral geniculate body**, **centromedian nucleus**, and, within the three colour-coded zones — anterior nuclei (blue), medial/dorsomedial nucleus (yellow), lateral nuclei (green) subdivided into LD, LP, VA, VL, VP (VPL, VPM).

2. Anterior nuclear group

- ▶ Lies between the arms of the internal medullary lamina; underlies the anterior thalamic tubercle.
- ▶ Three subnuclei: **anteroventral** (largest), **anteromedial**, **anterodorsal**.
- ▶ **Afferents**: mammillothalamic tract (from mammillary nuclei of hypothalamus, which themselves receive the fornix from the hippocampal formation) — medial mammillary nucleus → ipsilateral anteroventral/anteromedial nuclei; lateral mammillary nucleus → bilateral anterodorsal nuclei.
- ▶ **Efferents**: cingulate gyrus and parahippocampal gyrus (anterior thalamic radiation).
- ▶ **Function**: part of the **Papez circuit** — memory consolidation, alertness and attention (limbic relay).
- ▶ Lesions impair recent memory and the capacity for new learning.

3. Medial nuclear group — the dorsomedial (mediodorsal) nucleus

- ▶ Single, large nucleus, disproportionately well developed in humans; bounded laterally by the internal medullary lamina and intralaminar nuclei.
- ▶ Two parts: **anteromedial magnocellular** (olfactory, amygdaloid and ventral-pallidal input) and **posterolateral parvocellular** (reciprocal with dorsolateral/dorsomedial prefrontal cortex, anterior cingulate, supplementary motor area).
- ▶ **Function**: integration of olfactory, visceral and somatic information; mediates visceral–somatic reflexes; linked to affect, anxiety and aggression.
- ▶ Damage → decreased anxiety/tension/aggression, transient amnesia and confusion (effects parallel prefrontal lobotomy) — historically the target of prefrontal leucotomy.

4. Lateral nuclear group

The largest division, lateral to the internal medullary lamina, with a **dorsal tier** (association) and a **ventral tier** (relay).

Tier	Nucleus	Major subcortical afferent	Major cortical target	Function
Dorsal	Lateral dorsal (LD)	Pretectum, superior colliculus	Cingulate, parahippocampus	Limbic/association
Dorsal	Lateral posterior (LP)	—	Parieto-occipito-temporal cortex	Association
Dorsal	Pulvinar	Superior colliculus	Parieto-occipito-temporal cortex	Visual association
Ventral	Ventral anterior (VA)	Globus pallidus internus, substantia nigra pars reticularis	Premotor cortex	Motor relay
Ventral	Ventral lateral (VL)	Ipsilateral GPi (pars oralis); contralateral dentate/deep cerebellar nuclei (pars caudalis)	Supplementary + primary motor cortex	Motor relay
Ventral	Ventral posterolateral (VPL)	Medial lemniscus, spinothalamic tract	Postcentral gyrus (SI), SII	Sensory relay — body
Ventral	Ventral posteromedial (VPM)	Trigeminothalamic tract, taste fibres	Postcentral gyrus (SI), SII, insula	Sensory relay — face, taste
Ventral (posterior pole)	Medial geniculate body (MGB)	Inferior colliculus (auditory)	Primary auditory cortex	Auditory relay
Ventral (posterior pole)	Lateral geniculate body (LGB)	Optic tract	Primary visual cortex	Visual relay

- The **VP nucleus** shows precise somatotopy: sacral segments represented laterally, cervical medially in VPL, with the face (VPM) applied medially — a continuous body map.
- The **LGB** is a laminated, inverted U-shaped nucleus of **six layers**; the **MGB** shows tonotopic organisation (low frequencies laterally).
- **VL** contains "tremor cells" that fire synchronously with peripheral tremor — the anatomical basis for stereotactic VL (Vim) surgery in essential tremor.

5. Non-specific nuclei — intralaminar, midline and reticular

- **Intralaminar nuclei** — embedded in the internal medullary lamina; anterior (rostral) group = central medial, paracentral, central lateral; posterior (caudal) group = **centromedian (CM)** and parafascicular. CM is markedly enlarged in humans and closely related to the globus pallidus/striatum.
 - Afferents: spinothalamic and spinoreticulothalamic tracts, brainstem reticular formation (cholinergic), superior colliculus, pretectum.
 - Efferents: widespread cortex and striatum (thalamostriate projection).

- Function: cortical arousal, sensorimotor integration; damage → thalamic neglect / kinetic mutism.
- ▶ **Midline nuclei** — abut the third-ventricle wall (rhomboid, reuniens, parataenial); connect hypothalamus, periaqueductal grey and spinothalamic tract to hippocampus, amygdala and cingulate cortex — part of the limbic system; role in memory, arousal and seizure regulation.
- ▶ **Reticular nucleus** — a curved sheet of GABAergic neurones wrapping the lateral thalamus, separated from it by the external medullary lamina; receives collaterals of all thalamocortical/corticothalamic fibres and gates information flow through the thalamus. Unlike other thalamic nuclei, it does not project to the cortex.

6. Functional classification of thalamic nuclei

Group	Nuclei included
Motor relay	Ventral anterior (VA), ventral lateral (VL)
Sensory relay	Ventral posterolateral (VPL), ventral posteromedial (VPM), medial geniculate body, lateral geniculate body
Sensory modulator (association)	Lateral dorsal, lateral posterior, pulvinar
Limbic relay	Anterior nucleus, medial dorsal (dorsomedial) nucleus
Non-specific	Intralaminar nuclei, midline nuclei, reticular nucleus

7. Blood supply of the thalamus

- ▶ Chiefly by perforating branches of the posterior cerebral artery (PCA).
- ▶ **Thalamoperforating (paramedian) branches** supply the medial and anterior thalamus.
- ▶ **Thalamogeniculate branches** supply the posterolateral thalamus (VPL/VPM) — occlusion here produces the classical **thalamic (Dejerine–Roussy) syndrome**.
- ▶ Additional contributions from the **posterior communicating, anterior choroidal, posterior choroidal**, and, to a lesser extent, **middle cerebral arteries**.

Applied / Clinical anatomy

- ▶ **Thalamic syndrome of Dejerine–Roussy** — thrombosis of the thalamogeniculate branch of the PCA infarcts the posterolateral (VPL/VPM) thalamus. Contralateral hemianaesthesia recovers partially, followed by severe, spontaneous, poorly localised **thalamic pain (analgesia dolorosa)** with lowered pain threshold, delayed onset and persistence of pain after the stimulus is withdrawn, plus mild hemiparesis, choreoathetosis and astereognosis.
- ▶ **Anterior nuclear lesions** — impair recent memory (Papez circuit disruption), seen in Korsakoff-type amnesic states.
- ▶ **Dorsomedial nucleus** — surgical/pathological damage blunts affect and anxiety (basis of historic prefrontal leucotomy).

- ▶ **Thalamus as a deep-brain-stimulation (DBS) target** — recent advances: Gray's Anatomy (41e) tabulates current stereotactic targets — **VPL/VPM and periventricular grey** for chronic pain; **VL (Vim)** for essential tremor and myoclonus-dystonia; **anterior thalamus** for refractory epilepsy; **centromedian (CM)** nucleus for the minimally conscious state and Tourette's syndrome; **VL (Voa/Vop)** for dystonia; **inferior thalamic peduncle** for obsessive-compulsive disorder. This reflects the shift of thalamic surgery from ablative thalamotomy to reversible neuromodulation.
- ▶ **Pulvinar/LGB/MGB** enlargement or infarction (PCA territory) → visual field defects (macula-sparing homonymous hemianopia via LGB) or cortical deafness (rare, via MGB).
- ▶ Radiologically, the thalamus is a key landmark on axial CT/MRI at the level of the third ventricle — used to identify the internal capsule, basal ganglia and pineal gland (helpful in surface/cross-sectional anatomy questions).

High-yield exam pointers

- ▶ Internal medullary lamina is **Y-shaped**; it separates anterior, medial and lateral nuclear masses and houses the intralaminar nuclei.
- ▶ Anterior group ↔ mammillothalamic tract ↔ cingulate gyrus — **Papez circuit**, memory.
- ▶ Dorsomedial nucleus ↔ prefrontal cortex — affect, anxiety.
- ▶ Lateral group = **dorsal tier** (LD, LP, pulvinar — association) + **ventral tier** (VA, VL — motor relay; VPL/VPM — sensory relay; MGB/LGB — special sensory relay).
- ▶ VPL relays body (spinothalamic + medial lemniscus); VPM relays face + taste (trigeminothalamic tract).
- ▶ Centromedian nucleus = largest intralaminar nucleus, enlarged in humans, linked to striatum.
- ▶ Reticular nucleus is GABAergic, gates thalamocortical traffic, and — uniquely — does NOT project to cortex.
- ▶ Thalamogeniculate artery occlusion → Dejerine-Roussy thalamic (pain) syndrome.
- ▶ DBS targets by indication: pain (VPL/VPM), tremor (VL/Vim), epilepsy (anterior nucleus), OCD (inferior thalamic peduncle), Tourette's/minimally conscious state (centromedian).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; Vishram Singh — Clinical Neuroanatomy 4e; Snell — Clinical Neuroanatomy 7e.



Cerebrum, cortex & white matter



Describe the internal capsule

Asked in: Paper IV Nov 2018 · Paper IV Nov 2017 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction The internal capsule is a compact, V-shaped band of myelinated **projection fibres** situated in the inferomedial part of each cerebral hemisphere, connecting the cerebral cortex with subcortical grey matter, the brainstem and the spinal cord. It is bounded medially by the **caudate nucleus and thalamus** and laterally by the **lentiform nucleus**, continuous above with the fan-shaped **corona radiata** and below with the **crus cerebri** of the midbrain. Because virtually all the ascending and descending fibres of one half of the body are compressed into this narrow space, even a small capsular lesion produces widespread, disproportionately severe neurological deficit — making it one of the most clinically important white-matter structures in neuroanatomy.

1. Location, shape and boundaries

- ▶ A thick sheet of white fibres occupying the interval between the **thalamus and caudate nucleus medially** and the **lentiform nucleus laterally**.
- ▶ In **horizontal (axial) section** it appears **V-shaped**, with its concavity directed laterally — the concavity is occupied by the lentiform nucleus, and the apex (vertex) of the V, directed medially, is the **genu**.
- ▶ Cranially its fibres fan out to the cerebral cortex as the **corona radiata**; caudally its fibres converge and continue as the **crus cerebri (basis pedunculi)** of the midbrain — corona radiata, internal capsule and crus cerebri thus form one continuous fibre pathway.
- ▶ The **interventricular foramen (of Monro)** lies medial and adjacent to the genu — a useful radiological landmark for localising the genu on cross-sectional imaging.

2. Parts and relations

The internal capsule is divided, for descriptive purposes, into **five parts**:

Part	Boundaries / location
Anterior limb	Between the head of the caudate nucleus (medially) and the anterior part of the lentiform nucleus (laterally)
Genu	The bend where the anterior and posterior limbs meet at an angle open laterally; lies medial to the interventricular foramen
Posterior limb	Between the thalamus (medially) and the posterior part of the lentiform nucleus (laterally)
Retrolentiform part	Behind (posterior to) the lentiform nucleus
Sublentiform part	Below the lentiform nucleus, separating it from the optic tract, tail of caudate nucleus and inferior horn of the lateral ventricle

Governing principle — each group of fibres takes the most direct route between cortex and its destination: fibres to/from the **anterior frontal lobe** occupy the anterior limb; fibres to/from the **posterior frontal and most of the parietal lobe** occupy the genu and posterior limb; fibres to/from the

temporal lobe occupy the sublentiform part; and fibres to/from the **occipital lobe** occupy the retrolentiform part.

□ Fig 8.27 — Boundaries and parts of internal capsule (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.574)

3. Descending (corticofugal) fibres

- ▶ **Corticopontine fibres** — the single largest fibre group in the capsule; arise from all four cerebral lobes and are named accordingly, forming the first link of the corticopontocerebellar pathway:
 - **Frontopontine** fibres (largest subgroup) — anterior limb, genu and posterior limb.
 - **Parietopontine** and **occipitopontine** fibres — mainly retrolentiform part.
 - **Temporopontine** fibres — sublentiform part.
- ▶ **Pyramidal fibres:**
 - **Corticonuclear (corticobulbar)** fibres, to the motor cranial nerve nuclei — pass through the genu.
 - **Corticospinal** fibres, to anterior horn cells — form discrete bundles in the **posterior limb**, arranged antero-posteriorly in strict somatotopic order: fibres for the **face/head**, then **upper limb**, then **trunk**, then **lower limb**.
- ▶ **Corticthalamic fibres** — reciprocal fibres accompanying the thalamic radiations described below.
- ▶ **Extrapyramidal fibres:**
 - **Corticostriate** fibres — from the entire cerebral cortex to the caudate nucleus and putamen.
 - **Corticorubral** fibres — from the frontal motor cortex to the red nucleus.
 - **Corticoreticular** fibres — from the motor and parietal cortex to the brainstem reticular formation.

4. Ascending (corticopetal) fibres — the four thalamic radiations

These are chiefly third-order **thalamocortical** sensory fibres, together with a scatter of limbic/hypothalamic connections:

Radiation	Capsular part	Connects
Anterior thalamic radiation	Anterior limb	Anterior and medial thalamic nuclei (+ hypothalamic/limbic fibres) ↔ frontal cortex
Superior thalamic radiation	Genu and posterior limb	Ventral tier thalamic nuclei (VA, VL, VPL, VPM) ↔ sensorimotor cortex — carries somaesthetic sensation
Posterior thalamic radiation (includes optic radiation)	Retrolentiform part	Lateral geniculate body/pulvinar ↔ visual cortex (occipital lobe)
Inferior thalamic radiation (includes auditory radiation)	Sublentiform part	Medial geniculate body ↔ auditory cortex (temporal lobe)

5. Summary — fibre composition by part

Part	Descending (motor) fibres	Ascending (sensory) fibres
Anterior limb	Frontopontine; fronto-thalamic fibres	Anterior thalamic radiation
Genu	Corticonuclear fibres; frontopontine fibres	Anterior part of superior thalamic radiation
Posterior limb	Corticospinal fibres; corticorubral fibres; corticoreticular fibres	Bulk of the superior thalamic radiation
Retrolentiform part	Parietopontine and occipitopontine fibres; corticotectal fibres	Posterior thalamic radiation (incl. optic radiation)
Sublentiform part	Temporopontine fibres	Inferior thalamic radiation (incl. auditory radiation)

6. Arterial supply

The internal capsule receives a **segmental, "end-artery" type** blood supply from four sources, which is the single most clinically important fact about it:

Part	Chief supplying artery
Anterior limb	Recurrent artery of Heubner (medial striate branch of the anterior cerebral artery) and direct branches of the anterior cerebral artery
Genu	Direct branches of the internal carotid artery and the posterior communicating artery
Posterior limb	Lateral and medial striate (lenticulostriate) branches of the middle cerebral artery — the largest lateral striate branch is the artery of Charcot (Charcot's artery of cerebral haemorrhage) ; the posterior third also receives the anterior choroidal artery
Retrolentiform part	Anterior choroidal artery ($\pm$ posterolateral central branches of the posterior cerebral artery)
Sublentiform part	Anterior choroidal artery ($\pm$ branches of the posterior cerebral artery)

□ Fig 8.30 — Arteries supplying the internal capsule (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.575)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Horizontal section through the cerebrum** — V-shaped internal capsule, concavity lateral. Label caudate nucleus/thalamus (medial), lentiform nucleus (lateral), the five parts (**anterior limb, genu, posterior limb, retrolentiform, sublentiform**), interventricular foramen at the genu, and continuity with corona radiata above / crus cerebri below.
- ▶ **Same outline with fibre tracts** — corticopontine/frontopontine (anterior limb–genu–posterior limb), corticonuclear (genu), corticospinal in face→arm→trunk→leg order (posterior limb), optic radiation (retrolentiform), auditory radiation (sublentiform).
- ▶ **Arterial supply outline** — recurrent artery of Heubner + ACA branches (anterior limb), ICA/posterior communicating branches (genu), lenticulostriate MCA branches with Charcot's artery marked (posterior limb), anterior choroidal artery (retrolentiform + sublentiform).

Applied / Clinical anatomy

- ▶ **Capsular stroke (the classic "one-inch, whole-body" lesion)** — because motor, sensory and special-sensory fibres for the entire contralateral half of the body are compressed into a thumbnail-sized structure, even a small vascular lesion of the internal capsule produces **contralateral hemiplegia**, often with hemianaesthesia and, if the dominant hemisphere is involved, aphasia — a far larger deficit than an equivalent-sized cortical lesion.
- ▶ **Charcot's artery of cerebral haemorrhage** (largest lateral lenticulostriate branch of the middle cerebral artery, supplying the posterior limb) is the vessel most often ruptured in **hypertensive intracerebral haemorrhage**, historically termed the "artery of cerebral haemorrhage" — the single most common site of spontaneous hypertensive bleeds.
- ▶ **Pure motor hemiplegia** (a classical **lacunar syndrome**) results from a small infarct confined to the posterior limb/genu (corticospinal and corticonuclear fibres), sparing sensation — due to occlusion of a single lenticulostriate perforator.
- ▶ **Faciobrachial monoplegia** follows occlusion of the **recurrent artery of Heubner**, which damages corticonuclear fibres for the face and corticospinal fibres for the upper limb concentrated in the genu and adjoining anterior part of the posterior limb.
- ▶ **Anterior choroidal artery syndrome** — occlusion produces the classical triad of **contralateral hemiplegia, hemianaesthesia and homonymous hemianopia**, from involvement of the posterior limb, retrolentiform and sublentiform parts together.
- ▶ Lesions of the **retrolentiform/sublentiform parts** produce **contralateral homonymous hemianopia** (optic radiation) and, less clinically apparent because of bilateral cortical representation, diminished hearing (auditory radiation).
- ▶ **Capsular warning syndrome** — recurrent, stereotyped transient ischaemic episodes (limb weakness) from critical stenosis of a lenticulostriate perforator, carrying a high short-term risk of a completed capsular infarct; recognising this syndrome prompts urgent antiplatelet/anticoagulant and imaging work-up.
- ▶ **Radiological/surgical relevance** — the genu's position medial to the interventricular foramen and the capsule's characteristic V-shape are used to localise lesions on CT/MRI; the posterior

limb (corticospinal tract) is a critical structure to avoid during **stereotactic pallidotomy/thalamotomy or deep brain stimulation** electrode placement for movement disorders.

Recent advances

According to PubMed:

- ▶ **DTI of the corticospinal tract at the internal capsule** — fractional anisotropy in the posterior limb correlates with upper-limb motor recovery in chronic stroke patients undergoing robotic rehabilitation, a candidate biomarker for individualised therapy (Magouni et al, *Exp Ther Med* 2025) [DOI](<https://doi.org/10.3892/etm.2025.12932>).
- ▶ **Diffusion tensor-based morphometry**, more sensitive than plain FA mapping, detects focal capsular corticospinal-tract volume loss (Wallerian degeneration) within 30 days of stroke, correlating strongly with arm-motor recovery (Edwardson et al, *Neurology* 2025) [DOI](<https://doi.org/10.1212/WNL.0000000000213408>).
- ▶ A Human Connectome Project analysis found corticospinal tract diffusion strength at the capsule is **not related to handedness**, so handedness-matching is unnecessary in capsular DTI laterality-index stroke studies (Domin et al, *Sci Rep* 2025) [DOI](<https://doi.org/10.1038/s41598-025-19580-9>).
- ▶ A large prospective cohort confirmed **capsular warning syndrome** carries the highest short-term stroke risk of any TIA subtype (~30%), most often infarcting the internal capsule (60%), with **dual antiplatelet therapy** lowering subsequent stroke risk versus monotherapy (Foschi et al, *Cerebrovasc Dis* 2022) [DOI](<https://doi.org/10.1159/000525954>).
- ▶ A 2025 case report of capsular warning syndrome progressing to capsular infarct shows near-complete recovery with structured protocol-based rehabilitation (GRASP + proprioceptive balance training) (Nguyen et al, *SAGE Open Med Case Rep* 2025) [DOI](<https://doi.org/10.1177/2050313X251364366>).

High-yield exam pointers

- ▶ **V-shaped** in horizontal section, concavity lateral (occupied by lentiform nucleus); **5 parts** — anterior limb, genu, posterior limb, retrolentiform part, sublentiform part.
- ▶ Continuous **above with corona radiata**, **below with crus cerebri** — one continuous fibre highway from cortex to brainstem/cord.
- ▶ **Genu = corticonuclear fibres**; **posterior limb = corticospinal fibres** in face→arm→trunk→leg antero-posterior order.
- ▶ **Four thalamic radiations**: anterior (anterior limb), superior (genu + posterior limb), posterior/optic (retrolentiform), inferior/auditory (sublentiform).
- ▶ **Charcot's artery** = largest lateral lenticulostriate branch of MCA → supplies posterior limb → commonest site of **hypertensive intracerebral haemorrhage**.
- ▶ **Recurrent artery of Heubner** (ACA branch) → anterior limb + genu → occlusion causes **faciobrachial monoplegia**.
- ▶ **Anterior choroidal artery** → posterior 1/3 of posterior limb + retrolentiform + sublentiform parts → triad of hemiplegia + hemianaesthesia + homonymous hemianopia if occluded.

- ▶ A tiny capsular lesion causes a disproportionately large, whole-body-half deficit because all fibres are densely packed in a very small area — the classic examiner's teaching point.
- ▶ **Interventricular foramen (Monro)** lies medial to the genu — key radiological landmark.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3–4 8e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e.



White Matter of Cerebrum

Asked in: Paper IV 14-Jul-2023 · Paper IV Nov 2016 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

The white matter of the cerebral hemisphere is the compact core of myelinated axons, together with their supporting neuroglia, that lies deep to the grey mantle of the cerebral cortex and forms the bulk of the volume of each hemisphere. On the basis of the connections they establish, these fibres are classified into three groups — **association fibres** (link cortical areas within the same hemisphere), **commissural fibres** (link corresponding areas of the two hemispheres), and **projection fibres** (link the cortex to subcortical grey matter, brainstem and spinal cord). The **corpus callosum** (largest commissure) and the **internal capsule** (largest bundle of projection fibres) are of special clinical importance because of the sheer density of fibres they pack into a small space.

Classification of white matter fibres

Type	Connections established	Chief examples
Association fibres	Interconnect cortical areas of the same hemisphere (intrahemispheric)	Short (arcuate/U) fibres; long bundles — uncinate fasciculus, cingulum, superior/middle/inferior longitudinal fasciculi, inferior fronto-occipital fasciculus
Commissural fibres	Interconnect corresponding areas of the two hemispheres (interhemispheric)	Corpus callosum, anterior commissure, posterior commissure, hippocampal (fornix) commissure, habenular commissure
Projection fibres	Connect cortex to subcortical nuclei, brainstem and spinal cord	Corona radiata, internal capsule (neocortical); fornix, fimbria (allocortical)

□ Fig 14.1 — Frontal view of coronal section of the brain showing association, commissural, and projection fibres (Vishram Singh — Clinical Neuroanatomy — 4e, p.496)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Coronal section through the cerebral hemispheres; label: **cerebral cortex**, **short (U/arcuate) association fibres** hooking around a sulcus, **long association bundle** (e.g. cingulum) in one hemisphere, **corpus callosum** arching across the midline as the commissural fibres, **caudate nucleus**, **thalamus**, **lentiform nucleus (putamen + globus pallidus)**, and the **corona radiata/internal capsule** as the projection fibres converging between them.

Association fibres

- ▶ **Short association (arcuate/U) fibres** — entirely intracortical or immediately subcortical; hook around the depth of a sulcus to connect adjacent gyri subserving similar function.
- ▶ **Long association bundles** — connect anatomically distant but functionally related gyri of the same hemisphere:
- ▶ **Uncinate fasciculus** — hook-shaped; hooks around the stem of the lateral sulcus to connect the motor speech (orbitofrontal) cortex and orbital cortex of the frontal lobe with the temporal pole.
- ▶ **Cingulum** ("limbic association bundle") — lies within the cingulate and parahippocampal gyri; extends in a girdle from the paraterminal gyrus, below the rostrum of the corpus callosum, around to the uncus.
- ▶ **Superior longitudinal fasciculus (SLF)** — the longest association bundle; connects the frontal lobe to the parietal, occipital and temporal lobes. It has a frontoparietal (horizontal) segment, a temporoparietal (vertical) segment, and a temporofrontal segment that corresponds to the **arcuate fasciculus** proper, linking Broca's area to Wernicke's area.
- ▶ **Middle longitudinal fasciculus** — within the superior temporal gyrus; connects the angular gyrus to the temporal pole.
- ▶ **Inferior longitudinal fasciculus** — connects the visual association cortex of the occipital lobe to the temporal lobe, running through the fusiform gyrus.
- ▶ **Inferior fronto-occipital fasciculus** — runs from the frontal pole to the occipital and temporal lobes, lying deep to the SLF and separated from it by the fibres of the corona radiata.

Commissural fibres — corpus callosum and other commissures

- ▶ **Corpus callosum** — the largest commissure of the brain, containing **150–200 million fibres**, about **10 cm long** (nearly half the antero-posterior length of the hemisphere). It connects all parts of the neocortex of the two sides **except** the lower and anterior parts of the temporal lobes, which are connected instead by the anterior commissure. It is divided into four parts:
 - **Genu** — thick anterior end, 4 cm behind the frontal pole; forms the anterior wall of the frontal horn; its fibres curve forward as the **forceps minor**, connecting the two frontal lobes.
 - **Rostrum** — thin prolongation from the genu to the lamina terminalis; forms the floor of the frontal horn; connects the orbital surfaces of the two frontal lobes.
 - **Trunk (body)** — the main middle part; forms the roof of the central part of the lateral ventricle; related above to the anterior cerebral vessels and the falx cerebri, and below to the septum pellucidum and fornix; overlapped by the cingulate gyrus (separated by the callosal sulcus).

- **Splenium** — thick posterior end, 6 cm in front of the occipital pole; overhangs the thalamic pulvinar, pineal gland and tectum; its fibres curve back as the **forceps major**, connecting the two occipital lobes.
- **Tapetum** — fibres of the trunk and splenium not intersected by the corona radiata; forms the roof and lateral wall of the posterior horn and the lateral wall of the inferior horn of the lateral ventricle.
- **Blood supply** — mainly the **anterior cerebral artery** and **anterior communicating artery**; the splenium receives an additional supply from the **posterior cerebral artery**.
- ▶ **Anterior commissure** — compact, "bicycle-handlebar"-shaped bundle crossing the midline just anterior to the column of the fornix and the interventricular foramen; a smaller anterior (paleocortical/olfactory) part connects the olfactory bulbs, and a larger posterior (neocortical) part connects the antero-inferior temporal lobes.
- ▶ **Posterior commissure** — crosses the midline through the inferior lamina of the pineal stalk; connects the superior colliculi, pretectal and interstitial nuclei of the two sides, and carries corticotectal fibres and pretecto-Edinger-Westphal fibres important for the consensual light reflex.
- ▶ **Habenular commissure** — crosses through the superior lamina of the pineal stalk; connects the habenular nuclei.
- ▶ **Hippocampal commissure (commissure of the fornix)** — a thin triangular sheet between the crura of the fornix, lying beneath the splenium; connects the two hippocampal formations.

Corona radiata and internal capsule

- ▶ **Corona radiata** — the fan-shaped mass of corticofugal (descending) and corticopetal (ascending) projection fibres that converges from every lobe of the hemisphere; it continues below as the internal capsule.
- ▶ **Internal capsule** — a compact band of projection fibres lying between the **caudate nucleus and thalamus medially** and the **lentiform nucleus laterally**. In horizontal section it is **V-shaped**, with its concavity directed laterally and occupied by the lentiform nucleus; its fibres diverge above into the corona radiata and converge below to continue as the **crus cerebri** of the midbrain. It is divided into five parts:
 - **Anterior limb** — between the head of the caudate nucleus and the anterior part of the lentiform nucleus.
 - **Genu** — the bend between the anterior and posterior limbs, at the vertex of the "V".
 - **Posterior limb** — between the thalamus and the posterior part of the lentiform nucleus.
 - **Retrolentiform part** — behind the lentiform nucleus.
 - **Sublentiform part** — below the lentiform nucleus.

□ Fig 8.27 — Boundaries and parts of internal capsule (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.574)

Constituent fibres of the internal capsule

Part	Descending (motor) fibres	Ascending (sensory) fibres
Anterior limb	Frontopontine fibres (part of corticoponto-cerebellar pathway)	Anterior thalamic radiation (anterior/dorsomedial thalamic nuclei → frontal cortex)
Genu	Corticonuclear (corticobulbar) fibres to contralateral motor cranial nerve nuclei	Anterior fibres of superior thalamic radiation
Posterior limb	Corticospinal tract (fibres for upper limb anterior, trunk middle, lower limb posterior); corticorubral and corticoreticular fibres	Superior thalamic radiation (somaesthetic, ventral posterior nucleus → post-central gyrus)
Retrolentiform part	Parieto-pontine and occipito-pontine fibres; occipito-tectal fibres	Posterior thalamic radiation = optic radiation (lateral geniculate body → area 17)
Sublentiform part	Temporo-pontine fibres	Inferior thalamic radiation = auditory radiation (medial geniculate body → areas 41, 42)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Horizontal (axial) section through the cerebral hemisphere at the level of the thalamus; label: **head of caudate nucleus**, **thalamus**, **lentiform nucleus** (putamen + globus pallidus), and the V-shaped **internal capsule** with its five parts — **anterior limb**, **genu**, **posterior limb**, **retrolentiform part**, **sublentiform part** — plus the continuity above with **corona radiata** and below with the **crus cerebri**.

Blood supply of the internal capsule

The arterial supply is of major clinical importance because of the high frequency of vascular ("capsular") lesions here:

Part supplied	Artery
Anterior limb	Recurrent artery of Huebner (branch of anterior cerebral artery) + direct branches of anterior cerebral artery
Genu	Direct branches of internal carotid artery; central branches of posterior communicating artery
Posterior limb (bulk)	Medial and lateral striate (lenticulostriate) branches of middle cerebral artery — the larger lateral branch is Charcot's artery of cerebral haemorrhage ; also anterior choroidal artery
Sublentiform part	Central branches of anterior choroidal artery; branches of posterior cerebral artery

Part supplied	Artery
Retrolentiform part	Posterolateral central (choroidal/thalamogeniculate) branches of posterior cerebral artery

Applied / Clinical anatomy

- ▶ **Capsular stroke** — haemorrhage or infarction in the internal capsule is the **commonest cause of hemiplegia**; it produces contralateral upper motor neurone (spastic) hemiplegia with sensory loss, because the corticospinal, corticonuclear and thalamocortical fibres all lie tightly packed together. Rupture of **Charcot's artery of cerebral haemorrhage** (the larger lateral lenticulostriate branch of the MCA), supplying the posterior limb, is the classic cause.
- ▶ Thrombosis/rupture of the **recurrent artery of Huebner** (branch of the anterior cerebral artery, supplying the genu and anterior limb) causes contralateral upper motor neurone paralysis of the **face and upper limb**, sparing the lower limb.
- ▶ Occlusion of the **anterior choroidal artery**, supplying the sublentiform and retrolentiform parts, produces the classic triad of contralateral **hemiplegia, hemianaesthesia and homonymous hemianopia**.
- ▶ **Why a small capsular lesion causes widespread deficit**: unlike the widely-spread fibres of the corona radiata, the internal capsule packs the entire motor and sensory traffic of the opposite half of the body into a narrow space — a favourite viva/short-note question.
- ▶ **Corpus callosum lesions**: commissurotomy (for intractable epilepsy) or congenital absence produces **split-brain syndrome**, usually clinically silent since each hemisphere still independently controls/senses the contralateral body half. Anterior callosal lesions → akinetic mutism/tactile anomia; splenial lesions → **alexia without agraphia**.
- ▶ **DTI tractography** permits in-vivo "virtual dissection" of association bundles (SLF, IFOF, uncinate, ILF) and is now used for pre-operative neurosurgical mapping (e.g. awake craniotomy) to avoid injuring eloquent tracts; the **AC–PC line** remains the key stereotactic landmark for functional neurosurgery.

High-yield exam pointers

- ▶ Three fibre types: **association** (same side), **commissural** (opposite side), **projection** (cortex ↔ lower centres).
- ▶ **Corpus callosum** = largest commissure / largest single fibre pathway of the brain (150–200 million fibres, ~10 cm).
- ▶ **Internal capsule** = largest bundle of projection fibres; **V-shaped** in horizontal section, concavity lateral; 5 parts — anterior limb, genu, posterior limb, retrolentiform, sublentiform.
- ▶ **Superior longitudinal fasciculus** = longest association bundle; its temporofrontal segment = arcuate fasciculus (Broca's ↔ Wernicke's area).
- ▶ Corticospinal fibres in the posterior limb: **upper limb anterior** → **trunk** → **lower limb posterior**.
- ▶ **Charcot's artery of cerebral haemorrhage** (lateral lenticulostriate, from MCA) = commonest cause of capsular haemorrhage/hemiplegia.

- ▶ **Recurrent artery of Huebner** (from ACA) supplies genu + anterior limb → face + upper-limb paralysis if occluded.
- ▶ Small internal-capsule lesion → widespread deficit (dense fibre packing); a similar-sized corona radiata lesion → minimal deficit (fibres widely spread).
- ▶ Agenesis/division of corpus callosum → split-brain syndrome, often clinically silent.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Clinical Neuroanatomy 4e; BD Chaurasia — Human Anatomy Vol 3–4 8e; IB Singh — Textbook of Human Neuroanatomy.



Classify the white matter of cerebrum, describe internal capsule and its applied aspect?

Asked in: Paper IV May 2011 — RGUHS MD/MS Anatomy

Definition / Introduction The white matter of the cerebral hemisphere lies deep to the cortical grey matter and is made up of myelinated axons that link cortical areas to one another and to the rest of the CNS. On the basis of the connections they establish, these fibres are classified into three groups — **association**, **commissural** and **projection** fibres. The **internal capsule** is the most important and clinically significant bundle of projection fibres: it is the compact, V-shaped sheet through which almost all ascending and descending fibres pass between the cerebral cortex and the thalamus, brainstem and spinal cord, and it is the commonest anatomical site of a "capsular" vascular stroke.

1. Classification of white matter fibres of the cerebrum

Type	Fibres connect	Examples
Association fibres	Different cortical areas of the same hemisphere (intrahemispheric)	Short (arcuate/'U') fibres; long bundles — uncinate fasciculus, cingulum, superior longitudinal fasciculus, inferior longitudinal fasciculus, (inferior) fronto-occipital fasciculus
Commissural fibres	Corresponding areas of the two hemispheres (interhemispheric)	Corpus callosum, anterior commissure, posterior commissure, hippocampal (fornix) commissure, habenular commissure, hypothalamic commissures
Projection fibres	Cerebral cortex to subcortical grey matter, brainstem and spinal cord	Corona radiata + internal capsule (fibres of neocortex); fimbria + fornix (fibres of archicortex/paleocortex)

2. Association fibres

- ▶ **Short association** (arcuate/'U') fibres hook around a sulcus to connect adjacent gyri.

- ▶ **Long association fibres** connect gyri of different lobes and are grouped into named bundles:
 - **Uncinate fasciculus** — connects the motor speech area and orbital cortex of the frontal lobe to the temporal pole.
 - **Cingulum** — a girdle-shaped bundle running from the paraterminal gyrus, around the corpus callosum, to the uncus, within the cingulate and parahippocampal gyri.
 - **Superior longitudinal fasciculus** — the **longest** association bundle; connects the frontal lobe to the occipital and temporal lobes.
 - **Inferior longitudinal fasciculus** — connects the occipital and temporal lobes.
 - **(Inferior) fronto-occipital fasciculus** — connects frontal to occipital/temporal lobes, lying deep to the superior longitudinal fasciculus.

3. Commissural fibres

- ▶ **Corpus callosum** — the largest commissure of the brain (~10 cm), connecting the neopallial cortex of the two hemispheres. It has four parts: **rostrum** (joins the lamina terminalis), **genu** (thick curved anterior end, ~4 cm behind the frontal pole, gives the **forceps minor**), **trunk/body**, and **splenium** (massive posterior end, ~6 cm in front of the occipital pole, overhangs the thalamus, gives the **tapetum** and **forceps major**).
- ▶ **Anterior commissure** — has a large posterior **neocortical** component (interconnects middle and inferior temporal gyri) and a small anterior **paleocortical** component (olfactory bulbs and piriform area).
- ▶ **Posterior commissure** — connects the superior colliculi and carries corticotectal fibres and pretectal fibres to the Edinger–Westphal nucleus of the opposite side (light-reflex pathway).
- ▶ **Hippocampal (fornix) commissure** — connects the crura of the fornix and hence the two hippocampal formations.
- ▶ **Habenular commissure** — connects the habenular nuclei.
- ▶ **Hypothalamic commissures** — anterior hypothalamic commissure of **Ganser**, ventral supraoptic commissure of **Gudden**, dorsal supraoptic commissure of **Meynert**.

4. Projection fibres and the internal capsule

Projection fibres connect the cerebral cortex to subcortical grey matter, brainstem and spinal cord. Those of the **neocortex** form the **corona radiata** above and condense into the **internal capsule** below; those of the **archicortex/paleocortex** form the **fimbria and fornix**. The internal capsule is thus the largest and most important bundle of projection fibres.

- ▶ **Location** — a compact bundle of white fibres between the **thalamus and caudate nucleus** medially and the **lentiform nucleus** laterally.
- ▶ **Shape** — in a horizontal section it is **V-shaped**, with its concavity directed laterally.
- ▶ **Continuity** — continuous above with the corona radiata and below with the crus cerebri of the midbrain.

5. Parts of the internal capsule

The internal capsule is divided into **five parts**:

Part	Boundary / location
Anterior limb	Between the head of the caudate nucleus (medially) and the anterior part of the lentiform nucleus (laterally)
Genu	The bend between the anterior and posterior limbs, concavity directed laterally
Posterior limb	Between the thalamus (medially) and the posterior part of the lentiform nucleus (laterally)
Retrolentiform part	Behind the lentiform nucleus
Sublentiform part	Below the lentiform nucleus

6. Constituent fibres of the internal capsule

Motor (descending), sensory (ascending, thalamic radiation) and arterial supply are best learnt limb-by-limb:

Part	Descending (motor) fibres	Ascending (sensory) fibres	Arterial supply
Anterior limb	Frontopontine fibres (part of the corticopontocerebellar pathway)	Anterior thalamic radiation — anterior + dorsomedial thalamic nuclei to frontal cortex	Recurrent artery of Huebner (branch of anterior cerebral artery) + direct branches of anterior cerebral artery
Genu	Corticonuclear (corticobulbar) fibres to motor nuclei of cranial nerves III, IV, V, VI, VII, XII and nucleus ambiguus (IX, X, XI)	Anterior part of the superior thalamic radiation	Direct branches of internal carotid artery; posterior communicating artery
Posterior limb	Corticospinal (pyramidal) tract — fibres for upper limb anterior-most, then trunk, then lower limb (somatotopic); corticorubral and corticostriate (extrapyramidal) fibres lie close to the corticospinal fibres	Superior thalamic radiation (general sensory/somaesthetic radiation) — ventral posterior thalamic nuclei to postcentral gyrus	Medial and lateral striate branches of middle cerebral artery (the larger lateral striate branch = Charcot's artery of cerebral haemorrhage); anterior choroidal artery
Retrolentiform part	Parietopontine and occipitopontine fibres; corticotectal fibres to the superior colliculus/pretectal region	Posterior thalamic radiation = optic radiation (lateral geniculate body to visual cortex, area 17)	Branches of posterior cerebral artery

Part	Descending (motor) fibres	Ascending (sensory) fibres	Arterial supply
Sublentiform part	Temporopontine fibres	Inferior thalamic radiation = auditory radiation (medial geniculate body to primary auditory cortex)	Central branches of anterior choroidal artery; posterolateral central branches of posterior cerebral artery

Note: corticopontine fibres (fronto-, parieto-, occipito- and temporopontine) form the **largest single group** of projection fibres in the internal capsule — about two-thirds of its total fibre content — and relay in the ipsilateral pontine nuclei before crossing to the opposite cerebellar hemisphere as the corticoponto-cerebellar pathway, the phylogenetically most recent pathway in the internal capsule.

□ Fig 11.9 — Subdivisions of the internal capsule (IB Singh — *Textbook of Human Neuroanatomy*, p.201)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Horizontal section of the cerebrum at the level of the interventricular foramen, showing the V-shaped internal capsule:

- ▶ **Caudate nucleus** (head) — medial to anterior limb
- ▶ **Thalamus** — medial to posterior limb
- ▶ **Lentiform nucleus** (putamen + globus pallidus) — lateral to the whole capsule
- ▶ Label the five parts: **anterior limb**, **genu**, **posterior limb**, **retrolentiform part**, **sublentiform part**
- ▶ Within the posterior limb, mark the somatotopic order of corticospinal fibres front-to-back: **face/arm** → **trunk** → **leg**
- ▶ Arrows/labels for the four thalamic radiations at their respective sites: **anterior** (anterior limb), **superior** (genu/posterior limb), **posterior = optic radiation** (retrolentiform), **inferior = auditory radiation** (sublentiform)

Applied / Clinical anatomy

- ▶ **Capsular lesions and hemiplegia** — because motor and sensory fibres for the entire opposite half of the body are packed into a very small cross-sectional area, even a small vascular lesion of the internal capsule produces widespread contralateral **spastic (upper motor neuron) hemiplegia with hemianaesthesia** — in sharp contrast to a similarly sized lesion in the widely-fanned-out corona radiata, which causes only a limited deficit.
- ▶ **Charcot's artery of cerebral haemorrhage** — the larger of the lateral striate branches of the middle cerebral artery; it is the **commonest site of rupture in hypertensive intracerebral haemorrhage**, supplying the posterior limb and thereby producing the classical contralateral spastic hemiplegia.
- ▶ **Recurrent artery of Huebner** — a large striate branch of the anterior cerebral artery (arising just proximal to the anterior communicating artery) supplying the genu and anterior limb; its occlusion involves the corticonuclear fibres in the genu together with adjacent pyramidal fibres, giving a contralateral **facio-brachial (face + upper limb) paralysis**.

- ▶ **Anterior choroidal artery occlusion** — affects the sublenticular and retrolenticular parts and the posterior third of the posterior limb, giving the classical triad of contralateral **hemiplegia, hemianaesthesia and hemianopia**, sometimes with hearing loss.
- ▶ **Genu lesions** — produce sensory/motor loss of the contralateral side of the head that is often **incomplete**, because most cranial nerve motor nuclei (other than the lower facial and hypoglossal nuclei) receive **bilateral corticonuclear innervation**.
- ▶ **Somatotopic clinical correlation** — because corticospinal fibres in the posterior limb are arranged upper-limb-anterior, trunk-middle, lower-limb-posterior, a partial capsular infarct may produce a disproportionate weakness of one limb over another.
- ▶ **Radiological correlation** — on CT/MRI at the level of the third ventricle/foramen of Monro, the internal capsule is seen as the characteristic V-shaped band between the caudate nucleus/thalamus and the lentiform nucleus; precise localisation of an infarct/haemorrhage to a particular limb (anterior, genu, posterior) on imaging correlates directly with the clinical deficit and helps in prognostication of "capsular" or lacunar stroke syndromes such as pure motor hemiplegia.

Recent advances

- ▶ Diffusion-tensor tractography of the posterior limb of the internal capsule/corticospinal tract in the acute stage of stroke is now used as an **imaging biomarker for motor-recovery prognosis** — serial DTI in minor basal-ganglia haemorrhage shows measurable restoration of corticospinal tract volume and fibre count over the first month after treatment, correlating with functional recovery (Liao et al., *Frontiers in Neuroscience*, 2025) [DOI: 10.3389/fnins.2025.1526910].
- ▶ Large-cohort Human Connectome Project tractography (n = 1,065) of the corticospinal tract at the height of the internal capsule found its **structural lateralisation is not related to handedness**, refining long-standing assumptions about capsular fibre asymmetry (Domin, Lindenberg & Lotze, *Scientific Reports*, 2025) [DOI: 10.1038/s41598-025-19580-9].
- ▶ Connectomic **tractography-guided repositioning** of deep-brain-stimulation leads within the anterior limb of the internal capsule (targeting fibres to the ventromedial prefrontal cortex and mediodorsal thalamus) has improved outcomes in refractory obsessive-compulsive disorder and depression, extending the applied anatomy of the anterior limb beyond the classical fronto-pontine/anterior-thalamic-radiation description (Basich-Pease et al., *Frontiers in Human Neuroscience*, 2024;17) [DOI: 10.3389/fnhum.2023.1339340].
- ▶ (*According to PubMed-indexed literature.*)

High-yield exam pointers

- ▶ White matter of the cerebrum = **3 types** — association (intra-hemispheric), commissural (inter-hemispheric), projection (cortex ↔ subcortex/brainstem/cord).
- ▶ Internal capsule = largest bundle of projection fibres; **V-shaped** in horizontal section; **5 parts** — anterior limb, genu, posterior limb, retrolenticular part, sublenticular part.
- ▶ Bounded medially by caudate nucleus + thalamus, laterally by lentiform nucleus.
- ▶ **Genu** = corticonuclear fibres; **anterior two-thirds of posterior limb** = corticospinal tract, somatotopically arranged upper limb → trunk → lower limb.

- ▶ Retrolentiform part carries the **optic radiation**; sublentiform part carries the **auditory radiation**.
- ▶ **Charcot's artery** (lateral striate branch of MCA) is the commonest site of hypertensive capsular haemorrhage → posterior limb → contralateral hemiplegia.
- ▶ **Recurrent artery of Huebner** (ACA branch) supplies genu + anterior limb; **anterior choroidal artery** supplies the sublentiform part.
- ▶ Corticopontine fibres are the single largest fibre group (~2/3 of total) in the internal capsule.
- ▶ Corpus callosum (largest commissure, 4 parts: rostrum, genu, trunk, splenium) is the largest commissural bundle; internal capsule is the largest projection bundle.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3–4 8e; IB Singh's Textbook of Human Neuroanatomy; Snell's Clinical Neuroanatomy 7e. Recent-advances section per PubMed-indexed literature (see DOIs above).



Classify the white matter of the cerebrum. Describe parts, relations, arterial supply, fibre components and applied aspects of internal capsule

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction The cerebral white matter is a compact mass of myelinated nerve fibres, deep to the cerebral cortex, that interconnects different cortical areas with each other and with subcortical and spinal centres. On the basis of the connections they provide, these fibres are classified into association, commissural and projection fibres. The **internal capsule** is the most important bundle of projection fibres — a compact, V-shaped sheet of ascending and descending fibres between the thalamus/caudate nucleus medially and the lentiform nucleus laterally — and is the single commonest site where a small vascular lesion produces widespread contralateral motor and sensory deficit.

Classification of the white matter of the cerebrum

Type	Definition	Chief sub-types / examples
Association fibres	Connect different cortical areas of the same hemisphere (intrahemispheric)	Short (arcuate/U) fibres — hook around a sulcus to join adjacent gyri; Long fibres — uncinate fasciculus, cingulum, superior longitudinal fasciculus, inferior longitudinal fasciculus, fronto-occipital fasciculus

Type	Definition	Chief sub-types / examples
Commissural fibres	Connect corresponding areas of the two hemispheres (interhemispheric)	Corpus callosum (largest commissure — rostrum, genu, trunk, splenium; ~10 cm long, ~150–200 million fibres); anterior commissure; posterior commissure; hippocampal commissure; habenular commissure
Projection fibres	Connect the cerebral cortex to subcortical centres (corpus striatum, thalamus, brainstem) and the spinal cord	Neocortex → corona radiata + internal capsule ; Alloccortex (archi-/paleocortex) → fimbria + fornix



Classify the white matter of the cerebrum. Describe parts, relations, arterial supply, fibre components and applied aspects of internal capsule

Internal capsule — location, shape and boundaries

- The internal capsule is a compact bundle of projection fibres lying between the **caudate nucleus** and **thalamus medially** and the **lentiform nucleus laterally**.
- In a horizontal (axial) section it appears **V-shaped**, with its **concavity directed laterally** and its apex (**genu**) directed medially, lying between the head of the caudate nucleus and the thalamus.
- Rostrally, its fibres fan out into the **corona radiata**; caudally, they condense to continue as the **crus cerebri** of the midbrain (corticospinal/corticonuclear fibres occupy the middle two-fourths of the crus, frontopontine fibres lie medially, and parieto-temporo-occipitopontine fibres lie laterally).
- It is the **largest and longest bundle of projection fibres** in the brain, carrying both corticopetal (ascending, sensory) and corticofugal (descending, motor) fibres for the entire opposite half of the body.

Parts and relations of the internal capsule

Part	Extent / relations
Anterior limb	Between the head of the caudate nucleus (medial) and the anterior part of the lentiform nucleus/putamen (lateral)
Genu	The bend at the medially-directed apex of the V, at the junction of the anterior and posterior limbs; the interventricular foramen of Monroe lies medial and adjacent to it — an important radiological landmark
Posterior limb	Between the thalamus (medial) and the posterior part of the lentiform nucleus/putamen (lateral); the longest part

Part	Extent / relations
Retrolentiform part	Lies behind (posterior to) the lentiform nucleus
Sublentiform part	Lies below (inferior to) the lentiform nucleus

- ▶ Laterally, the lentiform nucleus (putamen + globus pallidus) is separated from the **claustrum** by the **external capsule**; the claustrum is in turn separated from the insular cortex by the **extreme capsule**.
- ▶ Corticospinal fibres arising from the precentral gyrus converge from the corona radiata and undergo an internal rotation of about 90° to enter the genu and anterior part of the posterior limb, retaining their somatotopic (homuncular) sequence throughout.

□ Fig 8.27 — Boundaries and parts of internal capsule (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.574)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A horizontal (axial) section through the cerebrum at the level of the basal nuclei, labelled:

- ▶ Head of caudate nucleus
- ▶ Thalamus
- ▶ Putamen (of lentiform nucleus)
- ▶ Globus pallidus (of lentiform nucleus)
- ▶ Anterior limb
- ▶ Genu
- ▶ Posterior limb
- ▶ Retrolentiform part
- ▶ Sublentiform part
- ▶ External capsule
- ▶ Claustrum

Fibre components of the internal capsule

Part	Descending / corticofugal (motor) fibres	Ascending / corticopetal (sensory) fibres
Anterior limb	Frontopontine fibres	Anterior thalamic radiation (fronto-thalamic — anterior & dorsomedial thalamic nuclei to frontal cortex)
Genu	Corticonuclear (corticobulbar) fibres — to contralateral motor cranial-nerve nuclei	Anterior fibres of the superior thalamic radiation
Posterior limb	Corticospinal fibres (somatotopic — upper limb most anterior , then trunk, then lower limb most posterior); corticorubral and other extrapyramidal fibres; frontopontine fibres	Superior thalamic radiation (somaesthetic; 3rd-order sensory neurons to the postcentral gyrus)

Part	Descending / corticofugal (motor) fibres	Ascending / corticopetal (sensory) fibres
Retrolentiform part	Parietopontine, occipitopontine and corticotectal fibres	Posterior thalamic radiation, including the optic radiation (lateral geniculate body → calcarine cortex)
Sublentiform part	Temporopontine fibres	Inferior thalamic radiation, including the auditory radiation (medial geniculate body → superior temporal gyrus)

- **Corticopontine fibres** (fronto-, parieto-, temporo- and occipito-pontine) form the single largest group of fibres in the internal capsule, accounting for roughly two-thirds of its total fibre content; they relay in the ipsilateral pontine nuclei, whose axons then cross to the opposite cerebellar hemisphere, forming the **cortico-ponto-cerebellar pathway**. Of the corticopontine fibres, the **frontopontine fibres are the most numerous** (about 55%).
- **Extrapyramidal fibres** (corticostriate, corticorubral, corticoreticular, corticonigral) run close to the corticospinal fibres in the posterior limb and are therefore also involved in posterior-limb lesions.

Arterial supply of the internal capsule

The arterial supply is of great clinical importance because of the high incidence of vascular ("capsular") lesions.

Artery	Part supplied
Medial striate artery (recurrent artery of Heubner , a branch of the proximal anterior cerebral artery, arising just proximal to the anterior communicating artery)	Anterior limb and genu (via the anterior perforated substance)
Lateral striate branches of the middle cerebral artery	Anterior limb, genu, and much of the posterior limb; one large lateral striate branch is the Charcot's artery of cerebral haemorrhage — the commonest site of hypertensive capsular haemorrhage
Anterior choroidal artery (from the internal carotid artery)	Ventral part of the posterior limb, and the retrolentiform and sublentiform parts
Direct branches of the internal carotid artery	Lower part of the genu
Branches of the posterior communicating artery	Lower parts of the genu and posterior limb
Posterolateral central branches of the posterior cerebral artery	Retrolentiform and sublentiform parts

□ Fig 8.30 — Arteries supplying the internal capsule (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.575)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

The circle of Willis with its striate/perforating branches feeding into the same horizontal section of the internal capsule, labelled:

- ▶ Internal carotid artery
- ▶ Anterior cerebral artery and anterior communicating artery
- ▶ Recurrent artery of Heubner (branch of anterior cerebral artery)
- ▶ Middle cerebral artery — medial and lateral striate branches (Charcot's artery)
- ▶ Posterior communicating artery
- ▶ Anterior choroidal artery
- ▶ Posterior cerebral artery — posterolateral central branches
- ▶ Basilar artery

Applied / Clinical anatomy

- ▶ **Capsular stroke ("stroke syndrome")**: occlusion (thrombo-embolic) or rupture of a striate branch — classically Charcot's artery of cerebral haemorrhage in a hypertensive patient — produces sudden **contralateral spastic hemiplegia** with contralateral sensory loss, ± **homonymous hemianopia** if the retrolentiform part is involved, and aphasia if the dominant hemisphere is affected. Because the tracts are so densely packed, even a small lesion causes a widespread deficit.
- ▶ **Faciobrachial monoplegia**: occlusion of the recurrent artery of Heubner damages the corticonuclear fibres for the face (genu) and the adjacent corticospinal fibres for the upper limb (anterior part of the posterior limb), producing weakness of the face and upper limb with the lower limb spared.
- ▶ **Posterior one-third of the posterior limb, retrolentiform and sublenticular lesions** (anterior choroidal artery territory) cause contralateral **hemianopia** (optic radiation) and **hearing loss** (auditory radiation) in addition to sensory loss.
- ▶ **Lacunar syndromes**: small deep infarcts ("lacunes") in the internal capsule, due to lipohyalinosis of the penetrating striate arteries in hypertensive/diabetic patients, produce classical lacunar syndromes such as **pure motor hemiparesis** (posterior limb) and **pure sensory stroke**.
- ▶ **Radiological/surgical landmark**: the genu, lying just medial to the interventricular foramen of Monro, is a key landmark for localising capsular lesions on axial CT/MRI; **DTI tractography** is used to map the corticospinal tract through the capsule before resecting tumours close to it, to avoid iatrogenic hemiplegia. Stereotactic **pallidotomy/thalamotomy** trajectories for movement disorders are similarly planned to avoid the immediately adjacent posterior limb.
- ▶ The internal capsule is often called the "**bottleneck of the brain**" because virtually all corticofugal and corticopetal traffic for the opposite half of the body must pass through this narrow compass — the anatomical basis for why a lesion here (unlike an equally sized cortical lesion) produces a combined, extensive motor-plus-sensory deficit.

High-yield exam pointers

- ▶ White matter fibres = **association** (intrahemispheric), **commissural** (interhemispheric), **projection** (cortex ↔ subcortex/cord).
- ▶ Internal capsule = largest and longest bundle of projection fibres; **V-shaped** in horizontal section, concavity lateral, genu medial.
- ▶ **Five parts**: anterior limb, genu, posterior limb, retrolentiform part, sublenticular part.
- ▶ Bounded medially by caudate nucleus + thalamus; laterally by lentiform nucleus (putamen + globus pallidus).
- ▶ Corticopontine fibres are the largest single fibre group (~2/3 of total); frontopontine fibres are the most numerous among them (~55%).
- ▶ Corticospinal fibres in the posterior limb are somatotopic: **upper limb anterior** → **trunk** → **lower limb posterior**.
- ▶ **Charcot's artery of cerebral haemorrhage** (lateral striate branch of the MCA) = commonest cause of hypertensive capsular haemorrhage → contralateral spastic hemiplegia.
- ▶ **Recurrent artery of Heubner** occlusion → faciobrachial monoplegia.
- ▶ **Anterior choroidal artery** supplies the retrolentiform and sublenticular parts → hemianopia + deafness on occlusion.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Clinical Neuroanatomy, 4e; IB Singh — Textbook of Human Neuroanatomy; Snell — Clinical Neuroanatomy, 7e; BD Chaurasia — Human Anatomy Vol 3-4, 8e (figures).



Classify white matter of cerebrum. Describe parts, relations, fibre components of internal capsule

Asked in: Paper IV May 2018 — RGUHS MD/MS Anatomy

Definition / Introduction

The **white matter of the cerebrum** is a compact mass of myelinated nerve fibres, together with associated neuroglia, lying deep to the cerebral cortex; it interconnects different cortical areas with one another and with the rest of the central nervous system. On the basis of the connections they provide, these fibres are classified into three groups — **association, commissural and projection fibres**. The **internal capsule** is the most clinically important bundle of projection fibres: a compact, V-shaped sheet of white matter between the thalamus/caudate nucleus medially and the lentiform nucleus laterally, through which almost the entire motor and sensory traffic between the cerebral cortex and the rest of the neuraxis is funnelled. Because of this concentration of fibres in a small area, even a small capsular lesion produces widespread contralateral sensorimotor deficits, making the internal capsule one of the most important applied-anatomy structures in clinical neurology.

1. Classification of white matter fibres of the cerebrum

Type	Definition	Connects
Association fibres	Intrahemispheric fibres	Different cortical areas of the same hemisphere
Commissural fibres	Interhemispheric fibres	Corresponding/identical areas of the two hemispheres
Projection fibres	Fibres passing between cortex and lower centres	Cerebral cortex ↔ corpus striatum, thalamus, brainstem and spinal cord

□ Fig 11.1 — Coronal section of the brain showing association, commissural and projection fibres (IB Singh — Textbook of Human Neuroanatomy, p.196)

2. Association fibres

- ▶ **Short association (arcuate/'U') fibres** — hook around a sulcus to connect adjacent gyri.
- ▶ **Long association fibres** — connect widely separated gyri of different lobes, grouped into named bundles:

Bundle	Connects
Uncinate fasciculus	Motor speech area + orbital cortex of frontal lobe ↔ temporal pole (hooks around stem of lateral sulcus)
Cingulum (limbic association bundle)	Paraterminal gyrus → cingulate gyrus → parahippocampal gyrus → uncus (girdle-like)
Superior longitudinal fasciculus	Frontal lobe ↔ occipital and temporal lobes (longest association bundle)
Inferior longitudinal fasciculus	Visual association cortex of occipital lobe ↔ temporal lobe
Fronto-occipital fasciculus	Frontal pole → occipital and temporal lobes (deep to superior longitudinal bundle, separated from it by corona radiata)

3. Commissural fibres

The important commissures are the corpus callosum, anterior commissure, posterior commissure, habenular commissure and hippocampal commissure (commissure of fornix); the primary visual cortex and the hand area of the primary somatosensory cortex have no known commissural connections.

Corpus callosum — the largest commissure in the body (~10 cm long, roughly 150–200 million fibres), connecting neocortex of the two hemispheres except the lower/anterior temporal lobes (connected instead by the anterior commissure). It forms an arched bridge in the floor of the longitudinal fissure and roofs both lateral ventricles.

Part	Position/feature
Rostrum	Thin, joins lamina terminalis; floor of anterior horn

Part	Position/feature
Genu	Thick anterior bend, 4 cm behind frontal pole; fibres curve forward as forceps minor ; forms anterior boundary of anterior horn
Trunk/body	Main middle part; roofs the central part of the lateral ventricle
Splenium	Massive posterior end, 6 cm in front of occipital pole; overhangs pulvinar, pineal gland, tectum; fibres curve back as forceps major

The **tapetum** — fibres of the trunk/splenium not intersected by corona radiata — forms the roof/lateral wall of the posterior horn and lateral wall of the inferior horn of the lateral ventricle. Blood supply is chiefly by the **anterior cerebral artery** (also anterior communicating and posterior cerebral arteries).

- ▶ **Anterior commissure** — crosses in the lamina terminalis; a larger **neocortical** part (lower/anterior temporal lobes) and a smaller **paleocortical** part (olfactory bulbs/tubercles).
- ▶ **Posterior commissure** — crosses through the inferior lamina of the pineal stalk; connects the superior colliculi, pretectal and interstitial nuclei.
- ▶ **Habenular commissure** — crosses through the superior lamina of the pineal stalk; connects habenular nuclei.
- ▶ **Hippocampal commissure (commissure of fornix)** — connects the crura of the fornix and hence the two hippocampal formations.

4. Internal capsule — location, boundaries, parts and relations

The internal capsule is a compact bundle of **projection fibres** lying between the **caudate nucleus** and **thalamus medially** and the **lentiform nucleus laterally**. In horizontal section it is **V-shaped**, concavity directed laterally, the concavity occupied by the lentiform nucleus. Rostrally its fibres fan out to form the **corona radiata**; caudally they condense and continue as the **crus cerebri** of the midbrain.

It is arbitrarily divided into **five parts**:

Part	Boundary
Anterior limb	Between head of caudate nucleus (medially) and anterior part of lentiform nucleus (laterally)
Genu	Bend between anterior and posterior limbs, concavity facing laterally
Posterior limb	Between thalamus (medially) and posterior part of lentiform nucleus (laterally)
Retrolentiform part	Behind the lentiform nucleus
Sublentiform part	Below the lentiform nucleus

Relations

- ▶ **Medially**: caudate nucleus (opposite anterior limb) and thalamus (opposite posterior limb), with the third ventricle further medial to the thalamus.

- **Laterally:** lentiform nucleus (putamen + globus pallidus); beyond it lie, in sequence, the external capsule, claustrum, extreme capsule and insular cortex.
- **Superiorly:** continuous with the corona radiata, related to the body of the lateral ventricle and the body of the caudate nucleus.
- **Inferiorly/caudally:** continuous with the crus cerebri of the midbrain.
- **Genu:** lies immediately adjacent and lateral to the **interventricular foramen of Monro**, a useful radiological landmark for its position.
- **Retrolentiform/sublentiform parts:** related to the pulvinar of the thalamus, the lateral and medial geniculate bodies, and the atrium/inferior horn of the lateral ventricle (via the sagittal stratum and temporal stem).

5. Fibre components of the internal capsule

Motor (descending/corticofugal) fibres

- **Corticopontine fibres** form the single largest group (~two-thirds of all capsular fibres); named by lobe of origin — frontopontine, parietopontine, occipitopontine, temporopontine — and relay in ipsilateral pontine nuclei before crossing to the opposite cerebellar hemisphere (corticoponto-cerebellar pathway).
- **Pyramidal fibres** — **corticonuclear (corticobulbar)** fibres, occupying the genu, synapse with contralateral cranial motor nuclei; **corticospinal** fibres occupy the posterior two-thirds of the posterior limb, arranged somatotopically with upper-limb fibres most anterior, followed by trunk, then lower-limb fibres.
- **Extrapyramidal fibres** (corticorubral, corticostriate, corticonigral) lie close to the corticospinal fibres in the posterior limb.

Sensory (ascending/corticopetal, thalamocortical) fibres — chiefly third-order thalamocortical relays, forming the **thalamic radiations**:

Radiation	Direction	Connection	Capsular part
Anterior thalamic radiation	Anterior	Anterior + dorsomedial thalamic nuclei → frontal cortex	Anterior limb
Superior thalamic radiation (somaesthetic)	Superior	Ventral posterior thalamic nuclei → sensory cortex of postcentral gyrus	Posterior limb (anterior fibres extend into genu)
Posterior thalamic radiation	Posterior	Lateral geniculate body → primary visual cortex (optic radiation)	Retrolentiform part
Inferior thalamic radiation	Inferior	Medial geniculate body → primary auditory cortex (auditory radiation)	Sublentiform part

□ Fig 25.44 — A horizontal section through the internal capsule illustrating its main fibre components (Gray's Anatomy — Standing — 41e, p.555)

6. Arterial supply of the internal capsule

Part	Chief artery
Anterior limb	Recurrent artery of Huebner (branch of anterior cerebral artery) + direct anterior cerebral branches
Genu	Direct branches of internal carotid artery + posterior communicating artery
Posterior limb	Medial and lateral lenticulostriate (striate) branches of middle cerebral artery — the larger lateral striate branch is Charcot's artery of cerebral haemorrhage ; also anterior choroidal artery
Retrolentiform part	Posterolateral central branches of posterior cerebral artery
Sublentiform part	Central branches of anterior choroidal artery

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a horizontal (axial) section through the cerebrum at the level of the basal ganglia and label: head of caudate nucleus, thalamus, lentiform nucleus (putamen + globus pallidus), and the V-shaped internal capsule with its five parts — anterior limb, genu, posterior limb, retrolentiform part, sublentiform part — plus the interventricular foramen (of Monro) adjacent to the genu, and arrows for ascending thalamocortical fibres and descending corticofugal fibres (corticospinal in posterior limb, optic radiation in retrolentiform part, auditory radiation in sublentiform part).

Applied / Clinical anatomy

- ▶ **Capsular hemiplegia** — the commonest cause of "stroke" hemiplegia; rupture of **Charcot's artery of cerebral haemorrhage** (largest lateral lenticulostriate branch of MCA) in the posterior limb causes contralateral **spastic hemiplegia with sensory loss** (upper motor neuron type), because corticospinal, corticonuclear/extrapyramidal and superior thalamic radiation fibres are all compressed into this small area.
- ▶ **"Bottleneck" phenomenon** — a small lesion in the internal capsule produces far more extensive motor/sensory loss than an equally small lesion in the corona radiata, because capsular fibres are tightly packed between the basal ganglia and thalamus whereas the same fibres are widely fanned out in the corona radiata.
- ▶ **Recurrent artery of Huebner** (branch of anterior cerebral artery) thrombosis/rupture → paralysis of the contralateral face and upper limb (involvement of corticonuclear fibres in the genu and adjacent anterior pyramidal fibres).
- ▶ **Anterior choroidal artery** thrombosis → lesion of the posterior one-third of the posterior limb and retrolentiform/sublentiform parts → contralateral **hemianopia** (optic radiation) and **hearing loss** (auditory radiation, often minimal owing to bilateral cortical representation).

- ▶ **Corpus callosum lesions** — congenital agenesis or surgical division (historically done for intractable epilepsy) produces **split-brain syndrome**; anterior lesions give akinetic mutism and tactile anomia, posterior (splenial) lesions give **alexia without agraphia**.
- ▶ **Stereotactic/functional neurosurgery** — the AC–PC line (anterior commissure–posterior commissure) is the principal landmark for stereotactic targeting; the **anterior limb of the internal capsule** is itself a target for **anterior capsulotomy/deep brain stimulation** in refractory obsessive-compulsive disorder and depression.
- ▶ **Radiology** — the genu of the internal capsule lying just lateral to the interventricular foramen of Monro is a key CT/MRI landmark for localising capsular infarcts/haemorrhages on axial cuts.

Recent advances

- ▶ Tractography-guided repositioning of a DBS lead within the **anterior limb of the internal capsule** (targeting its mediodorsal-thalamic connection) improved outcome in refractory OCD/depression after a failed initial implant (Basich-Pease et al., *Front Hum Neurosci*, 2024 [PMID 38384668]).
- ▶ Diffusion-tensor-based morphometry showed volume loss confined to the **corticospinal fibres of the posterior limb** after stroke correlates with poorer long-term motor recovery, supporting capsular tract integrity as an imaging prognostic biomarker (Edwardson et al., *Neurology*, 2025 [PMID 40030091]).
- ▶ Fusion of photorealistic 3D white-matter fibre dissection (association/commissural/projection systems, including internal capsule–corona radiata continuity) with diffusion tensor tractography now yields dynamic 3D teaching models correlating classical dissection with in-vivo tractography (Armocida et al., *Brain Spine*, 2025 [DOI 10.1016/j.bas.2025.104261]).
- ▶ (*According to PubMed.*)

High-yield exam pointers

- ▶ White matter fibres = **association** (intrahemispheric) + **commissural** (interhemispheric) + **projection** (cortex ↔ lower centres).
- ▶ Largest commissure = **corpus callosum**; largest bundle of projection fibres and longest fibre pathway in the brain = **internal capsule**.
- ▶ Internal capsule: **V-shaped**, medial boundary = caudate + thalamus, lateral boundary = lentiform nucleus; **5 parts** — anterior limb, genu, posterior limb, retrolentiform, sublenticular.
- ▶ Genu = corticonuclear (corticobulbar) fibres; posterior limb (anterior 2/3) = corticospinal fibres, somatotopic (UL–trunk–LL, anterior to posterior).
- ▶ Retrolenticular = optic radiation; sublenticular = auditory radiation.
- ▶ Corticopontine fibres are the single largest fibre group in the internal capsule (~2/3 of total).
- ▶ Blood supply: lateral striate branch of MCA = **Charcot's artery** (posterior limb, commonest site of capsular haemorrhage); recurrent artery of **Huebner** from ACA (anterior limb/genu); anterior choroidal artery (sublenticular/retrolenticular).
- ▶ A small capsular lesion causes disproportionately widespread deficits compared with an equal-sized corona radiata lesion, because fibres are concentrated, not fanned out, at capsular level.
- ▶ Corpus callosum division → split-brain syndrome; splenial lesion → alexia without agraphia.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy. Recent-advances section per PubMed/journal search (PMIDs/DOI above).

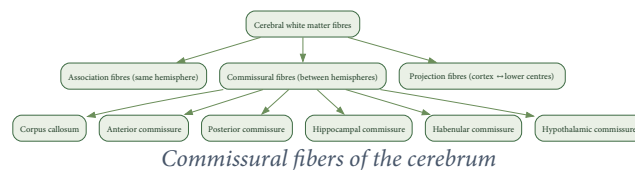


Commissural fibers of the cerebrum

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction The white matter core of each cerebral hemisphere is built of three fibre systems — **association**, **commissural** and **projection** fibres. **Commissural fibres** are those that cross the midline and connect functionally identical (homotopic) or related (heterotopic) areas of the two cerebral hemispheres, permitting interhemispheric transfer of information for bilateral, integrated responses and learning. They are distinct from mere **decussating fibres**, which cross the midline to end in a *different* mass of grey matter on the opposite side rather than linking corresponding structures. The commissures of the cerebrum are, in order of size: the **corpus callosum** (by far the largest), the **anterior commissure**, the **posterior commissure**, the **hippocampal commissure** (commissure of the fornix), the **habenular commissure**, and the small **hypothalamic commissures**.

1. Classification of cerebral white matter fibres



- ▶ **Teaching point:** not every midline-crossing bundle is a commissure — bundles such as the **medial lemniscus** or the **pyramidal decussation** are true **decussations** (nucleus on one side ending in a *different* nucleus on the other), not commissures.
- ▶ The **primary visual area** (calcarine cortex) and the **hand area** of the primary sensorimotor cortex have no direct callosal fibres — only midline-representation zones (macular vision, trunk) are homotopically linked, which is why callosal section spares fine skilled hand movements.

2. Corpus callosum — the principal commissure

- ▶ The **largest commissure of the brain**, connecting the **neocortex** of the two hemispheres; being a neopallial commissure it attains its enormous size only in man.
- ▶ Forms a **C-shaped arched mass** in the floor of the longitudinal fissure, roofing both lateral ventricles; about **10 cm long** and made up of **150–200 million myelinated fibres**; lies nearer the frontal pole (genu ~4 cm behind it) than the occipital pole (splenium ~6 cm in front of it).
- ▶ Superior surface is covered by the **cingulate gyrus** (separated by the callosal sulcus) and the thin **indusium griseum** bearing the medial/lateral longitudinal striae, with pericallosal (anterior cerebral) vessels running over it in the pia.

- Inferior (concave) surface is attached to the **septum pellucidum** (along trunk, genu, rostrum) and fuses with the **fornix crura** and hippocampal commissure beneath the splenium.

Parts of the corpus callosum

Part	Position / relations	Fibres it forms
Rostrum	Thin postero-inferior prolongation of the genu, joining the upper end of the lamina terminalis, anterior to the anterior commissure; forms the floor of the anterior horn of the lateral ventricle	Connects the orbital surfaces of the two frontal lobes
Genu	Thick, curved anterior extremity, ~4 cm from the frontal pole; forms the anterior wall/boundary of the anterior horn	Curves forward as the forceps minor , linking the medial and lateral frontal-lobe surfaces
Trunk (body)	Main middle part between genu and splenium; arches backward, convex above; roofs the body of the lateral ventricle	Fibres intersect the corona radiata to connect the frontal and anterior parietal neocortex of both sides; together with splenium fibres forms the tapetum
Splenium	Massive, thickest posterior end, ~6 cm from the occipital pole; overhangs the thalamic pulvinars, pineal gland and midbrain tectum, with the tela choroidea/great cerebral vein of Galen lying beneath it	Curves back as the forceps major , connecting the parietal, temporal and occipital neocortex; produces the "bulb" of the posterior horn

Tapetum, connection pattern and blood supply

- **Tapetum** — a thin sheet formed by trunk + splenium fibres *not* intersected by corona-radiata fibres; floors the roof/lateral wall of the atrium and posterior horn and the lateral wall of the inferior horn, lying just deep to the optic radiation.
- Callosal connections are not simple point-to-point mirroring: **homotopic connections** link identical loci (e.g., midline/macular retinal representation, trunk representation); **heterotopic connections** link functionally related but non-identical loci on the two sides.
- **Blood supply**: chiefly **pericallosal branches of the anterior cerebral artery** ($\pm$ anterior communicating artery); the splenium receives an added supply from the **posterior pericallosal branches of the posterior cerebral artery**.

□ Fig 8.25 — Parts of corpus callosum (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.572)

□ Fig 8.26 — Fibres of corpus callosum (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.573)

3. The other commissures of the cerebrum

Commissure	Site	Structures connected	Distinguishing feature
Anterior commissure	Crosses the midline in the upper part of the lamina terminalis , just below the interventricular foramen, anterior to the columns of the fornix	A small paleocortical (olfactory) component connecting the olfactory bulbs/tubercles of the two sides; a larger neocortical (hemispheric) component connecting the anterior/inferior temporal lobes (incl. parahippocampal gyrus)	Compact, ~4 mm diameter, ~3.5 million myelinated axons; shaped like a cupid's bow ; connects the temporal lobes even though the corpus callosum does not reach them
Posterior commissure	Crosses the midline through the caudal (inferior) lamina of the pineal stalk , at the upper end of the cerebral aqueduct, just below the pineal recess	Interstitial and dorsal nuclei of the posterior commissure, nucleus of Darkschewitsch , interstitial nucleus of Cajal (linked to the MLF), and posterior thalamic, pretectal, tectal and habenular nuclei of both sides	Contains a <i>mixture</i> of true commissural and decussating fibres; mediates the consensual pupillary light reflex and vertical-gaze/convergence mechanisms
Habenular commissure	Crosses the midline through the superior (rostral) lamina of the pineal stalk — pineal recess of the third ventricle lies between it and the posterior commissure	The habenular nuclei of the two sides, which relay olfactory/limbic input from the septal nuclei toward the habenulo-interpeduncular tract	Also carries decussating (e.g., tecto-habenular) fibres in addition to true commissural fibres
Hippocampal commissure (commissure of the fornix, "psalterium")	Thin triangular sheet lying between the crura of the fornix, applied to and overhung by the splenium	The hippocampal formations (hippocampus + dentate gyrus) of the two sides	Represents the commissure of the archipallium/allocortex, as opposed to the corpus callosum which is the neopallial commissure
Hypothalamic commissures	Small bundles within the hypothalamus, related to the optic chiasma/infundibulum	Hypothalamic nuclei of the two sides	Three named bundles: anterior hypothalamic commissure of Ganser , ventral supraoptic commissure of Gudden , dorsal supraoptic commissure of Meynert

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Median sagittal section of the cerebrum** — draw the C-shaped corpus callosum and label its four parts (**rostrum**, **genu**, **trunk**, **splenium**); show the **lamina terminalis**, **anterior commissure** (just below the genu/rostrum junction, anterior to the fornix column), the **fornix** with its **hippocampal commissure** beneath the splenium, the **pineal gland** with the **habenular commissure** (superior lamina) and **posterior commissure** (inferior lamina) flanking the pineal recess, and the **septum pellucidum** attached to the undersurface of the corpus callosum.
- ▶ **Superior/horizontal view of the corpus callosum fibres** — show fibres of the genu curving forward as the **forceps minor**, fibres of the splenium curving back as the **forceps major**, and the **tapetum** as a sheet along the lateral ventricle wall deep to the optic radiation; label the **medial and lateral longitudinal striae** on the indusium griseum.

Applied / Clinical anatomy

- ▶ **Agenesis of the corpus callosum (ACC)** — a relatively common congenital malformation, often clinically silent because transfer is partly rerouted through the surviving anterior/hippocampal commissures; imaging shows **Probst bundles** (uncrossed callosal fibres running antero-posteriorly along the medial ventricular walls), "bat-wing" frontal horns and **colpocephaly** (dilated occipital horns). Seen in Aicardi, Apert, Joubert, Meckel–Gruber and septo-optic dysplasia syndromes.
- ▶ **Split-brain syndrome** — callosal absence/section isolates the hemispheres functionally (a task learned with one hand cannot transfer to the other). **Anterior** lesions cause akinetic mutism/tactile anomia; **splenic** lesions cause **alexia without agraphia** (right visual cortex can no longer relay to the left angular gyrus).
- ▶ **Corpus callosotomy** — anterior or complete sectioning, used as palliative surgery for **refractory generalised epilepsy with drop attacks** to block interhemispheric seizure spread; increasingly done by **MRI-guided laser interstitial thermal therapy (LITT)** rather than open microsurgery, with comparable seizure control and shorter stay.
- ▶ **AC–PC line** — the anterior/posterior commissures together define the standard stereotactic reference plane for functional neurosurgery (e.g. deep brain stimulation targeting).
- ▶ **Parinaud (dorsal midbrain) syndrome** — pineal-region tumour compressing the posterior commissure causes loss of the consensual light reflex, convergence–retraction nystagmus and upward-gaze palsy.
- ▶ **ACoA aneurysm rupture/vasospasm** can infarct the genu/rostrum (ACA territory), producing interhemispheric disconnection signs.

Recent advances

According to PubMed:

- ▶ Two independent 2024 fetal cohorts (114 and 40 fetuses respectively) with agenesis of the corpus callosum used karyotype, CNV-sequencing and whole-exome sequencing to identify a genetic cause in a substantial proportion of cases, supporting routine trio genetic work-up after prenatal

ACC diagnosis (Yu et al, *Arch Gynecol Obstet* 2024;310(1):181–194

[DOI](https://doi.org/10.1007/s00404-024-07544-9); companion series [PubMed 38756055] (https://pubmed.ncbi.nlm.nih.gov/38756055/)).

- ▶ A 2024 systematic review and meta-analysis (240 patients) comparing **MRI-guided laser interstitial thermal therapy (LITT)** with open microsurgical corpus callosotomy for paediatric refractory epilepsy found equivalent seizure-control outcomes, with LITT giving a shorter hospital stay and less blood loss at the cost of longer operating time (Larcipretti et al, *Seizure* 2024;122:45–51) [DOI](https://doi.org/10.1016/j.seizure.2024.07.017), corroborated by a 2024 Mayo Clinic technical series standardising trajectories for MRI-guided stereotactic laser corpus callosotomy in children [PubMed 39329527](https://pubmed.ncbi.nlm.nih.gov/39329527/).
- ▶ The classical Sperry–Gazzaniga view of split-brain patients as harbouring "two separate consciousnesses" has been challenged: Pinto, de Haan and Lamme's "**conscious unity, split perception**" model argues split-brain patients remain a single conscious agent despite disconnected perceptual streams — an active, still-debated reinterpretation of the classic callosotomy experiments (Pinto et al, *Trends Cogn Sci* 2017;21(11):835–851) [DOI](https://doi.org/10.1016/j.tics.2017.09.003).

High-yield exam pointers

- ▶ Commissural fibres connect **identical/corresponding** areas of the two hemispheres (unlike decussating fibres, which end in a *different* nucleus on the opposite side).
- ▶ Six commissures of the cerebrum: **corpus callosum** (largest), **anterior**, **posterior**, **hippocampal (fornix)**, **habenular**, and the **hypothalamic commissures** (Ganser/Gudden/Meynert).
- ▶ Corpus callosum: **10 cm**, **150–200 million fibres**; four parts — **rostrum**, **genu**, **trunk**, **splenium**; genu → **forceps minor**; splenium → **forceps major**; trunk + splenium → **tapetum**.
- ▶ Anterior commissure connects the **two temporal lobes** (neocortical part) + **olfactory structures** (paleocortical part) — the only commissure linking areas the corpus callosum does not reach.
- ▶ Posterior commissure carries fibres for the **consensual light reflex**; lesion here → **Parinaud syndrome**.
- ▶ Hippocampal commissure = **psalterium/lyra**, lies beneath the splenium, connects the two hippocampi.
- ▶ **Split-brain syndrome** — anterior callosal lesion → akinetic mutism/tactile anomia; splenial lesion → **alexia without agraphia**.
- ▶ **Agenesis of corpus callosum** is often asymptomatic (compensation via anterior/hippocampal commissures); imaging shows **Probst bundles** and **colpocephaly**.
- ▶ **AC–PC line** = key stereotactic landmark for functional neurosurgery.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3–4 8e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e.



Corona radiata

Asked in: Paper IV Oct 2006 — RGUHS MD/MS Anatomy

Definition / Introduction The corona radiata is the fan- (crown-) shaped mass of **projection fibres** that occupies the subcortical white matter of each cerebral hemisphere, lying between the overlying cerebral cortex and the underlying **internal capsule**. Corticofugal (descending) and corticopetal (ascending) fibres converge from every lobe of the cortex, like the radiating spokes of a crown, to funnel into the narrow internal capsule below — hence the name (Latin *corona*, crown; *radiata*, radiating). It is the **cranial continuation of the internal capsule**, which in turn continues caudally as the crus cerebri of the midbrain, so that corona radiata–internal capsule–crus cerebri form one uninterrupted fibre highway linking the cortex to the brainstem and spinal cord. Together with the commissural and association fibres among which it lies, the corona radiata forms the greater part of the **centrum semiovale**, the oval mass of white matter seen in a horizontal section taken above the corpus callosum.

1. Location, extent and continuity

- Lies deep to the **subcortical (arcuate/U) fibres** of the cortex and deep to the **insula**; its fibres converge medially and inferiorly toward the interval between the **caudate nucleus and thalamus** (medially) and the **lentiform nucleus** (laterally) to form the internal capsule.
- **Cranially**, the fibres diverge and fan out to reach every part of the cerebral cortex; **caudally**, via the internal capsule, they condense to continue as the **crus cerebri (basis pedunculi)** of the midbrain — a dissection classically demonstrated by successive removal of the insular cortex, claustrum, external capsule and lentiform nucleus to expose the continuity of corona radiata → internal capsule → crus cerebri → pons → medullary pyramid.
- Lies on a **deeper plane** than the **superior longitudinal fasciculus**; the **inferior fronto-occipital fasciculus** runs a similar course but deeper still, so that the corona radiata forms the intervening layer separating the two association bundles from one another.
- Best appreciated on a **horizontal (axial) CT/MRI section** as a fan of white matter lateral to the bodies of the lateral ventricles, converging toward the internal capsule; on diffusion tensor imaging (DTI) it is reconstructed as a coherent fibre bundle continuous with the superior longitudinal fasciculus and inferior fronto-occipital fasciculus.

2. Composition — descending (corticofugal) fibres

Fibre group	Cortical origin	Termination
Corticospinal & corticonuclear (pyramidal)	Precentral gyrus (area 4) and adjacent postcentral gyrus	Anterior horn cells of spinal cord; motor cranial nerve nuclei
Corticopontine (fronto-, parieto-, temporo-, occipito-pontine)	All four lobes of the cortex	Pontine nuclei → opposite cerebellar hemisphere via middle cerebellar peduncle
Corticostriate	Widespread cortex	Caudate nucleus and putamen
Corticorubral	Frontal motor cortex	Red nucleus
Corticoreticular	Motor and parietal cortex	Brainstem reticular formation

Fibre group	Cortical origin	Termination
Corticothalamic	Widespread cortex	Thalamic nuclei (reciprocal to the thalamic radiations below)

- The **corticospinal tract** fibres, arising from the precentral gyrus, are disposed as a fan throughout the corona radiata and converge toward the genu/posterior limb of the internal capsule; in doing so they undergo an **internal rotation of about 90°** (since the long axis of the precentral gyrus is almost perpendicular to that of the internal capsule), while still preserving their **somatotopic (homuncular) arrangement** — upper limb fibres anterior, trunk and lower limb fibres progressively more posterior.

3. Composition — ascending (corticopetal) fibres: the thalamic radiations

Radiation	Connection	Comment
Anterior thalamic radiation	Anterior/medial thalamic nuclei ↔ frontal cortex	Also carries hypothalamic/limbic fibres
Superior thalamic radiation	Ventral thalamic nuclei (VA, VL, VPL, VPM) ↔ sensorimotor cortex	Third-order somaesthetic sensory fibres
Posterior thalamic radiation (incl. optic radiation)	Lateral geniculate body/pulvinar ↔ occipital (visual) cortex	
Inferior thalamic radiation (incl. auditory radiation)	Medial geniculate body ↔ temporal (auditory) cortex	

- A further, clinically quoted example is the **gustatory pathway**: taste fibres relayed in the ventral posteromedial thalamic nucleus pass through the internal capsule and corona radiata to end in the taste area at the lower end of the postcentral gyrus.

4. Relations to the corpus callosum and association fibres

- A large number of transversely running fibres from the **trunk of the corpus callosum** cross the vertically disposed fibres of the corona radiata at right angles — this intersection is a classic dissection finding.
- Fibres of the trunk and adjacent splenium of the corpus callosum that are **not** intersected by the corona radiata constitute the **tapetum**, related to the posterior and inferior horns of the lateral ventricle.
- The **superior longitudinal fasciculus** lies superficial to the corona radiata; the **inferior fronto-occipital fasciculus** pursues a similar course but lies deeper still, so the two long association bundles are separated from one another by the intervening fibres of the corona radiata.

□ Fig 1.13 — Right lateral view showing continuity of the corona radiata, the internal capsule, and the crus cerebri (Snell — *Clinical Neuroanatomy* — 7e, p.31)

5. Arterial supply

- The corona radiata straddles a vascular watershed. Its **more superficial part** receives cortical/subcortical branches of the anterior, middle and posterior cerebral arteries; its **deeper part** is continuous with, and supplied like, the internal capsule — by the **medial and lateral**

(lenticulo-) striate branches of the middle cerebral artery, the recurrent artery of Heubner (anterior cerebral artery), and the anterior choroidal artery.

- ▶ Within the white matter of the **centrum semiovale** and **corona radiata** there is an **internal (arterial) border/watershed zone**, lying between the deep lenticulostriate perforators and the deep penetrating branches of the distal middle cerebral artery — a site especially vulnerable to hypoperfusion (internal watershed infarction).

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Horizontal (axial) section through the cerebral hemisphere at the level of the basal ganglia** — draw the fan of corona radiata fibres converging from the cortex of all four lobes toward the interval between the caudate nucleus/thalamus (medial) and lentiform nucleus (lateral); label the convergence point as the **internal capsule**, and show its continuity caudally with the **crus cerebri**. Mark the transverse fibres of the **corpus callosum trunk** crossing the corona radiata at right angles, and show the **superior longitudinal fasciculus** superficial to it with the **fronto-occipital fasciculus** deeper still.
- ▶ **Same section with the four thalamic radiations superimposed** — anterior (to frontal lobe), superior (to sensorimotor cortex), posterior/optic (to occipital lobe) and inferior/auditory (to temporal lobe), each labelled with its thalamic nucleus of origin.

Applied / Clinical anatomy

- ▶ **Corona radiata lesion vs internal capsule lesion** — the single most important comparative exam point: because the projection fibres are still **widely spread out and separated** from one another in the corona radiata (unlike their tightly packed arrangement in the internal capsule), a small vascular lesion here often produces **little or no clinical deficit**, whereas an equally small lesion in the internal capsule produces a **severe, disproportionately widespread contralateral hemiplegia/hemianaesthesia** because the whole contralateral half of the body's fibres are compressed into that narrow gateway.
- ▶ **Pure motor hemiparesis** — a corona radiata infarct involving the compact, still-discrete corticospinal fascicle is a recognised **lacunar stroke syndrome**, typically due to lipohyalinosis/microatheroma of the small penetrating perforator vessels in a chronically hypertensive patient.
- ▶ **Internal (border-zone/watershed) infarction** — hypoperfusion (e.g. severe carotid stenosis, systemic hypotension) preferentially damages the internal border zone between the lenticulostriate perforators and the distal middle cerebral artery penetrators within the corona radiata/centrum semiovale, producing a characteristic chain of small infarcts running parallel to the lateral ventricle on cross-sectional imaging.
- ▶ **Radiological/DTI relevance** — the corona radiata is a key landmark and fibre-tracking target in diffusion tensor tractography, used pre-operatively to map the corticospinal tract and plan safe margins around intracranial tumours or during deep-brain-stimulation trajectory planning.
- ▶ **Myelination** — on the developmental/neuroimaging timeline of hemispheric white matter, myelination of the corona radiata begins comparatively late, around 24–32 weeks of gestation

(after the internal capsule and optic radiations), a useful benchmark when assessing normality on preterm/neonatal cranial imaging.

- ▶ **Periventricular white matter** in and around the corona radiata is a common site of demyelinating plaques in multiple sclerosis, correlating with the periventricular ("Dawson's finger") pattern seen on MRI.

High-yield exam pointers

- ▶ Corona radiata = fan-shaped mass of **projection fibres** between cortex and internal capsule; forms the bulk of the **centrum semiovale**; continuous below (via internal capsule) with the **crus cerebri**.
- ▶ Contains **corticofugal** fibres (corticospinal, corticonuclear, corticopontine, corticostriate, corticorubral, corticoreticular, corticothalamic) and **corticopetal** fibres (anterior, superior, posterior/optic, inferior/auditory thalamic radiations).
- ▶ Corticospinal fibres fan out through the corona radiata and undergo a **~90° rotation** while converging into the internal capsule, preserving **somatotopic** order.
- ▶ Lies **deep to the superior longitudinal fasciculus**, with the **fronto-occipital fasciculus** lying **deeper still** (the two are separated from each other by the corona radiata); also **intersected at right angles** by the transverse fibres of the corpus callosum trunk — fibres escaping this intersection form the **tapetum**.
- ▶ Vascular watershed: superficial cortical branches (ACA/MCA/PCA) + deep lenticulostriate/Heubner/anterior choroidal perforators, with an **internal border zone** between them — a key site of watershed infarction.
- ▶ **Key comparative fact**: a lesion of similar size causes **far less deficit in the corona radiata** than in the internal capsule, because fibres are widely separated here rather than tightly packed.
- ▶ Corona radiata infarcts are a classic cause of **pure motor hemiparesis** (lacunar stroke syndrome).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3–4 8e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy.



Describe in detail about the Functional areas of cerebrum and its applied anatomy

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction The functional (cortical) areas of the cerebrum are discrete territories of the cerebral cortex, each with a characteristic cytoarchitecture and a specific role in motor control, sensory reception, or higher cognitive/associative function. **Brodmann** mapped these territories numerically (1–52) by neuronal lamination, and many numbered areas correspond closely to functionally and clinically distinct regions — the primary motor and sensory cortices being the clearest examples. Functionally the cortex is grouped into **primary motor/sensory areas** (lowest threshold for eliciting movement or receiving a modality), **secondary/association areas** (interpret and integrate primary information), and **higher-order (supramodal) association cortex** (language, praxis, cognition, personality) concentrated in the prefrontal, parietal and temporal lobes. Because each area has a fixed location, predictable blood supply and characteristic connections, focal lesions produce recognisable clinical syndromes — the basis of clinico-anatomical correlation in neurology and neurosurgery.

□ Fig 27.1 — Functional cortical areas (of Brodmann) on the superolateral surface (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.1103)

□ Fig 27.2 — Functional cortical areas on the inferomedial surface of the cerebral hemisphere (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.1104)

1. Frontal lobe — motor and higher motor areas

Area (Brodmann)	Location	Function
Primary motor area (MI), area 4	Precentral gyrus (superolateral surface) + anterior part of paracentral lobule (medial surface)	Lowest threshold for eliciting contralateral muscle contraction; contains the motor homunculus (inverted, disproportionate — face and hand grossly over-represented); layer V holds giant Betz cells (up to ~80 µm) giving rise to the corticospinal/corticonuclear tracts
Premotor area, area 6	Posterior part of superior, middle and inferior frontal gyri, anterior to MI	Programmes/organises intended movement and skilled, learned motor sequences before MI executes it
Supplementary motor area (SMA/MII)	Medial frontal gyrus (medial surface), extension of areas 4, 6, 8	Body map with leg posterior, face anterior, arm in between ; concerned with temporal sequencing of complex bilateral movements and the "urge to move"
Frontal eye field, area 8	Middle frontal gyrus	Elicits conjugate (voluntary saccadic) eye movements to the opposite side on stimulation

Area (Brodmann)	Location	Function
Motor speech area of Broca, areas 44–45	Opercular + triangular parts of inferior frontal gyrus, dominant hemisphere only	Motor programming of speech articulation
Prefrontal area, areas 9–12, 46	Rest of frontal lobe (gyrus rectus, orbital gyri, most of medial/lateral frontal cortex anterior to premotor area)	Personality, judgement, foresight, prediction of consequences, emotional expression

2. Parietal lobe — somatosensory and its association cortex

Area (Brodmann)	Location	Function
Primary somatosensory area (SI), areas 3, 1, 2	Postcentral gyrus + posterior part of paracentral lobule	Receives general sensation via ventral posterolateral (body) and ventral posteromedial (head) thalamic nuclei ; contains an inverted sensory homunculus with disproportionate digit/lip/tongue representation. Area 3a (deep sensibility, abuts area 4) → 3b (cutaneous, buried in central sulcus) → area 1 (posterior lip) → area 2 (crown of gyrus)
Second somatosensory area (SII)	Superior lip of the posterior ramus of the lateral sulcus (parietal operculum)	Secondary somatosensory processing
Somatosensory association area, areas 5, 7	Superior parietal lobule (+ precuneus medially)	Integrates touch, pressure and proprioception to recognise shape, size and texture (stereognosis)
Inferior parietal lobule — supramarginal (40) and angular (39) gyri	Around the posterior end of the lateral sulcus and superior temporal sulcus	Secondary somatosensory function; forms the parietal component of Wernicke's sensory speech area ; body-scheme and calculation functions (dominant side)
Taste (gustatory) area, area 43	Lower end of postcentral gyrus + adjoining insula	Taste perception
Vestibular cortical area	Near the face part of the postcentral gyrus, opposite the auditory area in the superior temporal gyrus	Conscious appreciation of head position/movement

3. Occipital lobe — visual areas

Area (Brodmann)	Location	Function
Primary visual area (V1), area 17 (striate cortex)	Both banks of the calcarine sulcus — cuneus above, lingual gyrus below; extends around the occipital pole	Receives the optic radiation ; retinotopic map with macular (central) vision represented at the occipital pole , which uniquely receives a dual blood supply (MCA + PCA)
Visual association areas, areas 18 (parastriate) and 19 (peristriate)	Surround area 17	Interpretation of visual impulses (form, colour, movement — V2, V3, V4 territories); connect to the frontal eye field

4. Temporal lobe — auditory and other areas

Area (Brodmann)	Location	Function
Primary auditory area (AI), areas 41–42	Anterior transverse temporal gyrus of Heschl, floor of the posterior ramus of the lateral sulcus	Tonotopic map (high frequencies posterior, low anterior); receives bilateral cochlear input via each lateral lemniscus
Auditory association area, area 22	Superior temporal gyrus, anterior/posterior to AI	Interpretation of sound; posterior part forms part of Wernicke's area
Sensory speech area of Wernicke, areas 22 + 39 + 40	Posterior superior/middle temporal gyrus, extending into inferior parietal lobule, dominant hemisphere	Comprehension of spoken and written language
Entorhinal (olfactory) area, area 28	Parahippocampal gyrus, uncus, anterior perforated substance	Primary olfactory (pyriform) cortex — part of the phylogenetically old archipallium/paleopallium

5. Association cortex, language and cerebral dominance

- The premotor, parietal and temporal association cortices surrounding the lateral (Sylvian) fissure together constitute the "language area" of the dominant hemisphere; **Broca's and Wernicke's areas are linked by the arcuate fasciculus**, allowing repetition and monitoring of one's own speech.
- **Left (dominant) hemisphere:** language (grammar, vocabulary, literal meaning), arithmetic and fact retrieval, analytical/sequential/logical thought.
- **Right hemisphere:** prosody (rhythm, stress, intonation, emotional tone of speech), geometric/spatial understanding, facial perception, musical/artistic ability, holistic and creative thought.
- **Limbic lobe** (cingulate gyrus, areas 24/32, septal/subcallosal area, parahippocampal gyrus) is concerned with emotion and, via the **Papez circuit** (hippocampus–mammillary body–anterior thalamic nucleus–cingulate gyrus), with laying down episodic memory.

- Knowledge of lateralisation comes largely from **corpus callosotomy** ("split-brain") patients operated for intractable epilepsy (Sperry), and from functional imaging (PET, fMRI).

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the **superolateral and medial surfaces of the left cerebral hemisphere** and label:

- Central sulcus, lateral (Sylvian) fissure, precentral gyrus, postcentral gyrus.
- **Area 4** (motor, precentral gyrus), **area 6** (premotor), **area 8** (frontal eye field, middle frontal gyrus), **areas 44–45** (Broca's, inferior frontal gyrus).
- **Areas 3,1,2** (postcentral gyrus), **areas 5,7** (superior parietal lobule), **areas 39/40** (angular/supramarginal gyri).
- **Areas 41,42** (Heschl's transverse temporal gyri) and **area 22** (superior temporal gyrus) — mark **Wernicke's area**.
- On the medial surface: **paracentral lobule** (leg motor/sensory), **supplementary motor area** (medial frontal gyrus), **cingulate gyrus** (24/32), **cuneus/lingual gyrus** separated by the **calcarine sulcus** (area 17), **precuneus** (area 7).
- Draw an **arcuate fasciculus** arc connecting Broca's and Wernicke's areas.

Applied / Clinical anatomy

- **Area 4 (motor) lesion** — irritative lesion → focal (Jacksonian) epilepsy; destructive lesion → contralateral flaccid monoplegia (localised) or hemiplegia (extensive).
- **Area 6 (premotor) lesion** → apraxia (difficulty with skilled, learned movement) without paralysis.
- **Frontal eye field (area 8) lesion** → loss of contralateral voluntary conjugate gaze; eyes deviate **towards** the side of the lesion (pursuit movements, controlled by the occipital lobe, remain intact).
- **Broca's area lesion (dominant hemisphere)** → **expressive/motor aphasia** — non-fluent, telegraphic, effortful speech with intact comprehension; agraphia often coexists.
- **Wernicke's area lesion (dominant hemisphere)** → **receptive/sensory aphasia** — fluent speech full of paraphasias (word substitutions, neologisms) but comprehension of spoken/written language is lost.
- **Arcuate fasciculus (parietal) lesion** → **conduction aphasia** — fluent speech and preserved comprehension but impaired repetition (Gray's Anatomy groups Broca's, conduction and Wernicke's aphasias as corresponding respectively to frontal, parietal and temporal cortical lesions).
- **Left perisylvian lesion** (both Broca's + Wernicke's) → **global aphasia**; the homologous **right perisylvian area lesion** → **aprosodia** (loss of emotional colouring of speech).
- **Left inferior parietal lobule (39/40) lesion** → acalculia, agraphia, finger agnosia, left–right disorientation (**Gerstmann-type tetrad**).
- **Right inferior parietal lobule lesion** → left hemi-spatial **neglect**, construction and dressing apraxia, **anosognosia** (unawareness of one's own deficit).
- **Area 5/7 lesion** → **astereognosis/tactile agnosia** (cannot identify objects by touch alone).

- ▶ **Area 17 lesion** → contralateral **homonymous hemianopia with macular sparing** in vascular occlusion (macula has dual MCA + PCA supply); **no macular sparing** if the lesion is traumatic or a space-occupying tumour.
- ▶ **Areas 18/19 lesion** → visual agnosia, **alexia** (word blindness).
- ▶ **Area 22 (auditory association) lesion** → **word deafness** (auditory verbal agnosia) — sound is heard but not understood.
- ▶ **Vascular territory syndromes: MCA occlusion** — contralateral hemiplegia/sensory loss (face/arm > leg), astereognosis, mild bilateral hearing loss, aphasia or aprosodia, and Gerstmann-tetrad/neglect depending on the parietal lobule involved. **Unpaired/occluded ACA** — abulia (prefrontal), uninhibited bladder (medial frontal cortex), cortical paraplegia (paracentral lobule). **PCA occlusion** — contralateral homonymous hemianopia with macular sparing, visual hallucinations, and pure **alexia without agraphia** when a splenial/left-occipital lesion disconnects the intact right visual cortex from the left language area.
- ▶ **"Split-brain" (corpus callosotomy)** performed for intractable epilepsy demonstrates hemispheric specialisation: visual/tactile information confined to the right hemisphere cannot be named or described verbally because it is disconnected from the left language area.
- ▶ **Surgical/radiological localisation** — the "hand-knob" (an inverted-omega bulge of the precentral gyrus at the level of the superior frontal sulcus) is the MRI landmark for the motor hand area; awake craniotomy with direct cortical electrical stimulation is used to map and preserve Broca's/Wernicke's and the motor strip during tumour/epilepsy surgery in eloquent cortex.

Recent advances

According to PubMed:

- ▶ A **high-density micro-electrocorticography (μECoG) interface** ("Layer 7 Cortical Interface", 1024 channels) placed intraoperatively on motor/speech cortex during awake craniotomy achieved real-time speech classification (~77.5% accuracy) and cursor-direction decoding (78–84%), demonstrating brain–computer-interface-grade mapping of the eloquent cortex described above (Lehner et al, *Neurosurg Focus* 2026) [DOI](<https://doi.org/10.3171/2025.11.FOCUS25908>).
- ▶ **Connectome-guided neuronavigation** combined with awake intraoperative motor mapping enabled patient-specific delineation of motor-network parcels within a tumour, improving the balance between maximal resection and preservation of the primary motor area (Navarro-Olvera et al, *Surg Neurol Int* 2026) [DOI](<https://doi.org/10.25259/SNI9002025>).
- ▶ **Cortico-cortical evoked potential mapping** localised Wernicke's area intraoperatively without an awake craniotomy in a case where AVM-related neurovascular uncoupling made fMRI unreliable, allowing resection with no post-operative language deficit (Su et al, *J Clin Neurosci* 2025) [DOI](<https://doi.org/10.1016/j.jocn.2025.111611>).
- ▶ The largest probabilistic atlas to date (2,124 direct electrocortical stimulation trials, 125 patients) found eloquent motor, sensory and language responses organised along **graded probabilistic gradients rather than fixed Brodmann boundaries**, with the middle frontal gyrus a consistent naming/speech-arrest node — evidence that individualised intraoperative mapping is essential (Michalak et al, *bioRxiv* 2025) [DOI](<https://doi.org/10.1101/2025.09.15.676264>).

- ▶ An **awake trans-sulcal approach**, entering the primary motor cortex through natural sulcal corridors rather than a transcortical incision, allowed resection of motor-cortex glioblastomas with no permanent new motor deficit in a small case series (Gensler et al, *Clin Neurol Neurosurg* 2025) [DOI](<https://doi.org/10.1016/j.clineuro.2025.108912>).

High-yield exam pointers

- ▶ **Brodmann's map** is cited by number for every functional area — know areas **4, 6, 8, 44–45, 3-1-2, 5-7, 17, 18-19, 41-42, 22, 39-40**.
- ▶ **MI = area 4** (precentral gyrus + paracentral lobule) — Betz cells, inverted disproportionate homunculus (face/hand large).
- ▶ **Broca's (44–45)** = expressive/non-fluent aphasia, comprehension intact; **Wernicke's (22, 39, 40)** = receptive/fluent aphasia with paraphasias; both dominant-hemisphere only, linked by the **arcuate fasciculus** (its lesion → conduction aphasia).
- ▶ **Area 17 (striate cortex)** lesion → contralateral homonymous hemianopia **with macular sparing** (dual MCA + PCA supply to the occipital pole).
- ▶ **Left inferior parietal lobule (39/40)** → Gerstmann-type tetrad (acalculia, agraphia, finger agnosia, left-right disorientation); **right inferior parietal lobule** → neglect, anosognosia, dressing/construction apraxia.
- ▶ **Cerebral dominance**: left = language, calculation, analytical thought; right = prosody, spatial/musical/artistic sense — demonstrated by split-brain (corpus callosotomy) studies.
- ▶ **MCA territory** carries the largest share of the primary motor, sensory and language cortex — hence the commonest and most disabling ischaemic stroke syndrome.
- ▶ Frontal eye field (area 8) lesion → gaze deviates **towards** the lesion side; occipital (pursuit) eye movements remain unaffected.
- ▶ Awake craniotomy with direct electrical cortical stimulation is the clinical gold standard for intraoperative localisation of eloquent (motor/language) cortex.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh Textbook of Human Neuroanatomy; Vishram Singh Textbook of Anatomy Vol 3 4e; Vishram Singh Clinical Neuroanatomy 4e; Snell Clinical Neuroanatomy 7e.



Describe the cortical areas

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction The cerebral cortex is a 2-4 mm sheet of grey matter covering the cerebral hemispheres that is not functionally uniform. On the basis of cytoarchitecture (cell layering, cell type and myelin content), **Brodmann (1909)** parcellated the human cortex into **47 numbered areas**, and these correlate closely with functional localisation established by clinical lesion studies, electrical stimulation and, more recently, functional imaging. Functionally the cortex is grouped into three categories — **primary motor areas**, **primary sensory areas**, and **association areas** — each occupying a fixed gyrus/sulcus with a predictable blood supply, so that a focal lesion produces a reproducible clinico-anatomical syndrome. This is why the topic is examined together with its applied/clinical correlations.

1. Classification of cortical areas

- ▶ **Motor areas** — agranular cortex (thin/absent granular layers, prominent pyramidal cells); lowest threshold for eliciting a movement on electrical stimulation; give origin to corticospinal/corticonuclear (pyramidal) fibres.
- ▶ **Sensory areas** — granular cortex (konio-cortex); electrical activity recordable on applying the appropriate peripheral stimulus; receive relayed input mainly via the thalamus.
- ▶ **Association areas** — six-layered homotypical cortex; no direct motor or sensory response on stimulation; integrate, analyse and interpret information from multiple sources. Association cortex occupies **over 75% of the total cortical surface area** in humans — the primary areas form only a small fraction of the whole.
- ▶ Many areas show overlap of function and are labelled **Ms** (motor-sensory, motor predominant) or **Sm** (sensorimotor, sensory predominant) rather than being purely one or the other.

2. Functional areas of the frontal lobe

Area (Brodmann)	Location	Function
Primary motor area (M1), area 4	Precentral gyrus, extending onto the anterior part of the paracentral lobule (medial surface)	Lowest threshold for an isolated contralateral movement; contains the inverted motor homunculus (uppermost cortex → foot/leg; lowermost → head/face/fingers), disproportionately large for face, lips, hand and thumb (movements, not muscles, are represented); layer V houses the giant pyramidal (Betz) cells (up to ~120 µm long, 25,000–30,000 in number) which contribute only ~3% of corticospinal fibres

Area (Brodmann)	Location	Function
Premotor area, area 6	Posterior parts of superior, middle and inferior frontal gyri, anterior to MI	Stores programmes of learned motor activity assembled from past experience and relays them to MI for execution; controls extrapyramidal/postural activity via basal ganglia connections; needs stronger stimulation than area 4 to evoke movement
Supplementary motor area (SMA)	Medial frontal gyrus, part of area 6, anterior to the paracentral lobule	Bilateral limb movements on stimulation; programmes complex, sequential bilateral motor activity; ablation causes no permanent deficit
Frontal eye field, area 8 (+ adjoining parts of 6)	Posterior part of the middle frontal gyrus, anterior to the facial area of the precentral gyrus	Conjugate voluntary (saccadic) eye movements to the opposite side via the superior colliculus; independent of visual stimuli
Motor speech area of Broca, areas 44–45	Pars opercularis (44) + pars triangularis (45) of the inferior frontal gyrus, dominant hemisphere	Motor formation/programming of words, via connections to the adjacent primary motor area controlling larynx, tongue, lips, palate and respiratory muscles
Prefrontal cortex, areas 9, 10, 11, 12	Remaining large anterior part of the frontal lobe — superior/middle/inferior frontal gyri, orbital gyri, medial frontal gyrus, anterior cingulate gyrus	Personality, initiative, judgement, concentration and emotional depth; rich reciprocal connections with thalamus, hypothalamus, corpus striatum and (via frontopontine fibres) the cerebellum

3. Functional areas of the parietal lobe

Area (Brodmann)	Location	Function
Primary sensory area (SI), areas 3, 1, 2	Postcentral gyrus, extending onto the posterior part of the paracentral lobule (medial surface)	Perception of exteroceptive (pain, touch, temperature) and proprioceptive (vibration, muscle/joint) sensation from the opposite half of the body via the ventral posterolateral/posteromedial thalamic nuclei; inverted sensory homunculus , area proportional to receptor density (face, lips, thumb and index finger over-represented)
Second somesthetic area (SII)	Superior lip of the posterior ramus of the lateral (Sylvian) sulcus	Smaller, bilaterally represented (contralateral dominant); responds to transient cutaneous stimuli such as brushing/tapping

Area (Brodmann)	Location	Function
Sensory association area, areas 5 and 7	Superior parietal lobule, extending onto the medial surface	Integrates touch, pressure and proprioception with past sensory experience → stereognosis (recognising an object's size, shape and texture without vision)
Angular (39) and supramarginal (40) gyri — inferior parietal lobule	Around the posterior ends of the lateral and superior temporal sulci	Parietal extension of Wernicke's sensory speech area on the dominant side; body-scheme, reading, writing, calculation
Taste (gustatory) area, area 43	Lower end of the postcentral gyrus, superior wall of the lateral sulcus, adjoining the insula	Perception of taste, via the nucleus solitarius → ventral posteromedial thalamic nucleus
Vestibular area	Near the facial part of the postcentral gyrus, opposite the auditory area of the superior temporal gyrus	Conscious appreciation of head position/movement; influences posture through eye and limb/trunk musculature

4. Functional areas of the occipital lobe

Area (Brodmann)	Location	Function
Primary visual (striate) area, area 17	Walls and floor of the posterior calcarine sulcus (cuneus above, lingual gyrus below); may wrap around the occipital pole onto the lateral surface	Retinotopic map fed by the optic radiation from the lateral geniculate body; the macula is represented posteriorly at the occipital pole (~one-third of the visual cortex), peripheral retina anteriorly; each hemisphere receives the contralateral visual field; marked by the white line/stria of Gennari , hence "striate"
Secondary/visual association area, areas 18 and 19	Surrounds area 17 on the medial and lateral surfaces	Relates visual input to past visual experience — recognition and interpretation of what is seen
Occipital eye field	Within the secondary visual area	Reflex conjugate eye deviation while pursuing a moving object

5. Functional areas of the temporal lobe

Area (Brodmann)	Location	Function
Primary auditory area, areas 41 and 42	Anterior transverse temporal gyrus of Heschl, floor of the lateral sulcus	Tonotopic map (low frequency anterior, high frequency posterior); bilateral cochlear representation, so a unilateral lesion causes only partial, greater-contralateral hearing loss

Area (Brodmann)	Location	Function
Secondary auditory (association) area, area 22	Superior temporal gyrus, posterior to and surrounding the primary area	Interprets sound and correlates it with memory; posterior part contributes to Wernicke's area
Sensory speech area of Wernicke	Posterior superior temporal gyrus (area 22), extending around the posterior lateral sulcus into the angular/supramarginal gyri (39, 40) — dominant hemisphere	Comprehension of spoken and written language; linked to Broca's area by the arcuate fasciculus

6. Association cortex and cerebral dominance

- Beyond the primary sensory (granular) and primary motor (agranular) areas, the remaining homotypical six-layered cortex is the **association cortex**, classically divided into **prefrontal**, **anterior temporal** and **posterior parietal** regions, concerned with behaviour, discrimination and interpretation rather than direct relay.
- The **anterior temporal cortex** stores past sensory experience (stimulation can evoke recall of past sights/sounds); the **posterior parietal cortex** integrates visual and somatosensory input into concepts of size, form and body scheme.
- **Cerebral dominance**: in most people, handedness, language perception and speech production are governed by the **dominant hemisphere** — the left in roughly 80–95% of subjects (correlating with right-handedness); the **non-dominant** (usually right) hemisphere governs spatial perception, facial and musical recognition. Dominance is not fixed at birth — both hemispheres are equipotential in the neonate, and dominance is established only after the first decade.
- The dominant Wernicke's area is connected to Broca's area by the **arcuate fasciculus**, forming the perisylvian language circuit that allows comprehension, formulation and repetition of speech.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- Fig 27.1 — Functional cortical areas (of Brodmann) on the superolateral surface of the cerebral hemisphere (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.1103)
- Fig 27.2 — Functional cortical areas on the inferomedial surface of the cerebral hemisphere (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.1104)

Draw the **superolateral and medial surfaces of the left cerebral hemisphere** and label:

- ▶ Central sulcus, lateral (Sylvian) sulcus, precentral gyrus, postcentral gyrus, paracentral lobule.
- ▶ **Area 4** (primary motor — precentral gyrus), **area 6** (premotor, anterior to area 4), **area 8** (frontal eye field — middle frontal gyrus), **areas 44/45** (Broca's — inferior frontal gyrus), **areas 9–12** (prefrontal).
- ▶ **Areas 3, 1, 2** (postcentral gyrus — primary sensory), **areas 5, 7** (superior parietal lobule — sensory association), **areas 39/40** (angular/supramarginal gyri).
- ▶ **Areas 41, 42** (Heschl's transverse temporal gyri — primary auditory) and **area 22** (superior temporal gyrus) — ring and label **Wernicke's area**.
- ▶ On the medial surface: **supplementary motor area** (anterior to paracentral lobule), calcarine sulcus with **area 17** (cuneus above, lingual gyrus below), **areas 18/19** around it.
- ▶ Draw the **arcuate fasciculus** as a curved arrow connecting Broca's area to Wernicke's area.

Applied / Clinical anatomy

- ▶ **Area 4 lesion:** irritative → focal (**Jacksonian**) epilepsy, beginning in the represented body part and spreading with the irritation; destructive → contralateral flaccid paresis, more severe than a comparable area 6 lesion; combined 4 + 6 destruction produces the most complete spastic contralateral paralysis (loss of area 6 removes an inhibitory extrapyramidal influence, producing spasticity).
- ▶ **Area 6 (premotor) lesion:** difficulty performing previously learned skilled movements (apraxia) without true paralysis, ataxia or sensory loss.
- ▶ **Frontal eye field lesion:** destructive → both eyes deviate **towards** the side of the lesion, with loss of voluntary gaze to the opposite side (involuntary pursuit of a moving object is preserved, since the occipital visual cortex is intact); irritative → periodic deviation to the opposite side.
- ▶ **Broca's area lesion (dominant hemisphere): expressive (motor) aphasia** — hesitant, non-fluent, effortful speech with comprehension relatively preserved; the patient can think and write the intended words.
- ▶ **Wernicke's area lesion (dominant hemisphere): receptive (sensory) aphasia** — fluent but meaningless/jargon speech, with loss of comprehension of spoken and written language; the patient is unaware of the errors.
- ▶ **Combined Broca's + Wernicke's lesion: global aphasia** — loss of both production and comprehension of speech.
- ▶ **Dominant angular gyrus lesion:** disconnects the visual association cortex from Wernicke's area, producing **alexia** (word blindness) and **agraphia**.

- ▶ **Primary visual area (17) lesion:** contralateral **homonymous hemianopia**; a vascular (posterior cerebral artery/calcarine) occlusion classically **sparing the macula**, because the macular cortex at the occipital pole has a dual blood supply from both posterior and middle cerebral arteries.
- ▶ **Areas 18/19 lesion:** visual agnosia — inability to recognise or interpret what is seen despite intact primary vision.
- ▶ **Auditory area (41, 42) lesion:** mild bilateral diminution of hearing acuity, greater in the contralateral ear (bilateral cochlear projection makes unilateral deafness rare); a **22 lesion** impairs interpretation of sound.
- ▶ **Prefrontal cortex lesion:** no major loss of intelligence, but loss of initiative and judgement, euphoria, and disregard for social norms — the rationale for historical frontal leucotomy/lobectomy in intractable pain and obsessive states.
- ▶ **Surface landmark:** the "**hand-knob**" (omega-shaped bulge of the precentral gyrus at its junction with the superior frontal sulcus) is the radiological/surgical landmark for the motor hand area.

High-yield exam pointers

- ▶ **Brodmann numbers to know cold:** motor 4, premotor 6, frontal eye field 8, Broca's 44–45, prefrontal 9–12, sensory 3-1-2, sensory association 5-7, angular/supramarginal 39/40, visual 17, visual association 18-19, auditory 41-42, auditory association 22, taste 43.
- ▶ **Area 4 (MI)** = precentral gyrus + paracentral lobule; Betz cells (up to 120 µm, ~25,000–30,000, only ~3% of corticospinal fibres); inverted, disproportionate homunculus (face and hand largest).
- ▶ **Broca's (44–45)** → expressive/non-fluent aphasia with comprehension intact; **Wernicke's (22 + 39/40)** → receptive/fluent aphasia with paraphasias; both dominant-hemisphere-only, linked by the **arcuate fasciculus**.
- ▶ **Area 17 lesion** → contralateral homonymous hemianopia **with macular sparing** (dual MCA + PCA supply of the occipital pole).
- ▶ **Association cortex** occupies >75% of the total cortical surface — much larger than the primary motor + sensory areas combined.
- ▶ **Cerebral dominance:** left hemisphere in ~80–95% (language, calculation); right (non-dominant) — spatial perception, face/music recognition; dominance fixed only after the first decade of life.
- ▶ **Paracentral lobule** = leg/foot motor and sensory representation, and the cortical centre for voluntary control of micturition/defecation.
- ▶ Frontal eye field lesion → gaze deviates **towards** the lesion (voluntary saccades lost; pursuit preserved).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; BD Chaurasia Human Anatomy Vol 3–4 8e; Vishram Singh Textbook of Anatomy Vol 3 4e.



Describe the internal capsule in detail

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction The internal capsule is a thick, compact sheet of myelinated **projection fibres** occupying the inferomedial part of each cerebral hemisphere. It is bounded medially by the **caudate nucleus and thalamus** and laterally by the **lentiform nucleus**, and it links the cerebral cortex with subcortical grey matter, the brainstem and the spinal cord — continuous above with the fan-shaped **corona radiata** and below with the **crus cerebri** of the midbrain. Both ascending (corticopetal, sensory) and descending (corticofugal, motor) fibre systems of one entire half of the body traverse this narrow "gateway," so even a small capsular lesion produces a disproportionately widespread neurological deficit, making it one of the most clinically important white-matter structures in the brain.

1. Location, shape and boundaries

- Situated in the inferomedial part of the cerebral hemisphere, between the **thalamus and caudate nucleus medially** and the **lentiform nucleus laterally**.
- In a **horizontal (axial) section**, the internal capsule is **V-shaped**, with its **concavity directed laterally** — the concavity cups the lentiform nucleus, while the apex of the V, directed medially, forms the **genu**.
- Cranially, its fibres diverge and fan out to the cortex as the **corona radiata**; caudally they converge and continue as the **crus cerebri (basis pedunculi)** of the midbrain — corona radiata, internal capsule and crus cerebri thus constitute one uninterrupted fibre pathway from cortex to brainstem.
- The **interventricular foramen of Monro** lies immediately medial to the genu — a useful landmark for locating the genu on cross-sectional imaging.

2. Parts and relations

The internal capsule is described in **five parts**:

Part	Boundaries
Anterior limb	Between the head of the caudate nucleus (medially) and the anterior part of the lentiform nucleus (laterally)
Genu	The bend where the anterior and posterior limbs meet, the angle opening laterally; lies just lateral to the interventricular foramen
Posterior limb	Between the thalamus (medially) and the posterior part of the lentiform nucleus (laterally)
Retrolentiform part	Lies behind (posterior to) the lentiform nucleus
Sublentiform part	Lies below the lentiform nucleus; best seen in coronal section, separating it from the optic tract and the tail of the caudate nucleus

□ Fig 8.20 — Horizontal section through corpus striatum, thalamus and internal caps (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.568)

Governing principle — each fibre group takes the shortest route between the cortex and its destination: fibres to/from the **anterior frontal lobe** occupy the anterior limb; those to/from the **posterior frontal lobe and most of the parietal lobe** occupy the genu and posterior limb; fibres to/from the **temporal lobe** pass through the sublentiform part; and fibres to/from the **occipital lobe** pass through the retrolentiform part.

3. Descending (corticofugal) fibres

- ▶ **Corticopontine fibres** — the single largest fibre group in the capsule (about two-thirds of its total fibre content), forming the first relay of the corticoponto-cerebellar pathway; named according to the lobe of origin:
 - **Frontopontine fibres** — the most numerous subgroup (about 55% of all corticopontine fibres) — pass through the **anterior limb, genu and posterior limb**.
 - **Parietopontine fibres** — mainly **retrolentiform**, some through the sublentiform part.
 - **Occipitopontine fibres** — **retrolentiform** part.
 - **Temporopontine fibres** — **sublentiform** part.
- ▶ **Pyramidal fibres:**
 - **Corticonuclear (corticobulbar) fibres**, destined for the contralateral motor nuclei of cranial nerves III, IV, V, VI, VII, XII and the nucleus ambiguus (IX, X, XI) — occupy the **genu**.
 - **Corticospinal fibres**, to the anterior horn cells — form discrete bundles in the **anterior two-thirds of the posterior limb**, arranged strictly somatotopically: fibres for the **upper limb** lie most anteriorly, followed by **trunk**, then **lower limb**.
- ▶ **Corticothalamic fibres** — reciprocal fibres running alongside the thalamic radiations described below.
- ▶ **Extrapyramidal fibres:**
 - **Corticostriate fibres** — from the whole cerebral cortex to the caudate nucleus and putamen.
 - **Corticorubral fibres** — from the frontal motor cortex to the red nucleus.
 - **Corticoreticular fibres** — from the motor and parietal cortex to the brainstem reticular formation.
 - **Corticotectal fibres** — from the occipital cortex to the superior colliculus and pretectal region (retrolentiform part).

4. Ascending (corticopetal) fibres — the four thalamic radiations

These are predominantly **third-order thalamocortical** sensory fibres, together with scattered hypothalamic/limbic connections:

Radiation	Capsular part	Connection
Anterior thalamic radiation	Anterior limb	Anterior and medial (dorsomedial) thalamic nuclei ↔ frontal cortex (also carries hypothalamic/limbic fibres)

Radiation	Capsular part	Connection
Superior thalamic radiation	Genu and posterior limb	Ventral tier thalamic nuclei (VA, VL, VPL, VPM) ↔ sensorimotor cortex — conveys somesthetic sensation
Posterior thalamic radiation (includes optic radiation)	Retrolentiform part	Lateral geniculate body/pulvinar ↔ visual cortex (occipital lobe)
Inferior thalamic radiation (includes auditory radiation)	Sublentiform part	Medial geniculate body ↔ auditory cortex (superior/transverse temporal gyri, areas 41, 42)

5. Summary — fibre composition by part

Part	Descending (motor) fibres	Ascending (sensory) fibres
Anterior limb	Frontopontine; corticothalamic (fronto-thalamic) fibres	Anterior thalamic radiation
Genu	Corticonuclear (corticobulbar); frontopontine; corticoreticular	Anterior part of superior thalamic radiation
Posterior limb	Corticospinal; corticorubral; corticoreticular; frontopontine (some)	Bulk of superior thalamic radiation
Retrolentiform part	Parietopontine; occipitopontine; corticotectal	Posterior thalamic radiation (incl. optic radiation)
Sublentiform part	Temporopontine	Inferior thalamic radiation (incl. auditory radiation)

6. Arterial supply

The capsule receives a **segmental, near end-arterial** blood supply — the single most clinically important fact about it:

Part	Chief supplying artery
Anterior limb (upper)	Medial and lateral striate branches of the middle cerebral artery
Anterior limb (lower)	Recurrent artery of Heubner (medial striate branch of the anterior cerebral artery, arising just proximal to the anterior communicating artery)
Genu (upper)	Medial and lateral striate branches of the middle cerebral artery
Genu (lower)	Direct branches of the internal carotid artery and the posterior communicating artery

Part	Chief supplying artery
Posterior limb	Lateral and medial lenticulostriate branches of the middle cerebral artery — the largest lateral branch is Charcot's artery of cerebral haemorrhage; its posterior third also receives the anterior choroidal artery and a striate branch of the posterior cerebral artery
Retrolentiform part	Anterior choroidal artery ($\pm$ posterolateral central branches of the posterior cerebral artery)
Sublentiform part	Anterior choroidal artery ($\pm$ branches of the posterior cerebral artery)

□ Fig 11.13 — Arterial supply of the internal capsule (IB Singh — Textbook of Human Neuroanatomy, p.203)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Horizontal section of the cerebrum at the level of the internal capsule** — draw the V-shape with concavity lateral. Label: caudate nucleus and thalamus (medial), lentiform nucleus (lateral), the five parts (**anterior limb, genu, posterior limb, retrolentiform part, sublentiform part**), the interventricular foramen adjacent to the genu, and the continuity above with the corona radiata and below with the crus cerebri.
- ▶ **Same outline with arterial territories superimposed** — medial/lateral lenticulostriate (MCA) branches over the anterior limb/genu/posterior limb with Charcot's artery marked on the posterior limb; recurrent artery of Heubner (ACA) on the lower anterior limb; direct ICA and posterior communicating artery branches on the genu; anterior choroidal artery over the retrolentiform and sublentiform parts.

Applied / Clinical anatomy

- ▶ **Capsular hemiplegia** — because motor, sensory and special-sensory fibres for the entire contralateral half of the body are packed into this narrow gate, occlusion or rupture of a capsular vessel produces a **contralateral spastic (upper motor neuron) hemiplegia**, often with hemianaesthesia, and **aphasia if the dominant hemisphere** is involved — a far larger deficit than an equivalent-sized cortical lesion. The classic clinical posture is flexion of the paralysed upper limb with extension of the lower limb.
- ▶ **Charcot's artery of cerebral haemorrhage** — the largest lateral lenticulostriate branch of the middle cerebral artery, supplying the posterior limb — is the vessel most commonly ruptured in **hypertensive intracerebral (capsular) haemorrhage**.
- ▶ **Faciobrachial monoplegia** follows thrombosis/occlusion of the **recurrent artery of Heubner**, damaging the corticonuclear fibres for the face (genu) and corticospinal fibres for the upper limb (anterior part of the posterior limb), sparing the trunk and lower limb.
- ▶ A lesion confined to the **genu** produces contralateral sensorimotor loss in the head and face, but this is often incomplete because most cranial nerve motor nuclei have **bilateral cortical (corticonuclear) innervation**.

- ▶ **Anterior choroidal artery occlusion** gives the classical triad of contralateral **hemiplegia**, **hemianaesthesia** and **homonymous hemianopia**, from combined involvement of the posterior limb, retrolentiform and sublenticular parts.
- ▶ Lesions restricted to the **posterior limb** alone are the **commonest cause of hemiplegia**; a small, purely-motor lacunar infarct here (sparing the adjoining sensory fibres) is a classical example of a **lacunar stroke syndrome**.
- ▶ **Radiosurgical relevance** — the genu's constant relation to the interventricular foramen and the capsule's characteristic V-shape allow its parts to be localised reliably on CT/MRI; the corticospinal fibres of the posterior limb are a critical structure that neurosurgeons must identify and avoid during stereotactic pallidotomy, thalamotomy and deep-brain-stimulation electrode placement.

High-yield exam pointers

- ▶ **V-shaped** in horizontal section, concavity directed laterally (occupied by the lentiform nucleus); **5 parts** — anterior limb, genu, posterior limb, retrolentiform part, sublenticular part.
- ▶ Continuous **above with the corona radiata**, **below with the crus cerebri** — a single fibre highway from cortex to brainstem/spinal cord.
- ▶ **Genu = corticonuclear (corticobulbar) fibres**; **posterior limb = corticospinal fibres**, arranged upper limb (anterior) → trunk → lower limb (posterior).
- ▶ **Four thalamic radiations**: anterior (anterior limb), superior (genu + posterior limb), posterior/optic (retrolentiform), inferior/auditory (sublenticular).
- ▶ **Frontopontine fibres** are the largest single descending fibre group (~55% of all corticopontine fibres); corticopontine fibres overall form roughly two-thirds of the capsule.
- ▶ **Charcot's artery** (largest lateral lenticulostriate branch of the MCA) supplies the posterior limb and is the commonest site of hypertensive capsular haemorrhage.
- ▶ **Recurrent artery of Heubner** (ACA branch) supplies the lower anterior limb and genu; its occlusion causes **faciobrachial monoplegia**.
- ▶ **Anterior choroidal artery** supplies the retrolentiform and sublenticular parts (and the posterior third of the posterior limb); occlusion causes hemiplegia + hemianaesthesia + homonymous hemianopia.
- ▶ The **interventricular foramen of Monroe** lies medial to the genu — the key radiological landmark for locating the internal capsule.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3–4 8e; IB Singh Textbook of Human Neuroanatomy; IB Singh Textbook of Anatomy Vol 3 6e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e.



Functional areas of cerebrum

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction The cerebral cortex is not functionally uniform — discrete territories, first mapped by **Brodmann (1909)** on cytoarchitectural grounds (numbered areas 1–52), are dedicated to specific motor, sensory or associative roles. Functionally these are grouped into three categories: **primary motor/sensory areas** (agranular or granular cortex with the lowest threshold for producing a movement or receiving a modality), **secondary/association areas** immediately adjoining them (interpret and refine the primary information), and **higher-order (supramodal) association cortex** — prefrontal, parietal and temporal — subserving language, praxis, personality and cognition. Because each area occupies a fixed gyrus/sulcus with a predictable arterial territory and known connections, focal lesions produce reproducible clinico-anatomical syndromes, which is why this topic is examined together with its applied anatomy.

1. Functional areas of the frontal lobe

Area (Brodmann)	Location	Function
Primary motor area (MI), area 4	Precentral gyrus + anterior part of paracentral lobule (medial surface)	Lowest threshold for producing an isolated contralateral movement; contains the inverted, disproportionate motor homunculus (face/hand/thumb over-represented; area is proportional to skill, not muscle bulk); layer V contains giant pyramidal (Betz) cells (up to 120 μm long, 60 μm wide; 25,000–30,000 in number) giving rise to only ~3% of corticospinal fibres
Premotor area, area 6	Posterior part of superior, middle and inferior frontal gyri, anterior to MI	No Betz cells; stores and programmes learned motor sequences, which it relays to MI for execution; stronger stimulation than area 4 is needed to evoke movement
Supplementary motor area (SMA)	Medial frontal gyrus (medial surface), part of area 6, anterior to paracentral lobule	Bilateral limb movements on stimulation; organises sequential, complex bilateral motor activity; ablation causes no permanent deficit
Frontal eye field, area 8 (and adjoining parts of 6)	Middle frontal gyrus, anterior to the facial part of the precentral gyrus	Conjugate voluntary (saccadic) eye movements to the opposite side, via the superior colliculus; independent of visual stimuli

Area (Brodmann)	Location	Function
Motor speech area of Broca, areas 44–45	Pars opercularis (44) and pars triangularis (45) of the inferior frontal gyrus, dominant hemisphere (left in ~98% of right-handers and ~70% of left-handers)	Motor programming/formation of words via connections to the adjacent primary motor area (larynx, tongue, lips, palate, respiratory muscles)
Prefrontal cortex, areas 9, 10, 11, 12	Remaining large anterior part of frontal lobe — superior/middle/inferior frontal gyri, orbital gyri, medial frontal gyrus, anterior cingulate gyrus	Personality, initiative, judgement, emotional depth and concentration; rich reciprocal connections with thalamus, hypothalamus, corpus striatum and (via frontopontine fibres) cerebellum

2. Functional areas of the parietal lobe

Area (Brodmann)	Location	Function
Primary somatosensory area (SI), areas 3a, 3b, 1, 2	Postcentral gyrus + posterior part of paracentral lobule. 3a abuts area 4 (deep/proprioceptive sense); 3b buried in the posterior wall of the central sulcus (cutaneous); 1 on the posterior lip of the sulcus; 2 on the crown of the gyrus	Receives general sensation via the ventral posterolateral/posteromedial thalamic nuclei; inverted somatotopic sensory homunculus , area proportional to receptor density (face, thumb, index finger over-represented)
Second somatosensory area (SII)	Superior lip of the posterior ramus of the lateral (Sylvian) sulcus	Smaller, bilaterally represented (contralateral dominant); responds to transient cutaneous stimuli (brushing, tapping)
Somatosensory association area, areas 5 and 7	Superior parietal lobule, extending onto the medial surface	Integrates touch, pressure and proprioception with past experience → stereognosis (recognition of an object's size/shape/texture without vision)
Inferior parietal lobule — supramarginal (40) and angular (39) gyri	Around the posterior end of the lateral sulcus and superior temporal sulcus	Forms the parietal extension of Wernicke's sensory speech area ; body-scheme, reading, writing and calculation on the dominant side
Taste (gustatory) area, area 43	Lower end of postcentral gyrus, superior wall of lateral sulcus, adjoining insula	Perception of taste (via nucleus solitarius → ventral posteromedial thalamic nucleus)
Vestibular area	Near the facial part of the postcentral gyrus, opposite the auditory area of the superior temporal gyrus	Conscious appreciation of head position and movement; influences posture via eye and trunk/limb muscles

3. Functional areas of the occipital lobe

Area (Brodmann)	Location	Function
Primary visual area (V1), area 17 — striate cortex	Walls of the posterior calcarine sulcus (cuneus above, lingual gyrus below); occasionally wraps around the occipital pole	Receives the optic radiation from the lateral geniculate body; retinotopic map — macula occupies the posterior third (occipital pole), peripheral retina represented anteriorly; contralateral visual field of each eye is represented
Secondary/visual association area, areas 18 and 19	Surrounds area 17 (parastriate/peristriate cortex) on medial and lateral surfaces	Relates visual input to past visual experience — recognition and interpretation of what is seen; connects to the frontal eye field
Occipital eye field	Within the secondary visual area	Reflex conjugate eye deviation while tracking (pursuing) a moving object

4. Functional areas of the temporal lobe

Area (Brodmann)	Location	Function
Primary auditory area, areas 41 and 42	Anterior transverse temporal gyrus of Heschl, floor of the lateral sulcus	Tonotopic map (low frequency anterior, high frequency posterior); bilateral input via each medial geniculate body — unilateral lesion gives only partial, greater-contralateral deafness
Secondary/auditory association area, area 22	Superior temporal gyrus, posterior to the primary area	Interprets sound and correlates it with memory; posterior part contributes to Wernicke's area
Sensory speech area of Wernicke	Posterior superior temporal gyrus (area 22), extending around the posterior lateral sulcus into the inferior parietal lobule (areas 39, 40) — dominant hemisphere	Comprehension of spoken and written language; linked to Broca's area by the arcuate fasciculus
Olfactory (primary) area, area 28	Parahippocampal gyrus and uncus	Reception of smell; part of the phylogenetically older cortex; lesions may cause olfactory (uncinate) hallucinations

5. Association cortex and cerebral dominance

- Beyond the primary sensory (granular) and primary motor (agranular) areas — which occupy only a small fraction of the cortex — the remaining **six-layered homotypical cortex** forms the association areas: **prefrontal, anterior temporal and posterior parietal**, concerned with behaviour, discrimination and interpretation rather than simple relay.

- ▶ The **perisylvian language zone** of the dominant hemisphere links Broca's area (production) with Wernicke's area (comprehension) via the **arcuate fasciculus**, permitting repetition and self-monitoring of speech.
- ▶ **Cerebral dominance**: handedness, language/speech perception and production are controlled by the **dominant hemisphere** — left in over 90% of people (correlating with the ~90% right-handed population). The **non-dominant hemisphere** governs spatial perception, facial recognition and musical appreciation. Dominance is not fixed at birth — the two hemispheres are equipotential in the neonate and dominance is established only after the first decade, which is why a young child with dominant-hemisphere damage can still acquire normal speech and handedness on the opposite side.
- ▶ The **paracentral lobule** (medial continuation of the pre- and postcentral gyri) carries the leg/foot motor and sensory representation and is the cortical centre for voluntary control of micturition and defecation.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- Fig 12.11 — *The functional areas on the superolateral surface of the left cerebral* (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.456)
- Fig 12.12 — *The functional areas on the inferomedial surface of the right cerebral* (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.457)

Draw the **superolateral and medial surfaces of the left cerebral hemisphere** and label:

- ▶ Central sulcus, lateral (Sylvian) sulcus, precentral gyrus, postcentral gyrus, paracentral lobule.
- ▶ **Area 4** (motor — precentral gyrus), **area 6** (premotor), **area 8** (frontal eye field — middle frontal gyrus), **areas 44/45** (Broca's — inferior frontal gyrus), prefrontal areas 9–12.
- ▶ **Areas 3, 1, 2** (postcentral gyrus), **areas 5, 7** (superior parietal lobule), **areas 39/40** (angular/supramarginal gyri).
- ▶ **Areas 41, 42** (Heschl's transverse temporal gyri) and **area 22** (superior temporal gyrus) — ring and label Wernicke's area.
- ▶ On the medial surface: **supplementary motor area**, **cingulate gyrus**, **cuneus/lingual gyrus** separated by the **calcarine sulcus** (area 17), **precuneus** (area 7), **parahippocampal gyrus/uncus** (area 28).
- ▶ Draw the **arcuate fasciculus** as an arc connecting Broca's and Wernicke's areas.

Applied / Clinical anatomy

- ▶ **Area 4 (motor) lesion**: irritative → focal (**Jacksonian**) epilepsy, beginning in the represented body part and spreading with the irritation; destructive → contralateral flaccid paresis, more severe than a comparable area 6 lesion; combined 4+6 destruction gives the most complete spastic contralateral paralysis (area 6 loss removes an inhibitory extrapyramidal influence).
- ▶ **Area 6 (premotor) lesion**: apraxia/akinesia — difficulty performing previously learned skilled movements without paralysis, ataxia or sensory loss; if writing is affected, called agraphia.

- ▶ **Frontal eye field lesion:** destructive → eyes deviate **towards** the side of the lesion, with loss of voluntary gaze to the opposite side (involuntary pursuit of a moving object is preserved, as the occipital visual cortex is spared); irritative → periodic deviation to the opposite side.
- ▶ **Broca's area lesion (dominant hemisphere): expressive (motor) aphasia** — hesitant, non-fluent, distorted speech with comprehension relatively preserved.
- ▶ **Wernicke's area lesion (dominant hemisphere): receptive (sensory) aphasia** — fluent but meaningless speech (jargon), with loss of comprehension of spoken and written language; the patient is unaware of the errors.
- ▶ **Lesion of both Broca's and Wernicke's areas: global aphasia** — loss of both production and comprehension.
- ▶ **Dominant angular gyrus lesion:** interrupts the pathway between the visual association cortex and Wernicke's area, causing **alexia** (word blindness) and **agraphia**, with acalculia and anomia often co-existing, even without frank aphasia — the classical parietal disconnection (Gerstmann-type) picture.
- ▶ **Arcuate fasciculus (parietal) lesion: conduction aphasia** — fluent speech and preserved comprehension but impaired repetition; Gray's Anatomy groups Broca's, conduction and Wernicke's aphasias as corresponding to frontal, parietal and temporal cortical damage respectively.
- ▶ **Splenial/left occipital lesion** disconnecting the intact right visual cortex from the left language area produces **alexia without agraphia** (posterior cerebral artery territory, tumour or demyelination).
- ▶ **Area 17 lesion:** contralateral **homonymous hemianopia with macular sparing** — because the macular (central vision) cortex at the occipital pole receives a dual blood supply from both the posterior and middle cerebral arteries at their watershed, so a typical PCA (calcarine) thrombosis spares it; a traumatic or space-occupying lesion, which is not vascular, need not spare the macula.
- ▶ **Areas 18/19 lesion:** visual agnosia — inability to recognise or interpret what is seen despite intact primary vision.
- ▶ **Prefrontal cortex lesion:** no major loss of intelligence, but loss of initiative and judgement, euphoria and disregard for social norms/personal appearance; the prefrontal cortex's rich dopaminergic innervation links its dysfunction to some schizophrenia symptoms.
- ▶ **"Hand-knob" of the precentral gyrus** — an inverted-omega bulge at the level of the middle genu of the central sulcus (junction with the superior frontal sulcus) — is the fMRI/MRI landmark for the motor hand area, and is used for surgical/radiological localisation of the motor strip.
- ▶ **Split-brain (corpus callosotomy)**, performed for intractable epilepsy, demonstrates hemispheric lateralisation directly: information confined to the non-dominant (usually right) hemisphere cannot be verbally named because it is disconnected from the dominant language area.

Recent advances

According to PubMed:

- ▶ A high-density **micro-electrocorticography (μECoG) array** ("Layer 7 Cortical Interface", 1024 channels) placed intraoperatively on the motor cortex during awake craniotomy achieved real-

time 4-word speech classification (~77.5% accuracy) and 4-direction cursor decoding (78–84% accuracy), demonstrating brain–computer-interface-grade functional mapping of the eloquent cortex described above (Lehner et al, *Neurosurgical Focus* 2026) [DOI](<https://doi.org/10.3171/2025.11.FOCUS25908>).

- ▶ The largest probabilistic functional atlas to date — 2,124 direct electrocortical stimulation trials in 125 epilepsy patients — showed that motor, sensory and language responses are organised along **graded probabilistic gradients with marked inter-patient variability**, rather than fixed Brodmann boundaries; the middle frontal gyrus emerged as a consistent naming/speech-arrest node and motor responses extended into parietal association cortex, underscoring the need for individualised intraoperative mapping (Michalak et al, *bioRxiv* 2025) [DOI](<https://doi.org/10.1101/2025.09.15.676264>).
- ▶ **Connectome imaging** of the frontal aslant tract (linking the supplementary motor area to Broca's region) guided awake craniotomy in two patients with superior frontal gyrus lesions, allowing complete resection without postoperative **SMA syndrome** (contralateral akinesia and mutism) — extending functional localisation beyond the classical eloquent-cortex boundaries to include structurally connected "non-eloquent" regions (Shah et al, *Clinical Neurology and Neurosurgery* 2025) [DOI](<https://doi.org/10.1016/j.clineuro.2025.108726>).

High-yield exam pointers

- ▶ **Brodmann numbers to know cold:** motor 4, premotor 6, frontal eye field 8, Broca's 44–45, prefrontal 9–12, sensory 3-1-2, sensory association 5-7, angular/supramarginal 39/40, visual 17, visual association 18-19, auditory 41-42, auditory association 22, olfactory 28, taste 43.
- ▶ **MI (area 4)** — precentral gyrus + paracentral lobule; Betz cells (up to 120 µm, ~25,000–30,000, only 3% of corticospinal fibres); inverted, disproportionate homunculus (face and hand largest).
- ▶ **Broca's (44–45)** → expressive/non-fluent aphasia with intact comprehension; **Wernicke's (22 + 39/40)** → receptive/fluent aphasia with paraphasias; both are dominant-hemisphere-only and linked by the **arcuate fasciculus** (lesion → conduction aphasia).
- ▶ **Area 17 (striate cortex)** lesion → contralateral homonymous hemianopia **with macular sparing** (dual MCA + PCA supply of the occipital pole).
- ▶ **Dominant angular gyrus** lesion → alexia + agraphia (± acalculia/anomia) without necessarily causing aphasia.
- ▶ **Cerebral dominance:** left hemisphere in ~90% — language, calculation, analytical thought; right (non-dominant) — spatial perception, face recognition, music; demonstrated by split-brain (corpus callosotomy) studies.
- ▶ **Paracentral lobule** = leg/foot motor + sensory area, and the cortical centre for micturition/defecation control.
- ▶ Frontal eye field (area 8) lesion → gaze deviates **towards** the lesion (voluntary saccades lost, pursuit preserved).

SOURCE & COVERAGE

Snell Clinical Neuroanatomy 7e; BD Chaurasia Human Anatomy Vol 3–4 8e; Vishram Singh Clinical Neuroanatomy 4e; Gray's Anatomy (Standing) 41e.



Name the parts, arterial supply, structure and functional areas of the cerebral hemisphere

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction The **cerebral hemispheres** are the two large, ovoid masses that together form the **cerebrum**, the largest part of the human brain, filling most of the cranial cavity. They are incompletely separated by the **longitudinal cerebral fissure** (occupied by the falx cerebri, anterior cerebral vessels and arachnoid) and are united across the midline by the **corpus callosum**. Each hemisphere is built of an outer sheet of grey matter (**cerebral cortex**), an inner mass of **white matter**, deeply placed grey masses (**basal nuclei**) and a central cavity (**lateral ventricle**). Its blood supply comes from the **anterior, middle and posterior cerebral arteries**, and its cortex is functionally mapped into **motor, sensory and association areas**.

I. Parts (External Features) of the Cerebral Hemisphere

Each hemisphere presents **poles, surfaces, borders, sulci, gyri and lobes**.

- ▶ **Poles (3):** **frontal pole** (rounded, anterior end, opposite superciliary arch); **occipital pole** (pointed, posterior end); **temporal pole** (between the two, points forward into the middle cranial fossa — a primitive posterior pole that curved ventro-caudally during growth).
- ▶ **Surfaces (3):** **superolateral** (most convex/extensive, conforms to the cranial vault), **medial** (flat, vertical, shows the cut surface of the corpus callosum), and **inferior** — subdivided by the stem of the lateral sulcus into a small **orbital** part and a larger **tentorial** part.
- ▶ **Borders (6):** superomedial, superciliary, inferolateral (shows the **preoccipital notch**, ~3 cm in front of the occipital pole), medial orbital, medial occipital, and inferomedial (hippocampal) borders.
- ▶ **Lobes:** the superolateral surface is arbitrarily divided into **four lobes** using three main sulci (central, lateral, parieto-occipital) and two imaginary lines (parieto-occipital sulcus-to-preoccipital notch; backward continuation of the lateral sulcus).

Lobe	Boundary	Principal gyri
Frontal	Anterior to central sulcus, above posterior ramus of lateral sulcus	Precentral, superior/middle/inferior frontal gyri
Parietal	Behind central sulcus, in front of parieto-occipital line	Postcentral gyrus, superior & inferior parietal lobules
Temporal	Below posterior ramus of lateral sulcus	Superior, middle, inferior temporal gyri

Lobe	Boundary	Principal gyri
Occipital	Behind the parieto-occipital-preoccipital line	Cuneus, lingual gyrus (medial); occipital gyri (lateral)

In addition, the **insula** (island of Reil, "central lobe") lies buried in the floor of the lateral sulcus, hidden by frontal, fronto-parietal and temporal **opercula**; it shows 3–4 short (anterior) and 1–2 long (posterior) gyri, and the MCA runs on its surface. The **limbic lobe** (cingulate + parahippocampal gyri) forms a ring on the medial surface around the corpus callosum and brainstem.

□ Fig 12.6 — Superolateral surface of the left cerebral hemisphere showing lobes, sulci (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.443)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Superolateral surface of the left cerebral hemisphere, labelled:

- ▶ Poles: frontal pole, occipital pole, temporal pole (below/anterior)
- ▶ Sulci: central sulcus (Rolando), lateral sulcus (Sylvius) with its 3 rami, parieto-occipital sulcus (upper end), preoccipital notch
- ▶ Two imaginary boundary lines demarcating the four lobes
- ▶ Lobes: frontal, parietal, temporal, occipital
- ▶ Gyri: precentral, postcentral, superior/middle/inferior frontal, superior/middle/inferior temporal, supramarginal & angular gyri (inferior parietal lobule)

II. Arterial Supply of the Cerebral Hemisphere

Supply is via the **circle of Willis**: the internal carotid divides into the **anterior cerebral artery (ACA)** and **middle cerebral artery (MCA)**; the vertebrobasilar system gives the **posterior cerebral artery (PCA)**; the two sides are cross-linked by anterior and posterior communicating arteries. Each of the three cerebral arteries gives **cortical branches** (to the cortex) and **central/ganglionic branches** (to deep grey matter and internal capsule).

Artery	Surface / territory	Cortex supplied	Central branches
Anterior cerebral artery	Medial surface (anterior two-thirds) + a narrow (~2.5 cm) strip over the superomedial border onto the lateral surface, up to the parieto-occipital sulcus	Motor & sensory cortex of the lower limb/foot , supplementary motor area, orbital & medial frontal cortex, cingulate gyrus	Medial striate artery (of Heubner) → head of caudate nucleus, anterior putamen, anterior limb of internal capsule
Middle cerebral artery	About two-thirds of the superolateral surface + insula + temporal pole	Motor & sensory cortex of face, arm and trunk ; Broca's area (44, 45) and Wernicke's area in the dominant hemisphere; primary auditory area; insula	Lateral striate (lenticulostriate) arteries → caudate, putamen, globus pallidus, genu & posterior limb of internal capsule

Artery	Surface / territory	Cortex supplied	Central branches
Posterior cerebral artery	Tentorial (inferior) surface of temporal lobe + occipital lobe	Visual cortex in the calcarine sulcus, cuneus, lingual and parahippocampal gyri; uncus	Posteromedial/posterolateral central branches → thalamus, subthalamus, midbrain; posterior choroidal branches → choroid plexus

□ Fig 11.11 — The cortical branches of three cerebral arteries illustrated on the lateral surface of cerebrum (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.602)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Lateral and medial surfaces of the cerebral hemisphere with arterial territories shaded/outlined:

- ▶ **MCA territory** — bulk of the lateral surface (face/arm motor-sensory cortex, Broca's & Wernicke's areas, insula)
- ▶ **ACA territory** — medial surface + narrow superomedial strip (leg/foot area)
- ▶ **PCA territory** — occipital pole and tentorial surface (visual cortex)
- ▶ **Watershed (border-zone) areas** between ACA–MCA and MCA–PCA territories

III. Structure of the Cerebral Hemisphere

Each hemisphere is composed of cortex, white matter, basal nuclei and a ventricular cavity.

1. Cerebral cortex (grey matter)

- ▶ Phylogenetically classified as **archicortex** (hippocampus; 3-layered), **paleocortex** (cingulate gyrus), together forming the **allocortex**; and **neocortex** (~90% of cortex; 6-layered).
- ▶ **Six layers of neocortex** (superficial → deep): molecular (plexiform), external granular, external pyramidal, internal granular (contains the external band of Baillarger), internal pyramidal/ganglionic (Betz cells; internal band of Baillarger), and multiform (polymorphic).
- ▶ **Neuron types**: pyramidal cells (small/medium/large — the largest being **Betz cells**), stellate/granule cells, horizontal cells of Cajal, cells of Martinotti, fusiform cells.
- ▶ **Functional cell types**: projection neurons (→ striatum, thalamus, brainstem, cord), association neurons (→ same hemisphere), commissural neurons (→ opposite hemisphere).
- ▶ **Structural variants**: homotypical (all 6 layers distinct) vs heterotypical — **granular** (koniocortex; sensory areas) and **agranular** (motor areas, dense Betz cells).

2. White matter — three fibre systems



Name the parts, arterial supply, structure and functional areas of the cerebral hemisphere

- ▶ **Association fibres** connect cortex within the same hemisphere: short **arcuate (U) fibres** hook around adjacent gyri; long bundles include the **uncinate fasciculus** (orbital/temporal pole ↔ Broca's area), **cingulum** (girdles the cingulate/parahippocampal gyri), **superior longitudinal**

fasciculus (frontal ↔ occipital/temporal, longest bundle), **inferior longitudinal fasciculus** (occipital ↔ temporal) and **fronto-occipital fasciculus**.

- **Commissural fibres** link corresponding areas of the two hemispheres: **corpus callosum** (largest commissure, ~10 cm, 150–200 million fibres — rostrum, genu, trunk, splenium), **anterior commissure**, **posterior commissure**, **hippocampal (fornix) commissure**, **habenular commissure**.
- **Projection fibres** connect cortex to lower centres, chiefly via the **corona radiata** converging into the **internal capsule** (anterior limb, genu, posterior limb, retro-lentiform and sub-lentiform parts), which carries corticospinal, corticonuclear, thalamocortical and other fibres.

3. Basal nuclei (basal ganglia) — masses of grey matter in the basal white matter, lateral to the thalamus: **caudate nucleus**, **lentiform nucleus** (putamen + globus pallidus), **claustrum**, and **amygdaloid body**; caudate + putamen together form the **corpus striatum**, the principal component of the extrapyramidal system.

4. Lateral ventricle — a C-shaped cavity within each hemisphere (anterior/body/posterior/inferior horns + atrium), lined by ependyma, containing choroid plexus, and communicating with the third ventricle via the interventricular foramen (of Monro).

IV. Functional Areas of the Cerebral Cortex

Brodmann (1909) mapped the cortex into ~47 cytoarchitectural areas. Classically the cortex has three functional types — **motor**, **sensory**, and **association** areas (association cortex occupies >75% of total cortical surface).

Area	Brodmann #	Location	Function
Primary motor area	4	Precentral gyrus (+ paracentral lobule for leg)	Contralateral voluntary movement; contains Betz cells; inverted motor homunculus
Premotor area	6	Anterior to area 4	Programmes/stores learned motor sequences; origin of extrapyramidal fibres
Supplementary motor area	Medial area 6	Medial frontal gyrus	Bilateral postural/complex movements
Frontal eye field	8	Posterior middle frontal gyrus	Voluntary conjugate eye movements
Motor speech area of Broca	44, 45	Pars opercularis & triangularis, inferior frontal gyrus (dominant side)	Expressive speech production
Prefrontal area	Anterior to 6/8	Rostral frontal lobe	Personality, judgement, foresight

Area	Brodmann #	Location	Function
Primary sensory area	3, 1, 2	Postcentral gyrus (+ paracentral lobule for leg)	Contralateral exteroceptive & proprioceptive sensation; sensory homunculus
Secondary sensory area	SII	Upper lip of posterior ramus of lateral sulcus	Bilateral; relates to pain perception
Sensory association area	5, 7	Superior parietal lobule	Stereognosis (shape/size/texture recognition)
Sensory speech area of Wernicke	22, 39, 40	Posterior superior temporal + angular/supramarginal gyri (dominant side)	Comprehension of spoken/written language
Primary auditory area	41, 42	Heschl's gyrus (superior temporal gyrus)	Loudness, pitch, quality, sound localisation
Secondary auditory area	22	Around primary auditory area	Interpretation of sound
Primary visual (striate) area	17	Walls/floor of calcarine sulcus	Vision; contains the stria of Gennari
Visual association areas	18, 19	Surrounding area 17	Interpretation/integration of visual images

Cerebral dominance: the **left hemisphere** is dominant for language, speech, calculation and handedness in >90% of individuals (hence the preponderance of right-handedness); the **right (non-dominant/minor) hemisphere** specialises in spatial perception, facial recognition and non-verbal, creative ideation. Dominance is not fixed until after the first decade of life.

□ Fig 12.11 — The functional areas on the superolateral surface of the left cerebral hemisphere (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.456)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Superolateral surface with Brodmann numbers labelled:

- ▶ Area 4 (primary motor) — precentral gyrus
- ▶ Area 6 (premotor/supplementary motor)
- ▶ Area 8 (frontal eye field)
- ▶ Areas 44, 45 (Broca's area) — inferior frontal gyrus
- ▶ Areas 3, 1, 2 (primary sensory) — postcentral gyrus
- ▶ Areas 5, 7 (sensory association) — superior parietal lobule
- ▶ Areas 39, 40 (angular/supramarginal — part of Wernicke's area) — inferior parietal lobule
- ▶ Areas 41, 42 (primary auditory) — Heschl's gyrus
- ▶ Area 22 (auditory association/Wernicke's) — superior temporal gyrus
- ▶ Area 17 (primary visual) — occipital pole/calcarine region
- ▶ Areas 18, 19 (visual association)

Applied / Clinical anatomy

- ▶ **MCA territory infarct** — the **most commonly affected artery in cerebrovascular accidents**; produces contralateral face/arm-predominant hemiplegia and hemianaesthesia, and (in the dominant hemisphere) aphasia; homonymous hemianopia if optic radiation involved.
- ▶ **ACA territory infarct** — contralateral leg/foot weakness and sensory loss, urinary incontinence (paracentral lobule), abulia/personality change with bilateral involvement.
- ▶ **PCA territory infarct** — contralateral **homonymous hemianopia**, often with **macular sparing** because the occipital pole receives a dual/anastomotic supply from the MCA.
- ▶ **Watershed (border-zone) infarcts** occur at the junction of ACA–MCA and MCA–PCA territories in systemic hypotension/cardiac arrest, since these zones are farthest from the parent arteries.
- ▶ **Charcot's artery** (largest lateral lenticulostriate branch of MCA) is the classic **artery of cerebral haemorrhage** (Charcot–Bouchard microaneurysms → basal ganglia bleed); **Berry aneurysms** on the circle of Willis are the commonest cause of subarachnoid haemorrhage.
- ▶ **Aphasias:**

Feature	Broca's (motor) aphasia	Wernicke's (sensory) aphasia
Lesion site	Areas 44, 45 (inferior frontal gyrus)	Areas 22, 39, 40 (superior temporal + inferior parietal)
Speech	Non-fluent, effortful, telegraphic	Fluent but meaningless
Comprehension	Good	Poor
Reading/writing	Intact	Lost

- ▶ **Angular/supramarginal gyrus lesions** — alexia, agraphia, acalculia, anomia; combined Broca's + Wernicke's damage causes **global aphasia**.

- ▶ **Prefrontal cortex lesions** — disinhibition, poor judgement, socially inappropriate behaviour, loss of initiative.
- ▶ **Cerebral dominance** is clinically assessed before neurosurgery (e.g., anterior temporal lobe/hippocampal surgery) to protect the language-dominant hemisphere.

High-yield exam pointers

- ▶ Cerebral hemisphere = 3 poles + 3 surfaces + 6 borders + 4 lobes + insula + limbic lobe.
- ▶ MCA supplies ~2/3 of the superolateral surface (face/arm cortex, Broca's, Wernicke's, insula); ACA supplies the medial surface + leg area; PCA supplies the occipital/visual cortex.
- ▶ Lenticulostriate ("Charcot's") arteries from MCA supply the basal ganglia/internal capsule — classic site of hypertensive haemorrhage.
- ▶ Neocortex = 6 layers; Betz cells lie in the internal pyramidal layer of the primary motor cortex.
- ▶ White matter fibres = association (intra-hemispheric), commissural (inter-hemispheric, e.g. corpus callosum), projection (cortex ↔ subcortical, via internal capsule).
- ▶ Broca's area (44, 45) = expressive speech; Wernicke's area (22, 39, 40) = language comprehension; connected by the arcuate fasciculus.
- ▶ Primary motor (area 4) and primary sensory (areas 3,1,2) areas show an inverted, disproportionate homuncular representation.
- ▶ Left hemisphere is dominant for language/handedness in >90% of people.
- ▶ Watershed infarcts and Berry-aneurysm SAH are the classic applied-anatomy correlates of the circle of Willis.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Clinical Neuroanatomy 4e; BD Chaurasia — Human Anatomy Vol 3-4 8e; Snell — Clinical Neuroanatomy 7e; IB Singh — Textbook of Human Neuroanatomy.



Speech areas of brain

Asked in: Paper IV May 2018 — RGUHS MD/MS Anatomy

Definition / Introduction

The **speech (language) areas** are specialised association-cortex regions, present in only **one** cerebral hemisphere (the **dominant hemisphere** — left in the great majority of individuals), that together permit the production, comprehension and integration of spoken and written language. The two principal centres are the **motor speech area of Broca** (expressive/production) in the frontal lobe and the **sensory speech area of Wernicke** (receptive/comprehension) in the temporo-parietal region; they are physically linked by the **arcuate fasciculus** so that comprehended language can be converted into articulate speech. Adjoining association cortex — the angular and supramarginal gyri, the secondary auditory area and the insula — extends this network to reading, writing, calculation and articulatory planning. Because these areas exist unilaterally, their destruction produces the characteristic clinical syndromes of **aphasia**.

1. Motor speech area of Broca

- **Location:** pars opercularis (Brodmann area 44) and pars triangularis (area 45) of the **inferior frontal gyrus**, bounded by the anterior and ascending rami and the ascending and posterior rami of the lateral (Sylvian) fissure — immediately anterior to the facial/laryngeal part of the precentral gyrus.
- **Laterality:** present on the **left (dominant) side** in the great majority of individuals; ablation of the corresponding area on the non-dominant side has no effect on speech.
- **Function:** brings about the **formation of words** through its dense connections with the adjacent primary motor cortex, which appropriately activates the muscles of the **larynx, lips, tongue, soft palate and respiratory muscles** — i.e., it programmes **expressive/vocal speech**, not simple movement of these muscles.
- **Cytoarchitecture:** area 45 in humans contains a population of **large pyramidal neurones found only on the left side** — a structural correlate of functional lateralisation.

2. Sensory speech area of Wernicke

- **Location:** the **posterior part of the superior temporal gyrus**, extending around the posterior end of the lateral fissure into the **angular gyrus (area 39)** and **supramarginal gyrus (area 40)** of the inferior parietal lobule, in the dominant hemisphere.
- **Function:** permits the **interpretation of language received through both auditory and visual input** — it enables comprehension of the spoken and written word and the retrieval of correct words for expression; the motor and sensory speech areas exist together in only one hemisphere.
- **Anatomical extent:** the spine text stresses that Wernicke's area is "**not well defined anatomically**" — different authorities depict it as a large parieto-temporal territory including areas 39/40, sometimes extending along the middle temporal gyrus to within about 3 cm of the temporal pole; area 22 (secondary auditory cortex) and area 37 are regarded by some as further speech-associated auditory/visuo-auditory zones.
- **Secondary auditory area (area 22)**, lying posterior to the primary auditory area in the superior temporal gyrus, receives input from the primary auditory cortex and the thalamus and is necessary for the **interpretation of sounds** feeding into Wernicke's area.

3. Connecting white-matter pathways

Broca's and Wernicke's areas are linked by fibre systems that form part of the **superior longitudinal fasciculus (SLF)** complex:

Component	Course	Connection
Arcuate fasciculus (temporal–frontal segment)	Deep, direct pathway arching around the posterior lateral fissure	Wernicke's area (posterior superior/middle temporal gyri) directly to Broca's area
SLF (frontoparietal, indirect route)	Runs beneath the frontoparietal operculum	Broca's area ↔ inferior parietal lobule (angular + supramarginal gyri)

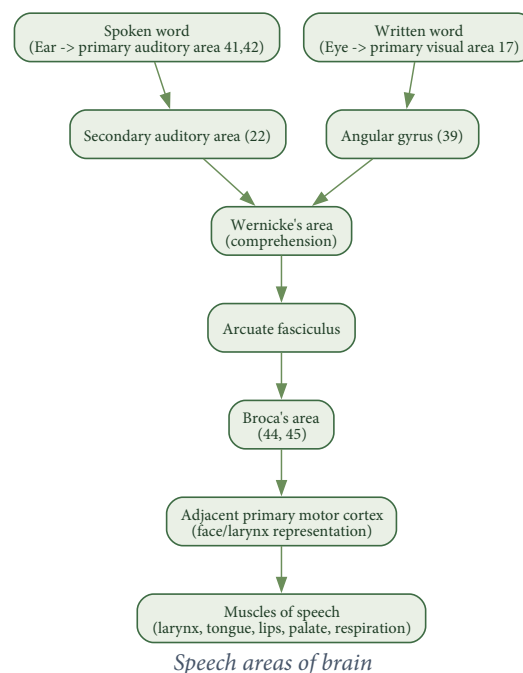
Component	Course	Connection
— SLF I	Superior parietal lobule/precuneus ↔ premotor/prefrontal cortex	Postural/spatial-motor integration
— SLF II	Angular gyrus ↔ dorsal premotor/prefrontal cortex	Indirect parieto-frontal language route
— SLF III	Supramarginal gyrus ↔ ventral premotor/prefrontal (Broca's) cortex	Indirect parieto-frontal language route

Thus the Wernicke–Broca circuit has both a **direct route** (arcuate fasciculus) and an **indirect route** (via the inferior parietal lobule and the SLF) — a fact clinically important because a lesion confined to the arcuate fasciculus alone produces **conduction aphasia** while the indirect route may still permit partial function.

4. Related speech-associated cortex

- **Angular and supramarginal gyri (areas 39, 40)** — essential for the learned processes of reading, writing and calculating; regarded by many authorities as part of Wernicke's area itself.
- **Insula** — buried in the floor of the lateral fissure; believed important for **planning/coordinating the articulatory movements** necessary for speech (its fibre connections are incompletely known).
- **Frontal eye field and premotor cortex** — the region anterior to the supplementary motor area representing the face (areas 44/45 overlap) is specifically important for vocalisation and speech production.
- **Primary and secondary auditory areas (41/42, 22)** — provide the auditory input on which Wernicke's area acts.

5. Circuit for speech production and comprehension



6. Cerebral dominance for speech

- ▶ Handedness, perception of language and speech are controlled by the **dominant hemisphere**; spatial perception, face recognition and music are the domain of the non-dominant hemisphere.
- ▶ **More than 90%** of adults are right-handed (left-hemisphere dominant for handedness), and about **96%** are left-hemisphere dominant for **speech**.
- ▶ Broca's area lies on the left in about **98% of right-handed persons**; even in left-handed individuals it remains left-sided in about **70%**, and is right-sided in only **30%**.
- ▶ **Yakolev and Rakic** showed that, in human fetuses/neonates, more descending fibres cross in the **left pyramidal decussation**, giving the right anterior horn cells greater corticospinal innervation — a proposed structural basis for right-hand dominance; the adult speech area is also anatomically larger on the left.
- ▶ The two hemispheres are functionally **equipotential at birth**; dominance is established only after the first decade of life — a 5-year-old with dominant-hemisphere damage can still learn to be left-handed and to speak normally, which is essentially impossible in an adult with the same lesion.
- ▶ Structural correlates of dominance: the **planum temporale** (posterior superior temporal plane) is usually larger on the left; the left BA45 uniquely contains large pyramidal neurones; cortex around the central sulcus (arm representation) is larger on the left.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 8.4 — Functional localization of the cerebral cortex. A: Lateral view of the left cerebral hemisphere (Snell — *Clinical Neuroanatomy* — 7e, p.310)

Reproduce a lateral view of the **left (dominant) cerebral hemisphere** and label: **inferior frontal gyrus with pars opercularis (area 44) and pars triangularis (area 45) = Broca's (motor speech) area**; **precentral gyrus/primary motor area (area 4)**; **premotor area (area 6)**; **lateral (Sylvian) fissure**; **superior temporal gyrus with primary auditory area (41, 42) and secondary auditory area (area 22)**; **Wernicke's (sensory speech) area** spanning the posterior superior temporal gyrus; **angular gyrus (area 39) and supramarginal gyrus (area 40) of the inferior parietal lobule**; and, as a connecting arc beneath the operculum, the **arcuate fasciculus** linking Wernicke's area to Broca's area.

Applied / Clinical anatomy

Aphasia	Site of lesion	Speech	Comprehension	Reading/writing/calculation
Motor (Broca's) aphasia	Posterior inferior frontal gyrus (areas 44, 45)	Effortful, dysarthric, telegraphic, non-fluent	Good	Intact

Aphasia	Site of lesion	Speech	Comprehension	Reading/writing/calculation
Sensory (Wernicke's) aphasia	Posterior superior temporal gyrus + inferior parietal lobule (areas 22, 39, 40)	Fluent but meaningless; incorrect/non-existent words; patient unaware of errors	Poor	Lost (word blindness present)
Global aphasia	Both Broca's and Wernicke's areas destroyed	Lost	Lost	Lost
Conduction aphasia	Parietal-lobe (arcuate fasciculus/SLF) territory, linking the frontal and temporal language areas	Paraphasic, poor repetition	Relatively preserved	Variable
Jargon aphasia	Wernicke's area + superior longitudinal/arcuate fasciculus	Fluent but unintelligible jargon	Poor	—

- ▶ **Angular gyrus lesion** (dominant hemisphere, posterior parietal lobe, often classed as part of Wernicke's area) interrupts the pathway between the visual association cortex and the anterior part of Wernicke's area, producing **alexia** (inability to read), **agraphia** (inability to write), **acalculia** and **anomia** (inability to name objects), typically without frank aphasia.
- ▶ **Insula lesions** cause difficulty sequencing phonemes correctly — speech that is close to, but not exactly, the intended word.
- ▶ **Middle cerebral artery occlusion** produces aphasia if the **dominant (usually left)** hemisphere is affected — rare if the non-dominant side is involved — together with contralateral face/arm weakness and sensory loss, since the MCA is the principal supply to both Broca's and Wernicke's territories.
- ▶ **Internal carotid artery occlusion** can reproduce the full MCA picture, including aphasia, agnosia, hemiplegia and hemianesthesia, depending on whether the dominant hemisphere is involved; occlusion of the **basilar artery**, by contrast, causes bilateral deficits without lateralised aphasia.
- ▶ **Semantic/transcortical aphasia**: bilateral or dominant-side lesions of the anterior temporal neocortex impair word meaning and naming, distinct from the classical Broca/Wernicke syndromes.
- ▶ These localisations underlie **awake craniotomy language mapping** during resection of dominant-hemisphere gliomas near the perisylvian region, where direct cortical stimulation is used to preserve Broca's/Wernicke's territory and the arcuate fasciculus.

Recent advances

- ▶ A 2025 editorial synthesising a *Frontiers in Language Sciences* research topic argues that Broca's area should be reconceived not as an isolated "speech-production centre" but as one **core node in a distributed, network-level language system**, with the classical division of labour between Broca's and Wernicke's areas now understood to be far less clear-cut than originally proposed (Ivanova, Riés & Llorens, *Frontiers in Language Sciences*, 2025) [DOI: 10.3389/flang.2025.1608928].
- ▶ A 2026 validation study showed that **automated TractSeg-based tractography** can reliably segment the **arcuate fasciculus** bilaterally (integrated directly into a clinical PACS workflow), succeeding in cases where manual/DSI-Studio tractography failed — supporting automated pre-operative mapping of the Wernicke–Broca connection in patients being assessed for temporal-lobe/hearing-related surgery (Kierońska-Siwak et al., *Frontiers in Neuroscience*, 2026) [DOI: 10.3389/fnins.2026.1830648].
- ▶ A 2026 study introduced the first intraoperative use of a sentence-level, verb-and-noun naming paradigm (VAN-POP) during awake craniotomy direct electrical stimulation, showing improved sensitivity for identifying grammar-related cortical sites beyond the classical Broca/Wernicke boundaries during dominant-hemisphere tumour surgery (Roberts et al., *Neurocase*, 2026) [DOI: 10.1080/13554794.2026.2666421].
- ▶ (Per *Frontiers/PubMed-indexed literature*.)

High-yield exam pointers

- ▶ **Broca's area** = areas 44 + 45 (pars opercularis + triangularis), inferior frontal gyrus, dominant hemisphere → expressive speech.
- ▶ **Wernicke's area** = posterior superior temporal gyrus + angular (39)/supramarginal (40) gyri, dominant hemisphere → language comprehension; anatomically not sharply defined (Gray's).
- ▶ **Arcuate fasciculus** connects Wernicke's → Broca's directly; the SLF (I/II/III) provides an indirect parieto-frontal route.
- ▶ Speech/motor and sensory speech areas exist together in **only one (dominant) hemisphere**.
- ▶ **Broca's (motor) aphasia** = non-fluent, telegraphic, comprehension good; **Wernicke's (sensory) aphasia** = fluent but meaningless, comprehension poor; **Global** = both lost; **Conduction aphasia** = parietal/arcuate-fasciculus lesion.
- ▶ **Angular gyrus** lesion → alexia, agraphia, acalculia, anomia.
- ▶ ~90–98% right-handed persons are left-hemisphere dominant for speech; even 70% of left-handers remain left-dominant.
- ▶ Hemispheres are equipotential at birth; dominance fixes only after the first decade (plasticity basis of childhood aphasia recovery).
- ▶ Blood supply of both speech areas = **middle cerebral artery**; left MCA/ICA occlusion is the classical cause of vascular aphasia.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e. Recent-advances section per Frontiers-indexed literature (DOIs above).



Speech areas of the brain

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction

The **speech (language) areas** are the cortical territories, clustered around the **lateral (Sylvian) fissure of one — the "dominant" — cerebral hemisphere**, that subserve the production and comprehension of spoken and written language. Classically two areas are described: the **motor speech area of Broca** (production) and the **sensory speech area of Wernicke** (comprehension), joined by the **arcuate fasciculus**. Together with the angular and supramarginal gyri they constitute the perisylvian "language area" (Ojemann et al 1989). Because the two areas exist together in only one hemisphere — the left in over 90% of individuals — focal lesions here produce well-defined **aphasic syndromes**, making this a favourite site for correlating gross cortical anatomy with clinical neurology.

1. The two classical speech areas at a glance

Feature	Motor speech area (Broca)	Sensory speech area (Wernicke)
Brodmann areas	44 (pars opercularis) and 45 (pars triangularis)	22 (posterior superior temporal gyrus) + extensions into 39 (angular gyrus) and 40 (supramarginal gyrus)
Gyrus/lobe	Inferior frontal gyrus, frontal lobe	Superior temporal gyrus + inferior parietal lobule
Precise site	Opercular + triangular parts of inferior frontal gyrus, immediately anterior to the lowermost precentral gyrus	Posterior end of superior temporal gyrus, extending onto the base of the supramarginal gyrus; may reach within 3 cm of the temporal pole
Function	Motor programming/production of spoken words	Comprehension of spoken and written language
Blood supply	Middle cerebral artery	Middle cerebral artery
Laterality	Left (dominant) hemisphere in ~90%	Left (dominant) hemisphere in ~90%

Both areas lie **within the territory of the middle cerebral artery**, which explains why a single MCA territory infarct on the dominant side can damage either or both areas.

2. Motor speech area of Broca

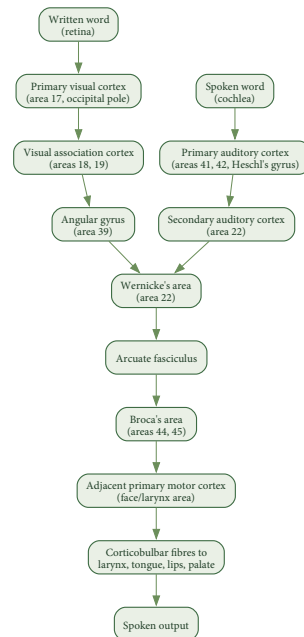
- ▶ Located in the **inferior frontal gyrus** — its **pars opercularis (area 44)** and **pars triangularis (area 45)** — immediately anterior to the face area of the precentral gyrus, in the **dominant hemisphere** (left in most individuals; right in left-handed persons in a minority of cases).
- ▶ Function: brings about the **formation of words** through its connections with the adjacent primary motor cortex, which appropriately stimulates the muscles of the speech apparatus — **lips, tongue, soft palate, larynx and respiratory muscles**.
- ▶ The **uncinate fasciculus** connects this area and adjoining inferior frontal gyrus with the cortex of the temporal pole; frontal association fibres also link it to the supplementary motor area.
- ▶ Destructive lesions produce **expressive (motor/Broca's) aphasia**: the patient cannot produce speech, yet can still think the words, write them, and understand their meaning when heard or read — speech is non-fluent, effortful, telegraphic.

3. Sensory speech area of Wernicke

- ▶ Located in the **dominant hemisphere**, occupying the **posterior part of the superior temporal gyrus** and extending into the **angular gyrus (area 39)** and **supramarginal gyrus (area 40)** of the inferior parietal lobule; corresponds mainly to **Brodmann area 22**.
- ▶ Lies immediately posterior to the **secondary (association) auditory cortex**, from which it receives fibres, and also receives visual association input — it is the convergence point of somatic, visual and auditory association pathways, which is why it is regarded as an area of major functional importance.
- ▶ Function: permits **understanding of spoken and written language** and enables a person to read a sentence, understand it, and repeat it correctly.
- ▶ Destructive lesions produce **receptive (sensory/Wernicke's) aphasia**: fluent but meaningless or paraphasic speech, with **poor comprehension** of both spoken and written language; the patient is often unaware of the errors.

4. Arcuate fasciculus and the connectionist speech pathway

- ▶ The **arcuate fasciculus** (the temporofrontal segment of the **superior longitudinal fasciculus**) is the principal direct link between Wernicke's and Broca's areas; an indirect route also runs through the inferior parietal lobule (supramarginal/angular gyri) via the horizontal (SLF III) and vertical (SLF-tp) components of the same fasciculus system.
- ▶ Wernicke's area organises the linguistic content to be uttered and transmits it, via the arcuate fasciculus, to Broca's area, which converts it into the motor programme for articulation.
- ▶ The classical "reading-aloud"/"hearing-and-answering" circuit combines visual, auditory and motor components:



Speech areas of the brain

- A lesion of the arcuate fasciculus itself, sparing both cortical areas, disconnects comprehension from production — the basis of **conduction aphasia** (fluent speech, intact comprehension, but impaired repetition).

5. Cerebral dominance and lateralization

Left (dominant) hemisphere — in ~90%	Right (non-dominant/minor) hemisphere
Language, speech, writing, calculation	Spatial/geometrical perception
Handedness (controls the skilful right hand)	Facial recognition
Analytical, verbal, mathematical processing	Creative acts of art and music, non-verbal ideation

- The **dominant hemisphere** is defined by which side carries the perception and production of language; it is the **left** hemisphere in over 90% of people (right-handed and most left-handed individuals), correlating with **right-handedness** since the left hemisphere controls the right half of the body.
- Dominance is not innate: during childhood one hemisphere gradually comes to dominate, becoming **fixed only after the first decade of life**.
- A structural correlate of this asymmetry is the **planum temporale**, the flat superior surface of the temporal lobe deep to the posterior ramus of the lateral fissure, which is usually **larger on the left** (Geschwind and Levitsky 1968); Brodmann area 45 (part of Broca's area) also contains a population of large pyramidal neurones found only on the left side.
- Lesions of the **angular gyrus**, immediately posterior to the language area, can cause **alexia, agraphia and acalculia even without frank aphasia**, by disconnecting the visual association cortex from Wernicke's area.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 25.16 — The lateral surface of the left cerebral hemisphere showing the frontal eye field (parts of areas 6, 8, 9), the motor speech (Broca's) area (areas 44, 45) and Wernicke's area (Gray's Anatomy — Standring — 41e, p.529)

Reproduce a lateral view of the left cerebral hemisphere and label: **central sulcus, lateral (Sylvian) sulcus, precentral and postcentral gyri, inferior frontal gyrus — pars opercularis (44) and pars triangularis (45) = Broca's area, superior temporal gyrus, supramarginal gyrus (40) and angular gyrus (39) = Wernicke's area (area 22 extending onto 39/40), the arcuate fasciculus arching deep to the fissure connecting the two areas, primary auditory area (Heschl's gyrus, areas 41/42), and primary visual cortex at the occipital pole.**

Applied / Clinical anatomy

Aphasia type	Site of lesion	Speech	Comprehension	Repetition
Motor (Broca's/expressive)	Inferior frontal gyrus (44, 45)	Non-fluent, effortful, telegraphic; agraphia	Good	Impaired
Sensory (Wernicke's/receptive)	Posterior superior temporal gyrus + parietal operculum (22, 39, 40)	Fluent but paraphasic/jargon; word blindness present	Poor	Impaired
Conduction	Arcuate fasciculus/parietal operculum	Fluent, paraphasic	Good	Markedly impaired
Global	Both Broca's and Wernicke's areas (large dominant MCA infarct)	Absent/severely reduced	Absent/severely reduced	Absent

- **Middle cerebral artery occlusion** on the dominant side is the classical cause of aphasia; since both speech areas lie in its territory, a total sensorimotor aphasia (with contralateral hemiplegia and hemianesthesia) results, whereas occlusion on the non-dominant side spares language.
- **Alexia without agraphia** — a disconnection syndrome from a posterior cerebral artery infarct damaging the left visual cortex and splenium of the corpus callosum: the patient can speak and write normally but cannot read, because visual input from the intact right hemisphere can no longer reach the left-sided language area.
- **Aprosodia** — lesions of the right-hemisphere areas homologous to Broca's and Wernicke's areas impair the rhythm, pitch, stress and emotional intonation (prosody) of speech, rather than its verbal content.
- The **Wada test** (intracarotid amobarbital injection) is used clinically to determine hemispheric language dominance before epilepsy or tumour surgery.
- Clinically, occlusion of the **superior (frontal) division of the MCA** typically produces a Broca-type non-fluent aphasia with contralateral facio-brachial weakness, while occlusion of the

inferior (temporal) division produces a Wernicke-type fluent aphasia, reflecting the differential MCA supply of the two areas.

Recent advances

- ▶ A 2025 meta-analysis of **4325 direct/subdural electrical stimulation sites** across 21 studies found that language disruption follows **graded probabilistic gradients with high inter-individual variability**, rather than being confined to sharply bordered "Broca" and "Wernicke" boxes — refining the classical model into a probabilistic cortical map (Alexandratou et al., *Brain Structure and Function*, 2025) [DOI: 10.1007/s00429-025-03015-2].
- ▶ Integrating **intraoperative direct electrical stimulation with normative structural/functional connectome data** (486 stimulations in 297 patients, connectivity from >1750 healthy subjects) allows accurate prediction of lesion-induced language impairment and of post-operative recovery trajectories in stroke and glioma patients — supporting a **network-based rather than purely focal model** of the speech areas (Communications Medicine, 2025) [DOI: 10.1038/s43856-025-01121-0].
- ▶ A 2025 systematic review of electrocortical stimulation mapping in epilepsy surgery proposes an **expanded six-region clinically relevant language network** — Broca's area, **Exner's graphemic motor area**, the **supplementary speech area** (dominant SMA/pre-SMA), the angular gyrus, the posterior superior temporal ("Wernicke") region, and the **basal temporal language area** — beyond the traditional two-centre model (*Brain Sciences*, 2025) [DOI: 10.3390/brainsci15121267].
- ▶ (*According to PubMed-indexed literature.*)

High-yield exam pointers

- ▶ Broca's area = areas **44 + 45**, inferior frontal gyrus, dominant hemisphere; lesion → **expressive (motor) aphasia** — nonfluent, comprehension intact.
- ▶ Wernicke's area = area **22** (+ extension into 39, 40), posterior superior temporal gyrus, dominant hemisphere; lesion → **receptive (sensory) aphasia** — fluent but meaningless, comprehension poor.
- ▶ **Arcuate fasciculus** connects Wernicke's to Broca's area; its isolated lesion → **conduction aphasia** (poor repetition, fluent speech, intact comprehension).
- ▶ Both speech areas lie in the **middle cerebral artery** territory; combined lesion → **global aphasia**.
- ▶ **Angular gyrus (39)** lesion → alexia, agraphia, acalculia without aphasia (visual-language disconnection).
- ▶ **Dominant hemisphere** = left in >90%; fixed only after the first decade; correlates with right-handedness and a larger left **planum temporale**.
- ▶ Non-dominant (right) hemisphere homologues of the speech areas govern **prosody**; their lesions cause **aprosodia**, not aphasia.
- ▶ **Alexia without agraphia** = posterior cerebral artery/splenic disconnection syndrome — reading lost, writing and speech preserved.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e. Recent-advances section per PubMed-indexed literature (DOIs above).

**Striate cortex**

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction — The **striate cortex** — also called the **primary visual area**, **Brodmann area 17**, or **V1** — is the primary cortical receiving area for vision. It lies on the medial surface of the **occipital lobe**, in the walls and floor of the **calcarine sulcus**, and takes its name from a macroscopically visible white line, the **stria (line) of Gennari**, running within its fourth layer. It receives a strictly retinotopically organised input from the retina via the lateral geniculate body and optic radiation, and relays processed visual information onward to the surrounding association (parastriate/peristriate) visual cortex.

1. Location, extent and boundaries

- ▶ Situated mainly on the **medial surface of the occipital lobe**, in the walls and floor of the posterior (post-calcarine) part of the **calcarine sulcus**; extends into the **cuneus** above and the **lingual gyrus** below the sulcus.
- ▶ Wraps around the **occipital pole** onto the adjoining lateral surface of the occipital lobe as far as the **lunate sulcus**.
- ▶ Surrounded, on both the medial and lateral occipital surfaces, by the **secondary (association) visual cortex** — **Brodmann areas 18 and 19** (parastriate/peristriate cortex).
- ▶ Macroscopically identified by two features on a fresh/fixed section: the cortex here is unusually **thin**, and a **visible white line (stria of Gennari)** streaks through its middle depth — hence the name "striate" cortex.
- ▶ Constant occipital sulci that form its landmarks: **parieto-occipital**, **calcarine**, **paracalcarine**, **lingual** and **lateral occipitotemporal** sulci.

2. Microscopic structure (cytoarchitecture)

Typical neocortex has six layers; the striate area is a **granular (koniocortex)** type, in which the granular laminae (II and IV) are maximally developed while laminae III and V are poorly defined — making it, despite its very high cell density, the **thinnest** of the five neocortical types.

Layer	Generic neocortical name	Feature in striate cortex
I	Molecular/plexiform	Receives thalamic afferents from the inferior pulvinar & intralaminar nuclei
II	External granular	Densely packed stellate cells; complex/hypercomplex cells

Layer	Generic neocortical name	Feature in striate cortex
III	External pyramidal	Poorly defined in this granular-type cortex
IV	Internal granular	Thickest, most cellular layer; subdivided IVA, IVB (stria of Gennari) and IVC — IVC further split into a superficial IVC α and deep IVC β ; main site of geniculocortical termination
V	Internal pyramidal (ganglionic)	Complex/hypercomplex cells; gives rise to efferents to the superior colliculus, pretectum and reticular formation
VI	Multiform/fusiform	Origin of descending geniculocortical and claustrorocortical feedback fibres

- ▶ The **external band of Baillarger** (lamina IV) is exceptionally well developed here and forms the **stria of Gennari** — the histological hallmark of area 17.
- ▶ Geniculocortical afferents terminate predominantly in **layers IVA and IVC**; other thalamic afferents (inferior pulvinar, intralaminar group) end in **layers I and VI**.
- ▶ **Ocular dominance columns**: geniculate laminae relaying the ipsilateral eye (laminae 2, 3, 5) and the contralateral eye (laminae 1, 4, 6) terminate in **alternating bands** within layer IVC, so neurones encountered in a vertical strip from pia to white matter show a preference for one eye — the anatomical basis of binocular integration.
- ▶ **Orientation columns**: a second, independent columnar system — an electrode passed at right angles through the cortical depth encounters cells that all prefer a line/edge of the same orientation.
- ▶ **Simple cells** (respond to a line in a fixed position and orientation) predominate in **layer IV**; **complex and hypercomplex cells** (position-invariant, and length-critical respectively) predominate in **layers II–III and V–VI**.

3. Retinotopic organization

- ▶ The visual cortex shows a strict **point-to-point (retinotopic) map** of the retina, relayed via the optic radiation.
- ▶ Each hemisphere's striate cortex receives from the two hemi-retinae of the **same side**, i.e. it represents the **contralateral half of the visual field**.
- ▶ **Upper retinal quadrants** (representing the **lower** half of the visual field) are represented **above** the calcarine sulcus, in the **cuneus**; **lower retinal quadrants** (representing the **upper** half of the visual field) are represented **below** the calcarine sulcus, in the **lingual gyrus**.
- ▶ **Cortical magnification**: the **macula** (central retina, sharpest acuity) has a disproportionately large cortical representation, occupying approximately the **posterior one-third** of the visual cortex near the occipital pole; the **peripheral retina** maps to the **anterior two-thirds**.

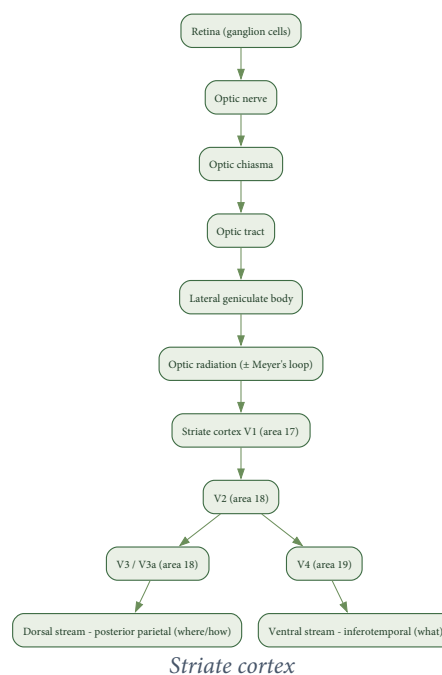
□ Fig 18.8 — Scheme to show the projection of retina on the lateral geniculate body and the visual cortex (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.653)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- **Medial surface of the right cerebral hemisphere at the occipital pole** — label: **parieto-occipital sulcus**, **calcarine sulcus**, **cuneus** (above the calcarine sulcus), **lingual gyrus** (below the calcarine sulcus), **occipital pole**, **lunate sulcus** (lateral extent), and the **striate area (17)** shaded around the calcarine sulcus with the surrounding **areas 18 and 19**.
- **Retinotopic key** alongside it: upper retinal quadrant → cuneus (above calcarine sulcus); lower retinal quadrant → lingual gyrus (below calcarine sulcus); macula → posterior one-third (near the pole); peripheral retina → anterior two-thirds.

4. Connections and columnar organisation

- **Afferent pathway:** retina (ganglion cells) → optic nerve → optic chiasma (nasal fibres cross) → optic tract → **lateral geniculate body** → **optic radiation** (curves through the retrolenticular internal capsule and occipital white matter; its inferior fibres loop through the temporal lobe as **Meyer's loop**) → terminates retinotopically in **layers IVA and IVC** of the striate cortex.
- **Efferent, ipsilateral corticocortical:** area 17 → area 18 (V2, V3, V3a) and area 19 (V4) → posterior parietal, posterior temporal and parieto-occipital association cortices → frontal eye fields.
- **Subcortical efferents** (mainly from layers V–VI): **superior colliculus, pretectum, brainstem reticular formation**; sparse projections to the tail of the caudate nucleus and the pontine nuclei; layer VI additionally sends descending feedback fibres back to the lateral geniculate body and claustrum.
- **Callosal connections** are restricted to the strip of cortex representing the **vertical meridian** at the 17/18 border — the anatomical basis for the sharp vertical split seen in homonymous field defects.



5. Higher visual areas and processing streams

- ▶ **V2 (area 18)** — a complete, mirror-image retinotopic map of the hemifield; receives the major feed-forward projection from V1; the vertical meridian is represented most posteriorly, at the shared 17/18 border.
- ▶ **V3/V3a (area 18)** — dorsal (V3/V3d) and ventral (VP/V3v) subdivisions with differing wavelength/direction selectivity; feed-forward input from V2 with reciprocal feedback; V3a shows complex, irregular topography.
- ▶ **V4 (area 19)** — colour-, orientation- and form-selective; bilateral damage causes **achromatopsia**.
- ▶ **Dorsal stream** (occipito-parietal, "where/how") — visuospatial discrimination; mediates visually guided action.
- ▶ **Ventral stream** (occipito-temporal via V4, "what") — object/form recognition; projects onward to inferior temporal and medial temporal (limbic) cortex.

6. Blood supply

Artery	Territory
Calcarine branch of the posterior cerebral artery (arising from its internal occipital branch, along with the parieto-occipital branch)	Main supply of the striate cortex — cuneus, lingual gyrus and rest of the medial occipital surface
Temporo-occipital branch of the posterior cerebral artery	Lateral occipital surface and inferior temporal lobe
Posterior/angular branches of the middle cerebral artery	Anastomotic contribution to the occipital pole (macular cortical representation)

- ▶ The **macular cortical representation** at the occipital pole thus has a **dual blood supply** from both the posterior cerebral and middle cerebral arteries — the anatomical basis of **macular sparing** in posterior-cerebral-artery-territory infarcts.

Recent advances

- ▶ **Anatomy-personalised prosthesis planning:** individually optimised electrode placement, combining retinotopic prediction with each patient's own cortical anatomy, outperformed generic "average-brain" solutions across 362 modelled brain hemispheres for high-channel intracortical visual prostheses targeting the retinotopic striate cortex (van Hoof et al., *J Neural Eng* 2025) [PMID 39870040] [DOI 10.1088/1741-2552/adaeef].
- ▶ **Ultra-high-field imaging resolves the stria of Gennari in vivo:** 10.5 Tesla, sub-0.4 mm functional MRI localised feedforward laminar BOLD activation specifically to layer IV/the stria of Gennari of the primary visual cortex — a resolution not achievable at standard 7 Tesla — bridging non-invasive imaging with this classical cytoarchitectural landmark (Knudsen et al., *bioRxiv* 2026, preprint) [PMID 42039502] [DOI 10.64898/2026.04.10.717824].
- ▶ **Safety monitoring during intracortical striate-cortex stimulation trials:** scalp EEG recorded over a 3-year, 900-plus-electrode human trial of intracortical visual prostheses implanted in the occipital (striate) cortex gave early warning of stimulation-induced seizures, shaping safety protocols for direct cortical-visual-prosthesis stimulation (Stephan et al., *Artif Organs* 2025; Clinical Trial NCT04634383) [PMID 40421717] [DOI 10.1111/aor.15023].

- ▶ **Gaze-linked phosphene localisation:** in patients with cortical visual prostheses (including one individual without eyes), intended eye movements systematically shifted the perceived location of phosphenes despite fixed striate-cortex electrode placement, and could be tracked to refine prosthetic-vision control algorithms (Waclawczyk et al., *IEEE Trans Neural Syst Rehabil Eng* 2025) [PMID 41021945] [DOI 10.1109/TNSRE.2025.3615286].

(According to PubMed indexing.)

Applied / Clinical anatomy

- ▶ **Homonymous hemianopia:** complete destruction of one striate cortex (or of the optic tract, lateral geniculate body, or optic radiation of that side) causes loss of the **opposite half of the visual field** in both eyes; the field cut is split sharply along the **vertical meridian**, reflecting the restriction of callosal connections to the 17/18 border.
- ▶ **Macular sparing:** seen specifically with **vascular** lesions (e.g. posterior-cerebral-artery infarction), because the macular (occipital-pole) cortex has a **dual PCA + MCA supply**; a **compressive** lesion (meningioma, glioma) does **not** spare the macula, since it destroys the macular cortex directly regardless of which vessel remains patent.
- ▶ **Quadrantanopia:** a lesion confined to the cortex **above** the calcarine sulcus (cuneus) removes the upper-retinal-quadrant representation, giving a contralateral **inferior** homonymous quadrantanopia; a lesion confined **below** it (lingual gyrus) removes the lower-retinal-quadrant representation, giving a contralateral **superior** homonymous quadrantanopia. A lesion of **Meyer's loop** in the temporal lobe, upstream of the cortex, likewise produces a superior quadrantanopia — the classic "pie in the sky" defect.
- ▶ **Visual hallucinations and colour distortion:** damage limited to the visual association cortex (areas 18/19) around a spared area 17 causes hallucinations or dyschromatopsia rather than simple field loss.
- ▶ **Cortical blindness:** bilateral destruction of the striate cortex (e.g. bilateral PCA infarcts, watershed hypoxic injury) causes blindness with a **preserved pupillary light reflex**, since that reflex arc is mediated via the pretectum rather than the striate cortex; denial of the blindness (Anton's syndrome) may accompany it.
- ▶ **Migraine with aura:** the visual "scintillating scotoma" aura is classically attributed to cortical spreading depression beginning in the richly vascular, retinotopically organised occipital cortex.

□ Fig 7.13 — Sites of lesion in the visual pathway and the corresponding field defects detected by perimetry (IB Singh — *Textbook of Human Neuroanatomy*, p.130)

High-yield exam pointers

- ▶ Striate cortex = **primary visual area** = **Brodmann area 17** = **V1**; in the walls/floor of the **calcarine sulcus**, medial occipital lobe; wraps round the occipital pole to the **lunate sulcus** laterally.
- ▶ Named for the **stria of Gennari** — a macroscopically visible white line in **layer IV**, itself subdivided into IVA / IVB / IVC(α , β).
- ▶ **Granular (konio)cortex** type — laminae II and IV maximal, III and V poorly defined; the thinnest of the five cortical types despite its densest cell packing.
- ▶ **Retinotopic map:** upper retinal quadrant → cuneus (above calcarine); lower retinal quadrant → lingual gyrus (below calcarine); **macula** → **posterior one-third**, periphery → anterior two-thirds.

- ▶ Afferents from the **LGB via the optic radiation** end in layers IVA/IVC; efferents from layers V/VI go to **superior colliculus, pretectum, reticular formation**, and, corticocortically, to **V2 (18) → V3/V3a/V4 (19)**.
- ▶ Two independent columnar systems: **ocular dominance columns** and **orientation columns**.
- ▶ Blood supply: **calcarine branch of the PCA** (main), with **MCA** contributing to the macular/occipital-pole territory — the basis of **macular sparing**.
- ▶ Complete unilateral destruction → **contralateral homonymous hemianopia**; vascular PCA lesion → **macular sparing**; compressive lesion → **no macular sparing**.
- ▶ Meyer's loop lesion (temporal lobe) or an isolated lingual-gyrus lesion → contralateral **superior quadrantanopia** ("pie in the sky"); an isolated cuneus lesion → contralateral **inferior quadrantanopia**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; IB Singh Textbook of Human Neuroanatomy; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e. Recent-advances citations per PubMed (PMIDs/DOIs as listed above).



Visual areas

Asked in: Paper IV Nov 2016 — RGUHS MD/MS Anatomy

Definition / Introduction

The **visual areas** are the cortical territories of the **occipital lobe** — classically **Brodmann's areas 17, 18 and 19** — concerned with reception, elaboration and interpretation of visual impulses. **Area 17 (primary visual/striate area, V1)** receives a strict, point-to-point retinotopic projection of the contralateral half-field of vision via the **optic radiation from the lateral geniculate body (LGB)**, while the surrounding **areas 18 and 19 (secondary/visual association areas)** — subdivided in the modern scheme into **V2, V3, V4 and V5** — analyse colour, form and motion and relate the raw visual sensation to past experience, giving it meaning. Because each stage of this afferent chain (retina → optic nerve/chiasma/tract → LGB → optic radiation → V1 → association cortex) has a precise, mappable location, lesions at different points produce characteristic, examiner-favourite visual-field defects.

1. Location and boundaries of the visual (occipital) cortex

- ▶ The **occipital lobe** lies posterior to a line joining the parieto-occipital fissure (medially) to the **preoccipital notch** (laterally, ~5 cm anterior to the occipital pole); medially it is bounded anteriorly by the **parieto-occipital sulcus**.
- ▶ Its medial surface is dominated by the **calcarine sulcus**, which divides it into the **cuneus** (above, between the parieto-occipital and calcarine sulci) and the **lingual gyrus** (below, between the calcarine and collateral sulci).
- ▶ The occipital lobe is composed almost entirely of **Brodmann's areas 17, 18 and 19**:

Area	Alternative name(s)	Location
Area 17	Primary visual area, striate area, V1	Walls and floor of the posterior (postcalcarine) part of the calcarine sulcus; extends around the occipital pole onto the lateral surface
Area 18	Parastriate area, secondary visual area (part)	Surrounds area 17; contains V2, V3 (dorsal/ventral) and V3a
Area 19	Peristriate area, secondary visual area (part)	Surrounds area 18, at the parieto-occipital and temporo-occipital junctions; contains V4

2. Primary visual area (area 17 / V1 / striate cortex)

- ▶ **Histology:** a thin, densely **granular cortex** (koniocortex) with abundant granule cells and few pyramidal cells; layer IV carries a prominent band of myelinated fibres, the **stria of Gennari** (= external band of Baillarger), visible to the naked eye on a freshly cut section — hence the name **striate cortex**. Layer IV is further split into IVA, IVB (bears the stria) and IVC (subdivided into IVC α and IVC β); geniculate afferents terminate mainly in IVA and IVC.
- ▶ **Retinotopic organisation:** each V1 receives from the two hemiretinae representing the **contralateral half of the visual field** — so the **right visual field is represented in the left visual cortex** and vice versa.
 - **Superior retinal quadrants** (representing the **inferior** field of vision) project to the cortex **above** the calcarine sulcus.
 - **Inferior retinal quadrants** (representing the **superior** field of vision) project to the cortex **below** the calcarine sulcus.
 - Peripheral retina maps to the more **anterior** part of V1; the **macula lutea** (keenest vision) has a disproportionately large representation occupying roughly the **posterior third** of V1, at and around the occipital pole.
- ▶ **Columnar organisation:** geniculate axons carrying **ipsilateral-eye** input (laminae 2, 3, 5) and **contralateral-eye** input (laminae 1, 4, 6) terminate in alternating bands within layer IVC, forming **ocular dominance columns**; orthogonal to these, **orientation columns** contain simple, complex and hypercomplex cells tuned to the orientation of a line/edge in the visual field. An ocular-dominance column together with a full set of orientation columns for one point in the visual field constitutes a **hypercolumn**.
- ▶ **Function:** reception and perception of elementary visual qualities — **colour, form, size, motion, illumination**.

3. Afferent visual pathway and the lateral geniculate body (LGB)

- ▶ **Pathway:** retina → optic nerve → optic chiasma (nasal fibres decussate) → optic tract → lateral geniculate body → optic radiation (geniculocalcarine tract) → area 17.
- ▶ The LGB, part of the **metathalamus**, is a small, ovoid, laminated relay nucleus on the inferior aspect of the pulvinar, separated from the medial geniculate body by the brachium of the superior colliculus.

- ▶ It has **six laminae** (numbered 1–6, ventral to dorsal): **laminae 1, 4 and 6** receive the **contralateral (nasal hemiretinal)** fibres, and **laminae 2, 3 and 5** receive the **ipsilateral (temporal hemiretinal)** fibres. **Laminae 1 and 2** consist of large cells — the **magnocellular** layers, receiving mainly the fast-conducting, transient-response **Y-type retinal ganglion cells** (and giving branches to the superior colliculus); **laminae 4–6** have smaller neurones — the **parvocellular** laminae, receiving the slower, sustained-response **X-type ganglion cells**. A third class, the large-field, slow **W-type ganglion cells**, projects diffusely to the interlaminar zones and an additional superficial **S lamina**, as well as to the superior colliculus.
- ▶ Besides retinal afferents, the LGB receives **cortico-fugal fibres from V1 and extrastriate areas**, from the **superior colliculus**, brainstem reticular formation, and noradrenergic/serotonergic afferents from the locus coeruleus/raphe nuclei — allowing cortical and subcortical modulation of the relay.
- ▶ Efferents form the **optic radiation**, which passes through the **retrolentiform part of the internal capsule**, sweeps through the deep white matter of the temporal and parietal lobes, and terminates in strict point-to-point fashion in area 17. Fibres subserving the **inferior retinal quadrants (superior visual field)** loop forward into the temporal lobe before turning back to reach the **lingual gyrus** (lower bank of the calcarine sulcus), while fibres subserving the **superior retinal quadrants (inferior visual field)** pass more directly to the **cuneus** (upper bank) — the basis of the quadrantic field defects described below.

4. Secondary / association visual areas (areas 18–19; V2–V5)

- ▶ **Classical description:** area 18 (parastriate) and area 19 (peristriate) surround area 17 and receive afferents from it (and from the thalamus); their function is to **relate the visual information received by area 17 to past visual experience**, enabling **recognition and appreciation** of what is being seen — hence "visual association areas." An **occipital eye field** within the secondary visual area produces conjugate deviation of the eyes to the opposite side on stimulation, and is connected to the frontal eye field by association fibres.
- ▶ **Modern functional subdivision** (mapped within areas 18/19):

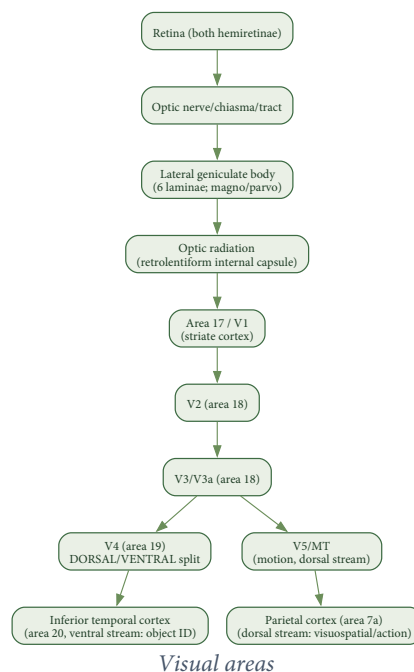
Area	Location	Key feature
V2	Occupies most of area 18	Complete, mirror-image retinotopic map of the visual hemifield; major feed-forward target of V1
V3 (dorsal V3/V3d and ventral VP/V3v) + V3a	Narrow strip anterior to V2, within/near area 18	Dorsal part: direction-selective, less colour-selective; ventral part: more wavelength-selective
V4	Within area 19, anterior to V3	Colour and orientation selectivity; bilateral damage → achromatopsia
V5 (medial temporal area, MT)	Occipito-temporo-parietal junction	Motion perception

Area	Location	Key feature
Inferior temporal cortex (area 20)	Temporal lobe	Higher visual association; coarse retinotopy; neurons responsive to faces

- Two processing streams arise from V1/V2: the **dorsal stream** ("where/how") projects to the superior temporal and parietal cortices (ultimately area 7a) and mediates **visuospatial discrimination and visually-guided action**; the **ventral stream** ("what"), relayed through **V4** to the inferior temporal cortex, mediates **perceptual identification of objects** and projects onward to the temporal pole.

5. Efferent connections and overall function

- Visual areas send efferents to: the **superior colliculus** and **pretectal region** (visual reflexes), the **contralateral visual cortex via the splenium of the corpus callosum** (linking the vertical-meridian representations of both hemispheres), other visual/association areas in both hemispheres, and oculomotor-related cortex (occipital and frontal eye fields) for reflex and voluntary eye movements.
- In summary: **area 17** performs elementary feature extraction (retinotopic, columnar); **areas 18/19 (V2–V5)** integrate these features into recognisable percepts of colour, form and motion via parallel dorsal ("where") and ventral ("what") streams.



DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 27.1 — Functional cortical areas (of Brodmann) (Vishram Singh — *Textbook of Anatomy Vol 3 — 4e*, p.1103)

Reproduce (i) the **medial surface of the cerebral hemisphere** at the occipital pole and label: **parieto-occipital sulcus**, **calcarine sulcus**, **cuneus**, **lingual gyrus**, **occipital pole**, and shade/label **area 17 (primary/striate)** in the walls of the calcarine sulcus with **area 18 (secondary, parastriate)** and **area 19 (tertiary, peristriate)** as concentric bands around it — mark the **cortex above the calcarine sulcus as representing the inferior visual field** and **below it as representing the superior visual field**, with the **macula** occupying the posterior pole. (ii) A small schematic of the **visual pathway**: retina → optic nerve → optic chiasma → optic tract → **lateral geniculate body (6 laminae)** → **optic radiation** (through the retrolentiform internal capsule) → area 17.

Applied / Clinical anatomy

- ▶ **Homonymous hemianopia with macular sparing**: the commonest cause is **thrombosis/occlusion of the posterior cerebral artery**, which supplies area 17; the **macular (occipital pole) representation is spared** because it lies at the watershed zone supplied by both the posterior and middle cerebral arteries.
- ▶ **Quadrantic (quadrantanopic) field defects**: a lesion confined to the **upper bank of the calcarine sulcus (cuneus)** causes a contralateral **inferior quadrantic hemianopia**; a lesion confined to the **lower bank (lingual gyrus)** — including the temporal-lobe loop of the optic radiation — causes a contralateral **superior quadrantic hemianopia**.
- ▶ **Bilateral primary visual area involvement** (e.g. bilateral occipital infarction) produces peripheral visual-field loss with macular sparing ("gun-barrel"/tunnel vision) or complete **cortical blindness**.
- ▶ **Lesions of the secondary/association visual area** cause **visual agnosia** — loss of the ability to recognise objects seen in the opposite field, because the store of past visual experience needed to interpret area 17's raw input is disrupted.
- ▶ **Lateralised association-cortex lesions**: a **right-hemisphere** lesion produces loss of recognition of visual percepts/faces (**prosopagnosia**); a **left-hemisphere** lesion (often with a splenial lesion disconnecting the intact right V1) produces **pure word blindness/alexia** — inability to read despite intact vision and speech.
- ▶ **Bilateral V4 damage** produces **achromatopsia** (cortical colour blindness) with preserved form and motion vision — the double dissociation from area-17 lesions (which abolish all visual qualities) is a classic teaching point on functional segregation within the visual areas.
- ▶ **Dorsal-stream (parietal) lesions** disturb visuospatial processing and can produce contralateral visual **neglect**, contrasted with **ventral-stream (inferior temporal)** lesions, which impair object recognition ("what") while sparing spatial localisation ("where").

High-yield exam pointers

- ▶ Occipital lobe = **areas 17, 18, 19 (Brodmann)**; area 17 = primary/striate area (V1); areas 18/19 = secondary/association visual areas (V2–V5).

- ▶ Area 17 lies in the walls/floor of the **postcalcarine sulcus**; hallmark = **stria of Gennari** (external band of Baillarger) → "striate cortex."
- ▶ Retinotopy: **contralateral visual field** represented; **field above calcarine sulcus** ← inferior retinal quadrants; **field below** ← superior retinal quadrants; **macula** = posterior pole, large representation, spared in PCA infarcts.
- ▶ **LGB** = metathalamus, **6 laminae**: 1,4,6 contralateral (nasal retina); 2,3,5 ipsilateral (temporal retina); laminae 1–2 magnocellular (Y cells), 4–6 parvocellular (X cells).
- ▶ **Optic radiation** runs in the **retrolentiform internal capsule**; lower fibres loop through the temporal lobe to the lingual gyrus (→ superior quadrantanopia if damaged); upper/parietal fibres go to the cuneus (→ inferior quadrantanopia if damaged).
- ▶ **V2–V5**: V2 (area 18, retinotopic mirror-map) → V3/V3a (motion/colour) → **V4 (area 19, colour; bilateral loss = achromatopsia)** and **V5/MT (motion)**.
- ▶ **Dorsal stream** ("where/action", parietal) vs **ventral stream** ("what/object ID", inferior temporal, area 20).
- ▶ PCA occlusion = contralateral homonymous hemianopia with macular sparing; association-cortex lesions = visual agnosia, prosopagnosia (right), alexia (left).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; Vishram Singh's Textbook of Anatomy Vol 3 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e (vascular lesion correlation).



Basal ganglia & limbic system



Describe the anatomy of limbic system

Asked in: Paper IV May 2018 · Paper IV Apr 2006 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction — The **limbic system** (Latin *limbus* = border/edge) is the ring of phylogenetically old cortex and related subcortical nuclei that surrounds the upper brainstem and diencephalon on the medial surface of each cerebral hemisphere. The term derives from Broca's (1877) description of a "**greater limbic lobe**" (cingulate + parahippocampal gyri) bounded by the limbic sulcus; because of its early association with smell it was once synonymous with the obsolete term **rhinencephalon**, though in humans only a small part of it actually subserves olfaction. Functionally the limbic system is the anatomical substrate for **emotion, drive, memory and the visceral ("autonomic") responses that accompany emotional states** — hence its alternative name, the "**visceral brain**."

1. Components of the limbic system

Category	Structures
Limbic lobe (cortical ring)	Cingulate gyrus, cingulate isthmus, parahippocampal gyrus, uncus, subcallosal area (paraolfactory + paraterminal gyri)
Hippocampal formation	Hippocampus (cornu ammonis), dentate gyrus, subiculum, gyrus fasciolaris, indusium griseum
Subcortical nuclei	Amygdaloid nuclear complex, septal nuclei/area, anterior nucleus of thalamus, mammillary bodies of hypothalamus
Connecting fibre bundles	Fornix, mammillothalamic tract, stria terminalis, stria medullaris thalami, cingulum, medial forebrain bundle, anterior commissure, diagonal band of Broca
Extended limbic system (Gray's 41e)	Nucleus accumbens, habenula, major areas of prefrontal cortex, parts of basal ganglia, ventral tegmental area, periaqueductal grey

2. The limbic lobe — cortical ring

- ▶ The **cingulate gyrus** lies above the callosal sulcus and below the cingulate sulcus, beginning in the subcallosal area below the rostrum of the corpus callosum, arching over the corpus callosum, and narrowing posterior to the splenium into the **isthmus**, which continues into the **parahippocampal gyrus**.
- ▶ The **parahippocampal gyrus** lies between the hippocampal fissure and the collateral sulcus on the medial temporal lobe; anteriorly it **folds back on itself to form the uncus**, whose medial surface is grooved by the semi-annular sulcus and overlies the amygdala.
- ▶ The **subcallosal area** (paraolfactory and paraterminal gyri, separated by the anterior paraolfactory sulcus) lies below the rostrum of the corpus callosum, anterior to the lamina terminalis.
- ▶ **Cortical lamination gradient**: the hippocampus is true **allocortex/archicortex** (three layers only); the cingulate and parahippocampal gyri are **mesocortex/juxta-allocortex** (transitional, 3–6

layers, with the **subiculum** being the actual transition zone); the rest of the hemisphere is six-layered **neocortex**.

3. Hippocampal formation

The hippocampal formation occupies the floor of the inferior horn of the lateral ventricle and comprises the **hippocampus**, **dentate gyrus**, **subiculum**, **gyrus fasciolaris** and **indusium griseum**.

- ▶ **Hippocampus (cornu ammonis/Ammon's horn)** — a curved elevation of grey matter, C-shaped on coronal section (hence "sea-horse"); its expanded anterior end forms the **pes hippocampi**; it ends posteriorly beneath the splenium of the corpus callosum. Its ventricular surface is covered by a thin sheet of white matter, the **alveus**, whose fibres converge on the medial border to form the **fimbria**, which continues as the crus of the fornix. Histologically it is three-layered archicortex: **molecular, pyramidal and polymorphic layers** (with fields CA1–CA3 recognised along its length; the field close to the subiculum, CA1, is also called **Sommer's sector**).
- ▶ **Dentate gyrus** — a narrow, notched (hence "toothed") band of grey matter lying between the fimbria and the parahippocampal gyrus; also three-layered (molecular, granular, polymorphic). Anteriorly its **tail** crosses the inferior surface of the uncus; posteriorly it continues as the **gyrus fasciolaris**, then as the **indusium griseum** — vestigial grey matter capping the corpus callosum, containing the **medial and lateral longitudinal striae** (white fibre remnants).
- ▶ **Subiculum** — the transitional cortex between the three-layered hippocampus and six-layered parahippocampal neocortex; it receives hippocampal output and projects, via the fornix, to the mammillary body and anterior thalamic nucleus.
- ▶ **Connections of the hippocampus** — *Afferents*: entorhinal area (Brodmann 28)/olfactory-associated cortex, cingulate gyrus, septal nuclei (via the fornix), the opposite hippocampus (via the commissure of the fornix), indusium griseum (via the longitudinal striae), and the dentate/parahippocampal gyri. *Efferents*: the **fornix is the sole major efferent pathway of the hippocampus**.

4. Fornix — the great efferent tract of the hippocampal formation

Part	Description
Alveus → Fimbria	White matter on ventricular surface of hippocampus converging on its medial border
Crus of fornix	Fimbria continues, arching postero-superiorly beneath the splenium and over the thalamus
Body of fornix	The two crura converge in the midline beneath the corpus callosum; interconnected here by the commissure of the fornix (hippocampal commissure) , which links the two hippocampi
Columns of fornix	Body splits anteriorly into two columns, each arching around the interventricular foramen and descending through the hypothalamus
Postcommissural fornix	Fibres passing behind the anterior commissure end in the medial mammillary nucleus

Part	Description
Precommissural fornix	Fibres passing in front of the anterior commissure end in the septal nuclei, lateral preoptic area and anterior hypothalamus
Dorsal fornix	Association fibres passing above the splenium to the cingulate gyrus

Additional fornical fibres reach the **anterior nuclei of the thalamus**, the **midbrain tegmentum**, and, via the stria medullaris thalami, the **habenular nuclei**. Uniquely among cerebral fibre bundles, the fornix contains all three fibre types — **projection, commissural and association fibres**. Bilateral fornix transection produces the **acute amnesic syndrome** — failure to consolidate short-term into long-term memory.

5. Amygdaloid nuclear complex and septal area

- ▶ The **amygdaloid nuclear complex (amygdala)** is an almond-shaped grey mass in the roof of the tip of the inferior horn of the lateral ventricle, anterior to the hippocampus, continuous posteriorly with the tail of the caudate nucleus; it is grouped into a larger **basolateral** and a smaller **corticomedial** nuclear group.
 - *Afferents*: chiefly from the primary olfactory cortex, entorhinal area and hippocampus.
 - *Efferents*: the **stria terminalis** (the principal efferent, running with the tail of caudate to the septal area and anterior hypothalamus, with some fibres crossing in the anterior commissure to the opposite amygdala) and the **ventral amygdalofugal pathway** (a more direct route to the septal area, hypothalamus and dorsomedial thalamic nucleus).
 - *Function*: fear, rage and sexual behaviour; bilateral destruction produces the **Klüver–Bucy syndrome** (see below).
- ▶ The **septal area** lies on the medial frontal lobe beneath the genu/rostrum of the corpus callosum, anterior to the lamina terminalis (paraterminal and parolfactory gyri); it receives hippocampal fibres via the fornix and olfactory input, and is regarded as a "**pleasure zone**"/centre of orgasm on the basis of animal self-stimulation experiments.

6. Connecting fibre bundles of the limbic system

Bundle	Connects
Alveus, fimbria, fornix	Hippocampus ↔ septal area/mammillary body/anterior thalamus
Mammillothalamic tract (bundle of Vicq d'Azyr)	Mammillary body → anterior nucleus of thalamus (→ cingulate gyrus, areas 23/24)
Stria terminalis	Amygdala ↔ septal area/hypothalamus
Stria medullaris thalami	Septal nuclei → habenular nuclei
Cingulum	Intracortical association bundle within the cingulate/parahippocampal gyri
Medial forebrain bundle	Septal area/hypothalamus ↔ midbrain limbic areas

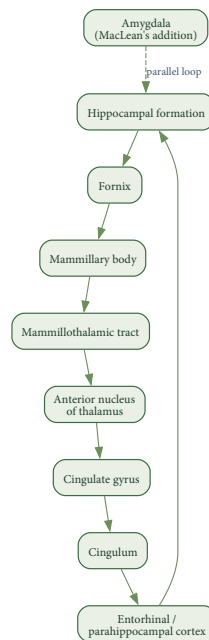
Bundle	Connects
Anterior commissure	Interconnects the two amygdalae/temporal lobes
Diagonal band (of Broca)	Septal area ↔ amygdala/olfactory structures

7. Papez circuit — the anatomical loop of memory and emotion

Described by **Papez in 1937**, this closed circuit begins and ends in the hippocampal formation and is regarded as the structural basis of emotion and recent memory:

Hippocampal formation → fornix → mammillary body → mamillothalamic tract → anterior nucleus of thalamus → cingulate gyrus → cingulum → entorhinal/parahippocampal cortex → back to hippocampal formation.

Within the thalamic relay, the **medial mammillary nucleus** projects (via the mamillothalamic tract) to the ipsilateral anteroventral/anteromedial thalamic nuclei, while the **lateral mammillary nucleus** projects bilaterally to the anterodorsal nucleus. **Paul MacLean's** modification of the circuit additionally incorporates the **amygdala** as a parallel emotional loop.



Describe the anatomy of limbic system

□ Fig 9.14 — Parts of limbic system (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.588)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A medial (sagittal) view of the cerebral hemisphere labelling: **cingulate gyrus**, **cingulate sulcus**, **isthmus**, **parahippocampal gyrus**, **uncus**, **subcallosal area**; a cut-away of the temporal horn showing **hippocampus**, **pes hippocampi**, **dentate gyrus**, **fimbria**, **alveus**; the **fornix** (crus, body, commissure, columns) arching from hippocampus to **mammillary body**; the **mammillothalamic tract** to the **anterior thalamic nucleus**; the **amygdaloid body** at the tip of the temporal horn with the **stria terminalis** curving along the caudate nucleus; and the **indusium griseum** with longitudinal striae over the corpus callosum.

Applied / Clinical anatomy

- ▶ **Bilateral hippocampal or fornix lesions** cause **anterograde amnesia** — inability to form new (recent) memories while remote memory, already consolidated elsewhere in the cortex, is preserved.
- ▶ **Klüver–Bucy syndrome**: bilateral destruction of the amygdala/anterior temporal lobe produces **docility and loss of fear/rage**, **hyperorality** (increased and indiscriminate oral exploration/appetite), **hypersexuality**, and **visual agnosia** (inability to recognise objects by sight).
- ▶ Stereotactic/surgical lesions of the amygdala in humans with pathological aggression reduce aggressiveness and increase placidity, appetite and sexual interest, **without causing memory loss** — distinguishing amygdalar from hippocampal function.
- ▶ **Temporal lobe (uncinate) epilepsy** may begin with an **olfactory aura** (an unpleasant smell, reflecting uncus/amygdala involvement) followed by impaired consciousness and automatisms (e.g. undressing, lip-smacking) with subsequent amnesia for the event.
- ▶ The **hippocampus is the most epileptogenic part of the cerebral hemisphere**; **Sommer's sector (CA1)** is the field classically implicated in **hippocampal sclerosis** of mesial temporal lobe epilepsy.
- ▶ **Chronic thiamine deficiency (Wernicke–Korsakoff syndrome)**, classically in alcoholism, damages the **mammillary bodies**, interrupting the Papez circuit and producing profound anterograde amnesia with confabulation — a standard clinical correlate of mammillary body anatomy.
- ▶ **Schizophrenia** has been linked to dysregulated limbic dopaminergic transmission; antipsychotics act partly by blocking limbic dopamine receptors.
- ▶ The **cingulate gyrus** is described as a "satisfaction centre" (post-prandial/post-coital) and the **septal area** as a "pleasure zone"/orgasm centre, based on self-stimulation studies.

High-yield exam pointers

- ▶ Limbic lobe (Broca, 1877) = **cingulate gyrus + isthmus + parahippocampal gyrus + uncus**; "rhinencephalon" is an obsolete synonym.
- ▶ Hippocampal formation = **hippocampus (cornu ammonis) + dentate gyrus + subiculum + gyrus fasciolaris + indusium griseum**.

- ▶ **Fornix = sole major efferent of the hippocampus**; the only fibre bundle in the brain containing projection, commissural and association fibres together.
- ▶ **Papez circuit (1937)**: hippocampus → fornix → mammillary body → mammillothalamic tract → anterior thalamic nucleus → cingulate gyrus → cingulum → entorhinal cortex → hippocampus; **MacLean** added the amygdala.
- ▶ Amygdala efferents = **stria terminalis + ventral amygdalofugal pathway**; amygdala nuclei = **basolateral + corticomedial** groups.
- ▶ **Klüver–Bucy syndrome** = bilateral amygdala/temporal lobe destruction → placidity, hyperorality, hypersexuality, visual agnosia.
- ▶ Limbic system = the "**visceral brain**" — substrate for emotion, drive, recent memory and visceral responses to emotion.
- ▶ Mammillothalamic tract = **bundle of Vicq d'Azyr**; connects mammillary body to anterior thalamic nucleus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e (figure).



Basal ganglia

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

The **basal ganglia** (currently preferred term: **basal nuclei**) are large, paired subcortical masses of grey matter embedded in the white core of each cerebral hemisphere, situated close to the thalamus and internal capsule and developing from the telencephalon. They possess **no direct afferent or efferent connection with the spinal cord**; instead, they modulate movement indirectly by shaping the output of the motor cortex through cortico-striato-pallido-thalamo-cortical loops. Anatomically the term traditionally comprised the **corpus striatum, claustrum and amygdaloid body**; functionally, the **substantia nigra and subthalamic nucleus** are so tightly integrated into basal-ganglia circuitry that they are described along with them. Disease of this system produces a spectrum of motor disorders — from the poverty of movement of Parkinson's disease to the excessive, unwanted movements (dyskinesias) of chorea, athetosis and ballismus.

1. Terminology and components

Clinical/collective term	Structures included
Corpus striatum	Caudate nucleus + lentiform nucleus
Neostriatum (striatum)	Caudate nucleus + putamen (recent phylogenetically)

Clinical/collective term	Structures included
Paleostriatum (pallidum)	Globus pallidus (phylogenetically older)
Lentiform (lenticular) nucleus	Putamen + globus pallidus
Archistriatum	Amygdaloid body + claustrum (oldest phylogenetically)
Ventral striatum	Nucleus accumbens + olfactory tubercle
Ventral pallidum	Part of globus pallidus below the anterior commissure

- **Traditional anatomical definition:** corpus striatum + claustrum + amygdaloid body.
- **Restricted functional definition** (now preferred, Jankovic): corpus striatum + **subthalamic nucleus** + **substantia nigra** ($\pm$ pedunculopontine nucleus) — a functional complex controlling movement and motivational behaviour. The claustrum's function remains unknown; the amygdala is now grouped with the limbic system, so both are frequently excluded from the functional grouping.
- The **striatum** (caudate + putamen) is the principal **input (receptive)** structure, receiving the bulk of afferents from the neuraxis; the **globus pallidus**, together with the pars reticularis of the substantia nigra, is the principal **output** structure, projecting chiefly to the thalamus.

2. Gross anatomy of the corpus striatum

The corpus striatum lies lateral to the thalamus and is almost completely divided by the **internal capsule** into the caudate nucleus and lentiform nucleus; anteroinferiorly, a few grey-matter bridges (the **fundus striati**) cross the anterior limb of the internal capsule and connect the two, producing the striated appearance responsible for the name.

Part	Description	Key relations
Caudate — head	Large, rounded	Floor and lateral wall of the anterior horn of the lateral ventricle; fused inferiorly with the putamen
Caudate — body	Long, narrow	Floor of the central part (body) of the lateral ventricle; separated from the thalamus by the stria terminalis and thalamostriate vein
Caudate — tail	Long, slender	Roof of the inferior horn of the lateral ventricle; ends anteriorly by fusing with the amygdaloid body
Lentiform nucleus	Wedge/biconvex, convex base lateral	Medially, the internal capsule (separating it from caudate/thalamus); laterally, the external capsule, then claustrum, then insula

The lentiform nucleus is split by the **external (lateral) medullary lamina** into a larger, darker lateral **putamen** and a smaller, paler medial **globus pallidus**; the globus pallidus is further divided by the **internal medullary lamina** into **external (lateral)** and **internal (medial)** segments, which differ in their connections. The putamen and caudate nucleus share the same chemo-cytoarchitecture and are together the **neostriatum/striatum**; the globus pallidus is the **paleostriatum/pallidum**.

Just below the fundus striati, near the anterior perforated substance, lie the **nucleus accumbens** and **olfactory tubercle**, together forming the **ventral striatum** — a major substrate of the mesolimbic dopamine reward system and implicated in the addictive potential of drugs of abuse; the corresponding part of the globus pallidus below the anterior commissure is the **ventral pallidum**.

3. Claustrum and amygdaloid body

- **Claustrum** — a thin sheet of grey matter between the external capsule (medially, separating it from the putamen) and the subcortical white matter of the insula (laterally); its function remains unknown.
- **Amygdaloid body (amygdala)** — an almond-shaped nuclear complex in the temporal lobe deep to the uncus, fused with the tip of the tail of the caudate nucleus. Developmentally related to the basal nuclei, it is functionally classified with the **limbic system**; its principal efferent tract is the **stria terminalis**.

4. Functionally related nuclei — subthalamic nucleus and substantia nigra

- **Subthalamic nucleus** — a small, biconvex, lens-shaped nucleus of the ventral diencephalon, medial to the internal capsule and inferomedial to the globus pallidus, separated from the thalamus by the **zona incerta**. Its neurons are **glutamatergic (excitatory)**, unique among basal-ganglia components, and connect reciprocally with the globus pallidus (subthalamic fasciculus) and substantia nigra pars reticularis.
- **Substantia nigra** — a midbrain nuclear complex deep to the crus cerebri, with a dorsal **pars compacta** (dopaminergic cell group A9, projecting heavily to caudate and putamen — the **nigrostriatal pathway**) and a ventral **pars reticularis** (GABAergic, an output nucleus functionally and developmentally akin to the internal globus pallidus, projecting mainly to the ventral anterior/ventral lateral thalamus and superior colliculus).

5. Connections of the corpus striatum and globus pallidus

Afferents to striatum	Source	Neurotransmitter
Corticostriate fibres	Entire ipsilateral cerebral cortex (largest input from sensorimotor cortex)	Glutamate (excitatory)
Thalamostriate fibres	Intralaminar/midline thalamic nuclei (centromedian → putamen)	Glutamate
Nigrostriatal fibres	Substantia nigra, pars compacta	Dopamine

Afferents to striatum	Source	Neurotransmitter
Brainstem-striatal fibres	Raphe nuclei (serotonin), locus coeruleus (noradrenaline)	Serotonin/noradrenaline

Efferents from striatum/pallidum	Destination	Neurotransmitter
Striatopallidal fibres	Globus pallidus (both segments)	GABA ($\pm$ enkephalin or substance P/dynorphin)
Striatonigral fibres	Substantia nigra, pars reticularis	GABA, substance P, acetylcholine
Pallidonigral/pallidosubthalamic fibres	Substantia nigra / subthalamic nucleus	GABA

The **pallidofugal outflow** — the classic "wiring" fact for exams — leaves the globus pallidus as four bundles:

- ▶ **Fasciculus lenticularis** — from the internal segment, penetrates the internal capsule directly to the subthalamic region.
- ▶ **Ansa lenticularis** — from both segments, loops around the anterior/inferior border of the internal capsule.
- ▶ **Pallidosubthalamic fibres** — reciprocal connections with the subthalamic nucleus.
- ▶ **Pallidotegmental fibres** — to the caudal midbrain tegmentum.

The lenticular and ansa fasciculi unite with dentatorubrothalamic fibres in the subthalamic region — the so-called "**H fields of Forel**" — to form the **thalamic fasciculus**, terminating in the **ventral anterior (VA)**, **ventral lateral (VL)** and **centromedian** thalamic nuclei, which relay to the motor and premotor cortex.

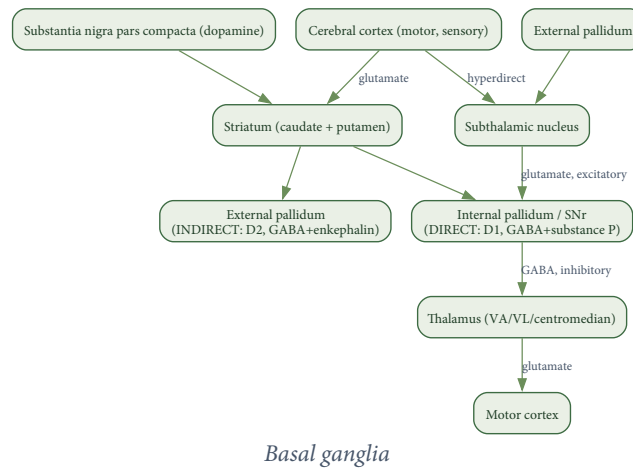
6. Direct, indirect and hyperdirect pathways

Two parallel striatopallidal circuits, distinguished by their projection neurons, govern the net inhibitory output of the basal ganglia onto the thalamus:

- ▶ **Direct pathway** — striatal medium spiny neurons bearing **D1 dopamine receptors** (co-expressing GABA + substance P/dynorphin) project straight to the **internal pallidum/substantia nigra pars reticularis**, inhibiting it; this *disinhibits* the thalamus and **facilitates** movement.
- ▶ **Indirect pathway** — striatal neurons bearing **D2 dopamine receptors** (co-expressing GABA + enkephalin) project to the **external pallidum**, which in turn inhibits the **subthalamic nucleus**; loss of this inhibition lets the (glutamatergic) subthalamic nucleus excite the internal pallidum/pars reticularis, **increasing** inhibitory output on the thalamus and **suppressing** movement.
- ▶ **Hyperdirect pathway** — a fast cortico-subthalamic glutamatergic projection that bypasses the striatum entirely, providing rapid braking of unwanted movement before the slower striatal pathways engage.

Nigrostriatal dopamine has a **dual, opposite action**: it excites direct-pathway neurons (via D1) and inhibits indirect-pathway neurons (via D2), together tilting the circuit towards facilitation of the

intended movement. This model underlies the pathophysiology of both Parkinson's disease (dopamine loss → indirect pathway overactive, direct pathway underactive → net over-inhibition of thalamus → akinesia/rigidity) and drug-induced dyskinesias (the converse imbalance).



7. Functions of the basal ganglia

- ▶ Planning and programming of voluntary movement — determining its **speed and amplitude**.
- ▶ Regulation of muscle tone and smoothing of ongoing voluntary motor activity.
- ▶ Control of automatic associated movements (e.g. arm-swing during walking) and preparatory postural adjustment of the trunk/limb girdles before the motor cortex activates discrete distal movements.
- ▶ Suppression of unwanted or "stimulus-bound" involuntary muscular activity; contribution to motor learning.
- ▶ Basic circuit logic: cerebral cortex/thalamus/brainstem → **striatum** → **globus pallidus**/substantia nigra pars reticularis → **thalamus** → back to motor cortex, which then acts on the spinal cord through corticospinal/corticonuclear fibres — the basal ganglia influence movement **only indirectly**, never through direct descending pathways.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 23.2 — The principal parts of the diencephalon and basal ganglia, coronal section (Gray's Anatomy — Standring — 41e, p.487)

Reproduce a coronal section at the level of the interventricular foramen/thalamus and label: **body of caudate nucleus, thalamus, internal capsule, putamen, globus pallidus (external and internal segments), external capsule, claustrum, insula, third ventricle, lateral ventricle** — and, on a slightly more caudal section, add the **subthalamic nucleus and substantia nigra**.

Applied / Clinical anatomy

- ▶ **Parkinson's disease (paralysis agitans)** — degeneration of dopaminergic neurons of the substantia nigra pars compacta severely depletes striatal dopamine (postsynaptic D1/D2 receptors are spared). This overactivates the indirect pathway and underactivates the direct pathway, producing net over-inhibition of the thalamus. Cardinal features: **resting ("pill-rolling") tremor** (abolished by movement, absent in sleep), **cogwheel/lead-pipe rigidity**,

bradykinesia/akinesia, and **postural instability** with stooped posture and shuffling gait, plus mask-like facies and micrographia. Onset typically 45–55 years; second commonest neurodegenerative disorder after Alzheimer's. Treatment: **L-dopa** (crosses the blood–brain barrier, unlike dopamine), dopamine agonists, **selegiline** (MAO-B inhibitor), stereotactic **pallidotomy/thalamotomy**, **deep brain stimulation (DBS)** of the subthalamic nucleus or internal globus pallidus, and fetal dopaminergic-neuron transplantation into caudate/putamen.

- ▶ **Huntington's disease** — autosomal dominant, CAG-repeat expansion in the **huntingtin** gene on chromosome 4. Degeneration of the GABA/substance-P/acetylcholine-secreting striatonigral (indirect-pathway) neurons removes inhibition on nigral dopaminergic neurons, whose resulting overactivity further inhibits the remaining caudate/putamen — producing choreiform movements and progressive dementia; death 15–20 years after onset. CT/MRI characteristically shows enlarged lateral ventricles from caudate atrophy.
- ▶ **Chorea** — **Sydenham's vs Huntington's**: both present with quick, jerky, non-repetitive involuntary movements but differ importantly —

Feature	Sydenham's chorea (St Vitus' dance)	Huntington's chorea
Age/sex	Children, 5–15 years, girls predominantly	Adults, 30–45 years
Cause	Post-streptococcal antibodies cross-react with striatal neuronal membrane antigens (association with rheumatic fever)	Autosomal dominant, CAG-repeat huntingtin gene
Course	Transient, full recovery	Progressive, fatal
Imaging	Normal	Enlarged lateral ventricles (caudate atrophy)

- ▶ **Hemiballismus** — sudden, violent, flinging movements of the proximal limb musculature, classically unilateral, from a small vascular (haemorrhagic/ischaemic) lesion of the **contralateral subthalamic nucleus** or its connections — the nucleus that normally integrates smooth movement of different body parts.
- ▶ **Athetosis** — slow, sinuous, writhing movements predominating in the distal limbs, from lesions of the neostriatum and globus pallidus disrupting basal-ganglia/cortical circuitry.
- ▶ **Wilson's disease (hepatolenticular degeneration)** — autosomal recessive disorder of copper metabolism with hepatic and lentiform-nucleus copper deposition; associated **Kayser–Fleischer rings** at the corneoscleral limbus.
- ▶ **Blood supply** — the basal nuclei are supplied chiefly by the **lenticulostriate (medial and lateral striate) branches of the middle cerebral artery** — one lateral striate branch is the most frequently ruptured vessel in hypertensive intracerebral haemorrhage, termed **Charcot's artery of cerebral haemorrhage** — the **recurrent artery (of Heubner)** from the anterior cerebral artery (thrombosis → contralateral upper-limb monoplegia), and the **anterior choroidal artery** (internal carotid artery, to the globus pallidus and adjoining structures).

Recent advances

- ▶ **Adaptive (closed-loop) deep brain stimulation** — in February 2025 the US FDA approved the world's first adaptive DBS system for Parkinson's disease; the device continuously senses basal-ganglia **beta-band (13–35 Hz) oscillations** from the subthalamic nucleus/globus pallidus and titrates stimulation in real time, building directly on the anatomical/electrophysiological finding that pathological beta synchrony in the cortico-basal ganglia loop correlates with akinesia and rigidity (Medtronic news release, Feb 2025; ADAPT-PD trial).
- ▶ **Patient-individual tractography** of basal-ganglia structural connectivity (diffusion-MRI) is now used to explain the variability of DBS outcomes — cortical fibres traversing the subthalamic/ventral tegmental region connect preferentially with the supplementary motor area, and stimulating the fibre bundle connected to primary motor cortex best reduces MDS-UPDRS-III scores (PMC12453574 / PMID 40532683, 2025).
- ▶ **Individualized cortico-basal ganglia effective-connectivity modelling** (resting-state fMRI) has been shown to predict which patients will respond best to subthalamic-nucleus DBS, moving basal-ganglia circuit anatomy toward pre-operative, patient-specific target selection (Frontiers in Neuroscience, 2025).

High-yield exam pointers

- ▶ Basal ganglia (traditional) = corpus striatum + claustrum + amygdaloid body; functional grouping adds subthalamic nucleus + substantia nigra.
- ▶ Neostriatum = caudate + putamen (afferent/input); paleostriatum/pallidum = globus pallidus (efferent/output).
- ▶ Corpus striatum = caudate + lentiform nucleus; lentiform = putamen + globus pallidus (external + internal segments).
- ▶ Striatal afferents: corticostriate (glutamate), thalamostriate, nigrostriatal (dopamine), raphe/locus-coeruleus (serotonin/noradrenaline).
- ▶ Pallidofugal outflow = ansa lenticularis + fasciculus lenticularis + dentatorubrothalamic fibres → thalamic fasciculus → VA/VL/centromedian thalamus.
- ▶ Direct pathway (D1) facilitates movement; indirect pathway (D2, via GPe–STN) suppresses movement; hyperdirect pathway = fast cortex→STN brake.
- ▶ Parkinson's disease = nigrostriatal dopamine loss; Huntington's = striatal GABAergic neuron loss with CAG-repeat huntingtin gene (chromosome 4).
- ▶ Hemiballismus = contralateral subthalamic nucleus lesion; Wilson's disease = lentiform nucleus degeneration + Kayser–Fleischer rings.
- ▶ Blood supply: lenticulostriate branches of MCA, recurrent artery of Heubner (ACA), anterior choroidal artery (ICA).
- ▶ Basal ganglia influence movement only via the cerebral cortex — no direct connection to the spinal cord.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy. Recent-advances section per Medtronic (FDA release, Feb 2025) and PubMed/PMC (PMID 40532683; Frontiers in Neuroscience 2025).



Basal nuclei

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction

The **basal nuclei** (older term: **basal ganglia**) are large, paired masses of grey matter embedded in the white core of each cerebral hemisphere, lying close to the thalamus and internal capsule. Developing from the telencephalon, they have no direct afferent or efferent connection with the spinal cord; instead they influence movement indirectly by modulating the output of the motor cortex. Traditionally the term comprised the **corpus striatum**, **claustrum** and **amygdaloid body**; functionally, the **subthalamic nucleus** and **substantia nigra** are so intimately linked to basal-nuclear circuitry that they are described together. Disorders of this system produce a spectrum from the poverty of movement of Parkinson's disease to the excessive, unwanted movements (dyskinesias) of chorea, athetosis and ballismus.

1. Terminology and components

Common/clinical term	Anatomical structure(s)
Corpus striatum	Caudate nucleus + lentiform nucleus
Neostriatum (striatum)	Caudate nucleus + putamen
Paleostriatum (pallidum)	Globus pallidus
Lentiform (lenticular) nucleus	Putamen + globus pallidus
Archistriatum	Amygdaloid body + claustrum (phylogenetically oldest)
Ventral striatum	Nucleus accumbens + olfactory tubercle
Ventral pallidum	Part of globus pallidus below the anterior commissure

- **Traditional (anatomical) definition:** corpus striatum, claustrum, amygdaloid body.
- **Restricted/functional definition** (now preferred): corpus striatum + **subthalamic nucleus** + **substantia nigra** ($\pm$ pedunculopontine nucleus), controlling movement and motivational behaviour — the claustrum's function is unknown and the amygdala is now classed with the limbic system, so both are often excluded.
- The **striatum** (caudate + putamen) is the principal **input** structure; the **globus pallidus**, with the pars reticularis of the substantia nigra, is the principal **output** structure, projecting mainly to the thalamus.

2. Gross anatomy of the corpus striatum

The corpus striatum lies lateral to the thalamus and is almost completely divided by the **internal capsule** into the caudate nucleus and the lentiform nucleus; a few grey-matter bridges (the **fundus striati**) cross the anterior limb of the internal capsule and connect the two, producing the "striated" appearance that gives the structure its name.

Part	Shape/description	Relations
Caudate nucleus — Head	Large, rounded	Forms the floor and lateral wall of the anterior horn of the lateral ventricle; continuous inferiorly with the putamen
— Body	Long, narrow	Forms part of the floor of the body of the lateral ventricle; separated from the thalamus by the stria terminalis and thalamostriate vein
— Tail	Long, slender	Curves in the roof of the inferior horn of the lateral ventricle; ends anteriorly by fusing with the amygdaloid body
Lentiform nucleus	Wedge/lens-shaped; convex base lateral, blade medial	Medially related to the internal capsule (separating it from caudate/thalamus); laterally related to the external capsule, then the claustrum, then the insula

The lentiform nucleus is divided by the **external (lateral) medullary lamina** into a larger, darker lateral part, the **putamen**, and a smaller, paler medial part, the **globus pallidus**; the globus pallidus is further subdivided by the **internal medullary lamina** into **external (lateral)** and **internal (medial)** segments. The putamen and caudate nucleus share the same chemo-cytoarchitecture and are together called the **neostriatum/striatum**; the globus pallidus, phylogenetically older, is the **paleostriatum/pallidum**.

Just below the fundus striati, near the anterior perforated substance, lie the **nucleus accumbens** and **olfactory tubercle**, together forming the **ventral striatum** (part of the mesolimbic dopamine system, implicated in reward and addiction); the corresponding part of globus pallidus below the anterior commissure is the **ventral pallidum**.

3. Claustrum and amygdaloid body

- ▶ **Claustrum** — a thin sheet of grey matter between the external capsule (medially) and the subcortical white matter of the insula (laterally); its function is unknown.
- ▶ **Amygdaloid body (amygdala)** — an almond-shaped mass in the temporal lobe deep to the uncus, continuous with the tail of the caudate nucleus; developmentally related to the basal nuclei but functionally part of the **limbic system** (its main efferent tract is the stria terminalis).

4. Functionally related nuclei — subthalamic nucleus and substantia nigra

- ▶ **Subthalamic nucleus** — a small, biconvex, lens-shaped nucleus in the ventral diencephalon, medial to the internal capsule and inferomedial to the globus pallidus, separated from the thalamus by the zona incerta. Its neurons are **glutamatergic (excitatory)** and connect reciprocally with the globus pallidus via the subthalamic fasciculus, and with the substantia nigra.
- ▶ **Substantia nigra** (midbrain) — divided into a dorsal **pars compacta** (dopaminergic neurons projecting to the striatum — the nigrostriatal pathway) and a ventral **pars reticularis** (GABAergic, functionally/developmentally a continuation of the internal globus pallidus, projecting chiefly to the ventral anterior nucleus of the thalamus).

5. Connections of the corpus striatum and globus pallidus

Afferent to striatum	Origin	Neurotransmitter
Corticostriate fibres	Entire cerebral cortex (largest input from sensori-motor cortex)	Glutamate (excitatory)
Thalamostriate fibres	Intralaminar/midline thalamic nuclei	—
Nigrostriatal fibres	Substantia nigra, pars compacta	Dopamine (inhibitory)
Brainstem-striatal fibres	Raphe nuclei, locus coeruleus	Serotonin/noradrenaline

Efferent from striatum/pallidum	Destination	Neurotransmitter
Striatopallidal fibres	Globus pallidus	GABA ($\pm$ enkephalin)
Striatonigral fibres	Substantia nigra, pars reticularis	GABA, substance P, acetylcholine
Pallidonigral fibres	Substantia nigra	GABA

Pallidofugal outflow (the four bundles arising from the globus pallidus) is the key "wiring" fact examiners look for:

- ▶ **Fasciculus lenticularis** — from the internal segment, penetrates the internal capsule directly, into the subthalamic region.
- ▶ **Ansa lenticularis** — from both segments, loops around the anterior/inferior border of the internal capsule.
- ▶ **Pallidosubthalamic fibres** — reciprocal connections with the subthalamic nucleus.
- ▶ **Pallidotegmental fibres** — to the caudal midbrain tegmentum.

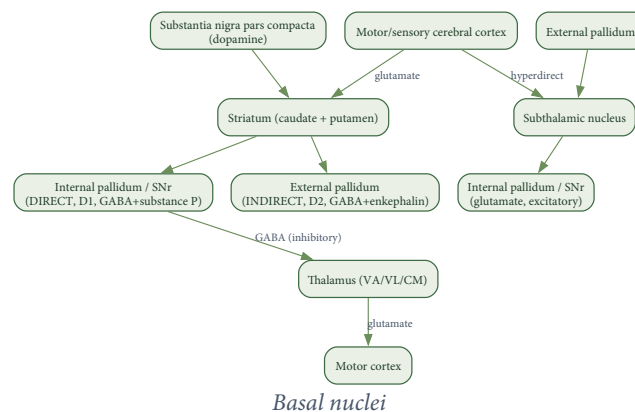
The lenticular and ansa fasciculi unite with dentatorubrothalamic fibres in the subthalamic region (the "H fields of Forel") to form the **thalamic fasciculus**, which terminates in the **ventral anterior (VA)**, **ventral lateral (VL)** and **centromedian** nuclei of the thalamus — relaying, in turn, to the motor and premotor cortex.

6. Direct, indirect and hyperdirect pathways

Two parallel striato-pallidal circuits, distinguished by their striatal projection neurons, regulate the net inhibitory outflow of the basal nuclei on the thalamus:

- **Direct pathway** — striatal neurons bearing **D1 dopamine receptors** (co-expressing substance P/dynorphin) project **directly** to the internal pallidum/pars reticularis, inhibiting it → *disinhibits* the thalamus → **facilitates** movement.
- **Indirect pathway** — striatal neurons bearing **D2 dopamine receptors** (co-expressing enkephalin) project to the **external** pallidum → subthalamic nucleus → internal pallidum/pars reticularis, **increasing** its inhibitory output on the thalamus → **suppresses** movement.
- **Hyperdirect pathway** — a fast cortico-subthalamic projection bypassing the striatum, allowing rapid braking of movement.

Nigrostriatal dopamine normally **excites** the direct pathway (via D1) and **inhibits** the indirect pathway (via D2), tilting the balance towards facilitation of intended movement.



7. Blood supply of the basal nuclei

Artery	Origin	Territory
Medial striate artery	Anterolateral central branches of the middle cerebral artery	Ascends through/supplies the lentiform nucleus, caudate nucleus and internal capsule
Lateral striate arteries	Anterolateral central branches of the middle cerebral artery	Lentiform nucleus and internal capsule; the largest branch is Charcot's artery of cerebral haemorrhage — the vessel most often ruptured in hypertensive intracerebral bleed
Recurrent artery of Heubner	Anterior cerebral artery	Head of caudate nucleus and anterior limb of internal capsule; thrombosis → contralateral upper-limb monoplegia
Anterior choroidal artery	Internal carotid artery	Globus pallidus and adjoining structures (in addition to choroid plexus)

8. Functions of the basal nuclei

- ▶ Planning and programming of voluntary movement; determining its speed and amplitude.
- ▶ Regulation of muscle tone and smoothing of ongoing voluntary motor activity.
- ▶ Control of automatic associated movements (e.g. arm-swing during walking) and postural adjustments in preparation for a movement.
- ▶ Suppression of unwanted/involuntary muscular activity.
- ▶ Contribution to motor learning and to emotional-expression movements (via limbic-related components).
- ▶ Basic circuit logic: cortex/thalamus/brainstem → striatum → globus pallidus → thalamus → back to motor cortex, which then acts on the spinal cord via corticospinal/corticonuclear fibres — i.e. the basal nuclei influence movement **only indirectly**, through the cerebral cortex.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 23.2 — *The principal parts of the diencephalon and basal ganglia, coronal section (Gray's Anatomy — Standring — 41e, p.487)*

Reproduce a coronal section at the interventricular-foramen/thalamus level and label: **body of caudate nucleus, thalamus, internal capsule, putamen, globus pallidus (external + internal segments), external capsule, claustrum, insula, third ventricle, lateral ventricle** — plus, on a slightly more inferior section, the **subthalamic nucleus and substantia nigra**.

Applied / Clinical anatomy

- ▶ **Parkinson's disease (paralysis agitans)** — degeneration of dopaminergic neurons of the substantia nigra pars compacta depletes striatal dopamine; loss of D1-mediated facilitation of the direct pathway and D2-mediated inhibition of the indirect pathway together *increase* basal-ganglia output, over-inhibiting the thalamus. Cardinal features: **resting ("pill-rolling") tremor, cogwheel/lead-pipe rigidity, bradykinesia/akinesia, and postural instability with stooped, shuffling gait and mask-like facies**. Treatment: **L-dopa, dopamine agonists, stereotactic pallidotomy/thalamotomy, deep brain stimulation (DBS)** of the subthalamic nucleus or internal globus pallidus, and fetal nigral-cell transplantation.
- ▶ **Huntington's disease** — autosomal dominant, CAG-repeat expansion in the **huntingtin** gene on chromosome 4; degeneration of GABA/enkephalin-secreting striatal (indirect-pathway) neurons removes inhibition on the substantia nigra, so nigrostriatal dopamine over-inhibits the remaining striatum, producing choreiform movements and progressive dementia. CT/MRI shows enlarged lateral ventricles from caudate atrophy.
- ▶ **Chorea, Sydenham's vs Huntington's** — both give quick, jerky, non-repetitive involuntary movements, but differ importantly:

Feature	Sydenham's chorea	Huntington's chorea
Age	Children (rheumatic fever)	Adults (30–45 y)
Inheritance	Acquired (post-streptococcal antibody cross-reaction with striatal neuron membranes)	Autosomal dominant

Feature	Sydenham's chorea	Huntington's chorea
Course	Transient, full recovery	Progressive, fatal in 15–20 years
CT brain	Normal	Enlarged lateral ventricles (caudate atrophy)

- ▶ **Hemiballismus** — sudden, violent, flinging movements of proximal limb musculature, classically from a small vascular lesion of the **contralateral subthalamic nucleus** or its connections.
- ▶ **Athetosis** — slow, sinuous, writhing movements of the distal limbs, from lesions of the neostriatum and globus pallidus disrupting basal-nuclear/cortical circuitry.
- ▶ **Wilson's disease (hepatolenticular degeneration)** — autosomal recessive disorder of copper metabolism with copper deposition and degeneration of the **lentiform nucleus**; associated **Kayser–Fleischer rings** at the corneoscleral limbus.

Recent advances

- ▶ High-density electrophysiology during subthalamic-nucleus DBS shows that the **evoked resonant neural activity (ERNA)** waveform is a direct electrophysiological signature of engagement of the **indirect pathway (GPe–STN) mesocircuit**, with each ERNA peak time-locked to STN inhibition — refining the anatomical target for optimal DBS lead placement (Steiner et al., *Nature Communications*, 2024) [DOI: 10.1038/s41467-024-47552-6].
- ▶ Combined electrophysiology in patients on/off dopaminergic medication and on/off DBS shows that **L-dopa and subthalamic DBS act through a shared pathway-specific mechanism** — both suppress excessive cortico-subthalamic beta-band synchrony carried by the **hyperdirect pathway** — unifying the pharmacological and surgical treatment models of Parkinson's disease (Binns et al., *Nature Communications*, 2025) [DOI: 10.1038/s41467-025-58825-z].
- ▶ Patient-individual diffusion-MRI **tractography** of basal-ganglia structural connectivity is emerging as key to explaining variable outcomes of DBS in Parkinson's disease, with cortical fibres traversing the ventral tegmental/subthalamic region shown to connect predominantly with the supplementary motor area (Loução et al., *Stereotactic and Functional Neurosurgery*, 2025) [DOI: 10.1159/000546716].
- ▶ (*According to PubMed.*)

High-yield exam pointers

- ▶ Basal nuclei = corpus striatum (caudate + lentiform) + claustrum + amygdaloid body (traditional); functionally add subthalamic nucleus + substantia nigra.
- ▶ Neostriatum = caudate + putamen (input, afferent); Paleostriatum/pallidum = globus pallidus (output, efferent).
- ▶ Striatum receives corticostriate (glutamate), thalamostriate, nigrostriatal (dopamine) and raphe/locus-coeruleus (serotonin/noradrenaline) afferents.
- ▶ Pallidofugal outflow = ansa lenticularis + fasciculus lenticularis + dentatorubrothalamic fibres → **thalamic fasciculus** → VA/VL/centromedian thalamus.
- ▶ **Direct pathway (D1)** facilitates movement; **indirect pathway (D2, via GPe–STN)** suppresses movement; **hyperdirect** = fast cortex→STN brake.

- ▶ Blood supply: medial + lateral lenticulostriate branches of MCA (Charcot's artery), recurrent artery of Heubner (ACA), anterior choroidal artery (ICA).
- ▶ Parkinson's disease = dopamine deficiency in striatum from nigral degeneration; Huntington's = striatal GABAergic neuron loss, CAG-repeat huntingtin gene, chromosome 4.
- ▶ Hemiballismus = contralateral subthalamic nucleus lesion; Wilson's disease = lentiform nucleus + Kayser–Fleischer rings.
- ▶ Basal nuclei influence movement only via the cerebral cortex — no direct spinal cord connection.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e (blood supply). Recent-advances section per PubMed (see DOIs above).



Caudate nucleus

Asked in: Paper IV Apr 2008 — RGUHS MD/MS Anatomy

Definition / Introduction

The **caudate nucleus** is a large, C-shaped (comma/tadpole-shaped) mass of grey matter that lies deep in the cerebral hemisphere, closely moulded to the curve of the lateral ventricle throughout its entire length. Together with the **lentiform nucleus** (putamen + globus pallidus) it constitutes the **corpus striatum**, the largest component of the **basal nuclei (basal ganglia)**. Phylogenetically recent, the caudate nucleus and putamen share identical cyto- and chemo-architecture and are together termed the **neostriatum (striatum)** — the principal *receptive* (afferent) part of the basal nuclei, in contrast to the older, efferent globus pallidus (paleostriatum). It is a key relay in the cortico-striato-pallido-thalamo-cortical motor loop and is also central to procedural learning, oculomotor control and limbic/cognitive circuitry — its degeneration or dysfunction underlies disorders ranging from Huntington's chorea to obsessive-compulsive disorder.

1. Gross anatomy — shape and subdivisions

- ▶ A curved, **tadpole/C-shaped** mass consisting of a large anterior **head**, a narrower **body**, and a long, slender, down-curving **tail** — the whole nucleus follows the curvature of the lateral ventricle because both develop together from the floor of the telencephalon.
- ▶ The **head** is large and rounded and forms the lateral wall and part of the floor of the **anterior horn** of the lateral ventricle; it is continuous inferiorly with the putamen of the lentiform nucleus at a fused zone called the **fundus striati**, just above the anterior perforated substance.
- ▶ The **body** is long and narrow, continuous with the head at the level of the **interventricular foramen (of Monro)**, and forms part of the floor of the **body (central part)** of the lateral ventricle.
- ▶ The **tail** is long and slender, continues from the body around the posterior end of the thalamus, curves downward and forward into the temporal lobe, and lies in the **roof of the inferior**

(**temporal**) **horn**; anteriorly it ends by fusing with the **amygdaloid body**, close to the tip of the inferior horn.

- Medially, almost throughout its length, the caudate nucleus abuts the **thalamus**; the junction is marked by a groove, the **sulcus terminalis**, which lodges the **stria terminalis** and the **thalamostriate vein**.
- Laterally, the **anterior limb of the internal capsule** separates the head of the caudate from the putamen (variable grey-matter bridges cross this limb, giving the "striated" appearance that names the corpus striatum).

2. Relations of the caudate nucleus (summary table)

Segment	Relation to lateral ventricle	Other key relations
Head	Lateral wall + floor of anterior horn	Fused inferiorly with putamen (fundus striati); anterior limb of internal capsule laterally; corpus callosum superiorly
Body	Floor of body (central part)	Thalamus medially (sulcus terminalis, stria terminalis, thalamostriate vein); internal capsule + putamen laterally; corpus callosum/fronto-occipital fasciculus superiorly
Tail	Roof of inferior (temporal) horn	Curves below and lateral to thalamus; ends anteriorly by fusing with amygdaloid body near the temporal pole

3. Development

- The caudate nucleus develops, along with the rest of the corpus striatum, from a proliferating mass of neuroblasts in the **floor of the telencephalic vesicle**, near the future interventricular foramen; this mass bulges into the floor of the developing lateral ventricle, giving it a striated appearance on transverse section — hence "**corpus striatum**".
- As the cerebral hemisphere enlarges and curves in a **C-shape** to accommodate the growing temporal lobe, the corpus striatum, being part of the hemisphere wall, is carried along with it — this is why the adult caudate nucleus (and the lateral ventricle it is moulded to) is C-shaped.
- Axons growing to and from the overlying cerebral cortex pierce through the corpus striatum mass; this fibre bundle becomes the **internal capsule**, and by splitting the mass it divides the corpus striatum into a **dorsomedial part** — the **caudate nucleus** — and a **ventrolateral part** — the **lentiform nucleus** (putamen + globus pallidus).
- Because the tail of the caudate nucleus follows the temporal lobe as it rotates around the Sylvian (lateral) fissure, it comes to lie in the roof of the inferior horn and fuses anteriorly with the amygdaloid body, which develops in situ in the temporal lobe.

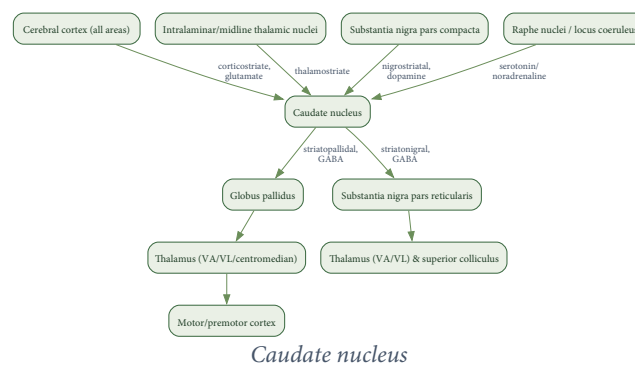
4. Blood supply

Segment	Chief arterial supply
Head	Medial striate artery (the recurrent artery of Heubner), arising from the A2 segment of the anterior cerebral artery near the anterior communicating artery, and lateral striate (lenticulostriate) arteries from the M1 segment of the middle cerebral artery
Body & tail	Continuing lateral striate branches of the middle cerebral artery, together with the anterior choroidal artery (a preterminal branch of the internal carotid artery) and, posteriorly, the posterior choroidal artery (from the posterior cerebral artery)

- The striate arteries are functional **end arteries**; one of the larger lateral striate branches of the middle cerebral artery is the classical "**Charcot's artery of cerebral haemorrhage**" — the most common site of rupture in hypertensive intracerebral haemorrhage, involving the caudate nucleus, putamen and adjoining internal capsule.

5. Connections

- **Afferent** (caudate nucleus is, with the putamen, the principal *input* structure of the basal nuclei):
 - **Corticostriate fibres** — glutamatergic, from the entire ipsilateral cerebral cortex; the orbitofrontal cortex projects to the inferomedial head, the dorsolateral frontal cortex/frontal eye fields to the rest of the head, the parietal cortex to the body, and the occipital/temporal cortex to the tail.
 - **Thalamostriate fibres** — from the intralaminar and midline thalamic nuclei.
 - **Nigrostriatal fibres** — dopaminergic, from the pars compacta of the substantia nigra.
 - **Brainstem-striatal fibres** — serotonergic (raphe nuclei) and noradrenergic (locus coeruleus).
- **Efferent**:
 - **Striatopallidal fibres** — GABAergic, to both segments of the globus pallidus.
 - **Striatonigral fibres** — GABAergic/substance-P, to the pars reticularis of the substantia nigra, which in turn relays to the ventral anterior/ventral lateral thalamus and superior colliculus (important for saccadic eye-movement control).



6. Functions

- ▶ Mediates automatic postural and associated movements (e.g. arm-swing on walking) and smooths ongoing voluntary motor activity.
- ▶ Regulates muscle tone and suppresses unwanted or stimulus-bound involuntary movement.
- ▶ Central to **procedural (habit) learning** and, through the ventral striatum, to reward-based learning and motivation.
- ▶ Contributes to **voluntary saccadic eye-movement control** via its projection to the substantia nigra pars reticularis and superior colliculus.
- ▶ Part of cortico-striato-thalamo-cortical loops implicated in **executive function and behaviour**; abnormal caudate/prefrontal circuit activity is described in obsessive-compulsive disorder, attention-deficit hyperactivity disorder and Gilles de la Tourette's syndrome.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 23.36 — Relationships of caudate nucleus with the cavity of the lateral ventricle and thalamus (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.435)

Reproduce a lateral "ghost" view of the left lateral ventricle with the caudate nucleus moulded onto it, labelling: **head of caudate nucleus** (anterior horn), **body of caudate nucleus** (body of ventricle), **tail of caudate nucleus** (roof of inferior horn), **interventricular foramen**, **thalamus**, **stria terminalis/thalamostriate vein** (sulcus terminalis), **amygdaloid body**, and the **fundus striati** where the head fuses with the putamen.

Applied / Clinical anatomy

- ▶ **Huntington's disease** — an autosomal dominant CAG-repeat expansion in the huntingtin gene (chromosome 4) causes selective degeneration of the GABAergic striatonigral (indirect-pathway) medium spiny neurons of the **caudate nucleus and putamen**, producing chorea and progressive dementia. Imaging (CT/MRI) characteristically shows **caudate and striatal atrophy with "boxcar" dilatation of the frontal horns** of the lateral ventricles, since the atrophying head of the caudate no longer bulges into the ventricular floor.
- ▶ **Parkinsonism** — degeneration of the nigrostriatal dopaminergic pathway depletes dopamine in the caudate nucleus and putamen, producing bradykinesia, rigidity and resting tremor.
- ▶ **Obsessive-compulsive disorder, ADHD and Tourette's syndrome** — associated with abnormal activity in the prefrontal cortex and caudate nuclei, reflecting the caudate's role in cortico-striatal behavioural-control loops.
- ▶ **Vascular lesions** — occlusion/haemorrhage of the **medial striate artery (recurrent artery of Heubner)**, an anterior cerebral artery branch supplying the head of the caudate, can produce contralateral personality change, apathy and abulia (part of the anterior cerebral artery territory syndrome); rupture of the larger **lateral striate ("Charcot's") artery** of the middle cerebral artery, supplying the caudate/putamen/internal capsule, is the classic site of hypertensive intracerebral haemorrhage, producing contralateral upper motor neuron hemiplegia.
- ▶ **Radiological landmark** — on axial CT/MRI at the level of the foramen of Monroe, the head of the caudate nucleus is seen bulging into the floor of the anterior horn; loss of its normal convexity or asymmetric effacement is a useful early sign of mass effect or hemispheric atrophy.

Recent advances

According to PubMed, three recent studies extend the clinical anatomy of the caudate nucleus:

- ▶ A 2025 study validated a simplified linear-measurement method (the **fronto-caudate ratio**, derived from frontal horn width and intercaudate distance) as a practical surrogate for automated caudate/putamen volumetry in staging Huntington's disease under the HD-ISS system, correlating strongly with true caudate volume ($r = 0.87$) and reproducing identical disease-stage classification (Heim et al., *J Neurol* 2025; [DOI](https://doi.org/10.1007/s00415-025-13409-1)).
- ▶ AI-assisted MRI volumetric analysis in premanifest Huntington's disease gene carriers from a Colombian cohort showed that individuals with ≥ 40 CAG repeats had significant **left caudate nucleus volume changes** years before motor onset, supporting caudate volumetry as a preclinical structural biomarker (Ríos-Anillo et al., *Biomedicines* 2024; [DOI](https://doi.org/10.3390/biomedicines12102166)).
- ▶ A functional-MRI connectivity study in patients with cognitive impairment after basal-ganglia stroke found that increased functional connectivity between the cerebellum and the **head of the caudate nucleus** correlated positively with recovery of episodic memory, visuospatial ability and attention, suggesting a compensatory cerebello-striatal circuit in post-stroke cognitive recovery (Zuo et al., *Front Aging Neurosci* 2025; [DOI](https://doi.org/10.3389/fnagi.2025.1478891)).

High-yield exam pointers

- ▶ Comma/tadpole/C-shaped mass with **head, body and tail**, moulded to the entire length of the lateral ventricle.
- ▶ Head → anterior horn; Body → body (central part); Tail → roof of inferior horn; tail fuses anteriorly with the **amygdaloid body**.
- ▶ With the lentiform nucleus (putamen + globus pallidus) forms the **corpus striatum**; with the putamen alone forms the **neostriatum/striatum** (afferent part); globus pallidus alone = **paleostriatum/pallidum** (efferent part).
- ▶ Separated from the lentiform nucleus by the **anterior limb of internal capsule**, except at the **fundus striati** where head and putamen fuse.
- ▶ Develops from the floor of the telencephalon near the foramen of Monro; ingrowing corticofugal fibres (future internal capsule) split the corpus striatum into caudate (dorsomedial) and lentiform (ventrolateral) parts.
- ▶ Blood supply: head — **medial striate artery (recurrent artery of Heubner)** from ACA + lateral striate arteries from MCA; body/tail — **anterior and posterior choroidal arteries**.
- ▶ Chief afferents: corticostriate (glutamate), thalamostriate, nigrostriatal (dopamine); chief efferents: striatopallidal and striatonigral (GABA).
- ▶ Principal site of degeneration in **Huntington's disease** (chorea, "boxcar" ventricles, CAG-repeat huntingtin gene, chromosome 4).
- ▶ Implicated in OCD, ADHD and Tourette's syndrome through cortico-caudate behavioural circuits.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; Vishram Singh's Textbook of Anatomy Vol 3 4e; IB Singh's Textbook of Human Neuroanatomy; IB Singh's Textbook of Anatomy Vol 3 6e; BD Chaurasia's Human Anatomy Vol 3–4 8e; Langman's Medical Embryology (Sadler) 14e; Junqueira's Basic Histology 17e (boxcar-ventricle imaging vignette). Recent-advances section per PubMed (Heim et al., *J Neurol* 2025, PMID 41239019; Ríos-Anillo et al., *Biomedicines* 2024, PMID 39457479; Zuo et al., *Front Aging Neurosci* 2025, PMID 39949537).



Describe in detail about the Limbic system

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction The limbic system (*limbus* = border/ring) is the group of cortical and subcortical structures that form a ring around the upper end of the brainstem and the hilum of the cerebral hemisphere, interposed between the diencephalon and the neocortex. The term derives from Broca's 1877 description of the cingulate and parahippocampal gyri as the "grande lobe limbique"; because Broca believed these structures were olfactory, the whole ring was long called the **rhinencephalon** ("smell brain") — a term now abandoned since, in humans, only a small part of it is actually concerned with smell. The limbic system is the anatomical substrate for **emotion, drive, visceral integration and recent memory**, and is therefore also called the **visceral brain**.

1. Concept, cortical lamination and historical circuit

- ▶ **Allocortex** — phylogenetically the oldest cerebral cortex, three-layered, forms the hippocampus/dentate gyrus (**archicortex**) and the olfactory/piriform cortex (**paleocortex**).
- ▶ **Neocortex** — six-layered, most of the hemisphere, phylogenetically newest.
- ▶ **Juxta-allocortex (mesocortex)** — a transitional 3–6 layered ring (cingulate gyrus, parahippocampal gyrus, subiculum, entorhinal cortex, area 28) between allocortex and neocortex.
- ▶ Landmark work: **Papez (1937)** proposed the hippocampo-mammillo-thalamo-cingulate circuit for emotion; **Klüver and Bucy (1937)** described the temporal-lobeectomy behavioural syndrome; **MacLean** later coined the term "limbic system" and extended Papez's circuit to include the amygdala; **Nauta (1958)** mapped its connections further.
- ▶ Modern imaging (MRI/DTI), deep-brain stimulation and behavioural studies now allow detailed study of the human limbic system in health and disease — most classical descriptions were extrapolated from primate/rodent work.

2. Components of the limbic system

Category	Structures
Limbic lobe (cortical ring, medial hemisphere surface)	Cingulate gyrus, cingulate isthmus, parahippocampal gyrus, uncus (its rostral, in-folded part), subcallosal/paraolfactory (paraterminal + paraolfactory) gyri
Hippocampal formation	Hippocampus proper (cornu Ammonis), dentate gyrus, subicular complex (subiculum, presubiculum, parasubiculum), gyrus fasciolaris, indusium griseum with medial and lateral longitudinal striae
Subcortical nuclei	Amygdaloid nuclear complex, septal nuclei, anterior nucleus of thalamus, hypothalamus (chiefly mammillary bodies), habenular nucleus, nucleus accumbens, olfactory areas (olfactory bulb/tract, primary olfactory cortex)
Connecting fibre bundles	Fornix, mammillothalamic tract (bundle of Vicq d'Azyr), stria terminalis, ventral amygdalofugal pathway, stria medullaris thalami, medial forebrain bundle, cingulum, anterior commissure, diagonal band of Broca, alveus, fimbria

□ Fig 9.7 — Diagram showing some important afferent and efferent connections of the limbic system. (Snell — Clinical Neuroanatomy — 7e, p.331)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Medial surface of the right cerebral hemisphere with the limbic ring, labelling: **cingulate gyrus** wrapping the corpus callosum (genu–body–splenium) → **isthmus** → **parahippocampal gyrus** → **uncus**; below it the **hippocampus** and **dentate gyrus** in the floor of the inferior horn, continuing as **fimbria** → **crus of fornix** → **body of fornix** → **column of fornix**; the column ending in the **mammillary body**, connected by the **mammillothalamic tract** to the **anterior nucleus of thalamus**, which projects back to the cingulate gyrus; show the **amygdaloid body** at the tip of the temporal horn with **stria terminalis** curving posteriorly along the tail of the caudate nucleus; mark **septal area**, **anterior commissure**, **indusium griseum** with **longitudinal striae**, and **olfactory bulb/tract** anteriorly.

3. Hippocampal formation — structure

- Lies as a curved elevation in the floor of the inferior horn of the lateral ventricle; its expanded anterior end is the **pes hippocampi**; it narrows posteriorly and ends beneath the **splenium of corpus callosum**.
- Named for its seahorse-like appearance in coronal section; also called **Ammon's horn/cornu ammonis** (ram's-horn resemblance, after the ram-headed Egyptian deity Ammon).
- **Trilaminar archicortex**: superficial **molecular layer**, middle **pyramidal cell layer** (subdivided into fields CA1, CA2, CA3 — CA3 borders the dentate hilus, CA1 abuts the subiculum), and deep **polymorphic layer**.

- ▶ **CA1 (Sommer's sector)** is the most vulnerable field to hypoxia/ischaemia and the principal site of new-memory formation via long-term potentiation.
- ▶ **Dentate gyrus** — also trilaminar, but its middle layer is a **granular layer** (not pyramidal); its granule cells give **mossy fibres** to CA3.
- ▶ Ventricular surface is covered by a thin sheet of white matter, the **alveus**, whose fibres converge medially into the **fimbria**, which continues as the crus of the fornix.
- ▶ **Parahippocampal gyrus** (six-layered neocortex) → **subiculum** (transitional juxta-allocortex) → **hippocampus** (three-layered archicortex) shows a gradual laminar transition — a classic viva point.

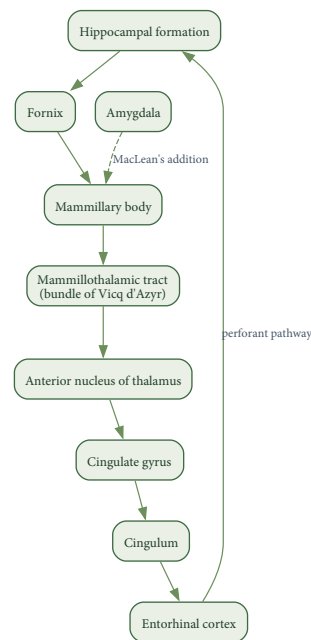
4. Connections

Structure	Afferents	Efferents
Hippocampus	Entorhinal cortex (area 28) — the major input, via the perforant pathway; cingulate gyrus; septal nuclei (via fornix); opposite hippocampus (commissure of fornix); indusium griseum via longitudinal striae	Sole efferent = fornix → mammillary body (medial nucleus), anterior nucleus of thalamus, septal nuclei/anterior hypothalamus (precommissural fibres), midbrain tegmentum, and habenular nuclei via stria medullaris thalami
Amygdala	Mainly primary olfactory cortex/olfactory bulb; also entorhinal and temporal neocortex	Stria terminalis (main tract; curves with tail of caudate to septal area, anterior hypothalamus, contralateral amygdala via anterior commissure, habenular nucleus via stria medullaris thalami) and the shorter, direct ventral amygdalofugal pathway

5. Fornix — the principal limbic outflow tract

- ▶ Origin: axons of hippocampal pyramidal cells → **alveus** → **fimbria** → **crus of fornix** (arches under splenium) → the two crura converge as the **body of fornix** (joined by the **commissure/hippocampal commissure**, which interconnects the two hippocampi) → splits anteriorly into the **columns of fornix**.
- ▶ Fibres of the column passing **behind** the anterior commissure (**postcommissural fornix**) end in the mammillary body and continue via the mammillothalamic tract to the anterior thalamic nucleus; fibres passing **in front of** it (**precommissural fornix**) end in the septal area and anterior hypothalamus.
- ▶ Uniquely among CNS fibre bundles, the fornix contains all three fibre types: **projection** (hippocampus–mammillary body), **commissural** (hippocampal commissure), and **association** (dorsal fornix fibres to the cingulate gyrus).
- ▶ **Applied point:** bilateral fornix transection (e.g. during colloid-cyst/third-ventricle surgery) produces the **acute amnesic syndrome** — inability to consolidate new (short-term) memory into long-term memory.

6. Papez circuit



Describe in detail about the Limbic system

The **circuit of Papez** begins and ends in the hippocampal formation: hippocampal formation → fornix → mammillary body → mammillothalamic tract → anterior nucleus of thalamus → cingulate gyrus → cingulum → entorhinal cortex → back to hippocampal formation. It is the anatomical substrate that links **memory and emotional expression**; MacLean's modification adds the **amygdala** as a parallel emotional-processing node.

7. Functions of the limbic system

- ▶ **Emotional behaviour** with its visceral accompaniments — especially fear, rage and sexual behaviour — serving self-preservation (feeding) and preservation of the species (mating, rearing young).
- ▶ **Memory** — the hippocampus categorises and consolidates recently acquired information ("new concepts") and correlates it with pre-existing memory before cortical storage; it is essential for converting recent (short-term) memory into long-term memory.
- ▶ **Integration of olfactory, visceral and somatic impulses** reaching the brain — visceral responses are expressed through the **hypothalamus**, now recognised as the **major output pathway of the limbic system**, acting via the autonomic and endocrine systems.
- ▶ **Special foci**: cingulate gyrus = "satisfaction centre" (post-meal/post-coital satisfaction); septal area = pleasure/reward zone (shown experimentally in animals); amygdala controls somatic responses to internal drives and, with olfactory input, smell-mediated sexual behaviour.
- ▶ No convincing evidence of a primary olfactory function for the limbic system in humans, despite its historical "rhinencephalon" label.

Applied / Clinical anatomy

- ▶ **Klüver–Bucy syndrome** — bilateral damage/ablation of the amygdala and adjacent temporal lobe (classically bilateral temporal lobectomy) causes docility, loss of fear and rage, hyperorality,

visual agnosia ("psychic blindness"), and hypersexuality (often perverse); originally described in monkeys, it is also recognised in humans after bilateral temporal lobe disease (e.g. herpes simplex encephalitis, trauma).

- ▶ **Amnesia** — bilateral hippocampal or fornix damage abolishes formation of new (anterograde) memory while remote memories, already stored diffusely in the neocortex, are preserved; combined amygdala + hippocampal injury causes greater memory loss than either alone.
- ▶ **Temporal lobe (psychomotor) epilepsy** — the hippocampus is the most epileptogenic region of the cerebral hemisphere; **hippocampal sclerosis** (loss of CA1/Sommer's-sector neurons) is the commonest pathological substrate of drug-resistant mesial temporal lobe epilepsy, and anterior temporal lobectomy/amygdalohippocampectomy is a recognised surgical cure.
- ▶ **Alzheimer's disease** — earliest and most severe neurofibrillary/atrophic change occurs in the entorhinal cortex and hippocampus (CA1 field); hippocampal and medial temporal lobe volumetry on structural MRI is a standard imaging biomarker of disease progression.
- ▶ **Schizophrenia and mood disorders** — limbic system dysfunction (hippocampal/amygdala volume change, altered cingulate–prefrontal connectivity) is implicated; **subcallosal cingulate (area 25)** deep-brain stimulation has been explored for treatment-resistant depression, and **anterior thalamic nucleus** DBS (targeting the Papez circuit) is now used for refractory epilepsy.
- ▶ **Imaging/connectomic correlates** — diffusion-tensor tractography now delineates the cingulum and fornix in vivo; resting-state fMRI shows the default-mode network overlapping substantially with limbic/paralimbic cortex — modern, non-invasive extensions of the classical gross-anatomical circuitry described above.

High-yield exam pointers

- ▶ **Limbic** = ring/border (Broca); formerly rhinencephalon — abandoned since minimal olfactory role in humans.
- ▶ Three components to enumerate: **limbic lobe** (cingulate + parahippocampal gyri + uncus), **hippocampal formation**, and **subcortical nuclei** (amygdala, septal area, anterior thalamic nucleus, mammillary body).
- ▶ **Hippocampus** = **archicortex**, 3 layers (**molecular–pyramidal–polymorphic**), fields CA1–CA3; CA1 = **Sommer's sector**, most hypoxia-sensitive and most affected in Alzheimer's disease.
- ▶ **Fornix** is the sole efferent tract of the hippocampus and the only CNS bundle containing projection + commissural + association fibres.
- ▶ **Papez circuit**: hippocampal formation → fornix → mammillary body → mammillothalamic tract → anterior thalamic nucleus → cingulate gyrus → entorhinal cortex → hippocampal formation; MacLean added the amygdala.
- ▶ **Amygdala efferents**: stria terminalis (long, curved) and ventral amygdalofugal pathway (short, direct).
- ▶ **Hypothalamus** = **major output pathway** of the limbic system to the autonomic/endocrine systems.
- ▶ **Klüver–Bucy syndrome** and **hippocampal sclerosis/temporal lobe epilepsy** are the classic clinical correlates to quote.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy.



Describe in detail the limbic system

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction

The **limbic system** is a phylogenetically ancient, functionally interconnected ring of cortical and subcortical grey-matter structures that lies in the border zone between the diencephalon (superolaterally) and the inferomedial surfaces of the two cerebral hemispheres. It comprises Broca's **limbic lobe** (cingulate gyrus, isthmus, parahippocampal gyrus, uncus) together with the **hippocampal formation**, **amygdaloid nuclear complex**, **septal area** and closely linked subcortical nuclei — the anterior thalamic nucleus, mammillary bodies of the hypothalamus and habenular nucleus. Because its major outflow is through the hypothalamus and the autonomic nervous system, it is also called the **visceral brain**; it governs **emotion**, **motivational drive**, **visceral/behavioural responses** and **recent memory**, rather than discriminative smell, for which it was originally (and now wrongly) named.

1. Terminology, definition and location

- ▶ **Limbus** = border/edge/margin. **Broca (1878)** described the cingulate and parahippocampal gyri, bounded by a common **limbic sulcus**, as the "**great limbic lobe**" forming a ring around the corpus callosum and upper brainstem.
- ▶ On phylogenetic grounds Broca linked these gyri to olfaction, and for many years the term **rhinencephalon** ("smell brain") was used synonymously with limbic lobe; this term is now obsolete — the limbic system has no proven olfactory function in man.
- ▶ The modern term **limbic system** is broader than Broca's anatomical lobe: it also includes functionally related subcortical grey matter (amygdala, septal nuclei, anterior thalamic nucleus, hypothalamus, habenular nucleus, and reticular formation) recruited into circuits of emotion, drive and memory.
- ▶ **Location**: interposed structures on the medial surface of each hemisphere, encircling the corpus callosum and diencephalon.

2. Components of the limbic system

Category	Structures
Cortical — limbic lobe	Cingulate gyrus, isthmus, parahippocampal gyrus, uncus
Cortical — hippocampal formation	Hippocampus (cornu ammonis), dentate gyrus, gyrus fasciolaris, indusium griseum with medial/lateral longitudinal striae

Category	Structures
Cortical — other	Septal area (paraterminal + parolfactory/subcallosal gyri); olfactory areas
Subcortical	Amygdaloid nuclear complex, anterior nucleus of thalamus, hypothalamus (mammillary bodies), habenular nucleus, reticular formation
Connecting fibre bundles	Alveus, fimbria, fornix, mamillothalamic tract, stria terminalis, stria medullaris thalami, cingulum, anterior commissure, medial forebrain bundle, diagonal band (of Broca)

□ Fig 9.14 — Parts of limbic system (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.588)

3. Hippocampal formation

- ▶ The **hippocampus (cornu ammonis)** is a curved elevation of archicortex on the floor of the inferior horn of the lateral ventricle, expanded anteriorly into the **pes hippocampi** and ending posteriorly beneath the splenium of the corpus callosum; in coronal section it resembles a sea-horse/ram's horn, hence "hippocampus"/"Ammon's horn."
- ▶ Structure — **three layers** (trilaminar archicortex): superficial **molecular layer**, middle **pyramidal cell layer**, deep **polymorphic layer**. The adjoining **parahippocampal gyrus** is six-layered neocortex, and the **subiculum** is the transitional (4–5 layered) zone between the two.
- ▶ The hippocampus is divided into **CA1, CA2 and CA3 fields** (CA = cornu Ammonis); CA2/CA3 border the hilus of the dentate gyrus, while **CA1 (Sommer's sector)** lies near the subiculum, is the most sensitive to hypoxia, and is the field most severely affected in **Alzheimer's disease** and in new-memory (long-term potentiation) formation.
- ▶ The **dentate gyrus** lies between the fimbria and the parahippocampal gyrus; its middle layer is a **granular layer** (not pyramidal), whose neurons project onto hippocampal pyramidal-cell dendrites.
- ▶ The ventricular surface of the hippocampus is covered by the **alveus**, whose fibres converge medially as the **fimbria**, continuing as the crus of the fornix.
- ▶ **Afferents**: entorhinal area/olfactory-related cortex, cingulate gyrus, septal nuclei (via fornix), opposite hippocampus (commissure of fornix), indusium griseum (longitudinal striae), dentate and parahippocampal gyri.
- ▶ **Efferents**: via the fornix to the mammillary body, anterior nucleus of thalamus, septal nuclei/anterior hypothalamus, midbrain tegmentum, and (via stria medullaris thalami) the habenular nuclei — the fornix is the **sole efferent pathway** of the hippocampus.

4. Amygdaloid nuclear complex and septal area

- ▶ The **amygdaloid nuclear complex (amygdala)** is an almond-shaped grey-matter mass in the temporal lobe, anterosuperior to the tip of the inferior horn of the lateral ventricle, fused posteriorly with the tip of the tail of the caudate nucleus; it is grouped into a larger **basolateral** and a smaller **corticomedial** nuclear group.
- ▶ **Afferents**: primary olfactory cortex, hippocampus, hypothalamus, thalamus (medial dorsal nucleus), cerebral cortex and brainstem reticular formation.

- **Efferents** — two major routes: the **stria terminalis** (main efferent tract, running with the tail of caudate to the septal area, anterior hypothalamus and, via stria medullaris thalami, the habenular nuclei) and the **ventral amygdalofugal pathway**.
- **Function**: control of emotional behaviour (fear, rage), and — through olfactory input — smell-mediated sexual behaviour; stimulation produces fear/rage, bilateral destruction reduces fear and increases sexual activity (basis of Klüver–Bucy syndrome, below).
- The **septal area**, on the medial frontal lobe beneath the genu/rostrum of corpus callosum, receives the olfactory tract (medial olfactory stria), amygdala (stria terminalis) and hippocampus (fornix), and projects mainly to the habenular nuclei; it has been shown to be a **pleasure/reward zone** in animal self-stimulation experiments.

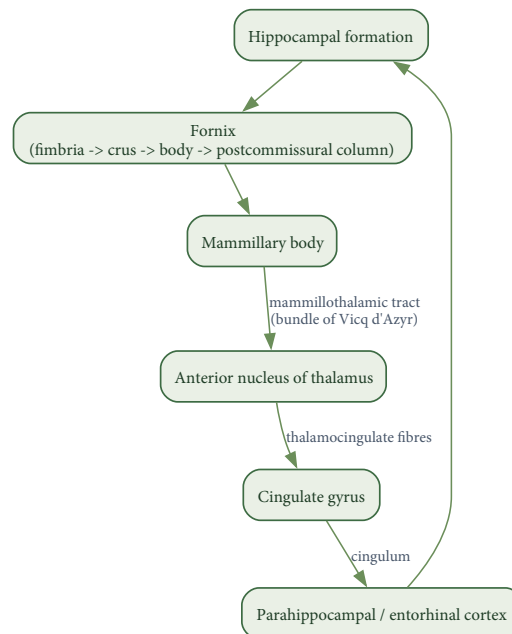
5. Fibre bundles (connecting pathways) of the limbic system

Bundle	Course / connection
Alveus → fimbria	Hippocampal efferents converge on its ventricular surface, collect medially as the fimbria
Fornix (crus → body → columns)	Fimbria continues as crus of fornix beneath the splenium; the two crura unite (connected by the commissure of the fornix) as the body, which splits into pre- and postcommissural columns ending in the septal area/anterior hypothalamus and mammillary body respectively
Mammillothalamic tract (bundle of Vicq d'Azyr)	Mammillary body → anterior nucleus of thalamus
Stria terminalis	Amygdala → septal area, hypothalamus, habenular nuclei
Stria medullaris thalami	Septal area/amygdala → habenular nuclei
Cingulum	Within the cingulate gyrus, linking it to the parahippocampal/entorhinal cortex
Indusium griseum + longitudinal striae	Vestigial grey matter over the corpus callosum, continuous with dentate gyrus/hippocampus
Anterior commissure	Interconnects olfactory structures and anterior temporal lobes of the two sides
Medial forebrain bundle; diagonal band of Broca	Link septal area/olfactory structures with hypothalamus and midbrain

□ Fig 9.3 — Medial aspect of the right cerebral hemisphere showing structures that form the limbic system (Snell — Clinical Neuroanatomy — 7e, p.328)

6. Papez circuit

- Described by **Papez (1937)**, this closed circuit begins and ends at the hippocampal formation and is the principal anatomical substrate for **memory and emotion**:



Describe in detail the limbic system

- **Modified Papez circuit (MacLean):** adds the **amygdala** as a parallel node, integrating emotional tone with the hippocampal memory loop.

7. Functions of the limbic system

- Integration of olfactory, visceral and somatic impulses reaching the brain.
- Control of activities necessary for survival of the individual — feeding/procuring-food behaviour.
- Control of activities necessary for survival of the species — sexual behaviour.
- Emotional behaviour — fear, rage, pleasure — expressed viscerally through the hypothalamus and autonomic outflow (hence "visceral brain").
- Retention of **recent memory** and its consolidation into long-term memory (hippocampus).
- No proven role in the special sense of smell itself, despite the historical "rhinencephalon" label.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce a medial (sagittal) view of the right cerebral hemisphere and label: cingulate gyrus, corpus callosum, septum pellucidum, indusium griseum with medial and lateral longitudinal striae, body/crus/column of fornix, anterior commissure, anterior nucleus of thalamus, mammillothalamic tract, mammillary body, habenular nuclei region, stria medullaris thalami, stria terminalis, fimbria, hippocampus, dentate gyrus, parahippocampal gyrus, uncus, amygdaloid body, olfactory bulb and tract, frontal/temporal/occipital lobes.

Applied / Clinical anatomy

- **Klüver–Bucy syndrome** — bilateral temporal lobectomy (amygdala + adjacent hippocampus) in monkeys produces docility, loss of fear/rage, visual agnosia, hyperphagia and hypersexuality; described occasionally in humans after bilateral temporal lobe destruction.

- ▶ **Amnesia** — hippocampal or bilateral fornix lesions abolish formation of new (recent) memory (**anterograde amnesia**/"acute amnesic syndrome") while remote memory, already stored diffusely in the cerebral cortex, is preserved; combined amygdala + hippocampus injury causes greater memory loss than either alone.
- ▶ **Korsakoff's psychosis** — memory defect with confabulation in chronic alcoholism; anatomical basis is damage to the anterior thalamic nucleus/mammillary bodies, key relay stations of the Papez memory circuit.
- ▶ **Alzheimer's disease** — degenerative loss of neurons in the hippocampus (especially the CA1/Sommer sector) and cerebral cortex, with reduced cholinergic input, producing progressive amnesia and disorientation.
- ▶ **Temporal lobe (psychomotor) epilepsy** — the hippocampus is the most epileptogenic part of the cerebral hemisphere; seizures may be preceded by an olfactory or gustatory aura followed by automatisms and post-ictal amnesia for the event.
- ▶ **Schizophrenia** — chronically disordered thinking, blunted affect and hallucinations are linked to dysregulated limbic dopamine transmission; antipsychotics act partly by blocking limbic dopamine receptors.
- ▶ **Septal area** — reward/pleasure zone on animal self-stimulation studies; cingulate gyrus is described as a "satisfaction centre."

Recent advances

- ▶ Diffusion-tensor tractography has produced an anatomical update to the classical five-structure Papez loop — the **cortico-limbo-thalamo-cortical circuit** — incorporating the prefrontal/orbitofrontal cortex, septal region, amygdalae and anterior temporal lobes as additional interconnected nodes of the human memory-emotion network (Kamali et al., *Brain Topography*, 2023) [DOI: 10.1007/s10548-023-00955-y].
- ▶ Multi-echo resting-state fMRI shows that the orbitofrontal and anterior temporal cortex ("limbic network") are not a functionally separate system but form part of an **extended default-mode network**, refining how limbic connectivity is mapped non-invasively in living subjects (Girn et al., *Network Neuroscience*, 2024) [DOI: 10.1162/netna00385].
- ▶ Intracranial recordings demonstrate **functional specialisation and bidirectional low-frequency coupling between the amygdala and hippocampus** during working-memory encoding and maintenance, refining the classic afferent/efferent scheme into a dynamic, task-dependent circuit (Li et al., *Nature Communications*, 2023) [DOI: 10.1038/s41467-023-38571-w].
- ▶ **Non-invasive temporal-interference (TI) electrical stimulation** can now focally modulate the human hippocampus without penetrating electrodes, opening a route to study/modulate limbic memory circuitry (e.g. in epilepsy and memory disorders) without stereotactic surgery (Violante et al., *Nature Neuroscience*, 2023) [DOI: 10.1038/s41593-023-01456-8].
- ▶ (*According to PubMed/indexed literature.*)

High-yield exam pointers

- ▶ Limbic lobe (Broca, 1878) = cingulate gyrus + isthmus + parahippocampal gyrus + uncus; "rhinencephalon" is an obsolete synonym.

- ▶ Hippocampal formation = hippocampus + dentate gyrus + gyrus fasciolaris + indusium griseum + longitudinal striae.
- ▶ Hippocampus = trilaminar archicortex (molecular, pyramidal, polymorphic); fields CA1 (Sommer's sector, Alzheimer-vulnerable)–CA3; fornix is its sole efferent pathway.
- ▶ Amygdala nuclear groups = basolateral + corticomедial; main efferent = stria terminalis (+ ventral amygdalofugal pathway).
- ▶ Papez circuit (1937): hippocampus → fornix → mammillary body → mammillothalamic tract → anterior thalamic nucleus → cingulate gyrus → cingulum → parahippocampal gyrus → hippocampus; MacLean's modification adds the amygdala.
- ▶ Functions: visceral/emotional integration ("visceral brain"), feeding and sexual behaviour, recent memory — no proven olfactory function.
- ▶ Klüver–Bucy syndrome (bilateral amygdala/temporal lobe loss) vs Korsakoff's psychosis (mammillary body/anterior thalamus) vs Alzheimer's (hippocampal CA1) — classic clinico-anatomic triad to differentiate.
- ▶ Septal area = pleasure/reward zone; cingulate gyrus = "satisfaction centre."

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e (figure). Recent-advances section per indexed literature/PubMed (see DOIs above).



Describe the areas of brain involved in parkinsonism disorder

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction Parkinsonism is a hypokinetic movement disorder arising from dysfunction of the **basal ganglia–thalamocortical motor circuit**, most commonly due to degeneration of dopaminergic neurons of the **substantia nigra pars compacta (SNc)**. The basal nuclei — corpus striatum, globus pallidus, substantia nigra and subthalamic nucleus — normally cooperate through parallel "direct" and "indirect" pathways to plan and smooth voluntary movement. Loss of nigrostriatal dopamine unbalances these pathways, so that the disease, though clinically expressed at the level of movement, is anatomically a disorder of a defined chain of subcortical grey-matter structures. This answer describes those structures, their connections, and how their imbalance produces the cardinal features of Parkinsonism.

1. Components of the Basal Ganglia (anatomical substrate)

Structure	Location / Description
Corpus striatum	Lateral to the thalamus; divided by the internal capsule into caudate nucleus + lentiform nucleus

Structure	Location / Description
Caudate nucleus	Comma/tadpole-shaped; head, body and tail follow the curve of the lateral ventricle; continuous anteriorly with putamen
Lentiform nucleus	Biconvex, wedge-shaped mass beneath the insula; split by the external medullary lamina into putamen (lateral, darker) and globus pallidus (medial, paler)
Globus pallidus (pallidum)	Subdivided by the internal medullary lamina into external segment (GPe) and internal segment (GPi)
Clastrum	Thin sheet of grey matter between putamen and insula; connections/function not established
Amygdaloid body	Continuous with the tip of the tail of caudate nucleus; developmentally a basal nucleus but functionally part of the limbic system
Substantia nigra (midbrain, functionally included)	Pars compacta — melanin-pigmented dopaminergic (A9) neurons; pars reticulata — GABAergic output neurons, functionally homologous to GPi
Subthalamic nucleus (diencephalon, functionally included)	Small biconvex nucleus ventral/medial to the thalamus, separated from it by the zona incerta; reciprocally connected to GPe via the subthalamic fasciculus

Phylogenetically the putamen + caudate form the **neostriatum (striatum)** — the receptive/afferent part — while the globus pallidus is the **paleostriatum (pallidum)** — the efferent/output part.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Real captioned plate — reproduce and label by hand:

embed: ![Fig 12.1 — Coronal section of cerebrum showing basal nuclei (IB Singh — Textbook of Human Neuroanatomy, p.206)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/cfefc8986d063c37.jpg)

Coronal section through the cerebrum at the level of the basal nuclei — label exactly:

- ▶ Longitudinal cerebral fissure and cerebral cortex
- ▶ Corpus callosum
- ▶ Caudate nucleus (projecting into the lateral ventricle)
- ▶ Claustrum
- ▶ Lentiform nucleus (putamen + globus pallidus)
- ▶ Amygdaloid nucleus
- ▶ Internal capsule (separating caudate/thalamus from lentiform nucleus)
- ▶ Thalamus
- ▶ Subthalamic nucleus
- ▶ Substantia nigra

2. Connections of the Corpus Striatum

Afferent (into striatum)	Source / Detail
Corticostriate fibres	Wide areas of ipsilateral cerebral cortex, via internal and external capsules
Thalamostriate fibres	Mediodorsal, intralaminar and midline thalamic nuclei — mostly to caudate nucleus
Nigrostriate fibres	Dopaminergic neurons of SNc → putamen and caudate nucleus (the pathway lost in Parkinsonism)

Efferent (from striatum)	Destination / Detail
Striatopallidal — direct pathway	Striatum → internal pallidum (GPi) directly; GABA + substance P/dynorphin
Striatopallidal — indirect pathway	Striatum → external pallidum (GPe); GABA + enkephalin
Striatonigral fibres	Striatum → substantia nigra pars reticulata

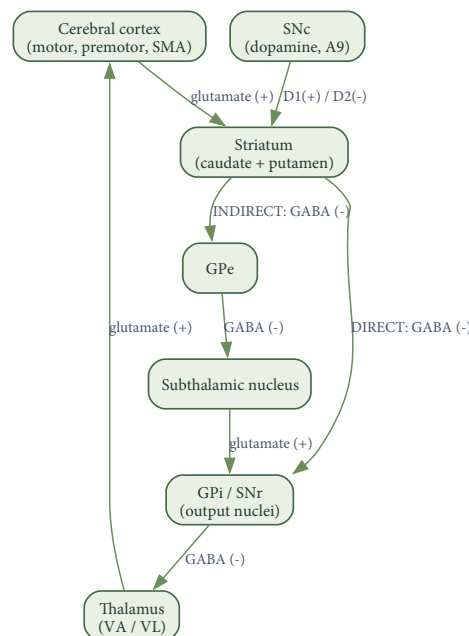
Output of the globus pallidus (the main efferent centre of the corpus striatum) reaches the thalamus via two fasciculi — the **ansa lenticularis** (looping around the internal capsule) and the **fasciculus lenticularis** (piercing it) — which join the dentatorubrothalamic fibres to form the **thalamic fasciculus**, ending in the **ventral anterior and ventral lateral (VA/VL) thalamic nuclei**; these in turn project to the

motor and premotor cortex. The **subthalamic fasciculus** provides the reciprocal GPe–subthalamic nucleus connection.

3. The Nigrostriatal Dopaminergic Pathway

- ▶ SNc neurons (dopaminergic cell group A9) send the **nigrostriatal (mesostriatal)** pathway to the caudate nucleus and putamen, traversing the H fields of Forel and the medial forebrain bundle.
- ▶ **Melanin** seen grossly in the substantia nigra is a by-product of dopamine metabolism — its loss explains the gross pallor of the SNc in Parkinson's disease.
- ▶ Dopamine has a **dual, receptor-specific action** on striatal medium spiny neurons: it **excites** direct-pathway neurons (D1 receptors) and **inhibits** indirect-pathway neurons (D2 receptors). This dual action is the anatomical key to the pathophysiology below.

4. Basal Ganglia Circuitry — Direct and Indirect Pathways (normal physiology)



Describe the areas of brain involved in parkinsonism disorder

- ▶ **Direct pathway** (striatum → GPi/SNr): inhibits the already-inhibitory GPi/SNr output, thereby **disinhibiting** the thalamus → net **facilitation** of movement.
- ▶ **Indirect pathway** (striatum → GPe → STN → GPi/SNr): inhibits GPe, disinhibiting STN, whose glutamatergic drive **excites** GPi/SNr → net **suppression** of movement via increased thalamic inhibition.
- ▶ Normally the two pathways are balanced by dopamine, allowing wanted movements to be selected and unwanted ones suppressed.

5. Pathophysiology — Areas Involved in Parkinsonism

The primary lesion is **degeneration of dopaminergic neurons of the substantia nigra pars compacta**, with consequent severe depletion of dopamine at its striatal terminals (striatal dopamine receptors themselves are spared).

Structure	Change in Parkinsonism	Consequence
Substantia nigra pars compacta	Neuronal degeneration; loss of nigrostriatal dopamine	Removes dual D1/D2 modulation of striatum
Direct pathway (striato-pallidal, to GPi/SNr)	Underactive (loss of D1 excitation)	Fails to inhibit GPi/SNr
Indirect pathway (striato-pallidal, to GPe)	Overactive (loss of D2 inhibition)	Excess inhibition of GPe
External globus pallidus (GPe)	Inhibited (underactive)	Disinhibits subthalamic nucleus
Subthalamic nucleus	Overactive	Excess glutamatergic drive to GPi/SNr
Internal globus pallidus / SN pars reticulata (GPi/SNr)	Overactive output (from both underactive direct and overactive indirect/STN input)	Excess GABAergic inhibition of thalamus
Thalamus (VA/VL)	Overinhibited	Reduced thalamocortical excitatory drive
Motor/supplementary motor cortex	Underdriven	Akinesia, bradykinesia, rigidity
Pedunculopontine nucleus	Inhibited by overactive GABAergic GPi/SNr efferents	Contributes to gait, posture and locomotor disturbance

Thus the areas of the brain classically involved in Parkinsonism form a single functional chain: **substantia nigra pars compacta** → **corpus striatum** (caudate + putamen) → **globus pallidus** (external and internal segments) → **subthalamic nucleus** → **thalamus** (VA/VL) → **motor cortex**, with the **pedunculopontine nucleus** additionally implicated in gait/postural components. This model, though a simplification (the "pallidotomy paradox" shows lesioning an overactive GPi can also relieve symptoms), underlies both the clinical features and the rational surgical targets described below.

Applied / Clinical anatomy

- **Cardinal features** (4 cardinal signs): resting ("pill-rolling") **tremor** diminished by voluntary movement; **cogwheel/lead-pipe rigidity**; **bradykinesia** (slowness, reduced arm-swing, micrographia, difficulty rising from a chair); **postural instability** with stooped posture and shuffling, festinant gait; mask-like facies.
- **Contrasting lesion** — **hemiballismus**: destruction of the subthalamic nucleus (e.g. lacunar infarct) produces violent, flinging involuntary movements of the **contralateral** limbs — the opposite functional derangement (STN underactivity) to that of Parkinsonism (STN overactivity), and a useful examiner's comparison.
- **MPTP model**: the neurotoxin MPTP selectively destroys SNc dopaminergic neurons in primates, reproducing parkinsonian signs and experimentally validating the nigrostriatal degeneration model.
- **Medical treatment**: levodopa (L-DOPA, the dopamine precursor) or dopamine agonists restore striatal dopaminergic tone; long-term use may cause **levodopa-induced dyskinesias**,

mechanistically explained by an overactive direct/underactive indirect pathway (a mirror-image imbalance resembling Huntington's disease and ballism).

- ▶ **Functional neurosurgery (recent advances):** lesioning or deep-brain stimulation (DBS) of the **subthalamic nucleus** and the **posteroventral internal globus pallidus** relieves rigidity, bradykinesia and tremor; pallidal stimulation is additionally effective against dyskinesias; **pedunculopontine nucleus DBS** is a more recent target used for drug-resistant gait freezing and postural instability. Tremor alone responds best to stimulation of the ventral intermediate thalamic nucleus or zona incerta.
- ▶ **Radiological correlate:** MRI localisation of DBS electrodes within the subthalamic nucleus or globus pallidus is now a standard pre- and post-operative imaging application in functional neurosurgery.

High-yield exam pointers

- ▶ Corpus striatum = caudate nucleus + lentiform nucleus (putamen + globus pallidus); functionally, basal ganglia also include the **substantia nigra** and **subthalamic nucleus**.
- ▶ **Striatum** = receptive/input part; **globus pallidus (and SNr)** = efferent/output part of the basal ganglia.
- ▶ Parkinsonism results from degeneration of **dopaminergic neurons of the SNc**, depleting dopamine in the corpus striatum via the nigrostriatal pathway.
- ▶ Dopamine action on striatum is dual: **excites** the direct pathway (D1) and **inhibits** the indirect pathway (D2).
- ▶ In Parkinsonism: **direct pathway underactive + indirect pathway overactive** → overactive GPi/SNr output → **overinhibited thalamus** → akinesia, rigidity, tremor.
- ▶ **Subthalamic nucleus destruction** causes contralateral **hemiballismus** — a useful contrast lesion.
- ▶ Surgical/DBS targets: **subthalamic nucleus** and **posteroventral GPi** for rigidity/bradykinesia/tremor; **pallidal stimulation** for dyskinesia; **pedunculopontine nucleus** for gait/postural symptoms.
- ▶ Melanin in the substantia nigra is a by-product of dopamine metabolism — explains its gross pallor in Parkinson's disease.
- ▶ 4 cardinal features: resting tremor, rigidity, bradykinesia, postural instability.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Clinical Neuroanatomy 4e; IB Singh — Textbook of Human Neuroanatomy.



Describe the Basal nuclei in detail

Asked in: Paper IV Nov 2016 — RGUHS MD/MS Anatomy

Definition / Introduction The basal nuclei (basal ganglia) are large masses of grey matter that develop from the telencephalon and lie buried in the white matter of each cerebral hemisphere, situated lateral to the thalamus in close relation to the internal capsule. Anatomically the term includes the **corpus striatum** (caudate nucleus + lentiform nucleus), the **claustrum** and the **amygdaloid nuclear complex**; the **subthalamic nucleus** (diencephalon) and the **substantia nigra** (midbrain) are functionally, though not anatomically, integrated with this system and are conventionally described along with it. The basal nuclei have no direct afferent or efferent connection with the spinal cord — they influence movement only indirectly, through feedback loops relayed via the thalamus back to the cerebral cortex — so lesions here produce disorders of movement, tone and posture (dyskinesias), never a flaccid paralysis.

1. Terminology and components

Term	Composition
Corpus striatum	Caudate nucleus + lentiform nucleus
Neostriatum (striatum)	Caudate nucleus + putamen
Paleostriatum (pallidum)	Globus pallidus
Lentiform (lenticular) nucleus	Putamen (lateral) + globus pallidus (medial)
Archistriatum (phylogenetically oldest)	Amygdaloid nuclear complex + claustrum
Basal nuclei (classical)	Corpus striatum + claustrum + amygdaloid nuclear complex
Functionally linked but not part of the basal nuclei proper	Subthalamic nucleus, substantia nigra

- ▶ The **claustrum** is a thin sheet of grey matter between the putamen and the insula; its function is unknown.
- ▶ The **amygdaloid nuclear complex** lies in the temporal lobe deep to the uncus, fused with the tip of the tail of the caudate nucleus; it is functionally part of the limbic system rather than the motor basal-nuclei circuitry.
- ▶ A **ventral striatum** (nucleus accumbens + olfactory tubercle) and **ventral pallidum** (part of globus pallidus below the anterior commissure) are recognised; these connect with the limbic lobe and mediate the rewarding effects of addictive drugs (mesolimbic dopamine system).

2. Gross anatomy — caudate nucleus and lentiform nucleus

Caudate nucleus

- ▶ A large, C ("comma")-shaped mass of grey matter, closely moulded to the lateral ventricle, divided into a head, body and tail.
- ▶ **Head** — large and rounded; forms the floor and lateral wall of the **anterior horn of the lateral ventricle**; continuous inferiorly with the putamen (region of fusion = **fundus striati**, continuous with the anterior perforated substance).

- ▶ **Body** — long and narrow; forms part of the floor of the **body of the lateral ventricle**.
- ▶ **Tail** — long and slender; curves into the roof of the **inferior horn of the lateral ventricle** in the temporal lobe and ends anteriorly by fusing with the **amygdaloid nucleus**.
- ▶ Medially related to the thalamus along the sulcus terminalis, which carries the **stria terminalis** and the **thalamostriate vein**; laterally related to the internal capsule, which separates it from the lentiform nucleus.

Lentiform (lenticular) nucleus

- ▶ Wedge-shaped in coronal section, with its broad convex base directed laterally and its blade directed medially; lies deep to the insular cortex.
- ▶ Divided by the **external medullary lamina** into a larger, darker lateral part, the **putamen**, and a smaller, paler medial part, the **globus pallidus** (pale because of a high density of myelinated fibres).
- ▶ The globus pallidus is further subdivided by the **internal medullary lamina** into an **external (lateral) segment** and an **internal (medial) segment**; the two segments have distinct afferent and efferent connections.
- ▶ Relations, medial to lateral: internal capsule (separating it from the caudate nucleus and thalamus) → globus pallidus → putamen → **external capsule** → **claustrum** → **extreme capsule** → insula.
- ▶ Inferiorly the putamen is continuous with the head of the caudate nucleus; the anterior perforated substance and the anterior commissure groove the base of the lentiform complex.

□ Fig 12.1 — Coronal section of cerebrum showing basal nuclei (IB Singh — Textbook of Human Neuroanatomy, p.206)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A coronal section through the cerebrum at the level of the third ventricle, labelled with:

- ▶ **Longitudinal cerebral fissure and cerebral cortex**
- ▶ **Corpus callosum**
- ▶ **Caudate nucleus** (body, abutting the lateral ventricle)
- ▶ **Thalamus**
- ▶ **Internal capsule** (separating caudate/thalamus from the lentiform nucleus)
- ▶ **Lentiform nucleus** — subdivide into **putamen** (lateral) and **globus pallidus** (medial)
- ▶ **External capsule, claustrum, extreme capsule, insula** (lateral to the lentiform nucleus, in that order)
- ▶ **Subthalamic nucleus and substantia nigra** (below the thalamus, for orientation)
- ▶ **Amygdaloid nucleus** (in the temporal lobe, for orientation)

3. Connections of the corpus striatum

The caudate nucleus and putamen (the striatum) form the principal **input** site of the basal nuclei; the globus pallidus (with the substantia nigra pars reticularis) forms the principal **output** site.

Afferent fibres to the striatum

Fibres	Source	Neurotransmitter
Corticostriate	Entire cerebral cortex (mainly sensorimotor cortex; layers V–VI)	Glutamate (excitatory)
Thalamostriate	Intralaminar nuclei of the thalamus (centromedian)	Glutamate
Nigrostriate	Substantia nigra, pars compacta	Dopamine (modulatory)
Brainstem-striatal	Raphe nuclei (serotonin), locus coeruleus (noradrenaline)	Serotonin / noradrenaline

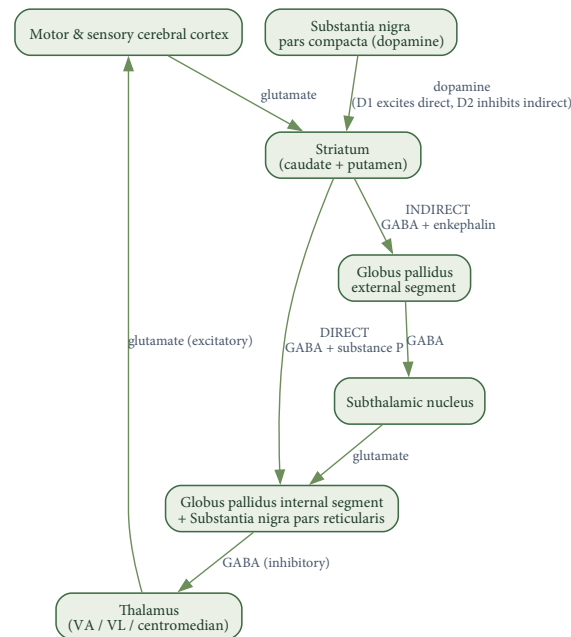
Efferent fibres from the striatum

Fibres	Destination	Neurotransmitter
Striatopallidal — to external segment	Globus pallidus (external)	GABA + enkephalin — "indirect pathway"
Striatopallidal — to internal segment	Globus pallidus (internal)	GABA + substance P — "direct pathway"
Striatonigral	Substantia nigra, pars reticularis	GABA, acetylcholine or substance P

Pallidofugal (efferent) fibres from the globus pallidus travel as four bundles — the **ansa lenticularis** (curves round the anterior border of the internal capsule), the **fasciculus lenticularis** (pierces the internal capsule directly), the **pallidotegmental** fibres (to the midbrain tegmentum) and the **pallidosubthalamic** fibres (to the subthalamic nucleus). The ansa and fasciculus lenticularis unite in the subthalamic region (creating the **H-fields of Forel**) to form the **thalamic fasciculus**, which ends in the **ventral anterior (VA)**, **ventral lateral (VL)** and **centromedian** nuclei of the thalamus; these relay, in turn, to the premotor and supplementary motor cortex — completing the cortico-striato-pallido-thalamo-cortical loop.

4. Functional circuitry — direct and indirect pathways

The basal nuclei form a closed loop: the cerebral cortex excites the striatum, the striatum's outflow (via the pallidum) is channelled back to the thalamus and thence to the motor cortex, which then acts on the spinal cord through the corticospinal tract — the basal nuclei themselves never act on the cord directly.



Describe the Basal nuclei in detail

- The **direct pathway** (striatum → GPi/SNr → thalamus) is net-facilitatory: it disinhibits the thalamus and so promotes the desired movement; dopamine (via D1 receptors) excites this pathway.
- The **indirect pathway** (striatum → GPe → subthalamic nucleus → GPi/SNr → thalamus) is net-inhibitory: it suppresses unwanted movement; dopamine (via D2 receptors) inhibits this pathway.
- Normal movement requires a balance between the two; loss of striatal dopamine (Parkinson disease) overactivates the indirect pathway and underactivates the direct pathway, producing akinesia and rigidity, while degeneration of the indirect-pathway striatal neurones (Huntington disease) has the opposite, hyperkinetic effect.

5. Blood supply of the basal nuclei

Structure	Artery
Caudate nucleus, putamen, globus pallidus (bulk)	Lateral striate arteries — central branches of the proximal (M1) segment of the middle cerebral artery; the largest is Charcot's artery of cerebral haemorrhage
Anterior limb & genu of internal capsule, head of caudate nucleus	Medial striate artery (recurrent artery of Heubner) — a recurrent branch of the anterior cerebral artery/anterior communicating artery (anteromedial group)
Tail of caudate nucleus, part of globus pallidus, posterior limb of internal capsule	Anterior choroidal artery — from the internal carotid artery
Thalamus, subthalamic nucleus, substantia nigra	Posteromedial and posterolateral central branches of the posterior cerebral, posterior communicating and basilar arteries

6. Functions of the basal nuclei

- ▶ Maintenance of **muscle tone** and **posture**, including the automatic swinging of the arms during walking.
- ▶ **Preparation and initiation** of voluntary movement — pallidal neurones fire before the motor cortex activates discrete distal-limb movements, positioning the trunk and proximal limb in readiness.
- ▶ **Smoothing** of ongoing voluntary movement and learning of skilled motor sequences (writing, speaking, throwing).
- ▶ **Suppression of unwanted movement** via the indirect pathway, allowing selection of the intended motor programme.
- ▶ Contribution, through the ventral striatum/nucleus accumbens, to motivation, reward and addictive behaviour.

Applied / Clinical anatomy

- ▶ **Parkinson disease (paralysis agitans)**: degeneration of dopaminergic neurones of the substantia nigra pars compacta depletes striatal dopamine, producing the classic triad — resting ("pill-rolling") **tremor**, cogwheel/plastic **rigidity** and **bradykinesia** — with a stooped, shuffling gait and mask-like facies. Treated medically with **levodopa** (dopamine cannot cross the blood–brain barrier) and, in advanced disease, with **deep-brain stimulation** of the subthalamic nucleus or internal globus pallidus, or stereotactic **pallidotomy**.
- ▶ **Huntington disease**: an autosomal-dominant disorder (chromosome 4, expanded CAG repeat in the huntingtin gene) with degeneration of GABA/enkephalin-secreting striatopallidal (indirect-pathway) neurones and consequent atrophy of the caudate nucleus (seen as enlarged lateral ventricles on CT); presents with chorea (rapid, jerky, involuntary movements) and progressive dementia.
- ▶ **Sydenham chorea (St Vitus' dance)**: a self-limiting, childhood chorea following rheumatic fever, due to antibody cross-reaction with striatal neuronal membranes; full recovery is the rule.
- ▶ **Hemiballismus**: sudden, violent, flinging movements of the proximal limb on one side, caused by a vascular lesion of the **contralateral subthalamic nucleus** or its connections.
- ▶ **Athetosis**: slow, sinuous, writhing movements of the distal limbs, associated with degeneration of the globus pallidus.
- ▶ **Wilson disease (hepatolenticular degeneration)**: an autosomal-recessive disorder of copper metabolism causing degeneration of the **lentiform nucleus** and hepatic copper deposition, with **Kayser–Fleischer rings** (copper deposits at the corneoscleral limbus) as the classic ocular sign.
- ▶ **Drug-induced parkinsonism**: dopamine (D2) receptor-blocking drugs (phenothiazines, butyrophenones) produce a reversible parkinsonian state by the same mechanism.
- ▶ **Vascular lesions**: thrombosis of the artery of Heubner causes contralateral faciobrachial monoplegia; rupture of a lateral striate (lenticulostriate) artery — Charcot's artery — is the classic cause of hypertensive basal ganglia haemorrhage.

High-yield exam pointers

- ▶ Corpus striatum = caudate nucleus + lentiform nucleus; neostriatum = caudate + putamen; lentiform nucleus = putamen + globus pallidus.
- ▶ Caudate nucleus is C-shaped (head/body/tail), moulded to the lateral ventricle throughout its length; tail ends in the amygdaloid nucleus. Lentiform nucleus is wedge-shaped: external medullary lamina separates putamen from globus pallidus, internal medullary lamina divides globus pallidus into external/internal segments.
- ▶ Striatum = input structure (afferents: corticostriate–glutamate, nigrostriate–dopamine, thalamostriate–glutamate); globus pallidus internal segment + substantia nigra pars reticularis = output structure, via the thalamic fasciculus to VA/VL/centromedian thalamic nuclei.
- ▶ Direct pathway facilitates movement; indirect pathway (via subthalamic nucleus) suppresses movement — both use GABA as the striatal efferent transmitter, distinguished by co-transmitter (substance P vs enkephalin).
- ▶ Blood supply: lateral striate arteries (MCA) and medial striate/Heubner's artery (ACA) supply the bulk of the corpus striatum; anterior choroidal artery (ICA) supplies the tail of caudate and part of the pallidum.
- ▶ Basal nuclei have **no direct spinal connection** — lesions cause dyskinesia (Parkinson disease, chorea, athetosis, ballismus), never a corticospinal-type paralysis.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell — Clinical Neuroanatomy, 7e; IB Singh — Textbook of Human Neuroanatomy; Vishram Singh — Clinical Neuroanatomy, 4e; BD Chaurasia — Human Anatomy Vol 3–4, 8e.



Describe the gross anatomy and applied anatomy of basal nuclei

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction The **basal nuclei (basal ganglia)** are large, paired subcortical masses of grey matter embedded in the white core of each cerebral hemisphere, developing from the telencephalon. Anatomically they comprise the **corpus striatum** (caudate nucleus + lentiform nucleus), the **claustrum**, and the **amygdaloid body**; functionally the **subthalamic nucleus** and **substantia nigra** are also grouped with them because of their intimate connections. They form the principal grey-matter component of the **extrapyramidal system**, regulating muscle tone, posture and the smoothness/automaticity of voluntary movement — their lesions therefore produce characteristic **dyskinesias** rather than paralysis.

1. Components and terminology

Anatomical group	Constituents
Corpus striatum	Caudate nucleus + lentiform nucleus (putamen + globus pallidus)

Anatomical group	Constituents
Clastrum	Thin sheet of grey matter lateral to the lentiform nucleus
Amygdaloid body	Almond-shaped mass in the temporal lobe (functionally part of the limbic system)
Functionally included	Subthalamic nucleus (diencephalic) and substantia nigra (midbrain)

Phylogenetic/functional subdivision:

Term	Structures	Note
Neostriatum (striatum)	Caudate nucleus + putamen	Recent in development; largely afferent/receptive
Paleostriatum (pallidum)	Globus pallidus	Phylogenetically older; largely efferent
Archistriatum	Amygdaloid body + claustrum	Oldest, related to the limbic system
Ventral striatum	Nucleus accumbens + olfactory tubercle	Below the fundus striati; part of the mesolimbic dopamine/reward system
Ventral pallidum	Part of globus pallidus below the anterior commissure	Connects ventral striatum to limbic cortex via thalamus

2. Caudate nucleus

- ▶ A C-shaped (comma-shaped) mass of grey matter with a **head, body and tail**, intimately related throughout its length to the **lateral ventricle**.
- ▶ **Head** — large and rounded; bulges into and forms the floor/lateral wall of the **anterior horn** of the lateral ventricle; fused inferiorly with the lentiform nucleus (**fundus striati**), continuous below with the **anterior perforated substance**.
- ▶ **Body** — forms the floor of the **central part** of the lateral ventricle; related medially to the **thalamus** (separated by the **stria terminalis** and **thalamostriate vein**) and laterally to the **internal capsule**, which separates it from the lentiform nucleus.
- ▶ **Tail** — long and slender; forms the **roof of the inferior horn** of the lateral ventricle; curves forward to become continuous with the **amygdaloid body** at the temporal pole.

3. Lentiform nucleus

- ▶ A large, wedge-shaped (biconvex) mass lying **lateral to the internal capsule**, beneath the insula.
- ▶ **Three surfaces and relations:**

Surface	Relation
Lateral	Convex; separated from the claustrum by the external capsule ; grooved by the lateral striate (lenticulostriate) branches of the middle cerebral artery

Surface	Relation
Medial	More convex; related to the internal capsule (limbs and genu), which separates it from the caudate nucleus and thalamus
Inferior	Related to the sublentiform part of the internal capsule ; close to the anterior perforated substance and grooved by the anterior commissure

- **Parts** — divided by the **external (lateral) medullary lamina** into a larger lateral **putamen** (darker, small densely-packed cells, structurally similar to caudate) and a smaller medial **globus pallidus** (paler, large motor cells), which is further subdivided by the **internal (medial) medullary lamina** into **outer and inner segments**.
- **Lateral-to-medial order** across the hemisphere at this level: insula → **extreme capsule** → **claustrum** → **external capsule** → **putamen** → **globus pallidus** → **internal capsule** → **thalamus/caudate nucleus**.

□ Fig 12.6 — Horizontal section of cerebrum to show the basal nuclei (IB Singh — Textbook of Human Neuroanatomy, p.208)

4. Claustrum and amygdaloid body

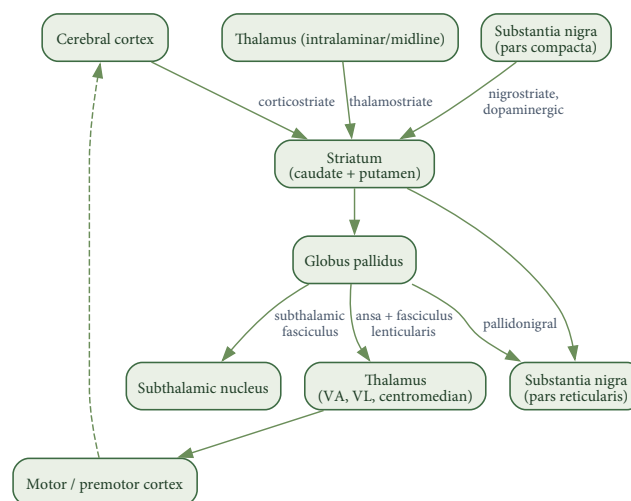
- **Claustrum** — a thin lamina of grey matter lying between the putamen and the insular cortex, separated from the lentiform nucleus by the external capsule and from the insula by the extreme capsule; considered functionally related to the limbic system; its connections are otherwise poorly defined.
- **Amygdaloid body (amygdala)** — lies in the temporal lobe, deep to the **uncus**, anterosuperior to the tip of the **inferior horn of the lateral ventricle**; topographically continuous with the tail of the caudate nucleus but functionally part of the **limbic system**. Afferents arise from the olfactory tract; the chief efferent is the **stria terminalis**, ending in the septal area, anterior perforated substance, anterior commissure and hypothalamic nuclei.

5. Connections of the corpus striatum

The **striatum** (caudate + putamen) is the receptive part; the **globus pallidus** is the outflow (efferent) part.

Afferents to striatum	Fibre	Origin
Corticostriate	Glutamatergic	Wide area of ipsilateral cerebral cortex
Thalamostriate	—	Intralaminar, midline and mediodorsal thalamic nuclei
Nigrostriate	Dopaminergic	Substantia nigra, pars compacta
—	Noradrenergic	Locus coeruleus
—	Serotonergic	Raphe nuclei (midbrain reticular formation)

Efferents from globus pallidus	Course
Ansa lenticularis	Loops round the inner + outer segments → subthalamic region
Fasciculus lenticularis	Direct from inner segment, through internal capsule → subthalamic region
(Ansa + fasciculus lenticularis + dentatorubrothalamic fibres unite as the) Thalamic fasciculus	→ ventral anterior (VA), ventral lateral (VL) and centromedian nuclei of thalamus → motor/premotor cortex
Subthalamic fasciculus	Reciprocal connections, globus pallidus ↔ subthalamic nucleus
Pallidonigral fibres	Globus pallidus → substantia nigra (pars reticularis)



Describe the gross anatomy and applied anatomy of basal nuclei

6. Related structures and functions

- **Subthalamic nucleus** — biconvex, diencephalic; lies caudal to the thalamus and inferomedial to the globus pallidus, separated from the thalamus by the zona incerta; reciprocally connected to the globus pallidus.
- **Substantia nigra** — midbrain; **pars compacta** (dopaminergic, projects to striatum) and **pars reticularis/reticulata** (relays to VA nucleus of thalamus, and to reticular formation/spinal cord).
- **Functions of the corpus striatum/basal nuclei:** regulate **muscle tone** and smoothen voluntary motor activity; control **automatic associated movements** (e.g. arm-swinging during walking) and movements of emotional expression; assist the cortex in subconscious execution of **learned motor patterns** and in planning/programming of movement. They do **not** receive direct spinal sensory input (unlike the cerebellum) and do **not initiate** movement — they modulate cortical motor output via the thalamus, not via direct descending pathways.

7. Blood supply

- **Lenticulostriate (lateral and medial striate) branches of the middle and anterior cerebral arteries** — supply the bulk of the putamen, globus pallidus and body/head of the caudate nucleus.

- **Recurrent artery of Heubner** (medial striate branch of the anterior cerebral artery) — supplies the head of the caudate nucleus.
- **Anterior choroidal artery** (branch of the internal carotid artery) — supplies the tail of the caudate nucleus and postero-medial globus pallidus.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Coronal section of the cerebrum at the level of the interventricular foramen, showing (label each): lateral ventricle (anterior horn) with **head of caudate nucleus** bulging into its floor; **thalamus** (medial); **internal capsule** (anterior limb + genu) separating caudate/thalamus from the lentiform nucleus; **lentiform nucleus** divided by the external and internal medullary laminae into **putamen** (lateral) and **globus pallidus** (medial, outer + inner segments); **external capsule**, **claustrum**, **extreme capsule** and **insula**, from medial to lateral; corpus callosum above; third ventricle and fornix medially. Mark the **lenticulostriate arteries** grooving the lateral surface of the lentiform nucleus.

Applied / Clinical anatomy

- **Lesions of the basal nuclei produce dyskinesias, not paralysis** — abnormal involuntary movements and altered tone, the fundamental teaching point distinguishing extrapyramidal from pyramidal (corticospinal) lesions.
- **Parkinsonism (paralysis agitans)** — degeneration of dopaminergic **nigrostriatal neurons** (substantia nigra pars compacta) causes striatal dopamine deficiency, producing a release phenomenon: **resting ("pill-rolling") tremor**, **cogwheel/lead-pipe rigidity**, **bradykinesia**, **mask-like facies**, **stooped posture** and **shuffling gait**, with loss of arm-swing. Treated with **L-dopa**, stereotactic **pallidotomy/thalamotomy** or fetal dopaminergic-neuron implants; modern practice extends this to **deep brain stimulation** of the pallidum/subthalamic nucleus.
- **Chorea** — rapid, jerky, purposeless, dancing movements of the distal limbs and face, due to striatal (caudate) disease:

Feature	Sydenham's chorea	Huntington's chorea
Age	Children (5–15 yr), girls	Adults (30–45 yr)
Cause	Post-streptococcal/rheumatic fever antibodies against striatal neurons	Autosomal-dominant degeneration of GABAergic striatal neurons
Movements	Relatively less rapid/jerky	Relatively more rapid/jerky
CT brain	No significant finding	Enlarged lateral ventricles (caudate degeneration)
Recovery	Usually complete	No recovery

- **Athetosis** — slow, sinuous, writhing movements of the distal limb segments, from lesions involving the **neostriatum** and **globus pallidus**, disrupting striato-pallido-cortical circuitry.
- **Ballismus / hemiballismus** — sudden, violent, flinging movements of the proximal limb musculature, classically **contralateral**, due to a vascular (often haemorrhagic) lesion of the

subthalamic nucleus; usually affects both limbs on the opposite side (hemiballismus), rarely a single limb (mono-ballismus).

- ▶ **Wilson's disease (hepatolenticular degeneration)** — autosomal-recessive disorder of copper metabolism with copper deposition and degeneration of the **lentiform nucleus** and liver; produces **Kayser–Fleischer rings** (copper deposits at the sclerocorneal limbus).
- ▶ **Vascular applied anatomy** — the lenticulostriate arteries are thin-walled, high-pressure direct branches of the MCA (prone to Charcot–Bouchard microaneurysm); their rupture is the **commonest site of hypertensive intracerebral haemorrhage**, involving putamen/internal capsule and producing contralateral hemiplegia besides dyskinesia.
- ▶ **Surgical/radiological relevance** — the globus pallidus and subthalamic nucleus are standard stereotactic targets for pallidotomy/deep brain stimulation in refractory Parkinsonism and dystonia; localisation depends on the constant relations of the lentiform nucleus to the internal capsule and thalamus described above.

High-yield exam pointers

- ▶ Basal nuclei = **corpus striatum** (caudate + lentiform) + **claustrum** + **amygdaloid body**; functionally add **subthalamic nucleus** + **substantia nigra**.
- ▶ **Neostriatum** = caudate + putamen (afferent); **paleostriatum** = globus pallidus (efferent); **archistriatum** = amygdaloid body + claustrum.
- ▶ Caudate nucleus: **C-shaped**, head/body/tail all related to the **lateral ventricle** (anterior horn, central part, inferior horn respectively).
- ▶ Lentiform nucleus: wedge-shaped, lateral to internal capsule; **putamen (lateral)** + **globus pallidus (medial)**.
- ▶ Lateral-to-medial order: **insula** → **extreme capsule** → **claustrum** → **external capsule** → **putamen** → **internal capsule** → **thalamus/caudate**.
- ▶ Striatum receives corticostriate (glutamatergic), thalamostriate, and **nigrostriate (dopaminergic)** afferents; globus pallidus is the main efferent outflow to the thalamus (VA/VL).
- ▶ **Parkinsonism** = nigrostriatal dopamine loss; **chorea** = caudate disease; **athetosis** = putamen/pallidum; **hemiballismus** = subthalamic nucleus; **Wilson's disease** = lentiform nucleus + copper.
- ▶ Blood supply: **lenticulostriate branches of MCA/ACA** + **recurrent artery of Heubner** + **anterior choroidal artery** — rupture of lenticulostriate vessels is the commonest cause of hypertensive intracerebral haemorrhage.
- ▶ Basal nuclei lesions cause **dyskinesia, not paralysis**, and the nuclei **do not initiate** movement — they only modulate cortical motor output.

SOURCE & COVERAGE

IB Singh Textbook of Human Neuroanatomy; Vishram Singh Clinical Neuroanatomy 4e; BD Chaurasia Human Anatomy Vol 3–4 8e. Coverage note: the digitised Gray's Anatomy 41e corpus covers basal nuclei chiefly under prenatal development; its adult descriptive account was not retrievable here, so the answer is grounded instead in the three specialty neuroanatomy texts above.



Describe the parts, connections and functions of extra pyramidal system. What are the presenting symptoms due to lesions in the various parts of the extra-pyramidal system

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

The **extrapyramidal system** comprises all the subcortical motor centres and their descending pathways — other than the corticospinal (pyramidal) and corticonuclear tracts — that influence the lower motor neuron. Phylogenetically **older** than the pyramidal system, it works hand-in-hand with it, acting on the spinal cord largely **indirectly** — through polysynaptic relays in the basal nuclei, brainstem nuclei and reticular formation, rather than by a direct monosynaptic route. It governs posture, muscle tone, and gross, automatic, associated movements, in contrast to the pyramidal system's fine, skilled, discrete voluntary movements. Lesions of its several components each produce a **characteristic movement disorder** rather than paralysis — the spectrum ranging from poverty and slowing of movement (Parkinsonism) to excessive unwanted movement (chorea, athetosis, ballismus).

1. Parts (components) of the extrapyramidal system

Category	Structures included
Cortical areas of origin	Premotor cortex (Brodmann area 6) mainly; some fibres from motor area (area 4) and parietal cortex
Basal nuclei — corpus striatum	Caudate nucleus + lentiform nucleus (putamen + globus pallidus); neostriatum (caudate + putamen) = input part, paleostriatum (globus pallidus) = output part
Basal nuclei — traditionally included	Clastrum, amygdaloid body (function/connections now regarded as unknown/limbic respectively)
Functionally linked diencephalic/midbrain nuclei	Subthalamic nucleus, substantia nigra (pars compacta + pars reticularis), red nucleus
Brainstem centres giving rise to descending tracts	Reticular formation (pontine and medullary), vestibular nuclei (lateral and medial), superior colliculus (tectum), inferior olivary nucleus
Cerebellar contribution	Neocerebellum, acting via the red nucleus and reticular formation (no direct spinal projection)

- ▶ The **striatum** (caudate nucleus + putamen) is the principal **afferent/input** structure; the **globus pallidus**, together with the pars reticularis of substantia nigra, is the principal **efferent/output** structure.
- ▶ Unlike the cerebellum, the basal nuclei receive **no direct sensory input from the spinal cord**; they influence movement only by looping back through the cerebral cortex.

2. Connections of the extrapyramidal system

Afferents to the striatum

Fibres	Origin	Neurotransmitter
Corticostriate	Wide areas of ipsilateral cerebral cortex (chiefly areas 4, 6)	Glutamate (excitatory)
Thalamostriate	Intralaminar/midline thalamic nuclei	—
Nigrostriatal	Substantia nigra, pars compacta	Dopamine

Efferents (pallidofugal outflow) — the globus pallidus (main efferent nucleus of corpus striatum) sends its outflow, chiefly to the **thalamus**, by three/four bundles:

- ▶ **Fasciculus lenticularis** — from the internal (medial) pallidal segment, penetrates directly through the internal capsule into the subthalamic region.
- ▶ **Ansa lenticularis** — from both pallidal segments, loops around the inferomedial border of the internal capsule.
- ▶ **Subthalamic fasciculus** — reciprocal fibres between globus pallidus and subthalamic nucleus.
- ▶ **Pallidonigral fibres** — to the substantia nigra.

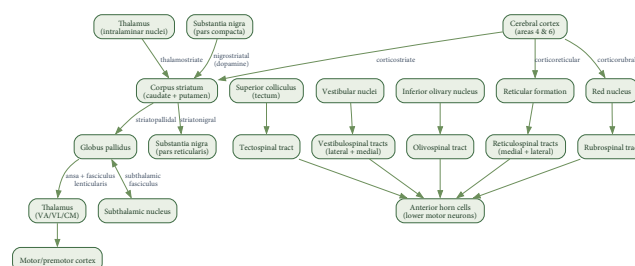
The lenticular and ansa fasciculi join dentatorubrothalamic fibres (from the cerebellum, via red nucleus) to form the **thalamic fasciculus**, ending in the **ventral anterior, ventral lateral and centromedian nuclei of thalamus**, which relay to the motor/premotor cortex — completing the cortex → striatum → pallidum → thalamus → cortex feedback loop. Other connections: **corticorubral** fibres (motor cortex → red nucleus) and **corticoreticular** fibres (motor/parietal cortex → reticular formation) also pass through the internal capsule as "extrapyramidal fibres."

Descending (extrapyramidal) tracts — each subcortical centre gives rise to a spinal tract:

Tract	Origin	Crossing	Termination	Funiculus	Function
Rubrospinal	Red nucleus (midbrain)	Crosses in ventral tegmental decussation	Cervical anterior horn (α & γ)	Lateral	Facilitates flexor tone of upper limb
Tectospinal	Superior colliculus	Crosses in dorsal tegmental decussation	Upper cervical anterior horn	Anterior	Reflex postural movement of head/neck to visual stimuli

Tract	Origin	Crossing	Termination	Funiculus	Function
Medial reticulospinal	Pontine reticular formation	Mainly uncrossed	Cervical cord (α & γ)	Anterior	Facilitates extensor tone; bladder/bowel control
Lateral reticulospinal	Medullary reticular formation	Crossed + uncrossed	α & γ neurons, various levels	Lateral	Facilitates flexor tone; automatic breathing; modulates pain transmission
Lateral vestibulospinal	Lateral vestibular nucleus	Uncrossed	α motor neurons	Anterior	Facilitates extensor tone — equilibratory control
Medial vestibulospinal (MLF)	Medial vestibular nucleus	Uncrossed	Cervical cord (α motor neurons)	Anterior	Turning movements of the head
Olivospinal	Inferior olivary nucleus	Uncrossed	Anterior horn cells	Anterolateral	Feedback control via spino-olivary tract; modulates motor-neuron activity

□ Fig 8.22 — Connections of corpus striatum (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.569)



Describe the parts, connections and functions of extra pyramidal system. What are the presenting symptoms due to lesions in the various parts of the extra-pyramidal system

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A horizontal section through the cerebrum at the level of the interventricular foramen (as in Fig 8.22 above), labelling: **caudate nucleus** (head, body, tail), **lentiform nucleus** (putamen + globus pallidus, external/internal segments), **internal capsule**, **external capsule**, **claustrum**, **thalamus**, and — on an adjoining lower section — **subthalamic nucleus**, **substantia nigra**, **red nucleus**. Draw arrows for: afferents (corticostriate, thalamostriate, nigrostriatal) converging on the striatum; efferents (ansa lenticularis, fasciculus lenticularis) leaving the globus pallidus to the ventral anterior/ventral lateral thalamus.

3. Functions of the extrapyramidal system

- ▶ **Postural adjustments** of the body to maintain balance and prepare for movement.
- ▶ **Gross, synergistic voluntary movements** of groups of muscles acting on proximal joints of the limbs.
- ▶ **Automatic associated movements** performed unconsciously, e.g. swinging of the arms while walking.
- ▶ **Regulation of muscle tone** and smoothing of ongoing voluntary motor activity.
- ▶ **Planning and programming** of voluntary movement — determining how rapidly and how large a movement should be (basal-nuclear contribution specifically).
- ▶ **Suppression of unwanted involuntary muscular activity.**
- ▶ **Regulatory influence over reflex activity**, and control of groups of movements used in emotional expression.
- ▶ Achieved entirely **indirectly** — via the cerebral cortex and brainstem nuclei — since the basal nuclei send no direct fibres to the spinal cord.

4. Pyramidal vs extrapyramidal system — key differences

Feature	Pyramidal system	Extrapyramidal system
Phylogeny	Recent; best developed in man	Older
Function	Precise, non-postural movement of small (distal) muscles	Gross, postural (stereotyped) movement of large muscle groups
Pathway to LMN	Direct (mono-/oligosynaptic)	Indirect, polysynaptic, via subcortical relays
Cortical origin	Predominantly area 4	Predominantly area 6
Role of basal nuclei	None	Central
Effect of lesion on tone	No increase	Increased (spasticity)

Note: naturally occurring human lesions rarely spare one system while damaging the other, so pure "pyramidal" and "extrapyramidal" clinical syndromes are uncommon in practice; the pyramidal tract tends to increase muscle tone while the other descending tracts inhibit it, and the net clinical tone reflects the balance between the two.

5. Presenting symptoms of lesions in the various parts of the extrapyramidal system

Site of lesion	Presenting clinical features
Extrapyramidal descending tracts as a group (rubro-, reticulo-, vestibulo-, tectospinal), sparing the pyramidal tract	Severe paralysis with little or no muscular atrophy (except disuse); spasticity/hypertonicity ; exaggerated deep tendon reflexes (knee, ankle jerk); clasp-knife rigidity
Reticular formation (loss of corticoreticular inhibitory control)	Release of the reticular formation's normal tone-facilitating activity → generalized increase in extensor muscle tone
Corpus striatum — caudate nucleus (neostriatum)	Chorea — quick, jerky, irregular, purposeless movements of face, tongue and limbs. Sydenham's chorea (children 5–15 yr, post-streptococcal/rheumatic fever, antibody-mediated striatal inflammation, full recovery) vs Huntington's chorea (adults 30–45 yr, autosomal dominant, degeneration of GABAergic striatal neurons, progressive, enlarged lateral ventricles on CT)
Substantia nigra pars compacta (dopaminergic neuron loss → striatal dopamine deficiency)	Parkinsonism (paralysis agitans) — resting "pill-rolling" tremor (diminished with movement), lead-pipe/cogwheel rigidity , bradykinesia , mask-like facies, stooped posture with short shuffling gait, loss of associated movements
Neostriatum + globus pallidus circuitry (putamen)	Athetosis — slow, sinuous, writhing movements, predominantly of the distal limb segments (fingers, toes)
Subthalamic nucleus (usually a small vascular lesion)	Hemiballismus — sudden, violent, flinging (ballistic) movements of the proximal musculature of the contralateral limb(s)
Lentiform nucleus (copper deposition — Wilson's disease)	Rigidity, tremor, dystonia; Kayser-Fleischer rings at the corneoscleral limbus

Applied / Clinical anatomy

- **Blood supply of the corpus striatum/internal capsule region:** **medial and lateral lenticulostriate (striate) branches of the middle cerebral artery** — the largest lateral branch is the **Charcot's artery of cerebral haemorrhage**, the vessel most often ruptured in hypertensive intracerebral bleed; **recurrent artery of Heubner** (from anterior cerebral artery) to the head of caudate nucleus/anterior limb of internal capsule; **anterior choroidal artery** (from internal carotid) to the globus pallidus.
- **Treatment of Parkinsonism:** **L-dopa** (dopamine precursor) replacement therapy; stereotactic **pallidotomy/thalamotomy**; **deep brain stimulation** of subthalamic nucleus/globus pallidus; fetal nigral-cell striatal implants.
- **Monoballismus vs hemiballismus:** usually both limbs of one side are involved (hemiballismus) because the subthalamic nucleus of one side projects mainly to the ipsilateral cortex via globus pallidus and thalamus; it may rarely be restricted to one limb.

- ▶ **Antipsychotic drugs** (dopamine-receptor blockers used for schizophrenia) commonly produce extrapyramidal side effects (abnormal involuntary movements) because the same dopaminergic receptors are blocked in the nigrostriatal pathway.
- ▶ Radiologically, basal-ganglia lesions and their mass effect are best assessed on **CT/MRI**; caudate atrophy with ventricular enlargement is characteristic of Huntington's disease.

High-yield exam pointers

- ▶ Extrapyramidal = all motor tracts/subcortical centres other than corticospinal tract; phylogenetically older; acts via polysynaptic relays, not directly on the LMN.
- ▶ Parts: corpus striatum (caudate + lentiform), subthalamic nucleus, substantia nigra, red nucleus, reticular formation, vestibular nuclei, tectum (superior colliculus), inferior olivary nucleus.
- ▶ Striatum = afferent/input part; globus pallidus = efferent/output part.
- ▶ Key afferents to striatum: corticostriate (glutamate), thalamostriate, nigrostriatal (dopamine).
- ▶ Pallidofugal outflow = ansa lenticularis + fasciculus lenticularis + subthalamic fasciculus → thalamic fasciculus → VA/VL/centromedian thalamus.
- ▶ Descending tracts: rubrospinal (flexor facilitation, upper limb), tectospinal (neck reflex to vision), medial/lateral reticulospinal (extensor/flexor tone), lateral/medial vestibulospinal (equilibrium, head movement), olivospinal.
- ▶ Functions: posture, muscle tone, gross synergistic and automatic associated movements, suppression of unwanted movement — never paralysis.
- ▶ Lesion localisation: caudate nucleus → chorea; substantia nigra → Parkinsonism; putamen/pallidum → athetosis; subthalamic nucleus → hemiballismus; lentiform nucleus (copper) → Wilson's disease.
- ▶ General extrapyramidal tract lesion (as opposed to pyramidal) → spasticity, exaggerated reflexes, clasp-knife rigidity, minimal atrophy.
- ▶ Charcot's artery of cerebral haemorrhage = largest lateral lenticulostriate branch of MCA.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3-4 8e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; Snell's Clinical Neuroanatomy 7e.



Hippocampal formation

Asked in: Paper IV Sep 2007 — RGUHS MD/MS Anatomy

Definition / Introduction — The hippocampal formation is a curved, archicortical (phylogenetically old, 3-layered) part of the medial temporal lobe that forms a longitudinal elevation in the floor of the inferior (temporal) horn of the lateral ventricle. Indian texts (Vishram Singh, IB Singh, BD Chaurasia) define it as the **hippocampus (cornu ammonis) + dentate gyrus + gyrus fasciolaris + indusium griseum** (with its medial and lateral longitudinal striae), while Gray's Anatomy (Standring) additionally includes the **subicular complex** (subiculum, presubiculum, parasubiculum) and the **entorhinal cortex** (area 28) under the same term. It is the principal cortical component of the limbic system and is central to consolidation of recent memory, spatial navigation, and (through its epileptogenic potential) temporal lobe epilepsy.

Location, development & gross anatomical features

- ▶ Lies in the **medial temporal lobe**, rolled into the floor of the inferior horn of the lateral ventricle, continuous medially with the subiculum and parahippocampal gyrus (which lies below the collateral/rhinal sulcus).
- ▶ **Development:** the cerebral cortex develops from the pallium, which has three phylogenetic divisions — paleopallium (paleocortex), **archipallium (archicortex)**, and neopallium (neocortex). The archipallium is associated with the olfactory cortex and gives rise to the **hippocampus**, making it one of the oldest parts of the cerebral cortex.
- ▶ **External features** (best seen in a dissection with the corpus callosum divided and the temporal horn opened):
 - Macroscopically divisible into a **head, body and tail** (~5 cm long).
 - The **head** is expanded and bears 2–3 shallow grooves/ridges resembling an animal's paw — the **pes hippocampi**.
 - Traced posteriorly it narrows and ends beneath the **splenium of the corpus callosum**.
 - Its ventricular (superior) surface is covered by a thin sheet of white fibres, the **alveus**; alveus fibres converge on the medial border to form the **fimbria**, which continues as the crus of the fornix.
 - In coronal section the hippocampus is **C-shaped/ram's-horn shaped**, hence "cornu ammonis" (Ammon's horn) after the ram-headed Egyptian deity Ammon; "hippocampus" itself means sea-horse, from its coronal-section profile.
 - The **dentate gyrus** lies along the medial margin of the hippocampus, separated from it by the **hippocampal sulcus**; its free edge is notched (tooth-like/dentate). Anteriorly it continues across the inferior surface of the uncus as its **tail**, which corresponds to the **band of Giacomini**.
 - Posteriorly the dentate gyrus continues as the **gyrus fasciolaris (splenial gyrus)**, then as the **indusium griseum** — a vestigial sheet of grey matter over the corpus callosum containing the **medial and lateral longitudinal striae**.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

embed: ![Fig 19.6 — Structures forming hippocampal formation (viz. hippocampus, dentate gyrus, gyrus fasciolaris and indusium griseum) and associated structures (Vishram Singh — Clinical Neuroanatomy — 4e, p.699)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/5abb347acaff3c09.jpg)

embed: ![Fig 9.5 — Coronal section of the hippocampus and related structures (Snell — Clinical Neuroanatomy — 7e, p.329)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/034eca28564300d2.jpg)

For the exam, reproduce a **labelled coronal section** through the temporal horn with these exact labels (the classic "S"-shaped cortical ribbon): lateral ventricle (inferior horn) → **dentate gyrus** → **hippocampus** (cornu ammonis, fields CA1–CA4) → **subiculum** → **presubiculum** → **parasubiculum** → **entorhinal cortex** → **parahippocampal gyrus**; plus **alveus**, **fimbria**, **hippocampal sulcus**, **fimbriodentate sulcus**, **choroid fissure**, and the **collateral sulcus** separating the parahippocampal from the fusiform gyrus.

Components of the hippocampal formation

Component	Nature	Key feature
Dentate gyrus	Trilaminar archicortex	Toothed free margin; granule-cell layer is its principal neuron type
Hippocampus proper (cornu ammonis)	Trilaminar archicortex	Subdivided into fields CA1–CA3 (CA4/hilus often grouped with the dentate gyrus)
Subicular complex (subiculum, presubiculum, parasubiculum)	Transitional (juxtallocortex)	Bridges 3-layered archicortex of hippocampus with 6-layered neocortex
Entorhinal cortex (Brodmann area 28)	6-layered, but atypical neocortex	Main gateway for cortical input to, and output from, the hippocampus
Gyrus fasciolaris, indusium griseum, longitudinal striae	Vestigial grey/white matter	Continuation of dentate gyrus/hippocampus over the corpus callosum

Microscopic structure (histology)

- **Hippocampus proper** is trilaminar (archicortex): a superficial **molecular layer**, a middle **pyramidal cell layer**, and a deep **polymorphic layer**. Working from the ventricular aspect, its named strata are: **alveus** (axons of pyramidal/subicular cells converging on the fimbria) → **stratum oriens** (basal dendrites, interneurons) → **stratum pyramidale** (the pyramidal cell bodies) → **stratum lucidum** (mossy fibres synapsing on CA3 proximal dendrites; present only in CA3, absent in CA1/CA2, and less prominent in humans than other primates) → **stratum radiatum** → **stratum lacunosum-moleculare** (site of the perforant-path synapse on distal apical dendrites).

- **Fields of the hippocampus:** CA3 (largest pyramidal cells, borders the dentate hilus, receives mossy-fibre input), CA2 (most compact pyramidal layer), CA1 (most complex field; ~10% interneurons; merges with subiculum) — CA4 corresponds to the **hilus** of the dentate gyrus.
- **Dentate gyrus** is also trilaminar; its principal cell is the **granule cell**, in a dense granule-cell layer, with dendrites in the overlying molecular layer that receive the perforant-path input from the entorhinal cortex.
- **Entorhinal cortex** is six-layered but distinctive: Layer I acellular/plexiform; Layer II shows islands of large pyramidal/stellate cells producing surface bumps (**verrucae hippocampi**); Layer III medium pyramidal cells; an acellular **lamina dissecans** (sometimes called layer IV) replaces the internal granular layer; Layer V has large pyramidal cells 5–6 deep; Layer VI is distinct only near the perirhinal border.
- **Intrinsic ("trisynaptic") hippocampal circuit:** entorhinal cortex → dentate gyrus (**perforant path**) → CA3 (**mossy fibres**) → CA1 (**Schaffer collaterals**) → subiculum → back to deep entorhinal layers — the structural basis of hippocampal information processing.

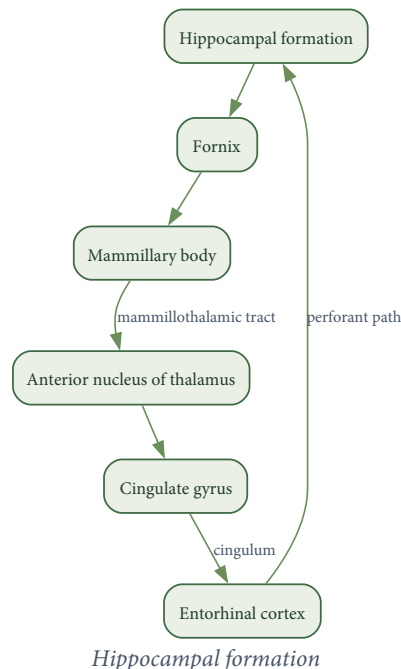
Connections

	Source/destination	Route
Afferent	Entorhinal cortex (area 28)	Perforant pathway — major input
	Olfactory cortex, amygdala	Direct cortical/subcortical fibres
	Contralateral hippocampus	Commissure of the fornix (hippocampal commissure)
	Parahippocampal gyrus, septal nuclei, supramammillary region	Direct/associational fibres
Efferent	Sole outflow = fornix (via alveus → fimbria)	
	Septal area & anterior hypothalamus	Precommissural fornix
	Mammillary body	Postcommissural fornix → mamillothalamic tract → anterior thalamic nucleus → cingulate gyrus → cingulum → entorhinal cortex (Papez circuit)
	Contralateral hippocampus	Hippocampal commissure (crossing fibres of the two crura)

Fornix and the Papez circuit

- The **fornix** is the sole efferent pathway of the hippocampus, formed by alveus → **fimbria** → **crus** (arching under the splenium) → paired crura fuse to form the **body** (below the corpus callosum, along the lower border of the septum pellucidum) → divides into two **columns**, which arch down in front of the interventricular foramen, around the anterior commissure, into the hypothalamus to end in the **mammillary body**.

- It uniquely contains all three fibre types: **projection** (hippocampus → mammillary body — the bulk, postcommissural), **commissural** (hippocampal commissure, interconnecting the crura) and **association** (dorsal fornix fibres to the cingulate gyrus) fibres.
- **Papez circuit (hippocampal circuit)**, described by Papez (1937), is the anatomical substrate of memory and emotion:



- A modified circuit (Paul MacLean) additionally incorporates the **amygdala**.

Blood supply

- The medial temporal lobe/hippocampus is supplied chiefly by the **anterior choroidal artery** (a branch of the internal carotid artery, entering the temporal horn at the inferior choroidal point near the head/uncus) and by **hippocampal/temporal branches of the posterior cerebral artery** (P2 segment), which supply the body and tail.
- **CA1 (Sommer's sector/area)** — close to the subiculum — lies in a vascular border/watershed zone and is the field **most vulnerable to hypoxia-ischemia**, the structural basis of selective CA1 loss in hippocampal (mesial temporal) sclerosis.

Applied / Clinical anatomy

- **Memory**: the hippocampus is essential for consolidating recent (short-term) memory into long-term memory; it does not store old memories. Bilateral hippocampal damage (e.g. bilateral medial temporal lobe resection, as in the classic case of patient H.M.) produces a dense **anterograde amnesia** — inability to form new memories — while remote memory and procedural learning are relatively spared.
- **Bilateral fornix transection** causes the **acute amnesic syndrome**: failure to consolidate short-term into long-term memory.
- **Hippocampal (mesial temporal) sclerosis**: neuronal loss and gliosis, classically maximal in **CA1 (Sommer's sector)** and the dentate hilus (CA4), is the commonest pathological substrate of **medically refractory temporal lobe epilepsy**; seizures may be preceded by an olfactory/gustatory

aura, automatisms (e.g. lip-smacking), and post-ictal amnesia. Surgical treatment is anterior temporal lobectomy or selective amygdalohippocampectomy.

- ▶ **The hippocampus is the most epileptogenic region of the cerebral hemisphere** — its lesions classically produce psychomotor (complex partial) epilepsy.
- ▶ **Alzheimer's disease:** early, disproportionate atrophy of the **entorhinal cortex and hippocampus (particularly CA1)** underlies the characteristic early loss of recent memory.
- ▶ **Klüver–Bucy-type syndrome:** bilateral resection of the temporal lobes (amygdala, hippocampus, uncus) produces docility, loss of fear/anger, hyperphagia and increased/perverse sexual activity.
- ▶ **Uncal herniation:** the uncus (anteromedial parahippocampal gyrus, immediately related to the head of the hippocampus) may herniate through the tentorial notch in raised supratentorial pressure, compressing the oculomotor nerve (fixed dilated pupil) and cerebral peduncle.
- ▶ **Cross-sectional/radiological anatomy:** coronal MRI (the plane of choice) through the temporal horn is used for hippocampal volumetry; hippocampal sclerosis appears as **reduced hippocampal volume with increased T2/FLAIR signal**, with loss of the normal internal architecture ("digitations")— key MRI findings in the pre-surgical work-up of temporal lobe epilepsy.

High-yield exam pointers

- ▶ Hippocampal formation (Indian texts) = hippocampus + dentate gyrus + gyrus fasciolaris + indusium griseum (+ longitudinal striae); Gray's Anatomy additionally includes subiculum/presubiculum/parasubiculum + entorhinal cortex.
- ▶ Hippocampus = archicortex, 3 layers (molecular, pyramidal, polymorphic); entorhinal cortex = 6 layers with a lamina dissecans.
- ▶ Fields: **CA1–CA3** (hippocampus proper) + **CA4** (hilus, with dentate gyrus); **CA1 (Sommer's sector)** most vulnerable to ischaemia.
- ▶ Main afferent = entorhinal cortex via **perforant path**; sole efferent = **fornix** (alveus → fimbria → crus → body → columns → mammillary body).
- ▶ **Papez circuit:** hippocampal formation → fornix → mammillary body → mammillothalamic tract → anterior thalamic nucleus → cingulate gyrus → cingulum → entorhinal cortex.
- ▶ Fornix is the only fibre bundle in the brain composed of **all three fibre types** — projection, commissural and association.
- ▶ Tail of the dentate gyrus at the uncus = **band of Giacomini**.
- ▶ Clinical: hippocampal (mesial temporal) sclerosis → temporal lobe epilepsy; bilateral fornix damage → acute amnesic syndrome; entorhinal/CA1 atrophy → Alzheimer's disease.
- ▶ Develops from the **archipallium (archicortex)**, phylogenetically one of the oldest cortical regions.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Clinical Neuroanatomy 4e; Snell — Clinical Neuroanatomy 7e; IB Singh — Textbook of Human Neuroanatomy; BD Chaurasia — Human Anatomy Vol 3–4 8e; Vishram Singh — Textbook of Anatomy Vol 3 4e; Langman's Medical Embryology (Sadler) 14e.



Hippocampus

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction

The **hippocampus** (hippocampus proper, **cornu ammonis**, Ammon's horn) is a curved, sea-horse-shaped elevation of grey matter, approximately **5 cm long**, that occupies the floor of the **inferior (temporal) horn of the lateral ventricle**. Together with the **dentate gyrus**, **subicular complex** and **entorhinal cortex** it constitutes the **hippocampal formation**, the core grey-matter component of the **limbic system**. Phylogenetically it represents **archicortex** (three-layered, in contrast to six-layered neocortex) and forms the pivotal station of the **Papez circuit**, the anatomical substrate of memory consolidation and emotion. It is of major clinical importance in epilepsy, amnesia and Alzheimer's disease.

1. Location, gross anatomy and relations

- ▶ Lies as a longitudinal elevation in the floor of the inferior horn of the lateral ventricle, extending from beneath the **splenium of the corpus callosum** posteriorly to the **uncus** anteriorly.
- ▶ Divisible grossly into a **head** (expanded, bears 2–3 shallow grooves/ridges — **pes hippocampi**, "foot of the hippocampus"), a **body**, and a **tail**.
- ▶ Named for its resemblance to a sea-horse in coronal section; the C-shaped outline also resembles a ram's horn — hence **Ammon's horn/cornu ammonis**.
- ▶ Its convex **ventricular surface** is covered by ependyma beneath which lies a thin sheet of white matter, the **alveus** (efferent/afferent fibres of the hippocampal cortex); alveus fibres converge on the medial border to form the **fimbria**, which becomes continuous with the **crus of the fornix**.
- ▶ Medially continuous with the **subiculum** and **parahippocampal gyrus**; separated from the **dentate gyrus** by the **hippocampal sulcus**.
- ▶ **Hippocampal formation** = hippocampus (cornu ammonis) + dentate gyrus + subicular complex (subiculum, presubiculum, parasubiculum) + entorhinal cortex (**area 28**). Older/Indian texts also group **gyrus fasciolaris** and **indusium griseum** (with medial and lateral longitudinal striae) with it, representing its vestigial rostral/dorsal continuation over the corpus callosum.

Component	Description
Hippocampus (CA1–CA3)	Trilaminar archicortex proper
Dentate gyrus	Notched grey band medial to fimbria, deep to it

Component	Description
Subiculum	4–5-layered transition zone to neocortex
Entorhinal cortex (area 28)	Six-layered; major input relay
Indusium griseum + longitudinal striae	Vestigial grey matter over corpus callosum (rostral continuation)

2. Development

- ▶ The hippocampus is **telencephalic** in origin — it arises as a longitudinal thickening of the medial wall of the developing forebrain (telencephalic) vesicle that protrudes into the cavity of the lateral ventricle.
- ▶ In the embryo the hippocampal formation is **C-shaped**; its poorly-developed upper part persists in the adult as the vestigial **indusium griseum** over the corpus callosum, continuous posteriorly with the **gyrus fasciolaris**, which in turn continues forward into the **dentate gyrus**.
- ▶ The **fornix** is the **second cerebral commissure to develop** (after the anterior commissure and before the corpus callosum), and it is this tract that interconnects the hippocampi of the two sides.
- ▶ The three-layered **archicortex** of the hippocampus develops earlier (phylogenetically and ontogenetically older) than the six-layered neocortex of the adjoining parahippocampal gyrus; the **subiculum** is the zone of gradual transition between the two.

3. Microscopic structure

- ▶ **Trilaminar archicortex**: superficial **molecular layer**, middle **pyramidal cell layer**, deep **polymorphic layer** — sandwiched, the pyramidal layer lies between two plexiform layers.
- ▶ **Finer lamination (ventricular to pial)**: **alveus** → **stratum oriens** (basal dendrites, interneurons) → **stratum pyramidale** → **stratum lucidum** (mossy fibres to CA3; poorly developed in humans, absent in CA1/CA2) → **stratum radiatum** → **stratum lacunosum-moleculare** (perforant-path terminations).
- ▶ Divided into three fields on the basis of pyramidal cell morphology:

Field	Position	Features
CA3	Borders hilus of dentate gyrus	Largest pyramidal cells; receives mossy fibre input from dentate granule cells
CA2	Between CA3 and CA1	Most compact pyramidal layer; border with CA3 indistinct

Field	Position	Features
CA1	Adjoins subiculum	Most complex field; ~10% interneurons; overlaps subiculum; = Sommer's sector — most vulnerable to hypoxia/ischaemia, key site of long-term potentiation (LTP) and new-memory formation, most severely affected in Alzheimer's disease

- ▶ **Dentate gyrus**: also trilaminar — molecular layer, densely packed **granule cell layer** (principal afferent target of the entorhinal cortex), and polymorphic (hilar) layer.
- ▶ **Entorhinal cortex**: uniquely six-layered; **layer II** shows islands of large pyramidal/stellate cells forming naked-eye-visible surface bumps (**verrucae hippocampi**); an acellular **lamina dissecans** replaces the internal granular layer (layer IV) — both classic distinguishing features.

4. Connections

Afferent (six recognised groups):

- ▶ **Entorhinal cortex (area 28)** and olfactory-associated cortex — the major input, via the **perforant pathway** to the dentate gyrus/hippocampus.
- ▶ **Cingulate gyrus**.
- ▶ **Septal nuclei** — via the fornix.
- ▶ **Contralateral hippocampus** — via the hippocampal commissure (commissure of the fornix).
- ▶ **Indusium griseum** — via the medial/lateral longitudinal striae.
- ▶ **Amygdala**, dentate gyrus and parahippocampal gyrus.

Efferent — the **fornix** is the principal (and, classically, sole) efferent pathway of the hippocampus, formed by alveus → fimbria → crus → body → columns of fornix:

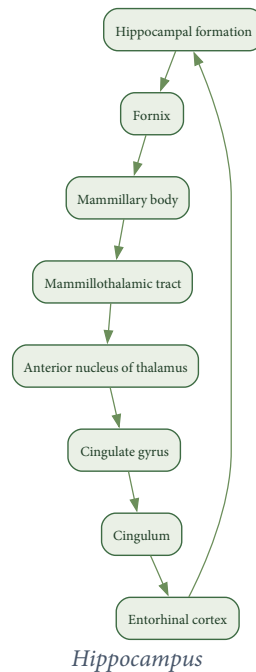
- ▶ **Postcommissural fornix** (posterior to anterior commissure) → **mammillary body** (medial nucleus) → **anterior nucleus of thalamus** (via mammillothalamic tract) and midbrain tegmentum.
- ▶ **Precommissural fornix** (anterior to anterior commissure) → septal nuclei, lateral preoptic area, anterior hypothalamus.
- ▶ Fibres via **stria medullaris thalami** → habenular nuclei.
- ▶ **Commissure of the fornix** → contralateral hippocampus.

Intrinsic (trisynaptic) circuit: entorhinal cortex → (perforant pathway) → dentate granule cells → (mossy fibres) → CA3 pyramidal cells → (Schaffer collaterals) → CA1 pyramidal cells → subiculum → back to entorhinal cortex — the classic unidirectional intra-hippocampal loop underlying memory encoding.

□ Fig 19.8 — Coronal section of the hippocampus and related structures. (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.703)

5. Papez circuit

Proposed by **James Papez (1937)**; begins and ends at the hippocampal formation and provides the anatomical substrate for **memory and emotion**. The **modified circuit (Paul MacLean)** additionally incorporates the **amygdala**.



6. Blood supply

- Predominantly by branches of the **posterior cerebral artery** (via its temporal/hippocampal and posterior choroidal branches, which reach the temporal horn along the tela choroidea) together with perforating twigs of the **anterior choroidal artery** (a branch of the internal carotid artery that enters the inferior horn of the lateral ventricle en route to the choroid plexus).
- This border-zone, relatively end-arterial supply — combined with the high metabolic/synaptic demand of CA1 pyramidal neurons — is the accepted explanation for the selective vulnerability of the CA1 (Sommer's) sector to transient global cerebral ischaemia/hypoxia.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a coronal section through the inferior horn of the lateral ventricle at the level of the hippocampus and label: **hippocampus (cornu ammonis)** with its CA1, CA2, CA3 fields; **dentate gyrus** (with molecular, granular and polymorphic layers); **subiculum**; **parahippocampal gyrus**; **hippocampal sulcus**; **alveus**; **fimbria of hippocampus**; **choroid fissure and choroid plexus**; **collateral sulcus and collateral eminence**; **tail of caudate nucleus**; **optic tract**; and the cavity of the inferior horn of the lateral ventricle. A second inset may show the **pes hippocampi** on a basal/dissection view with the **fornix**, **crus of fornix** and **mammillary body**.

Applied / Clinical anatomy

- **Memory consolidation:** the hippocampus converts new (recent/short-term) memory into stable long-term memory. Bilateral hippocampal lesions (or bilateral transection of the fornix) produce

anterograde amnesia — inability to form new memories — while memory for events preceding the lesion is preserved (remote memory is stored diffusely in the neocortex). Combined **hippocampal + amygdaloid** injury causes greater memory loss than either lesion alone.

- ▶ **Epilepsy**: the hippocampus is the **most epileptogenic part of the cerebral hemisphere**. Temporal lobe (psychomotor/uncinate) epilepsy characteristically begins with an **olfactory or gustatory aura**, automatisms, and post-ictal amnesia for the event.
- ▶ **Hippocampal (mesial temporal) sclerosis**: the CA1 (**Sommer's sector**) and CA4/hilar neurons are most susceptible to hypoxic/excitotoxic injury from prolonged or repeated seizures, leading to segmental neuronal loss and gliosis — the commonest pathological substrate of drug-resistant temporal lobe epilepsy, treated by **anterior temporal lobectomy/selective amygdalohippocampectomy**.
- ▶ **Alzheimer's disease**: bilateral hippocampal atrophy (with early, disproportionate CA1 involvement) underlies the progressive loss of recent memory and disorientation that characterises the disease; hippocampal volume loss is a recognised MRI biomarker.
- ▶ **Klüver–Bucy syndrome**: bilateral temporal lobectomy (removing hippocampus and amygdala) produces docility, loss of fear/rage, hyperorality, visual agnosia and hypersexuality.
- ▶ **Korsakoff psychosis** (chronic alcoholism) — damage along the hippocampus–fornix–mammillary body–anterior thalamic nucleus pathway (Papez circuit) causes anterograde and retrograde amnesia with confabulation.
- ▶ **Schizophrenia** has been linked to limbic (including hippocampal) dopaminergic dysfunction.

Recent advances

- ▶ A landmark single-cell/single-nucleus transcriptomic and machine-learning study directly identified **actively proliferating neural progenitor cells and neuroblasts** in the adult human hippocampal dentate gyrus, providing the most direct molecular confirmation yet that **adult hippocampal neurogenesis persists throughout life** in humans, settling much of the long-standing controversy (Dumitru I, Paterlini M, et al., *Science* 2025;389(6755):58–63) [DOI: 10.1126/science.adu9575].
- ▶ A multiomic single-cell atlas (snRNA-seq + snATAC-seq) of post-mortem human hippocampi across young adults, cognitively-normal aged adults, "SuperAgers" and Alzheimer's disease cases showed that **neural stem cell and immature granule-neuron populations are relatively preserved in SuperAgers but markedly depleted in Alzheimer's disease**, linking hippocampal neurogenic capacity directly to preserved versus declining memory in old age (Disouky A, Sanborn MA, Sabitha KR, et al., *Nature*, 2026) [DOI: 10.1038/s41586-026-10169-4].
- ▶ A comprehensive review reappraised the methodological controversies (antibody specificity, tissue-fixation artefacts) underlying conflicting reports of human adult hippocampal neurogenesis and outlined how next-generation sequencing approaches are resolving the debate (Simard S, Matosin N, Mechawar N, *The Neuroscientist* 2025;31(2):141–158) [DOI: 10.1177/10738584241252581].
- ▶ A refined **MRI-based radiologic classification of hippocampal sclerosis**, mirroring the ILAE histopathological types (CA1-predominant, CA1+CA4-predominant, CA4-predominant patterns), improves presurgical lateralisation and outcome prediction in temporal lobe epilepsy

surgery (Middlebrooks EH, et al., *American Journal of Neuroradiology* 2024;45(9):1185–1193) [DOI: 10.3174/ajnr.A8214].

► (According to PubMed/journal search.)

High-yield exam pointers

- Hippocampus = cornu ammonis/Ammon's horn; ~5 cm long; floor of inferior horn of lateral ventricle; parts = head (pes hippocampi), body, tail.
- Hippocampal formation = hippocampus + dentate gyrus + subiculum + entorhinal cortex (area 28).
- Trilaminar archicortex: molecular, pyramidal, polymorphic layers; three fields CA1–CA3; CA1 = **Sommer's sector**, most vulnerable to hypoxia, key to Alzheimer's and to LTP-based new-memory formation.
- Trisynaptic circuit: entorhinal cortex → perforant path → dentate gyrus → mossy fibres → CA3 → Schaffer collaterals → CA1 → subiculum → entorhinal cortex.
- Fornix = principal efferent tract; pre-commissural fibres → septum/hypothalamus; post-commissural fibres → mammillary body + anterior thalamic nucleus.
- **Papez circuit**: hippocampus → fornix → mammillary body → mamillothalamic tract → anterior thalamic nucleus → cingulate gyrus → cingulum → entorhinal cortex → hippocampus (memory + emotion).
- Blood supply: posterior cerebral artery (hippocampal/posterior choroidal branches) + anterior choroidal artery.
- Bilateral hippocampal/fornix damage → anterograde amnesia; hippocampus = most epileptogenic region of the brain (temporal lobe epilepsy, hippocampal sclerosis); combined hippocampus + amygdala ablation → Klüver–Bucy syndrome.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e. Recent-advances section per PubMed/journal search (DOIs above). Coverage note: none of the specialty neuroanatomy texts in the corpus name discrete "anterior/posterior hippocampal arteries" explicitly — the blood-supply statement above reflects standard, universally-taught vascular territory (posterior cerebral + anterior choroidal arteries) rather than a corpus-verbatim quote.



Lentiform nucleus

Asked in: Paper IV Apr 2006 — RGUHS MD/MS Anatomy

Definition / Introduction — The lentiform (lenticular) nucleus is a large, wedge-shaped mass of subcortical grey matter lying deep in the white matter of the cerebral hemisphere, buried lateral to the internal capsule. It consists of the **putamen** (laterally) and the **globus pallidus** (medially), which together with the caudate nucleus form the **corpus striatum**. Although grouped together as one anatomical unit because of their proximity, the putamen and globus pallidus have quite different connections — the putamen belongs functionally with the caudate nucleus (neostriatum/striatum), while the globus pallidus (pallidum) is the principal output nucleus of the basal ganglia.

Location, shape and subdivisions

- Lies deep to the **insula**, with which it is roughly coextensive, separated from it by the extreme capsule, claustrum and external capsule.
- Appears **triangular or wedge-shaped** in coronal section — its broad, convex **base is directed laterally** and its apex (blade) **medially**.
- A thin sheet of white matter, the **external medullary lamina**, divides it into a larger lateral part, the **putamen**, and a smaller medial part, the **globus pallidus** (pallidum — pale in fresh section).
- The globus pallidus is further subdivided by the **internal medullary lamina** into a **lateral (external) segment (GPe)** and a **medial (internal) segment (GPi)**, which differ in their connections.
- Inferiorly, the lentiform nucleus is grooved by the **anterior commissure**: the part above is the **dorsal pallidum**, the part below (continuous with the nucleus accumbens/olfactory tubercle) the **ventral pallidum**.

Feature	Putamen	Globus pallidus
Position	Lateral (larger)	Medial (smaller)
Colour	Darker	Paler ("pallidum")
Cytology	Densely packed medium-sized neurones, ~75% medium spiny GABAergic cells (D1/D2 receptor bearing) — architecture like caudate nucleus	Sparse, large multipolar GABAergic neurones ; cell density <1/20th of the striatum
Functional group	Neostriatum/striatum (with caudate) — chief input structure	Pallidum (with SNr) — chief output structure; further split into GPe & GPi by internal medullary lamina

Relations

Aspect	Relation
Medial	Internal capsule , which separates the lentiform nucleus from the caudate nucleus and thalamus

Aspect	Relation
Lateral	External capsule → claustrum → extreme capsule → cortex of the insula
Superior	Corona radiata
Inferior	Sublentiform part of the internal capsule; anteroinferiorly it fuses with the head of the caudate nucleus (fundus striati), continuous with the anterior perforated substance
Anteroinferior	Grooved by the anterior commissure (dorsal vs ventral pallidum, as above)

□ Fig 1.14 — Diagram showing the relationship between the lentiform nucleus, the caudate nucleus, the thalamus and related structures (Snell — Clinical Neuroanatomy — 7e, p.32)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Coronal section through the cerebral hemisphere at the level of the third ventricle — label:

- ▶ Lateral ventricle (body) and its choroid plexus
- ▶ Caudate nucleus (body)
- ▶ Thalamus
- ▶ Third ventricle
- ▶ Internal capsule (anterior limb, genu, posterior limb)
- ▶ Lentiform nucleus — **putamen** (lateral) and **globus pallidus** with its **lateral (GPe)** and **medial (GPi)** segments, separated by internal and external medullary laminae
- ▶ Claustrum
- ▶ External capsule and extreme capsule
- ▶ Insula (cortex)
- ▶ Corona radiata (superior relation)

Connections of the corpus striatum

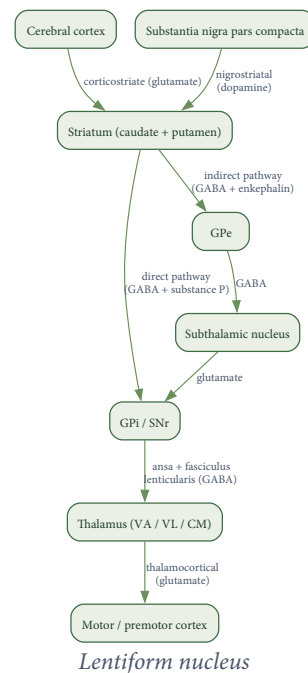
Afferents (to the striatum — caudate + putamen):

- ▶ **Corticostriate fibres** — glutamatergic, from the entire cerebral cortex
- ▶ **Thalamostriate fibres** — from intralaminar nuclei of the thalamus
- ▶ **Nigrostriatal fibres** — dopaminergic, from the substantia nigra pars compacta (mesostriatal dopamine system)
- ▶ Noradrenergic fibres from the **locus coeruleus**; serotonergic fibres from the **raphe nuclei**

Efferents (striatopallidal — GABAergic):

- ▶ To the **internal (medial) pallidal segment/GPi** (co-transmitters substance P and dynorphin) — this is the **direct pathway**
- ▶ To the **external (lateral) pallidal segment/GPe** (co-transmitter enkephalin) — this begins the **indirect pathway**, relaying via the **subthalamic nucleus** (subthalamic fasciculus) back to GPi/SNr

- Output from GPi/substantia nigra pars reticularis leaves via the **ansa lenticularis** (curves round the anterior border of the internal capsule) and the **fasciculus lenticularis** (pierces the internal capsule directly); the two unite in the subthalamic region (the **fields of Forel**, H/H1/H2) and ascend as the **thalamic fasciculus** to the **ventral anterior, ventral lateral and centromedian nuclei** of the thalamus, which project to the frontal (including supplementary motor) cortex
- GPi also sends fibres to the **pedunculopontine nucleus**



Blood supply

- **Medial striate artery** (from the anterior cerebral artery, incl. the recurrent artery of Heubner) ascends through the lentiform nucleus, supplying it along with the head of the caudate nucleus and the anterior limb of the internal capsule.
- **Lateral striate arteries (lenticulostriate)**, from the proximal middle cerebral artery, ascend lateral to the lentiform nucleus to supply the putamen, globus pallidus and the posterior limb of the internal capsule. One large lateral striate branch is termed **Charcot's artery of cerebral haemorrhage** — the vessel most frequently ruptured in hypertensive intracerebral bleeds.
- Smaller contributions reach the globus pallidus from the **anterior choroidal artery** and, posteriorly, from perforators of the posterior communicating/posterior cerebral arteries.

Functions

- Maintenance of muscle tone and posture (e.g. flexed posture on standing/sitting)
- Smoothing and grading of voluntary movement initiated by the cortex
- Suppression of unwanted (involuntary) movement
- Control of associated automatic movements, e.g. swinging of the arms during walking
- Part of the extrapyramidal motor system regulating reflex muscular activity and movements of emotional expression

- ▶ Ventral striatum/pallidum (nucleus accumbens, olfactory tubercle) — mesolimbic reward circuitry, implicated in addictive-drug reinforcement

Applied / Clinical anatomy

- ▶ **Wilson's disease (hepatolenticular degeneration)** — autosomal-recessive disorder of copper metabolism; copper deposition causes degeneration of the **lentiform nucleus** and cirrhosis of the liver; copper in the eye produces **Kayser-Fleischer rings** at the corneoscleral (sclerocorneal) limbus.
- ▶ **Hemiballismus** — sudden, violent flinging movements of proximal limb muscles on one side, due to a (usually vascular) lesion of the **contralateral subthalamic nucleus** or its connections.
- ▶ **Parkinsonism (paralysis agitans)** — degeneration of the substantia nigra (pars compacta) with striatal dopamine deficiency; rigidity, bradykinesia, resting "pill-rolling" tremor, mask-like face, stooped posture and shuffling gait. L-dopa (which, unlike dopamine, crosses the blood-brain barrier) is converted to dopamine within the CNS. Stereotactic **ventroposterolateral pallidotomy** (Laitinen et al., 1992) can abolish parkinsonian symptoms; deep brain stimulation of the subthalamic nucleus/GPi is the modern surgical option.
- ▶ **Chorea** — rapid, involuntary, purposeless, dancing movements from striatal pathology: **Huntington's chorea** (autosomal-dominant, progressive degeneration of striatum and cortex) and **Sydenham's chorea** (a complication of rheumatic fever, self-limiting).
- ▶ **Athetosis** — slow, continuous writhing movements from striatal disease.
- ▶ Because the lenticulostriate vessels are thin-walled end-arteries subjected to high pressure, the lentiform nucleus/internal capsule region is the **commonest site of hypertensive intracerebral (capsular) haemorrhage**, producing contralateral hemiplegia.

High-yield exam pointers

- ▶ Lentiform nucleus = **putamen + globus pallidus**; wedge-shaped, base lateral, apex medial; deep to the insula.
- ▶ **External medullary lamina** separates putamen from globus pallidus; **internal medullary lamina** splits globus pallidus into GPe and GPi.
- ▶ Medial relation = internal capsule (separates it from caudate nucleus and thalamus); lateral relation, in order = external capsule, claustrum, extreme capsule, insula.
- ▶ Caudate + putamen = **neostriatum/striatum** (input); globus pallidus + substantia nigra pars reticularis = **pallidum** (output).
- ▶ **Direct pathway** (striatum → GPi/SNr → thalamus, facilitates movement) vs **indirect pathway** (striatum → GPe → subthalamic nucleus → GPi/SNr → thalamus, suppresses movement).
- ▶ Pallidofugal efferents = **ansa lenticularis + fasciculus lenticularis** → **thalamic fasciculus**, through the **fields of Forel (H, H1, H2)**, to VA/VL/CM thalamic nuclei.
- ▶ Blood supply = medial striate artery (ACA) + lateral striate/lenticulostriate arteries (MCA), one of which is **Charcot's artery of cerebral haemorrhage**.
- ▶ Basal ganglia lesions cause **dyskinesias, not paralysis** — hyperkinetic (chorea, athetosis, ballismus) vs hypokinetic (Parkinsonism) disorders.

- **Wilson's disease** = lentiform nucleus degeneration + Kayser-Fleischer rings; **hemiballismus** = contralateral subthalamic nucleus lesion.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e; IB Singh's Textbook of Anatomy Vol 3 6e.

♦ ♦ ♦

Limbic system

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction The term **limbic lobe** (Latin *limbus* = border/ring) was coined by **Paul Broca (1878)** for the ring of primitive cortex — cingulate gyrus, isthmus, parahippocampal gyrus and uncus — that curves around the upper brainstem and corpus callosum on the medial surface of each cerebral hemisphere. The modern **limbic system** is a wider, functionally-defined network that adds to this lobe the hippocampal formation, amygdala, septal area, olfactory cortex and key diencephalic nuclei (mammillary body, anterior thalamic nucleus, habenula). It is phylogenetically the oldest part of the pallium (**allocortex**, three-layered), interposed between the neocortex of the hemispheres and the diencephalon. Functionally it is the anatomical substrate of **emotion, motivation, memory, and visceral/olfactory integration** — earning it the older name "**visceral brain**."

1. Components of the limbic system

Category	Structures
Limbic lobe (cortical)	Cingulate gyrus, cingulate isthmus, parahippocampal gyrus, uncus
Hippocampal formation (cortical)	Hippocampus (cornu ammonis), dentate gyrus, gyrus fasciolaris, indusium griseum, subiculum, entorhinal cortex (area 28)
Other cortical areas	Septal area, olfactory (piriform) cortex
Subcortical grey matter	Amygdaloid nuclear complex, septal nuclei, anterior nucleus of thalamus, habenular nucleus, mammillary bodies of hypothalamus, nucleus accumbens, rostral reticular formation

□ Fig 9.14 — Parts of limbic system (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.588)

2. Limbic lobe and hippocampal formation

- The **cingulate gyrus** arches over the corpus callosum from the subcallosal (paraolfactory) area anteriorly to the isthmus posteriorly, where it becomes continuous with the **parahippocampal gyrus**; the anterior tip of the latter is the hook-shaped **uncus**.
- The **hippocampus** ("sea-horse"/Ammon's horn) is a C-shaped elevation rolled into the floor of the inferior horn of the lateral ventricle; its expanded, grooved anterior end is the **pes hippocampi**. It is **trilaminar archicortex** — molecular, pyramidal-cell, and polymorphic layers

— and is subdivided into fields **CA1–CA3** (cornu ammonis), CA1 (Sommer's sector) lying closest to the subiculum and being the **most vulnerable field to hypoxia/ischaemia**.

- ▶ The **dentate gyrus** lies deep to the fimbria, has a toothed free margin, and is continuous posteriorly with the gyrus fasciolaris and indusium griseum (containing the medial and lateral longitudinal striae).
- ▶ Ventricular-surface fibres of the hippocampus form the **alveus**, which converges medially into the **fimbria**; the intrinsic wiring is the classic **trisynaptic circuit** — entorhinal cortex → dentate gyrus (**perforant pathway**) → CA3 (**mossy fibres**) → CA1 (**Schaffer collaterals**) → subiculum → fornix.
- ▶ The **fornix** is the sole efferent tract of the hippocampus and, uniquely, contains projection, commissural *and* association fibres together.

3. Amygdaloid nuclear complex

- ▶ An almond-shaped grey mass in the roof of the temporal horn, anterior to the hippocampus, continuous posteriorly with the tail of the caudate nucleus.
- ▶ Grouped into a **basolateral group** (lateral, basal, accessory-basal nuclei — quasi-cortical, reciprocally connected with temporal neocortex) and a **corticomedial (centromedial) group** (central, medial, cortical nuclei), the latter continuing into the **bed nucleus of the stria terminalis** as the so-called "**extended amygdala**."
- ▶ **Afferents**: primary olfactory cortex, hippocampus, hypothalamus, thalamus (medial dorsal nucleus), brainstem reticular formation.
- ▶ **Efferents**: chiefly the **stria terminalis** (to septal area, hypothalamus, habenular nucleus via stria medullaris thalami) and the shorter **ventral amygdalofugal pathway** (direct route to hypothalamus/basal forebrain).
- ▶ Function: integrates olfactory/visceral cues with emotional behaviour, especially **fear, rage and sexual behaviour**; bilateral destruction produces the Klüver–Bucy syndrome (below).

4. Septal area

- ▶ Grey matter (paraterminal + parolfactory gyri) on the medial frontal lobe, in front of the lamina terminalis and beneath the corpus callosum's rostrum/genu; continuous above with the septum pellucidum.
- ▶ Receives the **medial olfactory stria**, the **fornix** (from hippocampus) and the **stria terminalis** (from amygdala); projects mainly to the **habenular nucleus** via the stria medullaris thalami.
- ▶ Regarded as a "**pleasure zone**" of the brain (self-stimulation experiments) and linked to orgasmic response.

5. Fibre bundles connecting the limbic system

Bundle	Connection
Fornix	Hippocampus (alveus → fimbria → crus → body → column) to mammillary body; precommissural fibres also reach the septal area
Mammillothalamic tract (bundle of Vicq d'Azyr)	Mammillary body ↔ anterior nucleus of thalamus

Bundle	Connection
Stria terminalis	Amygdala to septal area, hypothalamus and habenular nucleus
Stria medullaris thalami	Septal nuclei/hypothalamus to habenular nucleus
Anterior commissure	Olfactory structures and anterior temporal lobes of the two hemispheres
Cingulum	Within cingulate/parahippocampal gyri — closes the Papez loop by linking cingulate cortex to entorhinal cortex
Medial forebrain bundle	Septal area/orbitofrontal cortex ↔ hypothalamus ↔ midbrain tegmentum
Diagonal band (of Broca)	Septal area ↔ amygdala/hippocampal formation

6. Papez circuit

- Described by **James Papez** in 1937 as the anatomical substrate of emotion and memory:
hippocampal formation → fornix → mammillary body → mammillothalamic tract → anterior nucleus of thalamus → cingulate gyrus → cingulum → entorhinal cortex/parahippocampal gyrus → back to hippocampal formation.
- This closed loop is essential for consolidating **short-term into long-term memory**; damage anywhere along it produces an amnesic syndrome.
- **Paul MacLean** later modified the circuit to incorporate the **amygdala** (and Yakovlev added the orbitofrontal cortex, septum and anterior temporal lobe), broadening "Papez's circuit" into the modern limbic system concept.

□ Fig 9.15 — Uncus and Papez circuit (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.589)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a medial (sagittal) view of the cerebral hemisphere and brainstem and label:

- ▶ **Limbic lobe:** cingulate gyrus, cingulate isthmus, parahippocampal gyrus, uncus, subcallosal area, corpus callosum.
- ▶ **Hippocampal formation** (inset, coronal section through temporal horn): hippocampus (CA1–CA3), dentate gyrus, subiculum, fimbria, alveus, entorhinal cortex.
- ▶ **Amygdala** in the roof of the inferior horn, anterior to the hippocampus.
- ▶ **Papez circuit** as a labelled arrow loop: Hippocampal formation → **Fornix** → Mammillary body → **Mammillothalamic tract** → Anterior nucleus of thalamus → Cingulate gyrus → **Cingulum** → Entorhinal cortex → back to Hippocampal formation (show the amygdala joining via the stria terminalis as MacLean's addition).
- ▶ Septal area, anterior commissure and stria terminalis on the medial wall beneath the septum pellucidum.

Applied / Clinical anatomy

- ▶ **Klüver–Bucy syndrome:** bilateral destruction of the amygdala and anterior temporal lobe (e.g. herpes simplex encephalitis, temporal lobectomy) causes **hyperorality, hyperphagia, hypersexuality, docility (loss of fear/rage) and visual agnosia ("psychic blindness")** — first described experimentally in monkeys, later recognised in humans.
- ▶ **Acute amnesic syndrome:** bilateral transection of the fornix (e.g. during resection of a colloid cyst of the third ventricle) abolishes the ability to consolidate new (short-term) memory into long-term memory, while old memories, already stored diffusely in the neocortex, are preserved.
- ▶ **Alzheimer's disease:** a degenerative disorder beginning in the entorhinal cortex and hippocampus, with progressive medial-temporal atrophy (visible on coronal MRI), loss of cortical/hippocampal neurons, and a cholinergic deficit producing progressive amnesia.
- ▶ **Hippocampal (mesial temporal) sclerosis:** CA1/Sommer's sector, being most sensitive to ischaemia, undergoes selective neuronal loss and gliosis — the commonest pathological substrate of drug-resistant **temporal lobe (psychomotor) epilepsy**; coronal T2/FLAIR MRI through the temporal horn is the imaging sequence of choice, and **anteromedial temporal lobectomy** (removing the amygdalohippocampal complex) is the definitive surgical treatment.
- ▶ **Psychosurgery: cingulotomy** (lesioning the cingulum) has been used for intractable pain, severe depression and obsessive–compulsive disorder, reflecting the cingulate gyrus's limbic role.
- ▶ Cingulate gyrus lesions and septal-area stimulation studies underlie its description as the "**satisfaction centre**"; broader limbic dysfunction is implicated in **schizophrenia** and mood disorders.

Recent advances

- ▶ **Tractography-based update of the Papez circuit:** diffusion-weighted imaging has revealed additional cortico-limbo-thalamo-cortical white-matter connections beyond the classical description, refining our understanding of the anatomical substrate of memory and emotion (Kamali A et al., *Brain Topogr* 2023, [DOI](https://doi.org/10.1007/s10548-023-00955-y)).

- ▶ **Hippocampal subfield–resting-network mapping:** 7T resting-state fMRI shows the subiculum/CA4/dentate-gyrus complex preferentially couples to the **default mode network**, while anterior CA1/CA3/CA4/dentate-gyrus fields couple to the somatomotor network — a finer-grained, subfield-specific picture than the classical single-circuit teaching (Ezama L et al., *Eur J Neurosci* 2021, [DOI](https://doi.org/10.1111/ejn.15213)).
- ▶ **Adult hippocampal neurogenesis:** direct histological evidence supports continued generation of new neurons in the human dentate gyrus persisting into the tenth decade of life, markedly reduced in Alzheimer's disease, helping resolve a long-standing controversy over whether adult neurogenesis occurs in humans (Moreno-Jiménez EP et al., *J Neurosci* 2021, [DOI](https://doi.org/10.1523/JNEUROSCI.0675-20.2020)); for the counter-debate see Lee H & Thuret S, *Trends Mol Med* 2018, [DOI](https://doi.org/10.1016/j.molmed.2018.04.002)).
- ▶ **Limbic circuit as a therapeutic target:** deep brain stimulation of the **subcallosal cingulate cortex** (Brodmann area 25, a Papez-circuit node) achieves response rates of 23–92% in treatment-resistant depression across a systematic review of 230 patients (Sobstyl M et al., *Front Neurol* 2022, [DOI](https://doi.org/10.3389/fneur.2022.780481)); cingulate local-field-potential recordings can now track individualised recovery trajectories during such stimulation (Alagapan S et al., *Nature* 2023, [DOI](https://doi.org/10.1038/s41586-023-06541-3)).

High-yield exam pointers

- ▶ Limbic lobe (**Broca, 1878**) = cingulate gyrus + isthmus + parahippocampal gyrus + uncus, forming a ring around the upper brainstem.
- ▶ Hippocampal formation = hippocampus (Ammon's horn/cornu ammonis, CA1–CA3) + dentate gyrus + gyrus fasciolaris + indusium griseum + subiculum.
- ▶ **Papez circuit (1937):** Hippocampus → fornix → mammillary body → mammillothalamic tract → anterior thalamic nucleus → cingulate gyrus → cingulum → entorhinal cortex → hippocampus; **MacLean** added the amygdala.
- ▶ Fornix = sole efferent of hippocampus, and the only fibre bundle with projection + commissural + association fibres together.
- ▶ Amygdaloid efferent = **stria terminalis** (+ ventral amygdalofugal pathway); septal efferent = stria medullaris thalami → habenula.
- ▶ CA1 (Sommer's sector) is most vulnerable to hypoxia → basis of hippocampal sclerosis/temporal lobe epilepsy.
- ▶ Bilateral fornix damage → acute amnesic syndrome; bilateral amygdala/temporal-pole damage → **Klüver–Bucy syndrome**.
- ▶ Cingulate gyrus = "satisfaction centre"; septal area = "pleasure zone"/orgasm centre.
- ▶ Limbic system = "**visceral brain**" — integrates olfactory, visceral and somatic input and expresses it via hypothalamic autonomic outflow; governs emotion, motivation and recent memory.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; IB Singh Textbook of Human Neuroanatomy; Vishram Singh Clinical Neuroanatomy 4e; BD Chaurasia Human Anatomy Vol 3–4 8e (text and figures); Snell Clinical Neuroanatomy 7e. Recent-advances citations from PubMed as linked above.



Ventricles, meninges, CSF & blood supply



Subarachnoid Cisterns

Asked in: Paper IV 17-Apr-2026 · Paper IV Nov 2016 · Paper IV May 2010 (3×) — RGUHS MD/MS Anatomy

Definition / Introduction — The subarachnoid space is the CSF-filled compartment between the arachnoid mater and the pia mater. Over the convexities of the brain the pia hugs every gyrus while the arachnoid bridges the sulci, so the space here is thin and uniform; but at the base of the brain, around the brainstem and cerebellum, and wherever the arachnoid has to bridge a large concavity (interpeduncular fossa, lateral sulcus, cerebellomedullary angle), the pia and arachnoid separate widely and pool large volumes of CSF. These localised, expanded, freely-communicating reservoirs of the subarachnoid space are called **subarachnoid cisterns**. They are crossed by long filamentous arachnoid trabeculae, act as a hydraulic "water-bed" that cushions the brainstem and basal vessels/nerves, and are the principal surgical corridors and CSF-diversion sites used in neurosurgery.

1. Formation and general architecture

- ▶ Formed because the **arachnoid follows a smoother, more direct course** than the pia, which dips into every sulcus and fossa; wherever the underlying surface is deeply concave, a gap — the cistern — opens up between the two membranes.
- ▶ Cisterns **communicate freely with one another and with the general subarachnoid space**, so CSF pressure equilibrates throughout; arterial pulsation within the cisterns helps drive CSF flow towards the cerebral convexities.
- ▶ They contain CSF, **arachnoid trabeculae, the proximal segments of major cerebral arteries and veins, and (in several cisterns) cranial nerve roots** — this combination of soft, mobile contents in a fluid pool is what makes cisterns the preferred plane for micro-neurosurgical dissection.
- ▶ Conventionally divided by location relative to the tentorium cerebelli into **supratentorial** and **infratentorial (posterior fossa)** cisterns.

2. Classification of the principal cisterns

Compartment	Cisterns
Supratentorial	Chiasmatic (suprasellar), cistern of the lamina terminalis, supracallosal (pericallosal), interpeduncular (basal), quadrigeminal (superior/vein of Galen), ambient, crural, Sylvian (cistern of the lateral fossa), paired olfactory cisterns

3. Major cisterns — location, boundaries and contents

Cistern	Location / boundaries	Contents
Cisterna magna (cerebellomedullary cistern)	Largest cistern; angle between inferior surface of cerebellum and dorsal medulla oblongata; continuous above with the fourth ventricle via the foramen of Magendie , below with the spinal subarachnoid space	Vertebral arteries; origins of the posterior inferior cerebellar arteries (PICA) ; roots of glossopharyngeal, vagus, accessory and hypoglossal nerves; choroid plexus of the fourth ventricle
Prepontine (pontine) cistern	Ventral to the pons; continuous below with the spinal subarachnoid space, laterally with the cerebellopontine angle cisterns, rostrally with the interpeduncular cistern	Basilar artery ; origins of AICA and superior cerebellar artery; abducens nerves
Cerebellopontine angle cistern (paired)	Lateral angle between cerebellum and pons	Trigeminal, facial and vestibulocochlear nerves; anterior inferior cerebellar artery; superior petrosal vein
Interpeduncular cistern (basal cistern)	Between the two cerebral peduncles; bounded above and below by the diencephalic and mesencephalic leaves of Liliequist's membrane ; extends forward to the optic chiasma	Circle of Willis ; basilar artery bifurcation and origins of posterior cerebral/thalamoperforating arteries; oculomotor nerves
Chiasmatic (suprasellar) cistern	Related to the optic chiasma, above the diaphragma sellae	Optic chiasma/nerves; anterior cerebral arteries and anterior communicating artery
Cistern of the lamina terminalis	Small midline space anterior to the third ventricle, an extension of the interpeduncular cistern	Anterior cerebral arteries
Supracallosal cistern	Superior surface of the corpus callosum	Pericallosal branch of the anterior cerebral artery
Quadrigenital cistern (superior/vein of Galen/peripineal cistern)	Posterior to the brainstem/third ventricle, between the splenium of corpus callosum and superior cerebellar surface; pineal gland protrudes into it	Great cerebral vein of Galen ; P3 segment of posterior cerebral artery; medial/lateral posterior choroidal arteries
Ambient cistern (paired; extension of quadrigenital cistern)	Between parahippocampal/dentate gyri laterally and the cerebral peduncle medially, wrapping around the midbrain to the interpeduncular cistern	Basal vein of Rosenthal; P2 segment of posterior cerebral artery; superior cerebellar artery; trochlear nerve
Crural cistern (paired)	Between the uncus posteriorly and the cerebral peduncle	P1 segment of posterior cerebral artery; anterior choroidal artery

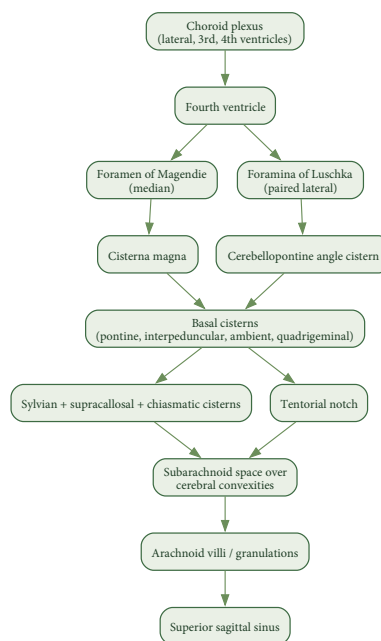
Cistern	Location / boundaries	Contents
Sylvian cistern (cistern of the lateral fossa)	Formed by arachnoid bridging the lateral sulcus, in front of the temporal pole	Middle cerebral artery and its veins
Lumbar cistern	Subarachnoid space around the cauda equina/filum terminale below the conus medullaris	No major artery — safe site for lumbar puncture

4. Lilliequist's membrane and subdivision of the basal cisterns

- **Lilliequist's membrane** is an arachnoid fold passing from the **dorsum sellae** to the **anterior edge of the mammillary bodies**, first described by Key and Retzius (1875) and characterised radiologically by Lilliequist in his classic 1956 study "The anatomy of the subarachnoid cisterns."
- It has a **diencephalic leaf** (roofing the interpeduncular cistern, separating it from the chiasmatic cistern) and a **mesencephalic leaf** (separating the interpeduncular from the prepontine cistern).
- Surgically important because it must be opened to allow free CSF flow between the third-ventricular floor and the prepontine cistern during **endoscopic third ventriculostomy (ETV)**.

5. CSF circulation through the cisternal system

- CSF is secreted mainly by the choroid plexuses of the lateral, third and fourth ventricles (adult volume 140–270 ml; production 0.2–0.7 ml/min, i.e. 600–700 ml/day — roughly four full volume-turnovers daily).
- It leaves the fourth ventricle through the median **foramen of Magendie** (into the cisterna magna) and the paired lateral **foramina of Luschka** (into the cerebellopontine angle cisterns), then percolates through the interconnected basal and posterior-fossa cisterns before ascending, via the tentorial notch, over the cerebral convexities to be absorbed at the **arachnoid villi/granulations** into the superior sagittal sinus.



Subarachnoid Cisterns

□ Fig 16.4 — Subarachnoid cisterns (IB Singh — Textbook of Human Neuroanatomy, p.258)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Median sagittal section of the brain, labelling: cerebellum, cisterna magna (cerebellomedullary cistern), medulla oblongata, fourth ventricle, pons, prepontine (pontine) cistern, interpeduncular cistern (basal cistern), optic chiasma, chiasmatic cistern (suprasellar cistern), cistern of the lamina terminalis, fornix, corpus callosum, supracallosal cistern, third ventricle, septum pellucidum, cistern of the great cerebral vein (quadrigeminal/superior cistern).

Applied / Clinical anatomy

- ▶ **Cisternal (suboccipital) puncture:** the cisterna magna is entered by a needle passed in the midline through the posterior atlanto-occipital membrane, between the posterior arch of the atlas and the margin of the foramen magnum; used when lumbar puncture is contraindicated or technically difficult. A needle-guard is essential — over-insertion can pierce the medulla and cause fatal respiratory arrest, so fluoroscopic/imaging guidance is preferred.
- ▶ **Lumbar puncture** exploits the **lumbar cistern**, which is free of neural/major vascular structures below the conus medullaris (adult cord ends at L1–L2); performed at the L3–L4 or L2–L3 interspace (the lumbar cistern is broadest between L2 and L4).
- ▶ **CT/MR cisternography**, especially high-resolution T2 steady-state sequences (FIESTA/CISS), delineates the individual cisterns and the cranial nerves and vessels running within them; used to plan the **retrosigmoid approach through the cerebellopontine angle cistern for microvascular decompression** of the trigeminal nerve (trigeminal neuralgia) or facial nerve (hemifacial spasm), and to detect neurovascular conflict pre-operatively.
- ▶ **Endoscopic third ventriculostomy** fenestrates the floor of the third ventricle into the **interpeduncular cistern**, exploiting the natural CSF pathway once Liliequist's membrane is opened — the anatomical basis of modern surgery for obstructive hydrocephalus.
- ▶ **Subarachnoid haemorrhage:** the circle of Willis lies within the interpeduncular (basal) cistern, so ruptured berry aneurysms bleed preferentially into the basal cisterns — the classic "star-shaped" hyperdensity on non-contrast CT centred on the suprasellar/interpeduncular cisterns.
- ▶ **Communicating vs obstructive hydrocephalus:** adhesions or exudate (e.g., post-tubercular/pyogenic meningitis) within the cisterns can produce **extraventricular obstruction** to CSF flow even though the ventricular system itself is patent.
- ▶ **CSF rhinorrhoea/otorrhoea:** fracture of the cribriform plate or petrous temporal bone communicates the basal subarachnoid cisterns with the nasal cavity or middle ear respectively.

High-yield exam pointers

- ▶ Cisterns = localised **wide separations of arachnoid and pia** at the base of the brain, around the brainstem/cerebellum, and at the tentorial notch — all continuous with one another and the general subarachnoid space.
- ▶ **Cisterna magna** is the largest cistern and the only one in **direct continuity with the ventricular system** (via the foramen of Magendie).

- ▶ Circle of Willis → interpeduncular (basal) cistern; MCA → Sylvian cistern; basilar artery → pontine cistern; vein of Galen → quadrigeminal cistern; PICA/vertebral arteries → cisterna magna.
- ▶ Liliequist's membrane (dorsum sellae → mammillary bodies) separates chiasmatic, interpeduncular and prepontine cisterns — key landmark in ETV.
- ▶ Lumbar cistern (below L1–L2) contains cauda equina + filum terminale, no major artery — site of lumbar puncture; cisterna magna — site of cisternal puncture.
- ▶ Cranial nerves III (interpeduncular), V/VII/VIII (cerebellopontine angle), IX/X/XI/XII (cisterna magna) traverse specific cisterns — relevant to skull-base surgical approaches.
- ▶ CSF production 0.2–0.7 ml/min (600–700 ml/day); total adult volume 140–270 ml; absorbed at arachnoid villi/granulations into the superior sagittal sinus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e; Moore's Clinically Oriented Anatomy 9e.



Blood brain barrier

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

The **blood-brain barrier (BBB)** — more accurately termed the **blood-brain-spinal cord barrier** — is a selectively semipermeable interface between the circulating blood and the neural tissue of the central nervous system. It isolates neurons and glia from fluctuations in plasma composition and from circulating toxins, bacteria and macromolecules, while still permitting the gases, water and nutrients needed for normal neuronal function to enter. The barrier is created principally by **tight junctions between the capillary endothelial cells** of the CNS, reinforced by a continuous basement membrane and a complete investment of **astrocytic foot processes**. Its integrity is not absolute — a handful of midline sites, the **circumventricular organs**, are physiologically devoid of the barrier, and this anatomical fact underlies much of the applied importance of the topic.

1. Historical background

- ▶ Paul Ehrlich (1882) demonstrated that an intravenously injected vital dye, **trypan blue**, stained every tissue of the body **except the brain and spinal cord** — the first experimental evidence of a barrier isolating the CNS from the blood.
- ▶ A small number of sites were noted to stain even after intravenous dye: the **pineal gland**, **posterior lobe of the pituitary**, **tuber cinereum**, **wall of the optic (supraoptic) recess**, and the **area postrema** at the lower end of the fourth ventricle — these are the anatomical precursors of what are now called the circumventricular organs.
- ▶ Because trypan blue binds avidly to the plasma protein albumin, these early experiments actually demonstrated that the barrier excludes **protein-bound dye**, not the dye itself — an observation

later confirmed by electron-dense tracer studies (lanthanum, horseradish peroxidase; Brightman and Reese, 1969), which localised the barrier precisely to the **tight junctions between endothelial cells**.

2. Structure of the blood-brain barrier

Between the lumen of a CNS capillary and the extracellular space around neurons and neuroglia lie three structural layers:

Component	Description	Contribution to the barrier
Capillary endothelial cells + tight junctions	Continuous, non-fenestrated endothelium; adjacent cells sealed by well-developed zonulae occludentes (tight junctions) encircling each cell like a belt	The principal and most important component — electron-dense tracers (lanthanum, HRP) fail to penetrate between endothelial cells because of these junctions; minimal transcytotic vesicular transport adds further tightness
Basement membrane	A continuous basal lamina surrounding the capillary external to the endothelium	Structural support; a compartment through which pericytes are embedded
Pericytes	Contractile mural cells applied to the abluminal endothelial surface, within/deep to the basal lamina	Support the endothelium and help maintain junctional integrity
Astrocytic foot processes (perivascular end-feet)	Foot processes of astrocytes closely invest the outer surface of the capillary wall, forming the glia limitans ; larger vessels also receive a pial investment	Do not themselves form the primary diffusion barrier but induce and maintain endothelial tight-junction formation and further regulate molecular passage
Perivascular macrophages	Lie just outside the endothelial basal lamina	Immune surveillance of the perivascular space

In molecular terms the BBB behaves as a **continuous lipid bilayer** encircling the endothelial cells: lipophilic (fat-soluble) molecules diffuse through it readily, while hydrophilic, charged or protein-bound molecules are excluded — this single principle explains almost all the applied pharmacology of the barrier (Section 3 and Applied anatomy, below).

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 15.23 — Structure of blood-brain barrier (BBB) (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.571)

Reproduce a transverse section of a CNS capillary and label: **capillary lumen with a red blood cell, endothelial cell, tight junction belting adjacent endothelial cells, basement membrane, pericyte** (embedded in/beneath the basement membrane), and the **foot processes of astrocytes** encircling the outer capillary wall.

3. Permeability characteristics

- ▶ Permeability across the BBB is **inversely proportional to molecular size** and **directly proportional to lipid solubility**.
- ▶ **Gases (O₂, CO₂) and water** pass freely and rapidly; **glucose and electrolytes** pass more slowly, via specific carrier-mediated transport.
- ▶ The barrier is **almost impermeable to plasma proteins** and other large organic molecules — compounds of molecular weight $\geq 60,000$ remain confined to the circulation.
- ▶ **Drugs/molecules that cross freely (lipid-soluble)**: chloramphenicol, tetracyclines, sulphonamides, thiopental, tertiary amines such as atropine, and **L-dopa** (precursor of dopamine).
- ▶ **Drugs/molecules excluded (polar, water-soluble, or protein-bound)**: dopamine itself, exogenous norepinephrine, phenylbutazone (protein-bound), penicillin (only a small fraction enters normally), and quaternary compounds such as atropine methylnitrate.
- ▶ The barrier **exists in the newborn but is more permeable** to certain substances than in the adult, and its structure is **not uniform** across the CNS — it is deliberately absent at the circumventricular organs (Section 4).

4. Circumventricular organs — areas devoid of the blood-brain barrier

At a small number of midline sites the capillary endothelium is **fenestrated** (true perforations closed only by a thin diaphragm), allowing proteins and small organic molecules to pass directly from blood to neural tissue. These are often called the "**seven windows of the brain**":

Circumventricular organ	Location
Pineal gland	Posterior to the third ventricle
Posterior lobe of the pituitary (neurohypophysis)	Below the hypothalamus
Tuber cinereum / median eminence	Floor of the hypothalamus
Wall of the supraoptic recess	Anteroinferior third ventricle
Inferior wall of the pineal recess	Posterior third ventricle
Interventricular foramen (subfornical organ)	Junction of third and lateral ventricles
Area postrema	Caudal floor of the fourth ventricle

Functionally, these sites act as "**sampling windows**" where specialised neurons directly monitor the chemical composition of plasma (osmolality, circulating peptides, toxins) and trigger appropriate

homeostatic or protective reflexes — the **hypothalamic** circumventricular organs regulate fluid balance and neuroendocrine secretion, while the **area postrema** functions as the **chemoreceptor trigger zone (CTZ)** for vomiting.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 18.13 — The locations of the circumventricular organs, median sagittal section of the brain (Gray's Anatomy — Standring — 41e, p.389)

On a median sagittal outline of the brain, mark and label the seven circumventricular organs listed above, positioned around the third and fourth ventricles.

5. Blood–cerebrospinal fluid (CSF) barrier — comparison

A second, structurally distinct barrier regulates exchange between blood and CSF at the choroid plexus.

Feature	Blood-brain barrier	Blood-CSF barrier
Site	Cerebral/spinal capillaries	Capillaries of the choroid plexus villi
Endothelium	Continuous, non-fenestrated , tight junctions between endothelial cells	Fenestrated (fenestrations closed by thin diaphragms) — leaky to small molecules
Structure providing the barrier	Tight junctions between endothelial cells	Tight junctions (zonulae occludentes) between choroidal epithelial cells
Additional layers	Basement membrane + astrocytic foot processes	Endothelial basement membrane, scattered pale cells, epithelial basement membrane, choroidal epithelial cells
Permeability	Free passage of gases, water, lipid-soluble substances; excludes plasma proteins and most large molecules	Free passage of water, gases, lipid-soluble substances; excludes proteins and most hexoses other than glucose

CSF–brain interface: there is, by contrast, **no comparable physiological barrier** between the CSF and the extracellular space of neural tissue — dyes injected into the subarachnoid space or ventricles enter the perineuronal extracellular space freely, via the loosely arranged pia-glial surface, perivascular (Virchow–Robin) spaces, and the ependymal lining of the ventricles.

Applied / Clinical anatomy

- **Kernicterus (bilirubin encephalopathy):** in the fetus, newborn and premature infant the BBB is not fully developed, so unconjugated bilirubin readily enters the CNS in severe neonatal jaundice, staining and damaging the basal nuclei — this cannot occur in the mature adult barrier.
- **Brain trauma, inflammation and infection:** direct injury, chemical toxins or inflammatory mediators disrupt endothelial cells and their tight junctions, causing **breakdown of the BBB** and free diffusion of large molecules and fluid into the brain (vasogenic oedema).
- **Meningitis and antibiotic choice:** systemic penicillin normally crosses the intact BBB poorly (fortunately, since high CNS concentrations are neurotoxic); in bacterial meningitis, however,

inflamed meninges become locally more permeable, allowing therapeutic antibiotic levels to reach the site of infection — the rationale for choosing BBB-penetrant agents (e.g. ceftriaxone) in suspected meningitis.

- ▶ **Parkinson disease:** striatal dopamine deficiency cannot be treated with dopamine itself, since it cannot cross the BBB; its lipid-soluble precursor **L-dopa** crosses freely and is decarboxylated to dopamine within the CNS.
- ▶ **Brain tumours: anaplastic astrocytomas, glioblastomas and metastatic tumours** develop abnormal, leaky vasculature that lacks a normal BBB — the structural basis for **contrast enhancement on CT/MRI**, which helps distinguish high-grade from low-grade (BBB-intact, non-enhancing) tumours, and for intra-arterial osmotic (mannitol) or focused-ultrasound BBB disruption used to improve chemotherapeutic drug delivery.
- ▶ **Area postrema/CTZ:** because this circumventricular organ lacks a BBB, blood-borne emetogenic agents (chemotherapy, opioids, apomorphine) act directly here to trigger vomiting — the anatomical basis for centrally acting antiemetics.
- ▶ **Blood-nerve barrier:** the endoneurial capillaries of peripheral nerves are likewise sealed by tight junctions, forming an analogous **blood-nerve barrier** that isolates peripheral axons from the systemic circulation.

Recent advances

- ▶ A **single-cell transcriptomic atlas of the human brain vasculature**, spanning fetal development, adulthood and five vascular-dependent CNS pathologies (over 600,000 endothelial and perivascular cells from 117 samples), has revealed extensive molecular heterogeneity of BBB-forming endothelium and pericytes across development and disease, providing a reference map for how the anatomical BBB is built and how it fails in tumours and vascular malformations (Wälchli, Ghobrial, Schwab, Takada, Zhong et al., *Nature*, 2024) [DOI: 10.1038/s41586-024-07493-y].
- ▶ Structural work on the tight-junction protein **claudin-5 (CLDN5)** — the key transmembrane sealing protein of BBB endothelial tight junctions — has produced a CLDN5-derived peptide that transiently and reversibly increases paracellular BBB permeability in vitro, clarifying how the extracellular domains of claudin-5 strands can be therapeutically manipulated to allow controlled, temporary drug delivery across an otherwise intact barrier (Trevisani, Berselli, Alberini et al., *Science Advances*, 2025) [DOI: 10.1126/sciadv.adq2616].
- ▶ **MRI-guided focused-ultrasound BBB opening**, already in human clinical trials for Alzheimer disease and paediatric diffuse midline glioma, has been shown by computational fluid-dynamic modelling to enhance not only local drug delivery but also **glymphatic clearance** — the perivascular CSF-mediated waste-clearance pathway — linking BBB anatomy to the newer glymphatic-system concept of CNS fluid dynamics (Gladwell, Fisher, Wythe, Highley, Lukens, Price, *Advanced Science*, 2025) [PMID: 40908557; DOI: 10.1002/adv.202510684].
- ▶ (*According to PubMed/journal literature.*)

High-yield exam pointers

- ▶ BBB = tight junctions between capillary endothelial cells (**principal component**) + continuous basement membrane + pericytes + astrocytic foot processes.

- ▶ Demonstrated by **Paul Ehrlich's trypan blue experiment (1882)**; localised precisely by electron-dense tracers (lanthanum, HRP — Brightman & Reese, 1969) to endothelial tight junctions.
- ▶ Permeability: **inversely** related to molecular size, **directly** related to lipid solubility; MW $\geq$ 60,000 essentially excluded.
- ▶ **Seven circumventricular organs devoid of BBB**: pineal gland, posterior pituitary, tuber cinereum, wall of supraoptic recess, inferior wall of pineal recess, interventricular foramen (subfornical organ), area postrema.
- ▶ Blood-CSF barrier (choroid plexus) is structurally different: endothelium is **fenestrated**; the barrier is formed instead by **tight junctions between choroidal epithelial cells**.
- ▶ No physiological barrier exists between CSF and brain extracellular fluid (pia-glial, perivascular and ependymal surfaces are freely permeable).
- ▶ Immature in the fetus/newborn $\rightarrow$ **kernicterus**; breaks down with trauma/inflammation; absent in most malignant brain tumours (basis of contrast-enhanced imaging).
- ▶ Classic pharmacology pairs: dopamine (excluded) vs L-dopa (crosses); atropine (tertiary amine, crosses) vs atropine methylnitrate (quaternary, excluded).
- ▶ Peripheral nerves have an analogous **blood-nerve barrier** formed by tight junctions of endoneurial capillary endothelium.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; Junqueira's Basic Histology 17e. Recent-advances section per PubMed/journal literature (see DOIs above).



Cerebrospinal fluid

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction — Cerebrospinal fluid (CSF) is a clear, colourless fluid that occupies the ventricular system of the brain, the central canal of the spinal cord, and the subarachnoid space surrounding the brain and spinal cord. It is actively secreted mainly by the choroid plexuses of the lateral, third and fourth ventricles, circulates through the ventricular system into the subarachnoid space, and is finally absorbed into the dural venous sinuses through the arachnoid villi and granulations. CSF provides mechanical protection, buoyancy, nutritive support and a route for metabolite clearance and neurohumoral transport for the central nervous system.

1. Formation of CSF

- ▶ Formed mainly (~80–90%) by the **choroid plexuses of the lateral ventricles**, with the remainder contributed by the choroid plexuses of the **third and fourth ventricles**.
- ▶ A small additional amount arises from the **ependymal lining** of the ventricles and from brain parenchymal extracellular fluid via perivascular spaces.

- ▶ Each choroid plexus is formed where vascular **pia mater (tela choroidea)** invaginates the ependymal roof/wall of a ventricle, producing a much-folded plexus whose core of vascular connective tissue is covered by a single layer of cuboidal **ependymal (choroidal epithelial) cells** bearing apical microvilli.
- ▶ Blood in the plexus capillaries is separated from the ventricular lumen by: fenestrated capillary endothelium → basement membrane → choroidal epithelium joined by apical **tight junctions** — this constitutes the **blood–CSF barrier**.
- ▶ Formation is by **active secretion** (not simple ultrafiltration) — hence CSF is not identical to a plasma dialysate: concentrations of K^+ , Ca^{2+} , Mg^{2+} , bicarbonate and glucose are lower than in plasma, while chloride is higher.
- ▶ Choroid plexus of the lateral ventricle is supplied by the anterior and posterior choroidal arteries; the fourth-ventricle plexus by the posterior-inferior cerebellar arteries.
- ▶ CSF production is **continuous and not pressure-regulated** — it continues even if the absorptive pathway is obstructed (basis of hydrocephalus).

2. Circulation of CSF

- ▶ **Lateral ventricle** (choroid plexus) → through the **interventricular foramen (of Monro)** → **third ventricle** → through the narrow **cerebral aqueduct (of Sylvius)** → **fourth ventricle** (receiving its own choroid plexus contribution).
- ▶ From the fourth ventricle, fluid leaves the ventricular system through the **median aperture (foramen of Magendie)** and the paired **lateral apertures (foramina of Luschka)** to enter the **subarachnoid space** via the cerebellomedullary (cisterna magna) and pontine cisterns.
- ▶ It then flows superiorly through the **tentorial notch**, over the inferior and superolateral surfaces of the cerebral hemispheres, to reach the **arachnoid villi/granulations** projecting into the superior sagittal sinus, where it is absorbed.
- ▶ A portion of the fluid also moves caudally in the spinal subarachnoid space around the cord and cauda equina, pooling in the **lumbar cistern**.
- ▶ Movement is aided by **ciliary beating** of ependymal cells, **choroidal arterial pulsations**, cerebral/spinal arterial pulsations, respiration, coughing and postural/spinal-column movements.

Diagram (embedded)

embed: ![Fig 16.7 — Circulation of cerebrospinal fluid from its sites of formation in the choroid plexuses of lateral ventricle to its sites of absorption into the superior sagittal sinus (Vishram Singh — Clinical Neuroanatomy — 4e, p.599)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/c686a3e78382c83e.jpg)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label, in sequence, on a midsagittal brain outline:

- ▶ Choroid plexus of **lateral ventricle**
- ▶ **Interventricular foramen (Monro)**
- ▶ Choroid plexus of **third ventricle**
- ▶ **Cerebral aqueduct (Sylvius)**
- ▶ Choroid plexus of **fourth ventricle**
- ▶ **Median aperture (Magendie) and lateral apertures (Luschka)**
- ▶ **Cerebellomedullary cistern / pontine cistern**
- ▶ **Tentorial notch** → over cerebral hemisphere surface
- ▶ **Arachnoid villi/granulations** → **superior sagittal sinus**
- ▶ Downward limb: subarachnoid space around spinal cord/cauda equina → **lumbar cistern**

3. Composition and physical characteristics

Parameter	Value
Appearance	Clear and colourless
Total volume (adult)	~150 mL (≈30 mL ventricular + ≈120 mL subarachnoid/spinal)
Rate of production	~0.3–0.5 mL/min (≈500 mL/day); turnover roughly 3–4×/day
Specific gravity	1.005–1.008
Pressure (lumbar puncture, lateral recumbent)	60–150 mm of water
Protein	15–45 mg/100 mL (far lower than plasma)
Glucose	50–85 mg/100 mL (≈½ of blood glucose)
Chloride	720–750 mg/100 mL (higher than plasma)
Cells	0–3 lymphocytes/cu mm

Note: Gray's Anatomy (Standring) 41e gives a wider adult range of 140–270 mL total volume (ventricular component ≈25 mL) with a production rate of 0.2–0.7 mL/min (≈600–700 mL/day, ~4 total turnovers/day); the values above are the classical teaching figures reproduced in Snell and Vishram Singh and are what is conventionally expected in the PG exam.

4. Absorption of CSF

- ▶ Principal site: **arachnoid villi**, finger-like diverticula of arachnoid mater (with enclosed subarachnoid space) that pierce the dura and project into the **dural venous sinuses**, chiefly the **superior sagittal sinus**; clusters of villi form visible **arachnoid granulations (Pacchionian bodies)**, also found in the transverse, superior petrosal and straight sinuses.

- ▶ Each villus/granulation is capped by a thin layer of arachnoid cells covered by sinus endothelium; fine tubules/channels through the cap permit bulk one-way flow of CSF into the sinus lumen.
- ▶ Absorption occurs whenever **CSF pressure exceeds venous sinus pressure**; if venous pressure rises above CSF pressure, the villus tips are compressed shut, preventing reflux of blood — the villi thus act as one-way **valves**.
- ▶ A minor amount of CSF is absorbed directly into subarachnoid veins and possibly escapes along perineural lymphatics of cranial and spinal nerves.
- ▶ Since production is constant, it is the **rate of absorption** through the arachnoid villi that principally regulates CSF pressure.
- ▶ Arachnoid granulations increase in number/size with age and often calcify in later life.

5. Functions of CSF

- ▶ **Mechanical protection** — a cushioning, shock-absorbing fluid medium between the CNS and surrounding bone.
- ▶ **Buoyancy/support** — because brain density is only slightly greater than that of CSF, a ~1500 g brain effectively weighs only ~50 g when floating in CSF, minimising traction on vessels and nerve roots.
- ▶ **Volume-regulatory reservoir** — CSF volume adjusts reciprocally to changes in brain/blood volume within the fixed cranial cavity (Monro–Kellie relationship).
- ▶ **Nutritive/homeostatic role** for neural tissue and **removal of metabolic waste products** of neuronal activity.
- ▶ **Pathway for neurohumoral transport** — e.g., pineal secretions are believed to reach the pituitary via the third-ventricular CSF.

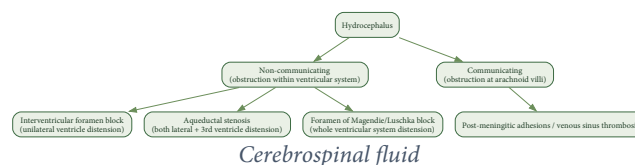
6. Blood–CSF and blood–brain barriers

- ▶ **Blood–CSF barrier**: located at the choroidal epithelium — tight junctions between choroid plexus epithelial cells (not the fenestrated choroidal capillary endothelium) restrict passage of proteins and most non-glucose hexoses from blood to CSF, while water, gases and lipid-soluble substances pass freely.
- ▶ **Blood–brain barrier**: formed by **tight junctions between cerebral capillary endothelial cells**, reinforced by a continuous basement membrane and enveloping **astrocytic foot processes**; permeability is inversely related to molecular size and directly related to lipid solubility (demonstrated classically by Ehrlich's trypan-blue experiments, which stained all tissues except brain/cord).
- ▶ Sites lacking a full barrier (fenestrated capillaries, stained by intravenous vital dyes) — **area postrema, pineal gland, posterior pituitary, tuber cinereum, and the wall of the optic recess** — function as chemoreceptive "windows" sampling plasma composition.
- ▶ No comparable barrier exists between **CSF and brain extracellular fluid**; substances placed in the subarachnoid space or ventricles (intrathecal drugs, anaesthetic agents, contrast media) diffuse freely into neural tissue.

- Clinically: antibodies and bile pigments normally do not enter CSF; most systemic drugs cross poorly (barrier basis of intrathecal chemotherapy/anaesthesia); inflammation (meningitis) increases barrier permeability, improving antibiotic penetration.

Applied / Clinical anatomy

- **Hydrocephalus** — abnormal accumulation/increase of CSF volume within the skull, usually with raised CSF pressure, due to (i) excess formation (rare — choroid plexus papilloma), (ii) obstruction of circulation (commonest — e.g. aqueductal stenosis, tumour at interventricular foramen, exudate blocking foramina of Magendie/Luschka or the tentorial notch), or (iii) defective absorption at the arachnoid villi (e.g. post-meningitic adhesions, venous sinus thrombosis).
 - **Non-communicating (internal/obstructive) hydrocephalus** — block lies within the ventricular system, proximal to the fourth-ventricular outlets; CSF cannot reach the subarachnoid space.
 - **Communicating (external) hydrocephalus** — ventricular outflow is patent; the block is at the arachnoid villi/granulations, so CSF freely enters but cannot be absorbed from the subarachnoid space.
 - In infants: disproportionately enlarged head, frontal bossing, separated sutures, tense bulging anterior fontanelle, dilated scalp veins, "setting-sun" eye sign, "cracked-pot" percussion note.
- **Lumbar puncture** — performed to withdraw CSF for diagnostic/therapeutic purposes. The spinal cord ends at the lower border of L1 in adults (L3 in the newborn), and the dural sac extends to S2; the roomy **lumbar cistern** below the conus (containing only cauda equina roots and filum terminale, which float away from the needle) makes the region below L1 safe. The needle is classically introduced in the midline in the **L3–L4 interspinous space** (the supracristal/Tuffier's line joining the highest points of the iliac crests crosses the L4 spine), traversing supraspinous ligament, interspinous ligament, ligamentum flavum, and dura mater (felt as a distinct "give").
- **CSF analysis** has major diagnostic value: turbid fluid with raised protein and cell count in bacterial meningitis; **Froin's syndrome** — spontaneous coagulation, xanthochromia (yellow discolouration) and very high protein below a spinal subarachnoid block, with loss of transmission of raised intracranial venous pressure.
- **Papilledema** — raised intracranial/CSF pressure is transmitted along the subarachnoid extension around the optic nerve, compressing the central retinal vein at the optic disc and producing bilateral disc oedema; longstanding papilledema may progress to optic atrophy and blindness.
- **Clinical imaging** — ventricular size/distortion is assessed by CT/MRI; CSF/ventricular studies help localise obstructing lesions along the pathway described above.



High-yield exam pointers

- ▶ CSF is formed chiefly by the **choroid plexuses of the lateral ventricles** (80–90%); production is continuous and independent of pressure.
- ▶ Circulation route: lateral ventricle → **foramen of Monro** → third ventricle → **aqueduct of Sylvius** → fourth ventricle → **foramina of Magendie (median) and Luschka (paired lateral)** → subarachnoid space → arachnoid villi.
- ▶ Total volume ≈ **150 mL**; production ≈ **500 mL/day** (turnover ~3–4×/day).
- ▶ Absorption occurs at **arachnoid villi/granulations** in the superior sagittal sinus, driven by a CSF-to-venous pressure gradient; villi act as one-way valves.
- ▶ Composition differs from plasma: **lower protein, lower glucose (~½ plasma), higher chloride**, 0–3 lymphocytes/cu mm.
- ▶ **Blood–CSF barrier** = tight junctions of choroidal epithelium; **blood–brain barrier** = tight junctions of cerebral capillary endothelium; no barrier exists between CSF and brain ECF.
- ▶ Hydrocephalus is **non-communicating** (block within ventricular system) or **communicating** (block at arachnoid villi); commonest cause is aqueductal stenosis.
- ▶ Lumbar puncture is safely performed in the **L3–L4 interspinous space**, below the adult cord termination at **L1**, using the intercrystal line (crosses L4) as landmark.
- ▶ Functions: cushioning/shock absorption, buoyancy (Monro–Kellie volume buffering), nourishment, waste removal, and a conduit for pineal-to-pituitary secretions.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e.



Choroid fissure of lateral ventricle

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction The **choroid fissure** (choroidal fissure) is a C-shaped cleft in the medial wall of the cerebral hemisphere, running from the **interventricular foramen of Monro**, backwards and around the thalamus, then forwards into the inferior horn as far as the uncus. It is not a defect in the ventricular wall but the line along which the vascular pia mater (**tela choroidea**) comes into direct contact with the ependymal lining of the ventricle — with no intervening brain tissue — and is invaginated into the ventricular cavity to form the **choroid plexus of the lateral ventricle**. The fissure exists only along the **central part (body)** and **inferior (temporal) horn** of the ventricle; it is absent from the anterior horn, the roof of the atrium proper, and the posterior horn, which is why the choroid plexus itself is confined to these same segments.

1. Site, course and extent

- ▶ Begins at the **interventricular foramen** (above and in front), where it is continuous with the roof of the third ventricle (tela choroidea/velum interpositum) across the **transverse fissure**.

- ▶ Passes backwards through the **central part (body)** of the lateral ventricle, arching around the superior and posterior surfaces of the **thalamus**.
- ▶ Turns at the **inferior choroidal point** — the point between the head and body of the hippocampus, also where the anterior choroidal artery enters the temporal pole of the ventricle — to descend into the **inferior (temporal) horn**.
- ▶ Runs forward within the inferior horn as far as the **hippocampus/uncus**, near the amygdala, where the plexus terminates.
- ▶ Net result: a single continuous **C-shaped** fissure, confined strictly to the body and inferior horn — **no choroid fissure and no choroid plexus in the anterior or posterior horns**.

2. Boundaries

Region	Convex (outer) margin	Concave (inner) margin
Central part (body)	Body and crus of the fornix	Superior and posterior surfaces of the thalamus , tail of caudate nucleus , stria terminalis
Inferior (temporal) horn	Fimbria of the fornix + hippocampus	Tail of caudate nucleus (proximally) and stria terminalis

- ▶ In the body, the fissure is simply the narrow gap between the free edge of the fornix above and the upper surface of the thalamus below.
- ▶ The **thalamostriate vein** runs medial to the stria terminalis, in the groove between thalamus and caudate — a key operative landmark just outside the concave margin of the fissure.
- ▶ In the inferior horn the relations invert: the fissure now lies **above** the fimbria/hippocampus and **below** the tail of caudate/stria terminalis.

□ Fig 9.5a — Boundaries of third ventricle and central part of lateral ventricle (coronal section) (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.583)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Two coronal sections. (a) Through the body of the lateral ventricle/third ventricle — label: **fornix (body)**, **septum pellucidum**, **thalamus**, **third ventricle**, **tela choroidea**, **choroid plexus**, **choroid fissure**, **tail of caudate nucleus**, **stria terminalis**, **thalamostriate vein**. (b) Through the inferior horn — label: **hippocampus**, **fimbria**, **choroid fissure**, **choroid plexus**, **collateral eminence**, **tail of caudate nucleus**, **stria terminalis**.

3. Relationship to the tela choroidea and formation of the choroid plexus

- ▶ Along the fissure, the ependyma lining the ventricle and the vascular pia mater covering the diencephalon come into **direct apposition**; both layers are together invaginated into the ventricular cavity by a tuft of capillaries.
- ▶ The invaginated fold of vascular pia is the **tela choroidea**; the capillary tuft within it, covered by the pushed-in ependyma (now modified to cuboidal choroidal epithelium), constitutes the **choroid plexus**.

- ▶ At the interventricular foramen the choroid plexus of one lateral ventricle is **continuous with its fellow of the opposite side** across the roof of the third ventricle, and also continuous with the choroid plexus of the third ventricle itself — all three plexuses share the same tela choroidea.

4. Blood supply through the fissure

Segment of choroid plexus	Artery entering via the fissure	Parent vessel
Inferior horn	Anterior choroidal artery, coursing backwards above the optic tract, entering the lower/inferior part of the fissure	Internal carotid artery
Body and atrium	Medial and lateral posterior choroidal arteries, entering the upper part of the fissure from the plexus of the third ventricle	Posterior cerebral artery

- ▶ The two supplies **anastomose** in the region of the atrium/trigone, where the plexus is bulkiest.
- ▶ Venous drainage is via a **single choroidal vein** into the internal cerebral vein.
- ▶ Because the plexus is fenestrated-capillary tissue resting on a basement membrane beneath choroidal epithelial cells joined by tight junctions, this is also the structural basis of the **blood–CSF barrier**.

5. Development

- ▶ The lateral ventricle begins as a spherical cavity within the telencephalic vesicle; anteroposterior growth elongates it, and downward-forward growth of its posterior end forms the temporal lobe and inferior horn, giving the ventricle its **C-shape**.
- ▶ As the two telencephalic vesicles enlarge, their **medial walls become apposed**, forming a groove whose floor becomes the roof of the third ventricle.
- ▶ **Just above this floor**, the thin medial wall of the hemisphere is **invaginated laterally into the lateral ventricle** — this line of invagination is the **choroid fissure**.
- ▶ A fold of vascular pia mater extends into the fissure to form the **tela choroidea**; a bunch of capillaries forms within this fold to become the **choroid plexus**, while the original thin ependymal wall lining the plexus persists as its ependymal covering.
- ▶ With subsequent establishment of the temporal pole and inferior horn, the **inferior part of the fissure invaginates into the inferior horn**, and the fissure attains its definitive **C-shaped** course.
- ▶ Immediately superior to the fissure, the thinned hemisphere wall thickens to form the **hippocampus**, which is carried posteroinferiorly into the temporal horn as the hemisphere expands — explaining why the fornix (an efferent tract of the hippocampus) runs along the convex margin of the fissure throughout its course.

6. Relations and surgical corridor

- ▶ Structures immediately bordering the fissure throughout its course: **fornix/fimbria**, **hippocampus**, **thalamus**, **tail of caudate nucleus**, **stria terminalis**, **thalamostriate vein**; at its origin it opens into the **velum interpositum/tela choroidea of the third ventricle**.

- ▶ Because pia and ependyma alone separate the ventricular cavity from the subarachnoid cisterns along this line — with no cortex intervening — the choroid fissure is a recognised **avascular surgical cleavage plane** once the plexus is mobilised (its microsurgical anatomy has been specifically mapped — Nagata, Rhoton & Barry 1988).
- ▶ This plane underlies the **transchoroidal/subchoroidal approaches** used to reach the third ventricle, pulvinar, and medial temporal structures without a transcortical incision, by opening the fissure between the fornix/fimbria and the thalamus.

Applied / Clinical anatomy

- ▶ **Anterior choroidal artery occlusion:** because this vessel has a long, narrow subarachnoid course before entering the inferior part of the fissure, it is especially prone to thrombosis (often termed the "artery of cerebral thrombosis"); infarction affects the posterior limb of internal capsule, optic tract and medial temporal structures it supplies en route, producing contralateral hemiplegia, hemianaesthesia and homonymous hemianopia.
- ▶ **Choroid plexus tumours** (papilloma, rarely carcinoma) arise from the plexus reached via the fissure — most often in the **atrium in children** — presenting with hydrocephalus from CSF overproduction and/or obstruction.
- ▶ **Colloid cyst of the third ventricle**, situated at the roof near the foramen of Monro (continuous with the choroid-fissure/tela-choroidea system), may intermittently obstruct one or both foramina, causing positional headache with sudden collapse ("drop attacks").
- ▶ **Physiological calcification of the choroid plexus** is one of the commonest incidental findings on head CT, increasing with age.
- ▶ **Surgical significance:** the transchoroidal/subchoroidal corridor along the fissure allows access to the third ventricle and pineal region while minimising retraction of the fornix, whose injury risks anterograde amnesia.
- ▶ **Hydrocephalus:** since the choroid-fissure plexus system is the principal site of CSF production, obstruction anywhere along its outflow (foramen of Monro, aqueduct, fourth-ventricle outlets) produces a predictable pattern of ventricular dilatation depending on the level blocked.

High-yield exam pointers

- ▶ C-shaped fissure from the **interventricular foramen** to the tip of the **inferior horn** (near the uncus); present **only** in the body and inferior horn — absent in anterior and posterior horns.
- ▶ Boundaries: body — **fornix** (convex) vs **thalamus/tail of caudate/stria terminalis** (concave); inferior horn — **fimbria + hippocampus** (convex) vs **tail of caudate/stria terminalis** (concave).
- ▶ Line of invagination of the **tela choroidea**; pia and ependyma meet directly here with **no intervening brain tissue** — the anatomical basis of the choroid plexus.
- ▶ Blood supply: **anterior choroidal artery** through the inferior part (supplies inferior-horn plexus) + **posterior choroidal arteries** through the upper part (supplies body/atrium plexus) — anastomose in the atrium.
- ▶ Continuous at the interventricular foramen with the **tela choroidea/roof of the third ventricle** across the transverse fissure.

- ▶ Develops where the medial hemisphere wall, opposite the roof of the diencephalon, fails to proliferate neuroblasts and is invaginated by vascular pia mater.
- ▶ Clinically: a recognised **microsurgical corridor** (transchoroidal/subchoroidal approach) to the third ventricle/pineal region; site of the vulnerable **anterior choroidal artery**; origin of **choroid plexus tumours** and related to **colloid cysts** of the third ventricle.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 3–4, 8e; IB Singh — Textbook of Human Neuroanatomy; Vishram Singh — Clinical Neuroanatomy 4e; Snell — Clinical Neuroanatomy 7e; IB Singh — Human Embryology (CBME 2021).



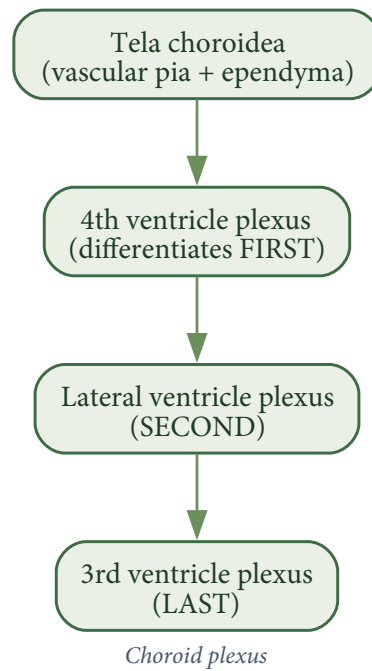
Choroid plexus

Asked in: Paper IV Apr 2006 — RGUHS MD/MS Anatomy

Definition / Introduction The choroid plexus is a highly vascular, villous outgrowth of the **tela choroidea** — vascularised pia mater directly apposed to the ependymal lining, with no intervening brain tissue — that projects into the cavities of the lateral, third and fourth ventricles. It is the principal site of formation of cerebrospinal fluid (CSF) and its specialised epithelium constitutes the **blood–CSF barrier**. It is absent from the anterior (frontal) horn and posterior (occipital) horn of the lateral ventricle and from the cerebral aqueduct.

Development

- ▶ The choroid plexus is formed by vascular mesenchyme (pia mater) invaginating the thin ependymal wall/roof of the neural tube at sites where no neural tissue intervenes — the choroid fissure of the lateral ventricle, and the roofs of the third and fourth ventricles.
- ▶ Rudiments of the plexus appear at the **7th week** of intrauterine life; between the **9th and 17th week** it expands and differentiates rapidly.
- ▶ From the **17th to 28th week**, growth of the brain tissue outstrips growth of the plexus (relative regression in proportion).
- ▶ From the **29th week** onward, histological changes in the choroid epithelial cells signal onset of active secretion; the enzymatic machinery for CSF secretion matures only **postnatally**, with a marked rise in CSF output after birth.
- ▶ There is a fixed **sequence of differentiation**: the fourth-ventricle plexus differentiates first, followed by the lateral-ventricle plexuses, and lastly the third-ventricle plexus.
- ▶ The foramina of Luschka (lateral) and Magendie (median) form by local resorption of the roof plate of the fourth ventricle between the 4th and 5th fetal months.



Location, extent and relations

Ventricle	Extent / course	Key boundary	Absent in
Lateral ventricle	From the interventricular foramen, runs posteriorly along the choroid fissure (between the fornix above and thalamus below) through the body, curves round the pulvinar into the atrium (glomus), and continues into the inferior (temporal) horn above the fimbria/hippocampus	Choroid fissure	Anterior horn, posterior (occipital) horn
Third ventricle	Paired strips in the roof, attached to the tela choroidea, extending from the interventricular foramen to the suprapineal recess	Continuous across the midline and, through each interventricular foramen, with both lateral-ventricle plexuses	Floor and most of the lateral wall

Ventricle	Extent / course	Key boundary	Absent in
Fourth ventricle	T-shaped: a vertical limb in the midline of the roof (paired limbs lie side by side) reaching down to the median aperture, and a horizontal limb passing into each lateral recess to the lateral aperture near the flocculus	Roof of the ventricle (tela choroidea between cerebellum and medulla)	Floor of the ventricle

- ▶ Mean thickness of the fourth-ventricle plexus in children is about **2.5 mm**.
- ▶ No choroid plexus exists in the cerebral aqueduct — CSF merely traverses this narrow channel.

Structure (histology)

□ Fig 9.20 — Choroid plexus. (Junqueira's Basic Histology — Text & Atlas — 17e, p.455)

- ▶ Each plexus is thrown into numerous folded villi; every villus has a **core of vascular connective tissue (pia mater)** carrying large **fenestrated capillaries**, covered on the ventricular surface by a **continuous single layer of cuboidal ependymal (choroidal epithelial) cells**.
- ▶ The apical (CSF-facing) surface of the epithelial cells bears numerous **microvilli**; adjacent epithelial cells are joined by apical **tight junctions (zonulae occludentes)** — the structural basis of the blood–CSF barrier.
- ▶ The capillary endothelium itself is fenestrated and freely permeable to plasma proteins — it is the epithelium, not the endothelium, that constitutes the actual barrier (the reverse of the situation at the blood–brain barrier).
- ▶ Isolated macrophage-like cells are present in the connective-tissue stroma of the plexus.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Panel A — sagittal section of the ventricular system, label: lateral-ventricle body choroid plexus (along choroid fissure, between fornix and thalamus) → interventricular foramen (of Monro) → third-ventricle roof choroid plexus → cerebral aqueduct (label "no choroid plexus") → fourth-ventricle T-shaped choroid plexus (vertical limb + horizontal limb) → foramen of Magendie (median aperture) → foramen of Luschka ×2 (lateral apertures) → cerebellomedullary cistern.

Panel B — cross-section of a single choroid villus (blood–CSF barrier), label: fenestrated capillary lumen (blood) → capillary endothelium → basement membrane of capillary → pial connective-tissue core (stroma) → basement membrane of ependymal cell → cuboidal ependymal (choroidal epithelial) cell with apical microvilli → apical tight junction (zonula occludens) → ventricular cavity (CSF).

Blood supply and venous drainage

- ▶ **Lateral and third ventricle plexus:** a single vessel from the **anterior choroidal artery** (branch of the internal carotid artery) supplies the plexus of the inferior horn; several **posterior choroidal branches (medial and lateral) of the posterior cerebral artery** supply the body/atrium and the

third-ventricle plexus. The two arterial territories anastomose to some extent, most notably in the atrium (trigone), where anterior and posterior choroidal branches meet.

- ▶ **Fourth ventricle plexus:** supplied by the **posterior inferior cerebellar artery (PICA)**.
- ▶ **Venous drainage:** capillaries drain into a rich venous plexus served by a single choroidal vein; the superior choroidal vein of the lateral ventricle courses through the plexus and joins the internal cerebral vein at the interventricular foramen.

Functions: CSF formation, circulation and composition

- ▶ The choroid plexus is the principal — though not the sole — source of CSF; the ependymal lining and the extracellular fluid of the brain parenchyma make a smaller, less well-defined additional contribution.
- ▶ Formation combines **ultrafiltration** across the fenestrated capillary with **active, energy-dependent secretion/transport** by the choroidal epithelium — CSF is not a simple plasma ultrafiltrate, which is why its composition differs materially from plasma.
- ▶ **Rate and volume:** production is continuous, roughly **0.3–0.5 mL/min** ($\approx 450\text{--}750\text{ mL over 24 hours}$); total CSF volume is about **140–150 mL**, of which only $\sim 25\text{ mL}$ lies within the ventricles — so the entire volume is replaced several times a day.
- ▶ Production is **autonomous and not pressure-regulated** — it continues even when the reabsorptive pathway (arachnoid villi) is obstructed; this is central to the pathophysiology of obstructive hydrocephalus.
- ▶ CSF is then reabsorbed at the arachnoid villi projecting into the dural venous sinuses, which act as one-way valves (CSF $\rightarrow$ blood only).

Substance	CSF	Blood plasma
Protein	20–40 mg%	$\sim 600\text{ mg\%}$
Glucose	40–60 mg% (about half of blood glucose)	$\sim 100\text{ mg\%}$
Chloride	120 mEq/L	100 mEq/L
Calcium	2.5 mEq/L	4.5 mEq/L
Cells	0–3 lymphocytes/cu mm	—

- ▶ Other functions performed via the CSF it secretes: cushions and protects the CNS from trauma; provides mechanical buoyancy/support, reducing the effective weight of the brain; serves as a reservoir that helps regulate intracranial volume/pressure; nourishes the CNS and removes metabolites; and acts as a pathway for pineal secretions to reach the pituitary/hypothalamic region.

Blood–CSF barrier

- ▶ Anatomical layers, from blood to CSF: **fenestrated capillary endothelium** $\rightarrow$ **basement membrane of the capillary** $\rightarrow$ **basement membrane of the ependymal (choroidal epithelial) cell** $\rightarrow$ **choroidal ependymal cell**, adjacent cells joined by apical tight junctions.

- ▶ Functionally it allows free passage of water, gases and lipid-soluble substances from blood to CSF, but restricts entry of macromolecules such as plasma proteins and most hexoses other than glucose.
- ▶ Transport across it is **selectively directional** (blood → CSF); this contrasts with the arachnoid villi, which are one-way valves permitting CSF → blood flow only, and with the blood–brain barrier, where the tight junctions lie in the capillary endothelium itself rather than in an overlying epithelium.

Applied / Clinical anatomy

- ▶ **Physiological calcification** of the choroid plexus (together with the pineal gland) is the **most frequently described incidental intracranial calcification** on head CT — usually bilateral, symmetrical glomus (atrial) calcification; marked asymmetry should raise suspicion of an adjacent mass lesion.
- ▶ **Choroid plexus papilloma**: a tumour arising from the choroidal epithelium; it may produce hydrocephalus through CSF overproduction and/or by obstructing CSF pathways.
- ▶ Tumours near the roof of the fourth ventricle (e.g., medulloblastoma) may block the median and lateral apertures, producing obstructive (non-communicating) hydrocephalus.
- ▶ **Arnold–Chiari malformation**: herniation of the medulla and cerebellar tonsils through the foramen magnum blocks the fourth-ventricle apertures, causing obstructive hydrocephalus, often with associated syringomyelia.
- ▶ The choroid plexus is a useful imaging landmark in non-communicating hydrocephalus (CT/USG/MRI), including neonatal cranial ultrasound.
- ▶ Because CSF production is continuous and autonomous, refractory hydrocephalus may be managed by choroid plexus coagulation/excision (choroid plexectomy) or by CSF diversion (ventriculo-peritoneal shunt) when obstruction cannot be relieved.
- ▶ The blood–CSF barrier governs drug penetration into CSF (relevant to antibiotic selection in meningitis) and underlies the diagnostic value of CSF biochemistry/cytology in CNS disease.

High-yield exam pointers

- ▶ Choroid plexus = vascular pia mater (tela choroidea) invaginating the ependyma; absent in anterior/posterior horns of the lateral ventricle and in the cerebral aqueduct.
- ▶ Fixed developmental sequence: **4th ventricle plexus differentiates first → lateral ventricles → 3rd ventricle (last)**.
- ▶ Arterial supply: **anterior choroidal artery (ICA) + posterior choroidal branches (PCA)** for the lateral/third-ventricle plexus (anastomosing in the atrium); **PICA** for the fourth-ventricle plexus.
- ▶ Histology: villus = vascular pial core + single layer of cuboidal ependymal epithelium with microvilli and apical tight junctions; capillary endothelium is fenestrated.
- ▶ CSF formation is by active secretion, not simple filtration; ≈500 mL secreted per day, total CSF volume ≈150 mL.
- ▶ Blood–CSF barrier = capillary endothelium + two basement membranes + tight-junctioned ependymal epithelium; permits selective blood → CSF passage only.

- ▶ CSF production is continuous and pressure-independent — the key mechanism underlying obstructive hydrocephalus.
- ▶ Physiological calcification of the choroid plexus/pineal is the commonest incidental intracranial calcification on CT.
- ▶ Choroid plexus papilloma is carbonic-anhydrase-C-positive and may cause CSF-overproduction hydrocephalus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; IB Singh's Textbook of Human Anatomy Vol 3 (Ventricles of the Brain); Junqueira's Basic Histology 17e.



Choroid plexus of ventricles and circulation of CSF

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction — The **choroid plexuses** are highly vascular, frond-like folds formed wherever the vascular pia mater (as the **tela choroidea**) lies directly against the ependymal lining of the ventricles, with no intervening neural tissue. They occur in the **lateral, third and fourth ventricles** and are the chief site of active secretion of **cerebrospinal fluid (CSF)** — the clear fluid filling the ventricles and subarachnoid space, which cushions and nourishes the CNS before being reabsorbed into venous blood through arachnoid villi.

1. Location and gross arrangement

- ▶ The tela choroidea is formed wherever pia is applied to ependyma — the roof of the third ventricle, the roof of the fourth ventricle, and along the **choroid fissure** in the medial wall of the lateral ventricle (between fornix above and thalamus below).
- ▶ **Lateral ventricle:** plexus lies in the choroid fissure, extending from the **interventricular foramen (of Monro)** back over the thalamus, curving into the **inferior (temporal) horn** to reach the hippocampus; bulkiest at the **atrium/trigone**. It is **absent from the anterior and posterior horns**.
- ▶ Through the foramen of Monro the lateral-ventricle plexus is **continuous with the plexus of the third ventricle** and, across the midline, with the opposite lateral ventricle.
- ▶ **Third ventricle:** two narrow plexuses hang from the ependymal roof within the tela choroidea stretched across the two thalami.
- ▶ **Fourth ventricle:** T-shaped — a double vertical limb in the roof, fusing at the **median aperture (foramen of Magendie)**, with horizontal limbs projecting into the **lateral recesses**; tufts may protrude through the **foramina of Luschka** into the cerebellopontine angle.

2. Structure and blood–CSF barrier

- ▶ Each plexus has a folded, villous surface: a **core of vascular connective tissue with fenestrated capillaries**, covered by cuboidal-to-columnar **modified ependymal (choroidal epithelial) cells** bearing apical **microvilli** (and scattered cilia).

- ▶ **Tight junctions** near the epithelial apex seal adjacent cells, so blood is separated from CSF by: fenestrated endothelium → its basement membrane → loose stroma → choroidal epithelium with apical tight junctions — together the **blood–CSF barrier**.

□ Fig 16-16 — Microscopic structure of the choroid plexus showing the path taken by fluids in the formation of cerebrospinal fluid (Snell — Clinical Neuroanatomy — 7e, p.479)

- ▶ **Blood supply:** lateral/third-ventricle plexus — **anterior choroidal artery** (from internal carotid, reaching the inferior horn) plus **medial and lateral posterior choroidal arteries** (from posterior cerebral artery), the two anastomosing freely, best marked at the atrium. **Fourth-ventricle plexus** — **inferior cerebellar arteries**.
- ▶ **Venous drainage:** a rich intra-plexus venous network drains into the **choroidal vein**, which joins the thalamostriate and septal veins at the interventricular foramen to form the **internal cerebral vein**.

3. Formation of CSF

- ▶ CSF is **not a simple ultrafiltrate**; it is **actively secreted** by the choroidal epithelium, with a smaller contribution from the general ependyma and brain interstitial fluid via perivascular (Virchow–Robin) spaces.
- ▶ Active transport explains why K^+ , Ca^{2+} , Mg^{2+} , bicarbonate and glucose are **lower** and chloride **higher** in CSF than in plasma (Table 1). Production is **not pressure-regulated** — it continues even if absorption is blocked, the basis of hydrocephalus.

Table 1 — CSF vs plasma composition

Parameter	CSF	Plasma
Protein	15–45 mg/dL	600–700 mg/dL
Glucose	50–60 mg/dL	~100 mg/dL
Chloride	120–125 mEq/L	~100 mEq/L
Calcium	2.5 mEq/L	4.5 mEq/L
Cells	0–5 lymphocytes/mm ³	—

- ▶ **Volume/rate:** total CSF ~140–150 mL (Gray's: adult range 140–270 mL), of which only ~25–30 mL is ventricular. Produced at ~0.3–0.5 mL/min (≈500–700 mL/day) — the whole volume turns over 3–4 times/day. Normal pressure (lumbar puncture, lateral recumbent): 60–150 mm H₂O.

4. Circulation of CSF

- ▶ Lateral-ventricle CSF → **interventricular foramina of Monro** → **third ventricle** → **cerebral aqueduct** → **fourth ventricle** (each ventricle adding secretion en route) → **median aperture (Magendie)** and paired **lateral apertures (Luschka)** → subarachnoid space, first filling the **cerebellomedullary cistern (cisterna magna)** and **pontine cistern**.
- ▶ From these basal cisterns CSF flows **upward through the tentorial notch**, over the base/inferior cerebrum, then **ascends over the cerebral convexity** to the **arachnoid villi/granulations** in the **superior sagittal sinus** for absorption. Some fluid descends around the **spinal cord and cauda equina** (a relative dead-end, dependent on arterial/postural movement).

- Flow is aided by **choroid-plexus and cerebral/spinal arterial pulsation, ependymal ciliary beat, and postural/respiratory movement.**

□ Fig 8.37 — Ventricles, subarachnoid spaces, and cisterns; ventricular system and circulation of CSF (Moore — *Clinically Oriented Anatomy* — 9e, p.1427)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Median sagittal section of the brain with the ventricular system outlined and arrows for the CSF pathway. Label, in sequence:

- Choroid plexus of lateral ventricle → interventricular foramen (of Monro)
- Third ventricle + its choroid plexus → cerebral aqueduct
- Fourth ventricle + its choroid plexus → foramen of Magendie / foramina of Luschka
- Cerebellomedullary and pontine cisterns → flow over cerebral convexity / around spinal cord
- Arachnoid villi/granulations → superior sagittal sinus (site of absorption)

5. Absorption of CSF

- Chiefly through **arachnoid villi**, clustering into macroscopic **arachnoid granulations (Pacchionian bodies)**, mainly in the **superior sagittal sinus** (also transverse, superior petrosal, straight sinuses).
- Each villus is a diverticulum of arachnoid/subarachnoid space piercing the dura, capped by arachnoid cells against venous endothelium; fine channels allow **one-way bulk flow into venous blood** when CSF pressure exceeds sinus pressure — the villi act as **pressure-valves** preventing reflux of blood.
- Granulations increase with age and calcify late in life. Since production is constant, **absorption rate through the villi regulates CSF pressure**. Minor routes: subarachnoid/pial veins and perineural lymphatics along cranial/spinal nerve sleeves.

6. Functions of CSF

- **Cushion/shock-absorber** against trauma; provides **mechanical buoyancy** (brain ~1500 g in air, ~50 g floating in CSF).
- **Reservoir** regulating intracranial volume (Monro–Kellie relationship); **nourishes** neural tissue and **removes metabolites**; pathway for **pineal secretions** to reach the pituitary via the third ventricle.

Recent advances

- **Choroid plexus and perivascular (glymphatic-type) clearance:** in-vivo imaging shows CSF flowing pulsatile and bidirectional along perivascular (Virchow–Robin) spaces, driven by arterial pulsation — extending the classical bulk-flow model above (Quirk et al, *Fluids Barriers CNS* 2026) [PMID: 41794761].
- **Advanced MRI of the choroid plexus in aging/dementia:** quantitative microstructure, perfusion and permeability MRI now characterises blood–CSF barrier integrity in vivo, with disruption linked to cognitive decline (Sun et al, *J Cereb Blood Flow Metab* 2026) [PMID: 41816863]; a 16-

study meta-analysis found significantly **larger choroid-plexus volume in Alzheimer's disease**, correlating with atrophy and amyloid/tau burden (Mahmoudi et al, *J Alzheimers Dis* 2026) [PMID: 42081200].

- **Choroid plexus as a neuroimmune "gatekeeper"**: plexus epithelium actively regulates leukocyte trafficking/CSF immune surveillance, relevant to CNS infection, tumour spread and neurodegeneration (Hehnly et al, *J Immunol* 2026) [PMID: 41876363]; plexus **enlargement on MRI** is similarly an emerging neuroinflammation biomarker in multiple sclerosis (Corlatescu et al, *Autoimmun Rev* 2026) [PMID: 41666989].
- **Astrocyte/aquaporin-4 dysfunction in hydrocephalus**: astrocytic end-feet mediate perivascular CSF transport; their dysregulation (mislocalised AQP4) impairs clearance and drives neuroinflammation in experimental communicating hydrocephalus, suggesting targets beyond CSF diversion (Deng et al, *Exp Neurol* 2026 [PMID: 42009272]; Wang et al, *Fluids Barriers CNS* 2026 [PMID: 41787552]).

(According to PubMed; DOIs: [10.1186/s12987-026-00782-w](https://doi.org/10.1186/s12987-026-00782-w), [10.1177/0271678X261429043](https://doi.org/10.1177/0271678X261429043), [10.1177/13872877261447404](https://doi.org/10.1177/13872877261447404), [10.1093/jimmun/vkaf322](https://doi.org/10.1093/jimmun/vkaf322), [10.1016/j.autrev.2026.104001](https://doi.org/10.1016/j.autrev.2026.104001), [10.1016/j.expneurol.2026.115790](https://doi.org/10.1016/j.expneurol.2026.115790), [10.1186/s12987-026-00787-5](https://doi.org/10.1186/s12987-026-00787-5).)

Applied / Clinical anatomy

- **Hydrocephalus** — abnormal CSF accumulation from excess production (rare; choroid-plexus tumour), obstructed circulation (common), or defective absorption.
 - **Non-communicating**: block at the interventricular foramen (unilateral/bilateral ventricular enlargement), the **cerebral aqueduct** (commonest site — congenital stenosis is the commonest cause of congenital hydrocephalus, enlarging both lateral ventricles + third ventricle), or foramina of Magendie/Luschka (whole ventricular system enlarges).
 - **Communicating**: free ventricular outflow but defective absorption at the villi (e.g. post-meningitic adhesions) or block at the tentorial notch; CSF pools in the subarachnoid space.
 - **Infantile features**: disproportionate head enlargement, frontal bossing, separated sutures, tense bulging anterior fontanelle, dilated scalp veins, "setting-sun" eyes, cracked-pot percussion note, progressive motor/cognitive decline.
- **Colloid cyst of the third ventricle**: near the foramina of Monro, produces intermittent **position-dependent headache** from ball-valve obstruction — a classic anatomy–radiology correlation.
- **Blood–CSF barrier in disease**: CSF normally lacks antibodies, so CNS infections can be rapidly fatal; the barrier limits antibiotic penetration (inflammation increases permeability) and excludes bile pigment even in severe jaundice.
- **CSF sampling**: lumbar, cisternal (via the cerebellomedullary cistern through the posterior atlanto-occipital membrane) or ventricular puncture; sudden removal lets the brain sag on its attachments, causing post-LP headache.

- ▶ **Queckenstedt's test and Froin's syndrome:** jugular compression normally raises lumbar CSF pressure promptly (failure = spinal block); CSF trapped below a block becomes xanthochromic and spontaneously coagulable (raised protein).
- ▶ **Papilloedema:** raised CSF pressure transmitted along the optic-nerve subarachnoid sleeve compresses the central retinal vein, causing bilateral disc swelling.

High-yield exam pointers

- ▶ Choroid plexus = **tela choroidea** (pia + capillaries) + **choroidal ependyma**; present in lateral, 3rd, 4th ventricles; **absent from anterior/posterior horns** of the lateral ventricle.
- ▶ Blood supply: **anterior + posterior choroidal arteries** (lateral/3rd ventricle); **inferior cerebellar arteries** (4th ventricle).
- ▶ Blood–CSF barrier = fenestrated capillary endothelium + basement membrane + **choroidal epithelium with apical tight junctions**.
- ▶ CSF is **actively secreted**, not filtered; production is **pressure-independent**.
- ▶ Volume ~150 mL; produced ~500–700 mL/day; turnover 3–4×/day; pressure 60–150 mm H₂O (lateral recumbent LP).
- ▶ Route: lateral ventricle → foramen of Monro → 3rd ventricle → aqueduct → 4th ventricle → foramina of Magendie/Luschka → basal cisterns → cerebral convexity → arachnoid villi → superior sagittal sinus.
- ▶ Functions: cushioning, buoyancy, ICP/volume regulation, nourishment, waste removal, pineal-to-pituitary pathway.
- ▶ **Aqueductal stenosis** = commonest cause of congenital (non-communicating) hydrocephalus; post-meningitic villous block = classic communicating hydrocephalus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; Moore's Clinically Oriented Anatomy 9e (figure).



Circle of Willis

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction The circle of Willis (**circulus arteriosus**) is a polygonal arterial anastomosis situated in the **interpeduncular fossa**, within the interpeduncular subarachnoid cistern at the base of the brain, closely related to the optic chiasma, tuber cinereum, mammillary bodies and posterior perforated substance. It unites the two great arterial systems of the brain — the paired **internal carotid (anterior/carotid)** system and the **vertebrobasilar (posterior)** system — into a single **six-sided polygon**, from which numerous central (perforating) branches supply the deep grey matter of the cerebrum. First described by **Thomas Willis (1664)**, it is the principal potential channel for collateral circulation between the two sides and between the anterior and posterior circulations of the brain, and its vessels are the commonest site of congenital (berry) aneurysm and consequent subarachnoid haemorrhage.

1. Location and relations

- ▶ Lies at the **base of the brain**, in the **interpeduncular fossa**, within the **interpeduncular (basal) subarachnoid cistern**.
- ▶ Extends from the **superior border of the pons** below to the **median longitudinal (interhemispheric) fissure** above.
- ▶ Related to the **optic chiasma** and **optic tracts** anterolaterally, the **tuber cinereum** and **mammillary bodies** in its floor, and the **posterior perforated substance** posteriorly; the **oculomotor nerve** emerges close to its posterolateral part, between the posterior cerebral and superior cerebellar arteries.
- ▶ Numerous small perforating vessels pierce the **anterior perforated substance** (from the anteromedial/anterolateral groups) and the **posterior perforated substance** (from the posteromedial/posterolateral groups) to reach deep structures.

2. Formation (constituent arteries)

The circle is formed by the anastomosis of branches of the two internal carotid arteries and the two vertebral arteries:

Boundary of circle	Constituent vessel(s)
Anteriorly	The two anterior cerebral arteries (terminal, smaller branches of each internal carotid artery), joined across the midline by the short anterior communicating artery
Anterolaterally (each side)	Terminal bifurcation of the internal carotid artery into anterior and middle cerebral arteries
Posterolaterally (each side)	The posterior communicating artery , connecting the internal carotid artery to the posterior cerebral artery of the same side
Posteriorly	The basilar artery (formed by union of the two vertebral arteries at the lower border of the pons), dividing at the upper border of the pons into the two posterior cerebral arteries

- The circle can thus be said to be completed by: 2 internal carotid arteries, 2 A1-segments of the anterior cerebral arteries + 1 anterior communicating artery, 2 posterior communicating arteries, 2 P1-segments of the posterior cerebral arteries, and the basilar artery bifurcation.
- **Anterior circulation** (internal carotid system) supplies the supratentorial cerebrum and diencephalon and contributes roughly **80%** of cerebral blood flow; **posterior circulation** (vertebrobasilar system) supplies the infratentorial brainstem and cerebellum and contributes the remaining **20%**; the two systems are linked at the circle chiefly through the posterior communicating arteries.

3. Central (perforating/ganglionic) branches

Numerous slender, thin-walled **end arteries** arise from the circle itself and from vessels near it, entering through the anterior and posterior perforated substances to supply the internal capsule, basal ganglia, thalamus and hypothalamus. They are grouped by origin:

Group	Origin	Chief structures supplied
Anteromedial	Anterior cerebral and anterior communicating arteries	Optic chiasma, hypothalamus (anterior/preoptic/supraoptic areas), septum pellucidum, anterior columns of fornix, anterior limb of internal capsule, head of caudate nucleus, anterior putamen
Anterolateral (lateral/medial striate arteries)	Proximal middle cerebral artery ($\pm$ anterior cerebral)	Caudate nucleus, putamen, globus pallidus, anterior limb/genu/posterior limb of internal capsule — includes Charcot's artery of cerebral haemorrhage
Posteromedial	Posterior communicating artery and proximal posterior cerebral artery	Hypothalamus, pituitary, thalamus (via thalamoperforating arteries), mammillary bodies, subthalamus
Posterolateral	Posterior cerebral artery distal to the posterior communicating junction	Cerebral peduncle, colliculi, pineal gland, posterior thalamus and medial geniculate body (via thalamogeniculate branches)

□ Fig 15.5 — Circle of Willis and the branches of constituent arteries supplying the brain (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.535)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Inferior (basal) view of the brain showing the circle of Willis in the interpeduncular fossa. Label: optic chiasma (anterior relation), tuber cinereum and mammillary bodies (in the floor), internal carotid artery (each side, with its bifurcation into anterior and middle cerebral arteries), anterior cerebral artery (×2) joined by the anterior communicating artery, posterior communicating artery (×2) linking each internal carotid to the posterior cerebral artery (×2), the basilar artery and its bifurcation, the oculomotor nerve emerging near the posterolateral angle of the circle, and arrows into the anterior/posterior perforated substance marking the four central-branch groups (anteromedial, anterolateral, posteromedial, posterolateral).

4. Functional significance and haemodynamics

- ▶ The circle's primary physiological role is to provide **collateral (anastomotic) channels**: if one of the major arteries supplying the brain is occluded proximally, blood can be redirected around the circle from the contralateral internal carotid and/or the vertebrobasilar system, functioning like an "arterial traffic circle."
- ▶ Normally, there is **little or no mixing** of the separate blood streams — of the two vertebral arteries within the basilar artery, of the two anterior cerebral arteries across the anterior communicating artery, and of internal carotid and posterior cerebral blood across the posterior communicating artery — so that, under resting conditions, each half of the brain is supplied predominantly by its own carotid and vertebral arteries.
- ▶ The circle is **anatomically complete** (a continuous channel) in the great majority of individuals, but it is **rarely haemodynamically complete**: one component vessel is usually narrow enough to limit its usefulness as a collateral route.
- ▶ The greatest variability in calibre is in the **posterior communicating artery**, which is normally very small; when the precommunicating (P1) segment of the posterior cerebral artery is larger than the posterior communicating artery, the occipital lobe is supplied mainly by the vertebrobasilar system, and vice versa.
- ▶ **Agenesis or hypoplasia of the proximal (A1) anterior cerebral artery** is more common than anomalies of the anterior communicating artery and contributes to defective collateral circulation in roughly **one-third** of individuals.

5. Variations

- ▶ A complete circular channel is almost always present, but individual vessels (cerebral or communicating) may be **absent, hypoplastic, duplicated or even triplicated**.
- ▶ **Absence of one or both posterior communicating arteries** has been reported.
- ▶ Variation in the calibre of the posterior communicating artery and the A1/P1 segments determines how effectively the circle can equalise flow between the carotid and vertebrobasilar territories.

Applied / Clinical anatomy

- ▶ **Berry (saccular) aneurysms** — the commonest vascular anomaly of the circle — arise from a congenital deficiency of the tunica media (muscularis) and internal elastic lamina at arterial junctions. The most frequent sites are the junction of the **anterior communicating and anterior cerebral arteries**, and at the origin of the **posterior communicating artery from the internal carotid artery** (its terminal bifurcation).
- ▶ **Subarachnoid haemorrhage (SAH)** most commonly follows rupture of a berry aneurysm and presents classically as a sudden, severe "thunderclap" headache ("worst headache of my life"/"like being hit on the head") with neck stiffness and, since the circle lies at the base of the brain, blood collects in the basal cisterns — visible as high attenuation around the interpeduncular/suprasellar cisterns on non-contrast CT.
- ▶ **Cranial nerve compression** — an aneurysm on the **posterior communicating artery**, the **superior cerebellar artery**, or the **tip of the basilar artery** can compress the adjacent **oculomotor nerve**, producing a painful third-nerve palsy (ptosis, a fixed dilated pupil, and a down-and-out eye). An aneurysm on the internal carotid artery near its termination may compress the lateral aspect of the **optic chiasma**, producing a nasal visual field defect.
- ▶ **Collateral protection in surgery/occlusion** — because of the circle, a major vessel such as the internal carotid artery can occasionally be occluded (e.g. during carotid endarterectomy, ligation, or slow-growing stenosis) without producing a stroke, provided the collateral supply through the circle is adequate; conversely, when the anterior and posterior communicating arteries are not patent, occlusion of one internal carotid artery is very likely to cause an **ischaemic stroke**, since the incomplete circle cannot recruit collateral flow.
- ▶ **Watershed (border-zone) infarcts** occur at the boundary between adjacent arterial territories (e.g. between middle and posterior cerebral artery territories) during systemic hypotension/hypoperfusion, reflecting the limits of collateralisation provided by the circle and its cortical branches.
- ▶ **Charcot–Bouchard microaneurysms** occur not on the circle itself but on its small **lenticulostriate (anterolateral) central branches**; their rupture is the classic cause of spontaneous **hypertensive intracerebral haemorrhage**, distinct from the berry aneurysm/SAH mechanism of the circle proper.
- ▶ The circle is the standard site examined on **cerebral (digital subtraction) angiography and CT/MR angiography** when screening for aneurysms, vasospasm, or assessing collateral reserve before carotid intervention.

High-yield exam pointers

- ▶ Circle of Willis = **circulus arteriosus**; a **six-sided (polygonal)** anastomosis in the **interpeduncular fossa/cistern**; first described by **Thomas Willis, 1664**.
- ▶ **Formed anteriorly** by the anterior communicating + 2 anterior cerebral arteries; **anterolaterally** by the internal carotid bifurcations; **posterolaterally** by the 2 posterior communicating arteries; **posteriorly** by the basilar artery bifurcating into 2 posterior cerebral arteries.
- ▶ Anterior (carotid) circulation ≈ **80%** of cerebral blood flow; posterior (vertebrobasilar) circulation ≈ **20%**.

- ▶ **Four central-branch groups** — anteromedial, anterolateral, posteromedial, posterolateral — supply the internal capsule, basal ganglia, thalamus and hypothalamus; anterolateral (lenticulostriate) branches include **Charcot's artery of cerebral haemorrhage**.
- ▶ Anatomically complete in most people but **rarely haemodynamically complete**; the **posterior communicating artery** is the most variable component.
- ▶ Function: **collateral circulation** between right/left and anterior/posterior cerebral circulations; normally little inter-mixing of the separate blood streams.
- ▶ **Berry aneurysms** most often occur at the anterior communicating–anterior cerebral junction or at the internal carotid–posterior communicating junction; their rupture is the commonest cause of **subarachnoid haemorrhage**.
- ▶ Aneurysm on the posterior communicating artery/basilar tip → **oculomotor nerve palsy**; on distal internal carotid artery → chiasmal compression and nasal field defect.
- ▶ **Charcot–Bouchard microaneurysms** (on lenticulostriate central branches, not the circle itself) cause hypertensive intracerebral haemorrhage — a key differentiating point from berry aneurysms of the circle.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh Clinical Neuroanatomy 4e; Snell Clinical Neuroanatomy 7e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3–4 8e; Moore's Clinically Oriented Anatomy 9e.



Describe in detail about "Lateral ventricle"

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction. The lateral ventricle is the paired cavity of the cerebral hemisphere, one lying within each hemisphere, representing the dilated remnant of the lumen of the embryonic telencephalic vesicle. It is lined by ependyma, filled with cerebrospinal fluid (CSF), and has a characteristic **C-shaped** profile produced by the developmental over-growth of the frontal, parietal and occipital lobes, which carries the temporal lobe downwards and forwards. Each lateral ventricle communicates with the midline third ventricle through the **interventricular foramen (of Monro)** and is the largest and most clinically important component of the ventricular system, both as the principal site of CSF formation and as the classic site of obstruction in hydrocephalus.

1. Gross features and parts

- ▶ The lateral ventricle is customarily described in **four parts**, all continuous with one another and forming a single C-shaped cavity that follows the curvature of the caudate nucleus and fornix:
- ▶ **Anterior (frontal) horn** — in the frontal lobe, anterior to the interventricular foramen.
- ▶ **Central part (body)** — in the parietal lobe, from the interventricular foramen to the splenium of the corpus callosum.
- ▶ **Posterior (occipital) horn** — curving back into the occipital lobe.

- ▶ **Inferior (temporal) horn** — the largest compartment, curving down and forward into the temporal lobe, ending close to the uncus.
- ▶ The **atrium (trigone/collateral trigone)** is not a separate horn but the site of confluence of the body with the posterior and inferior horns; it is the most dilated part of the ventricle and the usual site where the choroid plexus is bulkiest (glomus of the choroid plexus).
- ▶ Both the tail of the caudate nucleus and the fornix, which lie in its walls throughout, follow the same C-shaped course as the ventricle itself.
- ▶ The two lateral ventricles are separated in the midline by the **septum pellucidum** (anteriorly/centrally) and communicate with the third ventricle, but never directly with each other.

2. Boundaries of each part

Part	Roof	Floor / lateral wall	Medial wall	Anterior/posterior limit
Anterior horn	Trunk of corpus callosum (most anterior part)	Head of caudate nucleus (floor & lateral wall); a small part of the floor is the rostrum of the corpus callosum	Septum pellucidum (common to both sides)	Closed in front by genu & rostrum of corpus callosum; extends back to the interventricular foramen
Central part (body)	Trunk of corpus callosum	Caudate nucleus (lateral) and superior surface of thalamus (medial), separated by the stria terminalis and thalamostriate vein in a shallow groove	Septum pellucidum above, body of the fornix below (fornix separated from thalamus by the choroid fissure)	Interventricular foramen in front to splenium of corpus callosum behind
Posterior horn	Tapetum of corpus callosum (also forms lateral wall)	—	Bulb of posterior horn (forceps major fibres) above; calcar avis (calcarine sulcus infolding) below	Extends into occipital lobe; variable, often asymmetrical between sides
Inferior (temporal) horn	Tapetum, tail of caudate nucleus and stria terminalis (leading to amygdala anteriorly)	Hippocampus (medially, covered by the white-matter alveus converging as the fimbria) and collateral eminence (laterally, from the collateral sulcus)	(roof/floor orientation substitutes for separate walls)	Begins at posterior end of body; ends within about 2.5 cm of the temporal pole, near the uncus

Part	Roof	Floor / lateral wall	Medial wall	Anterior/posterior limit
Atrium/trigone	Confluence of body, posterior and inferior horns; contains the glomus of the choroid plexus	—	—	Lies medial to the pulvinar of the thalamus

- ▶ Throughout the body and inferior horn, the **choroid fissure** — the C-shaped slit between the fornix (above) and thalamus (below), continuing between the fimbria and stria terminalis in the inferior horn — is the line along which the choroid plexus invaginates the ventricle.

3. Communications

- ▶ Each lateral ventricle opens into the third ventricle through the **interventricular foramen of Monro**, bounded by the **column of the fornix anteriorly** and the **anterior (rostral) end of the thalamus posteriorly**.
- ▶ The two lateral ventricles never communicate directly with each other; CSF from each passes independently through its own foramen into the single median third ventricle.
- ▶ Via this route, the lateral ventricle is placed in series with the third ventricle → cerebral aqueduct → fourth ventricle → subarachnoid space, so that obstruction anywhere along this chain has predictable effects on the lateral ventricle (see Applied anatomy).

4. Choroid plexus of the lateral ventricle

- ▶ The choroid plexus is formed where the vascular pia mater (tela choroidea), applied to the ependyma along the line of the choroid fissure, invaginates the ventricular wall; it is **present only in the central part, atrium and inferior horn** — it does **not** extend into the anterior or posterior horns.
- ▶ From the interventricular foramen, where it is continuous across the midline with the choroid plexus of the third ventricle (and, through the foramen, with the opposite lateral ventricle's plexus), it runs backwards along the choroid fissure of the body, expands maximally at the **atrium (glomus)**, and continues forward into the inferior horn to end near the amygdala/hippocampal head.
- ▶ **Two arterial contributions form the plexus**, anastomosing with each other, chiefly at the atrium:
 - The **medial and lateral posterior choroidal arteries** (branches of the posterior cerebral artery) enter through the upper (posterior) part of the choroid fissure and supply the plexus of the central part, continuing round from the third ventricle.
 - The **anterior choroidal artery** (from the internal carotid artery) enters through the lower (inferior) part of the choroid fissure and supplies the plexus of the inferior horn.

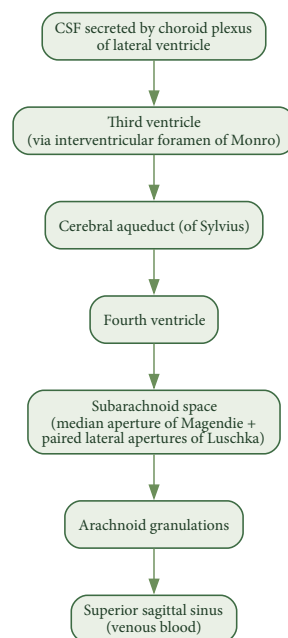
5. Blood supply

- ▶ **Arterial:** as above — anterior choroidal artery (internal carotid) to the inferior horn/atrium; medial and lateral posterior choroidal arteries (posterior cerebral artery) to the body/atrium; the two systems anastomose, chiefly in the region of the atrium.

- **Venous:** the **superior (thalamostriate) vein**, running in the groove between caudate nucleus and thalamus, and the **septal vein** converge near the interventricular foramen to form the **internal cerebral vein** of each side; a **superior choroidal vein** also drains the plexus into this system. The paired internal cerebral veins unite posteriorly with the basal veins (of Rosenthal) to form the **great cerebral vein (of Galen)**, which drains into the straight sinus.

6. CSF formed within the lateral ventricle and its circulation

- The choroid plexus epithelium actively secretes CSF (it is not a simple blood ultrafiltrate); together the choroid plexuses of the lateral, third and fourth ventricles produce CSF at a rate of about **0.2–0.7 ml/minute (roughly 600–700 ml/day)**. Total CSF volume in the adult is **140–270 ml**, of which only about **25 ml** occupies the ventricles at any time — so the entire CSF volume turns over several times a day.
- The choroid plexus epithelial cells, joined by tight (occluding) junctions, constitute the **blood–CSF barrier**, permitting selective, largely one-way transport from blood to CSF.



Describe in detail about "Lateral ventricle"

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 15.2 — Parts of the lateral ventricle (IB Singh — Textbook of Human Neuroanatomy, p.241)

Reproduce a lateral-view outline of the C-shaped ventricular cavity, labelling in sequence:

- ▶ **Anterior (frontal) horn** — in the frontal lobe
- ▶ **Central part (body)** — in the parietal lobe, extending from the **interventricular foramen** to the **splenium of corpus callosum**
- ▶ **Atrium (trigone)** — confluence of body, posterior and inferior horns
- ▶ **Posterior (occipital) horn** — into the occipital lobe
- ▶ **Inferior (temporal) horn** — curving into the temporal lobe towards the **uncus**
- ▶ **Interventricular foramen (of Monro)**, joining to the **third ventricle**
- ▶ Mark the **choroid plexus** (central part → atrium → inferior horn only, absent from both horns anterior/posterior)
- ▶ Mark the **caudate nucleus** (head in anterior horn, body along the body, tail in the roof of the inferior horn) and the **fornix/hippocampus** relations

Applied / Clinical anatomy

- ▶ **Hydrocephalus and the interventricular foramen** — unilateral obstruction (foramen-of-Monro tumour, ventriculitis) causes isolated, asymmetrical dilatation of one lateral ventricle; a midline mass at the foramina (classically a **colloid cyst of the third ventricle**) can obstruct both simultaneously, causing acute bilateral hydrocephalus with sudden postural headache and, rarely, drop attacks/sudden death.
- ▶ **Obstructive vs communicating hydrocephalus** — aqueduct obstruction (congenital stenosis, tectal glioma) enlarges both lateral ventricles and the third ventricle but spares the fourth; obstruction of the fourth-ventricular apertures, or diffuse arachnoid-granulation disease (post-meningitic/post-haemorrhagic "communicating hydrocephalus"), enlarges the entire system, including both lateral ventricles.
- ▶ **Choroid plexus papilloma**, the most common intraventricular neoplasm of infancy, characteristically arises at the **atrium** and causes hydrocephalus by both CSF overproduction and mechanical obstruction.
- ▶ **Germinal-matrix/intraventricular haemorrhage of prematurity** — the vascular subependymal germinal matrix at the caudothalamic groove (floor of the anterior horn/body) readily ruptures into the adjacent lateral ventricle in preterm neonates, screened for by cranial ultrasound.
- ▶ **Evans' index** (maximum frontal-horn width ÷ maximum internal skull diameter; >0.3 = ventriculomegaly) is the standard bedside CT/MRI measure of hydrocephalus; physiological calcification of the choroid plexus is a common incidental CT finding.
- ▶ **Endoscopic third ventriculostomy (ETV)** — the neuroendoscope is introduced through the frontal horn via a burr hole, so its coronal relations (caudate head, septum pellucidum, foramen of Monro, fornix column, thalamostriate/septal veins) must be respected to avoid injury en route to the third-ventricular floor.

- ▶ **Ventricular asymmetry** (often left > right) is a common normal variant, not to be over-read as pathological.

Recent advances

- ▶ **AI-based automated MRI volumetry** of the lateral ventricles now differentiates idiopathic normal-pressure hydrocephalus from Alzheimer's disease and controls: iNPH shows global ventriculomegaly (lateral ventricular volume +68% versus controls) with white-matter loss but preserved grey matter, and lateral ventricular volume correlates strongly with the classic Evans' index ($r > 0.83$), supporting volumetric software as an adjunct to bedside radiological indices (Bendella et al., *Diagnostics*, 2024) [DOI: 10.3390/diagnostics14131422]. According to PubMed.
- ▶ **The choroid plexus–glymphatic axis** links CSF dynamics to neurodegeneration: enlarged choroid plexus volume in Alzheimer's disease correlates with increased lateral-ventricular CSF volume and impaired glymphatic clearance, and mediation analysis shows this drives cognitive decline via CSF-volume expansion and cerebral hypometabolism (Lv et al., *Journal of Alzheimer's Disease*, 2026) [DOI: 10.1177/13872877261426578]. According to PubMed.
- ▶ **Endoscopic third ventriculostomy with choroid plexus cauterization (ETV+CPC)**, which ablates the choroid plexus contributing to lateral-ventricular CSF, showed a modestly higher mortality than ventriculoperitoneal shunting in a 2025 meta-analysis of over 7,000 paediatric patients, with comparable seizure/infection/failure rates — evidence favouring a more cautious, case-selected use of CPC (Donato et al., *Child's Nervous System*, 2025) [DOI: 10.1007/s00381-025-07043-5]. According to PubMed.

High-yield exam pointers

- ▶ Lateral ventricle = **4 parts** (anterior, central/body, posterior, inferior horns) + **atrium (trigone)** at their confluence; overall **C-shaped**, following the caudate nucleus and fornix.
- ▶ **Choroid plexus present only in central part, atrium and inferior horn** — absent from both anterior and posterior horns.
- ▶ Communicates with the **third ventricle** via the **interventricular foramen of Monro** (bounded by fornix column anteriorly, thalamus posteriorly) — never communicates directly with the opposite lateral ventricle.
- ▶ **Anterior choroidal artery** (ICA) → inferior horn/atrium plexus; **medial + lateral posterior choroidal arteries** (PCA) → body/atrium plexus; they anastomose at the atrium.
- ▶ Venous drainage: thalamostriate + septal veins → **internal cerebral vein** → (+ basal vein of Rosenthal) → **great cerebral vein of Galen** → straight sinus.
- ▶ Adult CSF: total **140–270 ml** (≈ 25 ml in ventricles), produced at **0.2–0.7 ml/min** (**600–700 ml/day**), turning over $\sim 4\times$ /day.
- ▶ Applied triad to remember: **unilateral foramen-of-Monro block** → asymmetrical hydrocephalus; **colloid cyst of third ventricle** → bilateral acute hydrocephalus; **aqueduct block** → both lateral ventricles + third ventricle dilated, fourth spared.
- ▶ Radiology: **Evans' index** (frontal-horn width/max skull width, >0.3 abnormal) is the standard bedside measure of ventriculomegaly.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e; BD Chaurasia's Human Anatomy Vol 3-4 8e. Recent-advances section per PubMed (see DOIs above).

**Describe lateral ventricle in detail**

Asked in: Paper IV May 2018 — RGUHS MD/MS Anatomy

Definition / Introduction — The lateral ventricles are a pair of large, **C-shaped** cavities, one buried within the white matter of each cerebral hemisphere, representing the dilated cavity of the **telencephalic vesicle**. Each is lined by ependyma, contains CSF-secreting **choroid plexus**, and communicates with the median third ventricle through an **interventricular foramen (of Monro)** — but the two lateral ventricles never communicate directly with each other. Each ventricle is described in **four parts** — a central part (body) and three horns (anterior, posterior, inferior) — which converge at the **atrium (trigone)**, the most dilated part of the cavity.

Parts and general configuration

- ▶ Each lateral ventricle is C-shaped because the frontal, parietal and occipital regions of the hemisphere expand faster in development, displacing the temporal lobe anteroinferiorly; the **caudate nucleus** and the **fornix**, both lying in the ventricular wall, adopt the same curved course as the ventricle itself.
- ▶ **Central part (body)** — lies in the parietal lobe, extending from the interventricular foramen to the splenium of the corpus callosum.
- ▶ **Anterior (frontal) horn** — projects forward into the frontal lobe, in front of the interventricular foramen.
- ▶ **Posterior (occipital) horn** — curves back into the occipital lobe.
- ▶ **Inferior (temporal) horn** — the largest compartment; curves down and forward into the temporal lobe, ending close to the uncus (within about 2.5 cm of the temporal pole).
- ▶ **Atrium (trigone)** — the site of confluence of the body with the posterior and inferior horns; it is the most dilated part of the ventricle.

Boundaries of each part

Part	Extent	Roof	Floor / medial wall	Notes
Anterior horn	Frontal lobe, in front of interventricular foramen; closed in front by genu/rostrum of corpus callosum	Anterior part of the trunk (body) of corpus callosum	Floor & lateral wall: head of caudate nucleus; a small part of the floor near the midline is the upper surface of the rostrum of corpus callosum. Medial wall: septum pellucidum (common to both ventricles)	Triangular in cross section; no choroid plexus enters here
Central part (body)	Parietal lobe; interventricular foramen → splenium of corpus callosum	Trunk (body) of corpus callosum	Floor: superior surface of thalamus (medially) and body of caudate nucleus (laterally) — separated by the groove for the stria terminalis and superior thalamostriate vein . Medial wall: septum pellucidum and body of the fornix	Triangular in cross section; the choroid fissure (C-shaped gap between fornix above and thalamus below) transmits the choroid plexus
Posterior horn	Occipital lobe	Roof & lateral wall: tapetum of corpus callosum	Medial wall: two elevations — the upper bulb of the posterior horn (produced by the forceps major) and the lower calcar avis (produced by the calcarine sulcus)	Often asymmetrical, occasionally rudimentary on one side (normal variant); no choroid plexus

Part	Extent	Roof	Floor / medial wall	Notes
Inferior horn	Temporal lobe; curves below the pulvinar of thalamus to end near the uncus	Roof ("lateral wall"): tapetum, plus tail of caudate nucleus and stria terminalis (which end at the amygdala anteriorly)	Floor ("medial wall"): hippocampus (covered by the white alveus , whose fibres converge medially as the fimbria), with the collateral eminence (from the collateral sulcus) laterally	Largest compartment; the inferior (temporal) part of the choroid fissure lies between fimbria and stria terminalis
Atrium (trigone)	Junction of body, posterior and inferior horns, in the parietal/occipital region	Tapetum of corpus callosum	Pulvinar of thalamus, crus of fornix; collateral trigone in the floor	Choroid plexus is richest here, formed by anastomosis of anterior and posterior choroidal arteries

Choroid fissure and choroid plexus

- ▶ The **choroid fissure** is a C-shaped cleft between the fornix (above) and the thalamus (below) in the body, continuing into the inferior horn as a gap between the fimbria and the stria terminalis. Vascular pia mater (the **tela choroidea**) invaginates through this fissure, carrying capillaries covered by ependyma, to form the **choroid plexus**.
- ▶ Choroid plexus is present in the **body, atrium and inferior horn** only; it is **absent from the anterior and posterior horns**.
- ▶ At the interventricular foramen, the choroid plexus of each lateral ventricle is continuous with that of the third ventricle, and, through it, with the plexus of the opposite lateral ventricle.
- ▶ **Arterial supply**: the plexus of the body and atrium is supplied chiefly by the **medial and lateral posterior choroidal arteries** (branches of the posterior cerebral artery); the plexus of the inferior horn is supplied by branches of the **anterior choroidal artery** (from the internal carotid artery); at the atrium the two systems anastomose.
- ▶ **Venous drainage**: choroidal veins drain into the **internal cerebral vein**, which joins its fellow to form the **great cerebral vein (of Galen)**, emptying into the straight sinus.
- ▶ **Function**: the choroid plexus is the principal site of **CSF secretion**; its epithelium, together with the ependyma, forms the **blood–CSF barrier** (capillary endothelium + its basement membrane + ependymal basement membrane + ependyma), which permits selective one-way passage of substances from blood to CSF.
- ▶ Physiological calcification of the choroid plexus (the "glomus" in the atrium) is a common incidental finding on skull radiographs/CT after adolescence.

Communications and CSF relations

- ▶ Each lateral ventricle opens into the third ventricle through the **interventricular foramen of Monro**, bounded by the **column of the fornix anteriorly** and the **anterior end (tubercle) of the thalamus posteriorly**.
- ▶ The two lateral ventricles have **no direct communication** with each other; they communicate only indirectly, via the third ventricle.
- ▶ **CSF circulation:** CSF formed in each lateral ventricle → third ventricle (via the foramen of Monro) → cerebral aqueduct → fourth ventricle → median and lateral apertures → subarachnoid space (cerebellomedullary and other cisterns) → arachnoid villi/granulations → dural venous sinuses (chiefly the superior sagittal sinus).
- ▶ Total CSF volume is about 140 mL, of which roughly 25 mL occupies the ventricles; about 500 mL is produced daily, so the entire pool is renewed several times over each day.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 24.2 — *Parts of the lateral ventricle (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.440)*

In addition to reproducing the C-shaped cast above (labelling **anterior horn, body, posterior horn, inferior horn, atrium/trigone, interventricular foramen**), draw a **coronal section through the body of the lateral ventricle** and label: corpus callosum (roof); septum pellucidum and body of fornix (medial wall); caudate nucleus and thalamus (floor), separated by the stria terminalis and thalamostriate vein; choroid plexus lying in the choroid fissure between fornix and thalamus; and the third ventricle below, between the two thalami.

Applied / Clinical anatomy

- ▶ **Hydrocephalus:** an increase in CSF volume that dilates the ventricles proximal to the site of block. It is **obstructive (non-communicating)** when CSF flow from the ventricular system to the subarachnoid space is blocked, or **communicating** when the block is distal (e.g., at the arachnoid villi). The interventricular foramen, being the narrowest point proximal to the lateral ventricle, is a classical obstruction site — a mass here (e.g., a colloid cyst of the third ventricle, or a tumour near the foramen) can produce **unilateral or bilateral dilation of the lateral ventricle(s)**.
- ▶ **Ventricular asymmetry** is a recognised normal variant, especially of the posterior horn (which may even be rudimentary on one side) — an important point when interpreting CT/MRI, so as not to over-call mild asymmetry as pathological.
- ▶ **Choroid plexus papilloma**, a tumour of the choroid plexus epithelium, is the classical intraventricular neoplasm of infancy; it characteristically arises in the **atrium (trigone)** in children (as against the fourth ventricle in adults), and can cause hydrocephalus by CSF overproduction as well as by obstruction.
- ▶ **Germinal-matrix/intraventricular haemorrhage** in preterm neonates classically originates in the subependymal germinal matrix adjacent to the head of the caudate nucleus and ruptures into the adjoining **anterior horn/body** of the lateral ventricle — the basis of cranial ultrasound screening in premature infants.

- ▶ **Relation of the inferior horn to the uncus:** an expanding supratentorial mass (especially in the temporal lobe) can push the uncus and parahippocampal gyrus medially through the tentorial notch (**uncal/transtentorial herniation**), compressing the oculomotor nerve against the free edge of the tentorium (a fixed, dilated pupil) and distorting the adjacent inferior horn and cerebral peduncle.
- ▶ **Ventricular access:** because it lacks choroid plexus and lies superficial beneath the corpus callosum, the **frontal (anterior) horn** is the standard site for catheterisation in external ventricular drainage, ventriculoperitoneal shunting, and neuroendoscopic procedures (e.g., endoscopic third ventriculostomy is approached through the frontal horn and interventricular foramen).
- ▶ **Cross-sectional imaging:** CT/MRI routinely assess ventricular size, symmetry and the integrity of the choroid plexus/fissure — relevant to Paper IV's radiological-anatomy component; asymmetric or "entrapped" dilation of a single horn (e.g., an isolated dilated temporal horn) points to a localised obstructive lesion along that horn.

High-yield exam pointers

- ▶ Lateral ventricle = C-shaped, telencephalic cavity; **4 parts** — anterior, posterior, inferior horn + central part (body) — meeting at the **atrium (trigone)**, its most dilated part.
- ▶ Choroid plexus is present in the **body, atrium and inferior horn**; it is **absent** from the anterior and posterior horns.
- ▶ Choroid fissure: between fornix and thalamus in the body; between fimbria and stria terminalis in the inferior horn.
- ▶ Roof of anterior horn, body and posterior horn is formed by the corpus callosum (trunk/tapetum); floor of the body/inferior horn involves the caudate nucleus and thalamus/hippocampus respectively.
- ▶ Only communication with the rest of the ventricular system is the **interventricular foramen of Monro** (bounded by the column of fornix anteriorly, anterior thalamus posteriorly) — the two lateral ventricles never communicate directly.
- ▶ Arterial supply of plexus: **anterior choroidal artery** → inferior horn; **medial + lateral posterior choroidal arteries** → body/atrium; anastomosis at the atrium.
- ▶ Posterior horn is frequently asymmetrical — a normal variant, not necessarily pathological.
- ▶ Foramen-of-Monro block → unilateral/bilateral hydrocephalus; frontal horn is the standard neurosurgical access route to the ventricular system.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; IB Singh — Textbook of Anatomy Vol 3 6e; Snell — Clinical Neuroanatomy 7e; Vishram Singh — Textbook of Anatomy Vol 3 4e; BD Chaurasia — Human Anatomy Vol 3-4 8e.



Describe lateral ventricle under the following headings -Location and extent. -Relations and boundaries. -Contents and applied aspects

Asked in: Paper IV May 2011 — RGUHS MD/MS Anatomy

Definition / Introduction: The lateral ventricles are two irregular, roughly C-shaped cavities, one situated within each cerebral hemisphere. They are the largest components of the cerebral ventricular system, derived developmentally from the cavity of the telencephalic vesicle. Each lateral ventricle communicates with the midline third ventricle through the **interventricular foramen (foramen of Monro)** and is lined by ependyma. Both ventricles contain CSF and a vascular fringe, the **choroid plexus**, which is the principal source of CSF production.

1. Location and Extent

- ▶ Each lateral ventricle lies deeply within its cerebral hemisphere and is described in **four parts**: a **central part (body)** and three **horns** — anterior (frontal), posterior (occipital) and inferior (temporal).
- ▶ The C-shaped course results from differential expansion of the frontal, parietal and occipital regions of the hemisphere in development, which displaces the temporal lobe anteriorly and inferiorly; the caudate nucleus and fornix, lying in the ventricular wall, follow the same curved course.

Part	Lobe occupied	Extent
Anterior (frontal) horn	Frontal lobe	From the genu/rostrum of corpus callosum (in front) to the interventricular foramen (behind)
Central part (body)	Frontal + parietal lobe	From the interventricular foramen to the splenium of the corpus callosum
Atrium (collateral trigone)	Junction zone, opposite the pulvinar of thalamus	Where body continues into posterior and inferior horns
Posterior (occipital) horn	Occipital lobe	Curves posteromedially into the occipital lobe
Inferior (temporal) horn	Temporal lobe	Curves around the pulvinar of the thalamus, passes down and forward, ending within about 2.5 cm of the temporal pole near the uncus

- ▶ Anteriorly, each ventricle opens into the third ventricle through the **interventricular foramen**, bounded anteriorly by the **column of the fornix** and posteriorly by the **anterior (tubercle of the) thalamus**.
- ▶ The two anterior horns and the two bodies are separated from each other only by the thin **septum pellucidum**.

embed: ![Fig 16.2 — Cast of the ventricular cavities of the brain. A: Lateral view. B: Anterior view. (Snell — Clinical Neuroanatomy — 7e, p.468)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/6a838a099a1be7b0.jpg)

2. Relations and Boundaries of Each Part

Part	Roof	Floor	Medial wall	Lateral wall
Anterior horn	Undersurface/ trunk of corpus callosum (anterior part)	Head of caudate nucleus; a small medial part by the rostrum of corpus callosum	Septum pellucidum + column of fornix	(Merges with roof/floor — caudate head forms floor and lateral wall)
Central part (body)	Undersurface of the trunk of corpus callosum	(Lateral→medial) body of caudate nucleus, stria terminalis, thalamostriate vein, superior surface of thalamus, choroid plexus, upper surface of body of fornix	Septum pellucidum + body of fornix	Roof and floor meet laterally
Posterior horn	Tapetum of corpus callosum; optic radiation fibres lie lateral to tapetum	— (floor merges with medial wall)	Two elevations: bulb of posterior horn (raised by forceps major above) and calcar avis (raised by calcarine sulcus, below)	Tapetum
Inferior horn	Chiefly tapetum; also tail of caudate nucleus and stria terminalis, both ending anteriorly at the amygdaloid body	Hippocampus medially (covered by white matter — the alveus, converging medially as the fimbria); collateral eminence (raised by collateral sulcus) laterally	—	—

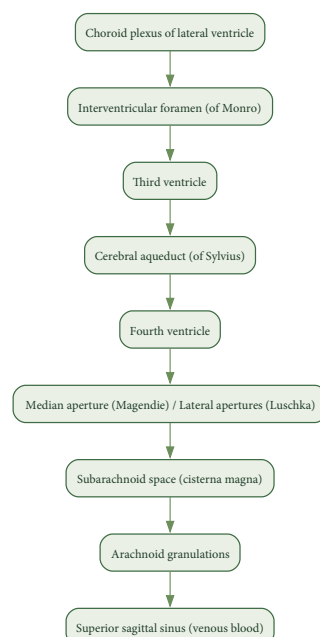
- **Choroid fissure:** a C-shaped slit along which the tela choroidea and choroid plexus invaginate the ventricle. It runs from the interventricular foramen, around the thalamus, to the uncus — present only along the central part and inferior horn (absent in the anterior and posterior horns). Its convex margin is bounded by the fornix (body/crus), fimbria and hippocampus; its concave margin by the thalamus, tail of caudate nucleus and stria terminalis.
- The **interthalamic adhesion (massa intermedia)** connects the two thalami and is related to the medial walls of the third ventricle continuous with this region.

3. Choroid Plexus and Blood Supply

- ▶ The choroid plexus is a vascular fringe of pia mater (tela choroidea) covered by ependyma, projecting into the ventricle through the choroid fissure; it is continuous with the choroid plexus of the third ventricle across the interventricular foramen and continues into the inferior horn at the junction of body and inferior horn.
- ▶ **Arterial supply:** the anterior choroidal branch of the **internal carotid artery** and several choroidal branches of the **posterior cerebral artery**; the two sets anastomose to a variable degree.
- ▶ **Venous drainage:** choroidal capillaries drain into a rich venous plexus served by a single choroidal vein; this, together with the thalamostriate and anterior septal veins converging near the interventricular foramen, feeds the **internal cerebral vein**, which unites with its fellow to form the **great cerebral vein**, joining the inferior sagittal sinus to form the **straight sinus**.
- ▶ Physiological calcification of the choroid plexus is among the commonest incidental findings on skull radiographs and CT.

4. Contents and CSF Circulation

- ▶ The lateral ventricle's true "contents" are **cerebrospinal fluid (CSF)** and the **choroid plexus**; the CSF is a clear, colourless fluid actively secreted (not a simple ultrafiltrate) by the choroid plexus epithelium, which constitutes the blood–CSF barrier.
- ▶ Total CSF volume in the adult ranges from **140 to 270 mL**, of which only a small fraction (roughly 20–25 mL) lies within the ventricular system at any time; the entire CSF volume is replaced about **four times a day**.
- ▶ CSF circulation is unidirectional: from the lateral ventricles, through the interventricular foramina, via the third ventricle and cerebral aqueduct, into the fourth ventricle, and out into the subarachnoid space, from where it is reabsorbed into the venous system through arachnoid granulations.



Describe lateral ventricle under the following headings -Location and extent. -Relations and boundaries. -Contents and applied aspects

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a **lateral (cast) view of the ventricular system** with these labels:

- ▶ Anterior (frontal) horn — in frontal lobe
- ▶ Central part (body) — in parietal lobe
- ▶ Atrium/collateral trigone
- ▶ Posterior (occipital) horn — in occipital lobe
- ▶ Inferior (temporal) horn — in temporal lobe, curving to the uncus
- ▶ Interventricular foramen (of Monro)
- ▶ Third ventricle
- ▶ Cerebral aqueduct
- ▶ Fourth ventricle
- ▶ Choroid plexus (shown within body and inferior horn)
- ▶ Corpus callosum (genu, trunk, splenium, tapetum) forming roof
- ▶ Caudate nucleus (head, body, tail) and thalamus forming floor
- ▶ Fornix (column, body, crus, fimbria) and septum pellucidum forming medial wall
- ▶ Hippocampus and collateral eminence in the floor of the inferior horn
- ▶ Bulb of posterior horn and calcar avis in the posterior horn

Applied / Clinical anatomy

- ▶ **Foramen of Monro obstruction:** a **colloid cyst of the third ventricle**, a mobile ball-like mass suspended from the choroid plexus near the foramen, may intermittently block one (or both) interventricular foramina on head movement, producing classic **positional, intermittent headache** with signs of acutely raised intracranial pressure; unilateral obstruction dilates only the lateral ventricle of that side.
- ▶ **Aqueductal obstruction** (congenital stenosis, inflammation, or tumour compression) causes **symmetrical dilatation of both lateral ventricles and the third ventricle** — the commonest cause of hydrocephalus in the newborn.
- ▶ **Obstruction at the fourth-ventricular outlets** (foramina of Magendie/Luschka), by inflammatory exudate or tumour, produces symmetrical dilatation of the entire ventricular system (**non-communicating hydrocephalus**).
- ▶ **Communicating hydrocephalus** results when CSF reaches the subarachnoid space freely but its reabsorption at the arachnoid granulations is impaired (e.g. post-meningitic exudate, subarachnoid haemorrhage, venous sinus thrombosis).
- ▶ **Choroid plexus tumours** (e.g. papilloma) are a rare cause of hydrocephalus through CSF over-production.
- ▶ **Periventricular germinal matrix haemorrhage:** in the premature neonate, the highly vascular, immature germinal matrix lining the floor/wall of the lateral ventricle is prone to rupture, producing **intraventricular haemorrhage** — an important cause of neonatal hydrocephalus.

- ▶ **Papilloedema:** ventricular dilatation and raised intracranial pressure are transmitted along the optic nerve sheath (a prolongation of the subarachnoid space), producing bilateral disc oedema.
- ▶ **Clinical/radiological access and imaging:** CSF may be sampled by lumbar puncture, cisternal puncture, or direct **ventricular puncture** (the anterior horn is a standard, safe access route for external ventricular drainage/ICP monitoring). The ventricles are studied clinically by CT and MRI, and historically by ventriculography (radiopaque dye) or pneumoencephalography; asymmetric or disproportionate dilatation of a horn localizes the site of obstruction or the underlying mass lesion.

High-yield exam pointers

- ▶ Lateral ventricle = **C-shaped cavity**; 4 parts — anterior horn, body (central part), posterior horn, inferior horn — meeting at the **atrium**.
- ▶ Communicates with 3rd ventricle via the **interventricular foramen of Monro** (bounded by column of fornix anteriorly, thalamus posteriorly).
- ▶ **Choroid fissure** is present only in the body and inferior horn (absent in anterior and posterior horns) — a common "trick" MCQ point.
- ▶ Roof of body/anterior horn = corpus callosum; floor of body = caudate nucleus + thalamus; floor of inferior horn = hippocampus + collateral eminence; roof/lateral wall of posterior & inferior horns = tapetum.
- ▶ Blood supply of choroid plexus: **anterior choroidal artery (from ICA) + posterior choroidal branches (from PCA)**; venous drainage via internal cerebral vein → great cerebral vein → straight sinus.
- ▶ Contents = **CSF + choroid plexus** only.
- ▶ Total CSF volume 140–270 mL, replaced ~4 times/day; secreted mainly by choroid plexus.
- ▶ Applied triad to remember: **colloid cyst** → **unilateral/positional hydrocephalus**; **aqueduct block** → **symmetric lateral + 3rd ventricle dilatation**; **germinal matrix bleed** → **neonatal IVH**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3–4 8e; IB Singh's Textbook of Anatomy Vol 3 6e; Snell's Clinical Neuroanatomy 7e.



Describe the blood supply of the cerebrum. Give its applied anatomy

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction The cerebrum is supplied by three pairs of cerebral arteries — **anterior, middle and posterior** — derived from the two internal carotid arteries (carotid/anterior circulation) and the vertebrobasilar system (posterior circulation), which anastomose at the base of the brain to form the **circle of Willis**. Each cerebral artery gives **cortical branches** (to the cerebral cortex and adjoining white matter) and **central/perforating branches** (to the basal ganglia, internal capsule, thalamus and hypothalamus). Although the brain forms only about 2% of body weight, it receives roughly 15% of resting cardiac output and consumes about 20% of total body oxygen, so any interruption of this supply — ischaemic or haemorrhagic — produces devastating and highly localisable neurological deficits, making this vascular anatomy the anatomical basis of stroke.

1. Source arteries and the two circulations

Circulation	Source vessel	Enters skull via	Supplies	Approx. share of cerebral blood flow
Anterior (carotid)	Internal carotid artery (each side)	Carotid canal → cavernous sinus → divides near medial end of lateral sulcus into ACA + MCA	Cerebrum and diencephalon (supratentorial)	≈ 80%
Posterior (vertebrobasilar)	Vertebral arteries → unite as basilar artery → terminate as 2 posterior cerebral arteries	Foramen magnum	Brainstem, cerebellum, and a variable posterior part of the cerebral hemispheres (occipital and inferior temporal lobes)	≈ 20%

Before its terminal bifurcation the internal carotid artery also gives the **ophthalmic artery**, the **posterior communicating artery** (to the posterior cerebral artery) and the **anterior choroidal artery** (to the choroid plexus, crus cerebri, lateral geniculate body, optic tract and posterior limb of internal capsule) — its long, narrow course predisposes to thrombosis, hence the "artery of cerebral thrombosis."

2. Anterior cerebral artery (ACA)

The smaller terminal branch of the internal carotid artery. Surgical nomenclature divides it into **A1** (to the anterior communicating artery), **A2** (to the origin of the callosomarginal artery) and **A3/pericallosal** segments. It runs anteromedially above the optic nerve into the great longitudinal fissure, is joined to its fellow by the short **anterior communicating artery**, curves around the genu of the corpus callosum as the **pericallosal artery**, gives the **callosomarginal artery** (in the cingulate sulcus), and finally anastomoses with the posterior cerebral artery near the splenium.

- ▶ **Cortical branches** — orbital, frontal (pericallosal/callosomarginal) and parietal (paracentral, precuneal) — supply most of the **medial surface** of the hemisphere up to the parieto-occipital sulcus, plus a narrow (~2.5 cm) strip on the adjoining superolateral surface — the "**leg and foot**" area of the motor/sensory cortex.
- ▶ **Central branches** (anteromedial group) enter the anterior perforated substance to supply the anterior limb of the internal capsule, head of caudate nucleus and anterior putamen; the **medial striate artery**, arising close to the anterior communicating junction, reinforces this territory.

3. Middle cerebral artery (MCA)

The larger, direct continuation of the internal carotid artery, carrying about 30% of carotid blood flow. Surgical segments: **M1** (sphenoidal, to the bi-/trifurcation), **M2** (insular, in the lateral/Sylvian fissure), **M3** (opercular) and **M4** (cortical).

- ▶ **Cortical branches** — orbital, frontal (prefrontal, precentral, central), parietal (postcentral, angular) and temporal (anterior, middle, posterior/temporo-occipital) — supply almost the whole **superolateral surface** (about two-thirds of the hemisphere): the motor and sensory cortices for face, arm and trunk, the auditory area, the insula, and — in the dominant (usually left) hemisphere — **Broca's and Wernicke's speech areas**.
- ▶ **Central branches** (anterolateral group), the **lateral striate/lenticulostriate arteries**, arise at its origin, pierce the anterior perforated substance, and supply the caudate nucleus, putamen, globus pallidus and the anterior limb, genu and much of the posterior limb of the internal capsule. The largest of these is **Charcot's artery of cerebral haemorrhage**, the commonest site of rupture in hypertensive intracerebral bleeds.

4. Posterior cerebral artery (PCA)

The paired terminal branches of the basilar artery, separated from the superior cerebellar artery by the oculomotor (medially) and trochlear (laterally) nerves. Segments: **P1** (to the posterior communicating junction), **P2** (perimesencephalic) and **P3** (calcarine).

- ▶ **Cortical branches** — temporal (to uncus, parahippocampal and occipitotemporal gyri), occipital (cuneus, lingual gyrus) and parieto-occipital/calcarine — supply the **occipital lobe (visual cortex)** and the inferolateral/medial **temporal lobe** (excluding the temporal pole, which is MCA territory).
- ▶ **Central branches**: posteromedial group (with the posterior communicating artery) to the thalamus, subthalamus and hypothalamus; posterolateral group to the cerebral peduncle, colliculi, pineal and medial geniculate body (via thalamogeniculate branches). A **posterior choroidal branch** supplies the choroid plexuses of the third and lateral ventricles.
- ▶ Near the occipital pole, MCA and PCA territories overlap over the macular (central) visual cortex — the basis of **macular sparing** in PCA occlusion.

5. Arterial territories of the three cerebral surfaces

Surface	Chief artery (bulk)	Contribution of the other two
Superolateral	Middle cerebral artery (~2/3)	Anterior cerebral artery — narrow superomedial strip (leg/foot); posterior cerebral artery — narrow strip along inferior temporal/occipital border
Medial	Anterior cerebral artery (anterior 2/3, to parieto-occipital sulcus)	Middle cerebral artery — temporal pole; posterior cerebral artery — occipital lobe (visual cortex)
Inferior	Posterior cerebral artery (bulk, except temporal pole)	Middle cerebral artery — orbital surface (lateral part) and temporal pole; anterior cerebral artery — medial orbital surface

□ Fig 17.3 — Areas supplied by the cerebral arteries: A, lateral surface; B, medial surface of the right cerebral hemisphere (Snell — *Clinical Neuroanatomy* — 7e, p.498)

6. Central branches as a group, and the internal capsule

Collectively the central branches described above (anteromedial from ACA/ACom, anterolateral/lenticulostriate from MCA, posteromedial and posterolateral from the posterior circulation) are numerous slender, thin-walled **end arteries** that do not anastomose once inside the brain substance. The **internal capsule** receives contributions from all three cerebral arteries but chiefly from the **lenticulostriate branches of the MCA** — so a small-volume lesion here produces a large, dense contralateral deficit, since it is the sole conduit for corticospinal, corticonuclear and thalamocortical fibres.

7. Circle of Willis — collateral role

The anterior communicating artery links the two ACAs; each posterior communicating artery links the internal carotid to the posterior cerebral artery of the same side, closing a hexagonal anastomosis in the interpeduncular fossa. Normally the carotid and vertebrobasilar streams do not mix across it, but if a major feeding artery is occluded proximally, the circle can redirect flow from the opposite carotid or the vertebrobasilar system — though it is anatomically complete in most people yet **rarely haemodynamically complete** (the posterior communicating artery is the most variable component), so collateralisation is often inadequate. (See "Circle of Willis" answer for full detail.)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Basal (inferior) view of the brain showing the **circle of Willis** in the interpeduncular fossa. Label: **optic chiasma**, **internal carotid artery** (×2) dividing into **anterior** and **middle cerebral arteries**, **anterior communicating artery**, **posterior communicating artery** (×2), **basilar artery** formed by the two **vertebral arteries** and dividing into two **posterior cerebral arteries**, the **oculomotor nerve** emerging beside the posterior cerebral/superior cerebellar arteries, and arrows into the anterior/posterior perforated substance for the four central-branch groups (**anteromedial**, **anterolateral**, **posteromedial**, **posterolateral**).

8. Venous drainage of the cerebrum

Cerebral veins are thin-walled, valveless, and drain (against the direction of dural sinus flow, in an oblique course that resists collapse) into the dural venous sinuses.

- ▶ **Superficial (external) veins** — three groups: (i) 8–12 **superior cerebral veins** drain the superolateral and medial surfaces into the **superior sagittal sinus**; (ii) the **superficial middle cerebral vein**, in the lateral sulcus, drains into the **cavernous sinus**, linked to the sagittal sinus by the **superior anastomotic vein (of Trolard)** and to the transverse sinus by the **inferior anastomotic vein (of Labbé)**; (iii) **inferior cerebral veins** drain the inferior surface into neighbouring sinuses.
- ▶ **Deep veins** — the **deep middle cerebral vein** (insula) joins **anterior cerebral** and **striate veins** to form the **basal vein (of Rosenthal)**; the paired **internal cerebral veins** (union of thalamostriate and choroidal veins at the interventricular foramen) run back beneath the splenium and unite with the basal veins to form the median **great cerebral vein (of Galen)**, which drains into the **straight sinus**.

Applied / Clinical anatomy

- ▶ **ACA occlusion** (distal to the anterior communicating artery): contralateral hemiparesis/hemisensory loss chiefly of the **leg and foot**, with apathy and personality change; proximal occlusion is often silent owing to good collateral flow.
- ▶ **MCA occlusion** (commonest site of cerebral thrombosis): contralateral hemiplegia/hemianaesthesia of the **face and arm**; **aphasia** if dominant hemisphere; homonymous hemianopia; neglect/anosognosia if non-dominant.
- ▶ **PCA occlusion**: contralateral homonymous hemianopia **with macular sparing** (MCA collateral to the occipital pole); visual agnosia; memory impairment if the medial temporal lobe is involved.
- ▶ **ICA occlusion**: may be silent, or reproduce the MCA picture, plus transient/permanent monocular blindness (emboli reaching the retina via the ophthalmic artery).
- ▶ **Watershed (zone of diminished nutrition) infarcts**: cortical and central branches are end arteries; the border zone between adjacent territories (e.g. ACA–MCA) is most vulnerable to systemic hypotension.

- ▶ **Hypertensive intracerebral haemorrhage:** rupture of **Charcot's artery of cerebral haemorrhage** (a lenticulostriate MCA branch) into the internal capsule; **Charcot–Bouchard microaneurysms** on these vessels are the substrate.
- ▶ **Subarachnoid haemorrhage:** usually from a ruptured **berry aneurysm** at a circle-of-Willis junction (commonly ACom–ACA or ICA–PCom) — sudden "thunderclap" headache with neck stiffness; may compress the oculomotor nerve.
- ▶ **Subdural haemorrhage:** tearing of the **superior cerebral (bridging) veins** entering the superior sagittal sinus, typically after antero-posterior head trauma.
- ▶ **Cerebral angiography:** carotid injection outlines ACA/MCA; vertebral injection outlines the vertebrobasilar/PCA system — used for occlusion, aneurysm, AVM or tumour vascularity, now largely supplemented by CT/MR angiography.
- ▶ **Autoregulation:** cerebral blood flow ($\approx 50\text{--}60$ mL/100 g brain/min) stays constant over a wide arterial pressure range; a rise in CO_2/H^+ is the strongest local vasodilator — the basis of hyperventilation to lower raised intracranial pressure.

High-yield exam pointers

- ▶ Three cerebral arteries — **anterior, middle, posterior** — each give **cortical** (end arteries) and **central/perforating** (to basal ganglia, internal capsule, thalamus) branches.
- ▶ MCA supplies $\sim 2/3$ of the superolateral surface (face/arm cortex, speech areas); ACA supplies the medial surface + leg/foot strip; PCA supplies the occipital lobe + inferomedial temporal lobe.
- ▶ **Lenticulostriate branches of MCA** supply the internal capsule/corpus striatum; the largest is **Charcot's artery of cerebral haemorrhage**.
- ▶ **Anterior choroidal artery** (from ICA) = "artery of cerebral thrombosis."
- ▶ Anterior (carotid) $\approx 80\%$ and posterior (vertebrobasilar) $\approx 20\%$ of cerebral blood flow, linked by the **circle of Willis** — anatomically complete but rarely haemodynamically complete.
- ▶ **Macular sparing** in PCA occlusion is due to MCA–PCA collateral anastomosis at the occipital pole.
- ▶ Deep venous drainage: internal cerebral veins + basal vein (of Rosenthal) $\rightarrow$ **great cerebral vein of Galen** $\rightarrow$ straight sinus.
- ▶ Berry aneurysm $\rightarrow$ subarachnoid haemorrhage; Charcot–Bouchard microaneurysm $\rightarrow$ intracerebral haemorrhage; bridging-vein tear $\rightarrow$ subdural haemorrhage.
- ▶ Normal cerebral blood flow $\approx 50\text{--}60$ mL/100 g brain/min; brain = 2% body weight but $\sim 15\%$ of cardiac output and $\sim 20\%$ of body oxygen consumption.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell — Clinical Neuroanatomy 7e; Vishram Singh — Clinical Neuroanatomy 4e.



Describe the fourth ventricle in detail

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction — The **fourth ventricle** is the CSF-filled cavity of the hindbrain (rhombencephalon), lying **ventral to the cerebellum** and **dorsal to the pons and the upper (open) half of the medulla oblongata** in the posterior cranial fossa. It is **tent-shaped** in sagittal section and **rhomboidal (diamond/lozenge-shaped)** in horizontal section, continuous rostrally with the **cerebral aqueduct** of the midbrain and caudally with the **central canal** of the medulla and spinal cord. Understanding it is essential because its floor is strategically packed with **cranial nerve nuclei (V–XII)** and vital centres, and its roof carries three apertures through which CSF escapes into the subarachnoid space.

1. Situation, shape and extent

- ▶ Lies in the posterior cranial fossa, in the midst of pons, medulla and cerebellum; widest at the **pontomedullary junction**, where a **lateral recess** on each side extends to the lateral border of the brainstem.
- ▶ Lined throughout by **ependyma**; possesses lateral boundaries, a roof, a rhomboid-shaped floor, four angles and five recesses.
- ▶ Continuous **rostrally** with the cerebral aqueduct (at the midbrain–pons junction) and **caudally** with the central canal of the closed part of the medulla and the spinal cord.

2. Boundaries (lateral walls)

- ▶ **Superolaterally** (cranial part of each wall) — **superior cerebellar peduncle**.
- ▶ **Inferolaterally** (caudal part) — **inferior cerebellar peduncle**, supplemented by the **gracile and cuneate tubercles**, which contain the underlying gracile and cuneate (dorsal column) nuclei.

3. Floor — rhomboid fossa (calamus scriptorius)

- ▶ Formed by the **dorsal surface of the pons** (upper triangular part) and the **dorsal surface of the upper medulla** (lower triangular part), joined by an **intermediate part** at the pontomedullary junction that is prolonged laterally, over the inferior cerebellar peduncle, as the floor of the lateral recess; this intermediate strip is marked by transverse fibre bundles, the **striae medullares** (arcuate nucleus → opposite cerebellum).
- ▶ Structural layers (superficial to deep): **ependyma** → **subependymal neuroglia** → **grey matter** containing the cranial nerve nuclei.
- ▶ A **median sulcus** divides the floor into symmetrical halves; each half is further divided by the **sulcus limitans** into a medial **medial eminence** and a lateral **vestibular area** (overlies the vestibular nuclei; lies partly in pons, partly in medulla).
- ▶ The sulcus limitans widens above into the **superior fovea** and below into the **inferior fovea**. Above the superior fovea it flattens into a bluish-grey patch, the **locus coeruleus**, produced by pigmented noradrenergic neurons of the **substantia ferruginea** (reticular formation; important in paradoxical/REM sleep).
- ▶ In the pontine part, the medial eminence bears the **facial colliculus** — an oval swelling produced by the **internal genu of the facial nerve** looping around the **abducens nucleus**.

- From the inferior fovea an oblique furrow descends to the median sulcus, dividing the medullary medial eminence into the **hypoglossal triangle** (medial, over the hypoglossal nucleus) and the **vagal triangle** (lateral, over the dorsal motor nucleus of the vagus).
- The vagal triangle is crossed below by the **funiculus separans**, beyond which — between it and the **gracile tubercle** — lies the **area postrema**, a small, highly vascular, BBB-deficient chemoreceptor patch.
- The **inferolateral margins** of the floor are marked by a ridge, the **taenia**; the two taeniae meet at the inferior angle to form the **obex**, which is also used to denote the inferior angle itself. The tapering lower floor resembles a pen-nib — **calamus scriptorius**.

Surface landmark	Structure/nucleus deep to it
Facial colliculus	Abducens nucleus (VI) + looping facial nerve fibres (VII)
Locus coeruleus	Noradrenergic nucleus (substantia ferruginea)
Vestibular area	Vestibular nuclear complex (VIII)
Hypoglossal triangle	Hypoglossal nucleus (XII)
Vagal triangle	Dorsal motor nucleus of vagus (X)
Area postrema	Chemoreceptor trigger zone — no blood–brain barrier
Striae medullares	Arcuate-nucleus fibres to contralateral cerebellum

□ Fig 10.16 — The rhomboid fossa or floor of the fourth ventricle. (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.386)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Posterior view of the brainstem (cerebellum removed) showing the floor of the fourth ventricle. Label: **superior cerebellar peduncle** and **inferior cerebellar peduncle** (lateral boundaries) — **median sulcus** — **sulcus limitans** with **superior fovea** and **inferior fovea** — **medial eminence** with **facial colliculus** and **locus coeruleus** — **vestibular area** — **hypoglossal triangle** and **vagal triangle** — **striae medullares** — **funiculus separans** and **area postrema** — **gracile tubercle** / **cuneate tubercle** — **taenia** meeting at the **obex**.

4. Roof

- **Tent-shaped**, its apex projecting posteriorly into the white core of the cerebellum.
- **Upper part** — formed by the two converging **superior cerebellar peduncles** and the **superior medullary velum**, a thin nervous-tissue sheet bridging them, covered dorsally by the **lingula** of the superior vermis.
- **Lower part** — the **inferior medullary velum**, a non-nervous sheet of ventricular ependyma covered posteriorly by the pia of the tela choroidea; pierced in the midline by the large **median aperture (foramen of Magendie)**, through which the ventricle communicates with the **cerebellomedullary cistern (cisterna magna)**.

- *Development note:* the foramen of Magendie forms when a transient membranous structure, **Blake's pouch**, perforates into the fourth ventricle around the **9th week** of fetal life; its persistence causes cystic obstruction of the median outlet (**Blake's pouch cyst**).

5. Angles, recesses and communications

- **Four angles:** **superior angle** — continuous with the cerebral aqueduct; **inferior angle** — continuous with the central canal (marked by the obex); **two lateral angles** — carried outward across the dorsal inferior cerebellar peduncle as the lateral recesses.
- **Five recesses:** two **lateral recesses** (between the inferior cerebellar peduncle ventrally and the peduncle of the flocculus dorsally, reaching the flocculus and opening as the **lateral aperture/foramen of Luschka**); one **median dorsal recess** (into the cerebellar white core, above the nodule); two **lateral dorsal recesses** (above the inferior medullary velum, lateral to the nodule).
- **Communications:** rostrally with the third ventricle via the **cerebral aqueduct**; caudally with the spinal cord via the **central canal**; and, through the roof, with the subarachnoid space via a single **median aperture (foramen of Magendie)** and paired **lateral apertures (foramina of Luschka)** — these three openings are the only route for CSF from the ventricular system into the subarachnoid space.

6. Tela choroidea and choroid plexus

- **Tela choroidea:** a double-layered fold of pia mater occupying the gap between the inferior vermis and the lower roof; its dorsal layer covers the inferior vermis and is reflected, at the nodule, into the ventral layer lining the roof, continuous laterally with the pia over the cerebellar hemisphere/medulla.
- **Choroid plexus:** formed by the vascular fringe of the tela choroidea covered by secretory ependyma; overall **T-shaped** — a double vertical limb flanking the median aperture, and horizontal limbs running into each lateral recess to protrude through the foramen of Luschka near the flocculus. Supplied by the **posterior inferior cerebellar artery (PICA)**.
- CSF formed here joins that from the lateral and third ventricles, completing the classical route: lateral ventricle → foramen of Monro → third ventricle → cerebral aqueduct → **fourth ventricle** → foramina of Magendie/Luschka → basal cisterns → subarachnoid space → arachnoid villi.

Recent advances

- **Rhomboid-fossa morphometry for safe brainstem surgery:** a cadaveric morphometric study (45 brainstems) mapped the rhomboid fossa (mean length 34.65 mm, width 22.61 mm) and the facial colliculus (~4.3 mm), refining the classical **supra-/infra-facial safe-entry triangles** used to approach intrinsic brainstem lesions through the ventricular floor without injuring cranial nerve nuclei (Erturk et al, *World Neurosurgery* 2024) [PMID 39181240].
- **Far-lateral corridor to the lower brainstem:** quantitative cadaveric analysis has further defined safe-entry zones around the obex/calamus scriptorius region reached via the far-lateral approach, complementing telovelar exposure of the fourth ventricle (Cavalcanti et al, *Neurosurgical Review* 2026) [DOI 10.1007/s10143-026-04171-7].

- ▶ **Molecular subgrouping of posterior-fossa ependymoma:** a 412-case retrospective series confirms that ependymomas arising from the fourth-ventricular floor/roof stratify into **PFA** (poorer prognosis, needs adjuvant radiotherapy) and **PFB** (favourable, often cured by surgery alone) methylation subgroups, now shaping WHO CNS5 grading and treatment planning (Wang et al, *Neurosurgery* 2024) [PMID 38529997].
- ▶ **Prenatal imaging of the developing fourth ventricle:** refined fetal MRI criteria now better distinguish **Blake's pouch cyst** (normal vermis, transient posterior membranous area failing to involute) from Dandy-Walker malformation, improving prenatal counselling given the generally favourable natural history of an isolated Blake's pouch cyst (Pomar et al, *Ultrasound Obstet Gynecol* 2025) [DOI 10.1002/uog.29239].

(According to PubMed/journal indexing.)

Applied / Clinical anatomy

- ▶ **Vital centres:** respiratory, cardiovascular and vasomotor centres lie in the floor near the vagal triangle; injury here (e.g. odontoid/atlando-occipital displacement striking the floor, as in judicial hanging) is rapidly fatal.
- ▶ **Area postrema:** the chemoreceptor trigger zone for vomiting — stimulated by circulating emetics (apomorphine, digitalis) because it lacks a blood–brain barrier.
- ▶ **Medulloblastoma:** the commonest posterior-fossa tumour of childhood, arising from primitive neuroectodermal cells of the cerebellar vermis and bulging into the roof/cavity of the fourth ventricle; may obstruct the median/lateral apertures.
- ▶ **Ependymoma:** arises from the ependymal lining of the floor/roof; a common childhood posterior-fossa tumour that likewise narrows the ventricular cavity (see Recent advances — PFA/PFB subgroups).
- ▶ **Obstructive (non-communicating) hydrocephalus:** blockage of the foramen of Magendie/Luschka by tumour or post-meningitic adhesions causes symmetrical dilatation of the whole ventricular system, with early rise in intracranial pressure — headache, vomiting, papilloedema.
- ▶ **Arnold–Chiari malformation:** herniation of the medulla and cerebellar tonsils through the foramen magnum blocks the roof apertures, producing internal hydrocephalus and stretching the lower cranial nerves.
- ▶ **Dandy–Walker malformation / Blake's pouch cyst:** developmental cystic dilatation of the fourth ventricle, distinguished by vermian hypoplasia/rotation (Dandy–Walker) versus a normal vermis with a persistent posterior membranous outpouching (Blake's pouch cyst).
- ▶ **Cisternal (suboccipital) puncture:** CSF can be sampled by passing a needle through the posterior atlanto-occipital membrane into the cerebellomedullary cistern below the ventricular roof, an alternative when lumbar puncture is contraindicated.
- ▶ **Surgical access:** the **telovelar approach** (splitting the tela choroidea and inferior medullary velum) is the standard route to fourth-ventricular tumours; entry through the floor itself is confined to the safe-entry triangles described above.

High-yield exam pointers

- ▶ Fourth ventricle = cavity of the hindbrain; **tent-shaped** (sagittal), **rhomboidal** (horizontal); between cerebellar aqueduct above and central canal below.
- ▶ Lateral boundaries: **superior cerebellar peduncle** (above) + **inferior cerebellar peduncle** (below).
- ▶ Floor = **rhomboid fossa**; median sulcus + sulcus limitans define **facial colliculus** (VI/VII), **vestibular area** (VIII), **hypoglossal** (XII) and **vagal** (X) triangles, **locus coeruleus**, **area postrema** (CTZ, no BBB).
- ▶ Roof: superior medullary velum + inferior cerebellar peduncles (upper); inferior medullary velum + tela choroidea (lower), pierced by **foramen of Magendie** (Blake's pouch, week 9).
- ▶ **3 openings to subarachnoid space**: 1 median (Magendie) + 2 lateral (Luschka); total **5 recesses** (2 lateral, 1 median dorsal, 2 lateral dorsal) and **4 angles**.
- ▶ Choroid plexus is **T-shaped**, supplied by **PICA**.
- ▶ **Obex** = inferior angle landmark (fold of the two taeniae); **calamus scriptorius** = pen-nib-shaped lower floor.
- ▶ Clinically: vital-centre injury is fatal; area postrema drives vomiting; medulloblastoma/ependymoma are the classic space-occupying lesions; blocked apertures → non-communicating hydrocephalus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3-4 8e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e.



Describe the Lateral ventricle of the brain in detail

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction — The lateral ventricles are a pair of large, C-shaped, ependyma-lined cavities buried one within each cerebral hemisphere, representing the persisting lumen of the paired embryonic telencephalic vesicles. Each is described as a central part (body) from which three horns radiate — an anterior (frontal), a posterior (occipital) and an inferior (temporal) horn — the body and the three horns meeting at a dilated junctional zone called the atrium or collateral trigone. Each lateral ventricle communicates with the single midline third ventricle through the interventricular foramen of Monro, and for most of its course its wall carries a vascular choroid plexus that is the chief source of cerebrospinal fluid (CSF). The C-shaped course of the ventricle — and of the caudate nucleus and fornix that lie curled within its wall — is a direct consequence of the disproportionate growth of the frontal, parietal and occipital poles of the hemisphere during development, which sweeps the temporal lobe downward and forward.

1. Parts and general architecture

- ▶ Each lateral ventricle lies within the telencephalic part of the cerebral hemisphere and has a roughly **C-shaped** profile when viewed from the side.
- ▶ It is conventionally divided into a **central part (body)**, situated in the parietal lobe, and three horns: **anterior (frontal) horn** in the frontal lobe, **posterior (occipital) horn** in the occipital lobe, and **inferior (temporal) horn**, the largest compartment, curving down into the temporal lobe.
- ▶ The **atrium (trigone or collateral trigone)** is the confluence at which the body, posterior horn and inferior horn all meet; it is the widest, most dilatable part of the ventricle.
- ▶ The two lateral ventricles are separated from one another in the midline (anterior horn and body) by the twin laminae of the **septum pellucidum**; both the **caudate nucleus** and the **fornix**, embedded in the ventricular wall, follow the same C-shaped course as the ventricle — the tail of the caudate nucleus arches over the thalamus into the roof of the inferior horn, mirroring the ventricular curve.

2. Boundaries of each part

Part	Extent	Roof	Floor / lateral relation	Medial wall
Anterior (frontal) horn	Anterior to the interventricular foramen; closed in front by genu/rostrum of corpus callosum	Anterior trunk of corpus callosum	Head of caudate nucleus; a small medial part is the rostrum of corpus callosum	Septum pellucidum (common to both ventricles) and column of fornix

Part	Extent	Roof	Floor / lateral relation	Medial wall
Central part (body)	Foramen of Monro to splenium of corpus callosum; triangular on cross-section	Trunk of corpus callosum	Thalamus medially, body of caudate nucleus laterally, separated by the groove for stria terminalis and thalamostriate vein	Septum pellucidum above, body of fornix below; choroid fissure (with plexus) between fornix and thalamus
Atrium (trigone)	Where body, posterior and inferior horns meet	—	Floor raised by the collateral trigone	—
Posterior (occipital) horn	Behind splenium of corpus callosum; often asymmetrical between sides	Tapetum , which also forms the lateral wall	—	Bulb of posterior horn (forceps major) above; calcar avis (calcarine sulcus) below
Inferior (temporal) horn	Curves round the thalamic pulvinar into the temporal lobe, ending ~2.5 cm from the temporal pole near the uncus	Tapetum + tail of caudate nucleus + stria terminalis (end at amygdala)	Hippocampus medially (alveus converging as fimbria); collateral eminence laterally	Choroid fissure, between fimbria and stria terminalis

3. Choroid fissure and choroid plexus

- ▶ The **choroid fissure** is the C-shaped slit through which the vascular pia mater (tela choroidea) invaginates the ependyma to form the choroid plexus; it runs from the interventricular foramen, between fornix and thalamus in the body, then into the inferior horn between fimbria and stria terminalis, ending near the hippocampal tail.
- ▶ The **choroid plexus** is present only in the body, atrium and inferior horn — it is absent from both the anterior and posterior horns.
- ▶ Through the interventricular foramen the choroid plexus of one lateral ventricle is continuous with that of the third ventricle, and, across the third ventricle's roof, with the plexus of the opposite lateral ventricle.
- ▶ Structurally each tuft is a fold of pia mater with a core of fenestrated capillaries, covered by a single layer of cuboidal **choroidal epithelium** (modified ependyma) whose apical tight junctions constitute the anatomical basis of the blood–CSF barrier.

Region of plexus	Arterial supply	Notes
Body and atrium	Medial and lateral posterior choroidal arteries (branches of the posterior cerebral artery), reaching the ventricle through the upper part of the choroid fissure	Continuous with the third-ventricle plexus at the foramen of Monro
Inferior (temporal) horn	Anterior choroidal artery (a slender branch of the internal carotid artery), entering through the lower part of the choroid fissure	Same vessel also supplies the optic tract, part of the internal capsule and thalamus
Atrium	Free anastomosis of anterior and posterior choroidal arteries	Forms the bulky, often calcified tuft, the glomus choroideum

- **Venous drainage:** superior and inferior choroidal veins drain the plexus and join the thalamostriate and septal veins at the interventricular foramen to form the **internal cerebral vein**; the paired internal cerebral veins unite behind the pineal body as the **great cerebral vein of Galen**, which empties into the straight sinus.

4. Communications

- Each lateral ventricle opens into the third ventricle through the **interventricular foramen of Monro**, bounded anteriorly by the column of the fornix and posteriorly by the anterior (rostral) thalamus; the two lateral ventricles have **no direct communication with each other**, linking only indirectly across the midline through the third ventricle.
- There is **no direct opening into the subarachnoid space** — CSF formed here must traverse the third ventricle, cerebral aqueduct and fourth ventricle before reaching the subarachnoid cisterns.

embed: ![Fig 14.14 — Ventricular system of the brain; lateral view. Note the different parts of the (Vishram Singh — Clinical Neuroanatomy — 4e, p.519)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/f3f5028baa827ee3.jpg)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

In addition to the lateral (C-shaped) view above, reproduce a **coronal section through the body of the lateral ventricle** and label exactly: corpus callosum (roof); septum pellucidum and body of fornix (medial wall); choroid plexus lying in the choroid fissure between fornix and thalamus; thalamus and body of caudate nucleus (floor), separated by the stria terminalis and thalamostriate vein; third ventricle and interthalamic adhesion below the fornix in the midline. A second small coronal panel through the inferior horn should label: tapetum and tail of caudate nucleus (roof), hippocampus with alveus and fimbria (floor), and collateral eminence.

5. Development

- The lateral ventricles are the cavities of the paired **telencephalic vesicles**, outpouchings of the prosencephalon appearing around the fifth week, each communicating with the diencephalic cavity (future third ventricle) through the interventricular foramen of Monro from the outset.

- ▶ From about the fifth to seventh week, the floor of each hemisphere bulges into the lumen as the rapidly proliferating, striated **corpus striatum** (precursor of caudate and lentiform nuclei); where the thin medial wall abuts the diencephalic roof instead, ependyma with overlying vascular mesenchyme invaginates along the **choroid fissure** to form the choroid plexus — differentiating after that of the fourth ventricle but before that of the third. Immediately above the fissure, the thickening wall forms the **hippocampus**.
- ▶ With continued, disproportionate expansion of the frontal, parietal, occipital and temporal poles, the hemisphere — and with it the caudate nucleus, fornix and ventricle — assumes the definitive **C-shaped** configuration, producing the three horns; choroidal secretion matures mainly after the 29th week, with a marked rise in CSF production after birth.
- ▶ Failure of the two hemispheres/ventricles to separate in the midline (loss of midline tissue, often linked to *SHH* mutation) produces **holoprosencephaly**, in which the lateral ventricles remain fused as a single midline cavity.

6. CSF: formation and circulation through the ventricle

- ▶ CSF is secreted continuously by the choroid plexus and passes: lateral ventricle → **interventricular foramen** → third ventricle → **cerebral aqueduct** → fourth ventricle → **median aperture (of Magendie)** and paired **lateral apertures (of Luschka)** → subarachnoid space (cisterna magna and related cisterns) → over the cerebral convexities → reabsorbed at the **arachnoid granulations** into the superior sagittal sinus.
- ▶ Total adult CSF volume is **140–270 mL** (only ~25 mL ventricular); production is **0.2–0.7 mL/minute** (**≈600–700 mL/day**), so the whole volume turns over about **four times a day**.
- ▶ Compared with plasma, CSF has much lower protein (20–40 mg% vs ≈600 mg%) and slightly lower glucose (40–60 mg% vs ≈100 mg%), but higher chloride (≈120 mEq/L vs ≈100 mEq/L); specific gravity is 1.003–1.008.

Applied / Clinical anatomy

- ▶ **Obstructive (non-communicating) hydrocephalus** — the level of block dictates the pattern of dilatation: block at one **interventricular foramen** enlarges that ventricle alone; block at the **cerebral aqueduct** (commonest site, e.g. congenital aqueductal stenosis) enlarges both lateral ventricles and the third; block/atresia of the fourth-ventricle apertures enlarges the **entire ventricular system**.
- ▶ **Colloid cyst of the third ventricle**, near the interventricular foramina, can act as a ball valve and intermittently block one or both foramina, producing classic **positional headache**, occasionally with sudden loss of consciousness.
- ▶ **Choroid plexus papilloma/carcinoma** most often arises in the atrium in children, causing hydrocephalus by both CSF over-production and mechanical obstruction.
- ▶ **Anterior choroidal artery occlusion** — this vessel also supplies the posterior limb of the internal capsule, optic tract and thalamus, so its infarction classically produces contralateral hemiplegia, hemisensory loss and homonymous hemianopia in addition to compromising the inferior-horn choroid plexus.

- ▶ **Germinal-matrix haemorrhage** — in preterm neonates, bleeding from the fragile subependymal germinal matrix near the caudate head (floor of the anterior horn/body) may rupture into the ventricle, the leading cause of neonatal intraventricular haemorrhage.
- ▶ **Ventricular access and variants** — the frontal horn, constantly related to the caudate head, is the standard target for an external ventricular drain/shunt catheter (endoscopic third ventriculostomy passes through the interventricular foramen). The frontal horns/atria are the key CT/MRI landmarks for midline shift; a CSF-containing **cavum septum pellucidum** is a normal, regressing fetal variant, while mild occipital-horn asymmetry (colpocephaly) is a normal variant unless marked, when it suggests a mass lesion or callosal dysgenesis.

High-yield exam pointers

- ▶ Four parts around a central body — anterior, posterior, inferior horns — meeting at the **atrium/trigone**; overall C-shaped, mirroring caudate nucleus and fornix.
- ▶ **No choroid plexus** in the anterior or posterior horn — present only in body, atrium and inferior horn.
- ▶ Roof is corpus callosum throughout (trunk, then tapetum posteriorly); floor/medial relations centre on caudate nucleus and thalamus, then hippocampus in the inferior horn.
- ▶ Choroid plexus supply: **posterior choroidal arteries** (body/atrium) + **anterior choroidal artery** (inferior horn), anastomosing at the atrium (glomus choroideum); drainage → internal cerebral vein → great cerebral vein of Galen.
- ▶ Only communication is with the third ventricle via the **foramen of Monro** (fornix column in front, anterior thalamus behind); the two lateral ventricles never communicate directly.
- ▶ Develops from the paired telencephalic vesicles (5th week onward); choroid plexus forms along the choroid fissure, where the hemisphere wall fails to thicken.
- ▶ Site of obstruction determines the hydrocephalus pattern; anterior choroidal artery occlusion and germinal-matrix haemorrhage are classic clinical correlates.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; IB Singh — Textbook of Anatomy Vol 3 (6e); BD Chaurasia — Human Anatomy Vol 3-4 (8e); Snell — Clinical Neuroanatomy (7e); Vishram Singh — Clinical Neuroanatomy (4e); Langman's Medical Embryology (Sadler) 14e.



Describe the third ventricle in detail

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction — The third ventricle is the median, unpaired, slit-like cavity of the **diencephalon**. It lies in the centre of the brain between the two thalami and parts of the hypothalami, and is lined throughout by ciliated ependyma. It extends from the **lamina terminalis** anteriorly to the **cerebral aqueduct** of the midbrain posteriorly, and its outline is made irregular by several recesses. Anteriorly on each side it communicates with a lateral ventricle through the interventricular foramen (of Monro), and posteriorly it is continuous with the fourth ventricle through the cerebral aqueduct (of Sylvius) — so it forms the middle link of the continuous CSF-filled ventricular system.

Location, shape and extent

- Situated in the median plane, between the two thalami and the hypothalami; because the two lateral walls are normally closely apposed, the cavity appears as a narrow **vertical slit** in coronal section.
- Traversed horizontally, near its middle, by a band of grey matter, the **interthalamic adhesion (massa intermedia)**, connecting the two thalami; it is almost always present in humans and is, on average, somewhat larger in women.
- Extent: from the lamina terminalis (anteriorly) to the point where the roof narrows down and the ventricle becomes continuous with the cerebral aqueduct of the midbrain (posteriorly).

Boundaries

The third ventricle has an anterior wall, a posterior wall, a roof, a floor, and two lateral walls.

Wall	Formed by (listed from above downward)
Anterior wall	(a) Columns of the fornix (b) Anterior commissure (c) Lamina terminalis
Posterior wall	(a) Pineal gland (b) Habenular commissure (c) Posterior commissure, below which lies the commencement of the cerebral aqueduct
Roof	A thin ependymal layer stretching across the upper limits of the two thalami; above it lies the tela choroidea (vascular pia mater) carrying the choroid plexus, and above that the body of the fornix
Floor (before backward)	(a) Optic chiasma (b) Tuber cinereum and infundibulum (c) Mammillary bodies (d) Posterior perforated substance (e) Tegmentum of the midbrain — all of these except the optic chiasma and the tegmentum belong to the interpeduncular fossa

Wall	Formed by (listed from above downward)
Lateral wall (each side)	Marked by the curved hypothalamic sulcus , running from the interventricular foramen to the upper end of the cerebral aqueduct, dividing the wall into a larger upper part (medial surface of the anterior two-thirds of the thalamus) and a smaller lower part (hypothalamus, continuous with the floor); dorsally the wall is limited by a ridge over the stria medullaris thalami

- ▶ The **interventricular foramen** lies on the lateral wall just behind the column of the fornix, separating it from the anterior nucleus of the thalamus.
- ▶ The **lamina terminalis** stretches from the optic chiasma to the rostrum of the corpus callosum and represents the rostral end of the embryonic neural tube; below it lies the cistern of the lamina terminalis (an extension of the interpeduncular cistern) containing the anterior communicating artery.

Recesses (extensions)

Because of these outpouchings the cavity is irregular in outline:

Recess	Site / extent
Optic (chiasmatic) recess	Angular recess at the junction of the anterior wall and the floor, just above the optic chiasma
Infundibular recess	Deep, tunnel-shaped; extends downward through the tuber cinereum into the infundibulum (pituitary stalk)
Anterior recess ("vulva" of the ventricle)	Triangular; lies in front of the interventricular foramen and behind the anterior commissure, between the diverging columns of the fornix
Suprapineal recess	A capacious blind pouch extending posteriorly above the pineal stalk and below the tela choroidea
Pineal (epiphysial) recess	Small diverticulum extending between the superior and inferior laminae of the pineal stalk

Communications

- ▶ **Anteriorly**, on each side: with the corresponding lateral ventricle through the **interventricular foramen of Monro**.
- ▶ **Posteriorly**: continuous with the **cerebral aqueduct of Sylvius**, which in turn opens into the fourth ventricle.
- ▶ Through these two routes the third ventricle is an obligatory relay in CSF flow: lateral ventricles → third ventricle (via foramen of Monro) → cerebral aqueduct → fourth ventricle → median and lateral apertures → subarachnoid space → arachnoid granulations → superior sagittal sinus.

Choroid plexus and blood supply

- ▶ The **tela choroidea** is the vascular pia mater applied to the ependymal roof; it is triangular, with its apex between the two interventricular foramina.
- ▶ The **choroid plexus of the third ventricle** hangs down from the tela choroidea as **two longitudinal (anteroposterior) vascular fringes**, one on each side of the midline; through the interventricular foramen it is continuous with the choroid plexus of each lateral ventricle.
- ▶ **Arterial supply**: the medial and lateral posterior choroidal branches of the **posterior cerebral artery**; these anastomose to a degree with the anterior choroidal branch of the internal carotid artery supplying the adjoining lateral-ventricle plexus.
- ▶ **Venous drainage**: into a rich choroidal venous plexus that empties into the **internal cerebral veins**, which unite to form the great cerebral vein (of Galen) draining into the straight sinus.

Development

- ▶ The third ventricle is the cavity of the **diencephalon**, derived directly from the lumen of the embryonic neural tube/forebrain (prosencephalic) vesicle; it remains continuous rostrally with the lateral ventricles (telencephalic cavities, via the foramina of Monro) and caudally with the aqueduct and fourth ventricle (rhombencephalic cavity).
- ▶ The **roof plate of the diencephalon** consists of a single layer of ependymal cells covered by vascular mesenchyme (pia); this combination gives rise to the **choroid plexus of the third ventricle**.
- ▶ The most caudal part of the same roof plate evaginates to form the **pineal body (epiphysis)**.
- ▶ Radiological correlate: the third ventricle is reported to be larger in infants with trisomy 21 than in controls.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 11.14 — Boundaries and recesses of third ventricle as seen in sagittal section (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.425)

Reproduce a median sagittal outline of the third ventricle and label: interthalamic adhesion (massa intermedia); hypothalamic sulcus; column of fornix and interventricular foramen; anterior commissure; lamina terminalis; optic recess; optic chiasma; infundibular recess/infundibulum; tuber cinereum; mammillary body; posterior perforated substance; tegmentum of midbrain and cerebral aqueduct; habenular commissure; pineal body with pineal recess; suprapineal recess; posterior commissure; and the tela choroidea/choroid plexus in the roof.

Applied / Clinical anatomy

- ▶ **Obstruction**: because the third ventricle is a narrow slit-like space, it is easily obstructed by local tumours or congenital anomalies, producing internal hydrocephalus in children or raised intracranial pressure in adults; the site of block can be localised by ventriculography/imaging.
- ▶ **Colloid cyst of the third ventricle**: a classical lesion sited near the roof/anterior part of the ventricle close to the interventricular foramina; by intermittently obstructing one or both

foramina of Monro (a "ball-valve" effect) it produces episodic, often positional headache with sudden deterioration — a recognised neurosurgical emergency.

- ▶ **Pineal-region tumours** (e.g., germinoma/pinealoma) arising in relation to the posterior wall compress the adjoining cerebral aqueduct, causing obstructive hydrocephalus, and may compress the tectum/superior colliculi to produce **Parinaud syndrome** (paralysis of upward gaze).
- ▶ **Craniopharyngioma**, a tumour arising from Rathke pouch remnants, lies close to the floor/optic-recess region; it compresses the optic chiasma (bitemporal hemianopia) and the hypothalamus (diabetes insipidus, adiposity, temperature-regulation disturbance).
- ▶ **Aqueductal stenosis**, congenital or acquired, obstructs the aqueductal outlet of the third ventricle and is an important cause of hydrocephalus in children.
- ▶ **Anterior communicating artery aneurysms** lie in the cistern of the lamina terminalis immediately below the anterior wall; their rupture may cause intraventricular haemorrhage through the thin lamina terminalis.
- ▶ **Endoscopic third ventriculostomy (ETV)**: the thin floor of the third ventricle, between the infundibular recess and the mammillary bodies, is fenestrated endoscopically to create a new CSF pathway into the interpeduncular cistern, bypassing an obstructed aqueduct.
- ▶ Physiological calcification of the choroid plexus/pineal gland is a common incidental finding on CT and is used as a midline radiological landmark; its shift indicates a space-occupying lesion.

High-yield exam pointers

- ▶ Third ventricle = cavity of the diencephalon; median slit between the two thalami and hypothalami; ependyma-lined.
- ▶ Anterior wall (top→down): fornix columns, anterior commissure, lamina terminalis.
- ▶ Posterior wall (top→down): pineal gland, habenular commissure, posterior commissure/aqueduct.
- ▶ Floor structures all belong to the interpeduncular fossa **except** the optic chiasma and midbrain tegmentum.
- ▶ Five recesses: optic, infundibular, anterior (vulva), suprapineal, pineal.
- ▶ Communicates anteriorly with each lateral ventricle via the foramen of Monro; posteriorly with the fourth ventricle via the cerebral aqueduct.
- ▶ Choroid plexus = two vascular fringes from the tela choroidea, supplied by medial/lateral posterior choroidal branches of the posterior cerebral artery.
- ▶ Develops from the roof plate of the diencephalon, which also gives rise to the pineal body.
- ▶ Clinically vital: colloid cyst → positional headache/foramen-of-Monro block; pineal tumours → Parinaud syndrome; ETV is done through its floor.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Textbook of Anatomy Vol 3 4e; Vishram Singh — Clinical Neuroanatomy 4e; IB Singh — Textbook of Human Neuroanatomy; Snell — Clinical Neuroanatomy 7e.



Describe the ventricles of the brain

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — The ventricles are a series of four interconnected, ependyma-lined cavities within the brain — two **lateral ventricles** (one in each cerebral hemisphere), a median **third ventricle** in the diencephalon, and a median **fourth ventricle** between the pons/medulla and cerebellum — that together form the ventricular system. They are continuous with one another and with the central canal of the spinal cord, are filled with cerebrospinal fluid (CSF), and communicate with the subarachnoid space through defined apertures. Each ventricle bears a **choroid plexus**, the principal site of CSF formation.

General organisation

Cavity	Part of brain it occupies	Shape
Lateral ventricle (paired)	Cerebral hemisphere (telencephalon)	C-shaped, follows the curve of the caudate nucleus
Third ventricle	Diencephalon	Median, slit-like, between the two thalami
Cerebral aqueduct	Midbrain (mesencephalon)	Narrow channel, no choroid plexus
Fourth ventricle	Hindbrain (pons, medulla, cerebellum)	Rhomboid (diamond-shaped)
Central canal	Caudal medulla and spinal cord	Narrow canal, continuous with terminal ventricle

Lateral ventricles

Each lateral ventricle is a **C-shaped cavity** with a central part (**body**) and three horns — **anterior** (frontal), **posterior** (occipital) and **inferior** (temporal) — that meet at the **atrium (trigone)**, the most dilated part of the ventricle, where body, posterior horn and inferior horn converge.

Part	Roof	Floor / lateral wall	Medial wall
Central part (body) — parietal lobe, from interventricular foramen to splenium of corpus callosum	Trunk of corpus callosum	Floor: superior surface of thalamus (medially), caudate nucleus (laterally); stria terminalis and thalamostriate vein lie between them	Septum pellucidum + body of fornix (common to both ventricles)
Anterior horn — frontal lobe, closed anteriorly by genu/rostrum of corpus callosum	Anterior trunk of corpus callosum	Floor: head of caudate nucleus (+ rostrum of corpus callosum medially)	Septum pellucidum
Posterior horn — occipital lobe	Tapetum (fibres from splenium)	Lateral wall: tapetum	Two elevations: bulb (forceps major) above, calcar avis (calcarine sulcus) below
Inferior horn — temporal lobe, up to the uncus	Tapetum + tail of caudate nucleus + stria terminalis (anteriorly related to amygdala)	Floor: hippocampus (covered by alveus , converging medially as the fimbria); collateral eminence laterally	—
Atrium (trigone)	Confluence of body + posterior horn + inferior horn; largest choroid plexus mass here		

Communications — Each lateral ventricle opens into the third ventricle through the **interventricular foramen (of Monro)**, bounded by the **column of the fornix** anteriorly and the **anterior end of the thalamus** posteriorly.

Choroid plexus — Lies in the **choroid fissure** (between fornix above and thalamus/fimbria-hippocampus below), running through the body, atrium and inferior horn; it is **absent from the anterior and posterior horns**. Supply: body/atrium plexus from the **posterior choroidal arteries** (of the posterior cerebral artery), inferior-horn plexus from the **anterior choroidal artery**; the two anastomose in the atrium.

Third ventricle

A median, slit-like cavity of the **diencephalon**, between the two thalami.

Boundary	Structures
Lateral wall (×2)	Above the hypothalamic sulcus — medial surface of thalamus (the two thalami often joined by the interthalamic adhesion / massa intermedia); below the sulcus — medial surface of hypothalamus ; a small posterosuperior part — epithalamus

Boundary	Structures
Anterior wall	Lamina terminalis below; anterior commissure and diverging columns of the fornix above
Posterior wall	Epithalamus — pineal body, posterior commissure, habenular commissure
Floor	Optic chiasma, tuber cinereum, infundibulum, mamillary bodies, posterior perforated substance, midbrain tegmentum
Roof	Ependyma stretched between the two fornices, covered by tela choroidea bearing two vascular fringes — the choroid plexus of the third ventricle

Recesses: optic recess (above optic chiasma), infundibular recess (into the infundibulum), pineal recess and suprapineal recess (around the pineal stalk).

Communications — Anterolaterally with each lateral ventricle via the interventricular foramen; posteriorly continues into the **cerebral aqueduct (of Sylvius)**, which has no choroid plexus, leading to the fourth ventricle.

Choroid plexus — Formed by the **medial and lateral posterior choroidal arteries** (branches of the posterior cerebral artery); continuous through the interventricular foramen with the plexus of the lateral ventricles.

Fourth ventricle

The cavity of the **rhombencephalon**, ventral to the cerebellum and dorsal to the pons and medulla; diamond/tent-shaped.

Floor (rhomboid fossa) — divided by the median sulcus into right and left halves; each half shows a **medial eminence** bounded laterally by the **sulcus limitans**. Lateral to the sulcus limitans lies the **vestibular area**. Key landmarks (rostral to caudal): **locus coeruleus** (deep to it), **facial colliculus** (facial nerve fibres looping around the abducens nucleus), **striae medullares** (junction of pons/medulla), **hypoglossal triangle** and **vagal triangle** (separated by an oblique sulcus from the inferior fovea), **area postrema** (vomiting centre, between the vagal triangle and the gracile tubercle), and the **calamus scriptorius** narrowing to the **obex**.

Roof — tent-shaped: upper part formed by the **superior cerebellar peduncles** and **superior medullary velum**; lower part is membranous (ependyma + pia = **tela choroidea of the fourth ventricle**), pierced in the midline by the **median aperture (foramen of Magendie)**, and prolonged laterally over each **lateral recess** to the two **lateral apertures (foramina of Luschka)**.

Lateral walls — upper part by the **superior cerebellar peduncle**; lower part by the **inferior cerebellar peduncle** with the gracile and cuneate tubercles.

Communications — Superiorly with the cerebral aqueduct; inferiorly with the **central canal** of the medulla/spinal cord; and with the subarachnoid space (cerebellomedullary cistern) via **one median aperture (Magendie)** and **two lateral apertures (Luschka)**.

Recesses — paired **lateral recesses** (between inferior cerebellar peduncle and peduncle of the flocculus, opening at the lateral aperture), **median dorsal recess**, and paired **lateral dorsal recesses**.

Choroid plexus — T-shaped: a vertical limb near the midline (reaching the median aperture) and a horizontal limb in each lateral recess (reaching the lateral aperture, visible near the flocculus); supplied by the **posterior inferior cerebellar artery (PICA)**.

Ventricles of the brain — real plate

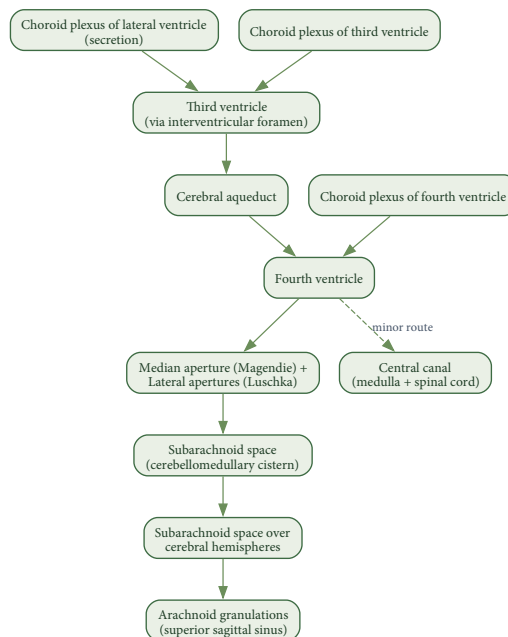
□ Fig 6.14 — *The ventricles of the brain.* (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.169)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a lateral (cast/projection) view of the ventricular system on the outline of the brain, and label:

- ▶ Lateral ventricle — **anterior (frontal) horn**, **body**, **atrium (trigone)**, **posterior (occipital) horn**, **inferior (temporal) horn**
- ▶ **Interventricular foramen (of Monro)**
- ▶ **Third ventricle** (with **optic** and **infundibular recesses**)
- ▶ **Cerebral aqueduct (of Sylvius)**
- ▶ **Fourth ventricle**, with the **lateral recess**, **median aperture (Magendie)** and **lateral aperture (Luschka)** marked
- ▶ **Central canal** of the medulla/spinal cord
- ▶ **Choroid plexus** shaded in each of the lateral, third and fourth ventricles

CSF: formation and circulation



Describe the ventricles of the brain

Feature	Value
Total CSF volume (adult)	~140–270 ml (commonly cited as ~150 ml)
Volume within the ventricles	~25 ml
Rate of production	0.2–0.7 ml/min (≈600–700 ml/day)
Turnover	Entire CSF volume replaced ~4 times/day
Site of production	Choroid plexuses (mainly); a small fraction from ependyma/brain interstitium
Site of absorption	Arachnoid granulations/villi projecting into the superior sagittal sinus
Barrier	Blood–CSF barrier — capillary endothelium + its basement membrane + ependymal basement membrane + choroid ependymal cells (tight junctions)

Applied / Clinical anatomy

- ▶ **Hydrocephalus** — abnormal accumulation of CSF causing ventricular dilatation.
 - **Non-communicating (obstructive)**: block within the ventricular system itself — at the interventricular foramen (unilateral ventricle enlargement), cerebral aqueduct (commonest site; symmetrical dilatation of both lateral + third ventricles), or the median/lateral apertures of the fourth ventricle (dilatation of all four cavities).
 - **Communicating**: CSF reaches the subarachnoid space freely but is not reabsorbed — e.g. meningitis affecting the arachnoid granulations.
- ▶ **Arnold–Chiari malformation** — congenital herniation of the medulla and cerebellar tonsils through the foramen magnum; blocks the apertures of the fourth ventricle, causing internal hydrocephalus; often associated with syringomyelia.
- ▶ **Colloid cyst of the third ventricle** — arises near the roof/interventricular foramen; causes intermittent, posture-related obstruction of both foramina with sudden severe headache.
- ▶ **Choroid plexus tumours (papilloma/medulloblastoma near the roof of the fourth ventricle)** — obstruct the median/lateral apertures, producing hydrocephalus.
- ▶ **Area postrema** in the floor of the fourth ventricle lies outside the blood–brain barrier and is the chemoreceptor trigger zone for vomiting.
- ▶ **Facial colliculus** — surgical landmark on the floor of the fourth ventricle; injury during floor surgery risks the abducens nucleus and the internal genu of the facial nerve.
- ▶ **Papilloedema** — raised CSF pressure transmitted along the optic nerve's subarachnoid extension causes disc swelling; a key sign of raised intracranial tension from ventricular obstruction.
- ▶ **Lumbar puncture / cisternal puncture** — used to sample CSF for diagnosis; contraindicated when a mass obstructs CSF flow (risk of coning/herniation).
- ▶ **Imaging correlation** — CT/MRI ventriculography is the standard method to localise the level of obstruction in hydrocephalus (dilated ventricles proximal to the block, normal-sized ones distal to it).

High-yield exam pointers

- ▶ Four ventricles: two lateral (telencephalon), one third (diencephalon), one fourth (rhombencephalon) — connected by the interventricular foramina and the cerebral aqueduct.
- ▶ Lateral ventricle = C-shaped: anterior, posterior, inferior horns + body, meeting at the atrium; choroid plexus present only in body, atrium and inferior horn (absent in both horns' terminal parts — anterior and posterior horns).
- ▶ Interventricular foramen (Monro) bounded by column of fornix (anterior) and anterior thalamus (posterior).
- ▶ Third ventricle boundaries: lamina terminalis (anterior), epithalamus/pineal (posterior), thalamus + hypothalamus (lateral walls, divided by hypothalamic sulcus), optic chiasma/tuber cinereum/mamillary bodies (floor).
- ▶ Fourth ventricle floor = rhomboid fossa; facial colliculus, striae medullares, hypoglossal/vagal triangles and area postrema are must-know landmarks.
- ▶ Fourth ventricle communicates with subarachnoid space via one median (Magendie) + two lateral (Luschka) apertures.
- ▶ CSF pathway: lateral ventricle → interventricular foramen → third ventricle → cerebral aqueduct → fourth ventricle → median/lateral apertures → subarachnoid space → arachnoid granulations → superior sagittal sinus.
- ▶ Aqueductal obstruction is the commonest cause of congenital non-communicating hydrocephalus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; Snell — Clinical Neuroanatomy 7e; Vishram Singh — Clinical Neuroanatomy 4e; BD Chaurasia — Human Anatomy Vol 3–4 8e.



Cerebrospinal Fluid: Formation, Circulation, Biochemistry and Clinical Significance

Asked in: Paper IV Oct 2008 — RGUHS MD/MS Anatomy

Definition / Introduction Cerebrospinal fluid (CSF) is a clear, colourless, watery fluid that fills the ventricular system of the brain and the subarachnoid space surrounding the brain and spinal cord. It is not a simple ultrafiltrate of plasma but is actively secreted, chiefly by the choroid plexuses, and continuously circulated and reabsorbed into the venous system. CSF provides mechanical protection, chemical homeostasis and a route for intercellular signalling within the CNS, and its examination (lumbar puncture) is one of the commonest diagnostic procedures in neurology. A sound grasp of its formation, circulation, composition and the anatomical basis of its disorders (hydrocephalus, CSF leaks, raised ICP) is essential PG-level anatomy.

1. Anatomical basis — ventricular system and choroid plexus

- ▶ CSF occupies two continuous compartments: the **ventricular system** (paired lateral ventricles → third ventricle → cerebral aqueduct → fourth ventricle → central canal) and the **subarachnoid space** around the brain and spinal cord.
- ▶ The **choroid plexus**, the principal CSF-forming structure, forms where pia mater and its capillary tuft (tela choroidea) invaginate the ependymal roof/wall of a ventricle, producing a folded, villous mass covered by modified ependymal (choroidal) epithelium.
- ▶ Present at four sites: **body/atrium of each lateral ventricle** (largest, continuous through the interventricular foramen), **roof of the third ventricle**, and **roof of the fourth ventricle** (T-shaped, limbs reaching the foramina of Luschka).
- ▶ Blood supply: lateral/third-ventricle plexuses — **anterior choroidal artery** (internal carotid) and **posterior choroidal branches** (posterior cerebral artery); fourth-ventricle plexus — **inferior cerebellar arteries** (AICA/PICA).
- ▶ CSF also pools in the **subarachnoid cisterns**: cerebellomedullary cistern (cisterna magna — largest), pontine cistern, interpeduncular/basal cistern (commonest site of subarachnoid haemorrhage), chiasmatic cistern, cisterna ambiens.

2. Formation of CSF

- ▶ **Site**: 80–90% is formed by the choroid plexuses of the **lateral ventricles**, the rest by the third- and fourth-ventricle plexuses; a small extra contribution comes from the ependyma and brain extracellular fluid via perivascular (Virchow–Robin) spaces.
- ▶ **Mechanism**: choroidal epithelial cells (microvillous, tight-junctioned) actively secrete CSF — an **energy-dependent process** (not simple filtration/dialysis), driven by ionic pumps (chiefly Na^+/K^+ -ATPase) that set up a small pressure gradient. This same epithelium constitutes the **blood–CSF barrier**.
- ▶ CSF **production is not pressure-regulated** — secretion continues even if the outflow/absorption pathway is obstructed, which underlies ventricular distension in hydrocephalus.
- ▶ **Rate and volume**: produced at ~0.3–0.5 mL/min (~500 mL/day). Total adult volume ~150 mL (Gray's cites a wider 140–270 mL range), of which only **25–30 mL is intraventricular**, the rest

subarachnoid/spinal. This gives a turnover time of ~5 hours, i.e. the whole pool is renewed 3–4 times/day.

3. Circulation and absorption of CSF

- ▶ **Pathway** (see diagram box below for the full labelled sequence): lateral ventricle → interventricular foramen (Monro) → third ventricle → cerebral aqueduct → fourth ventricle → median aperture (Magendie)/lateral apertures (Luschka) → cerebellomedullary and pontine cisterns → up through the tentorial notch over the cerebral hemispheres to the **arachnoid villi/granulations** in the **superior sagittal sinus** (a smaller stream descends around the cord/cauda equina into the lumbar cistern).
- ▶ **Absorption** is mainly through arachnoid villi, which act as **one-way valves**: CSF enters the sinus when CSF pressure exceeds venous pressure, while villous compression prevents backflow of blood when venous pressure rises. A minor amount is absorbed via pial veins and perineural lymphatics of nerve roots.
- ▶ **Aids to flow**: pulsations of choroidal and subarachnoid arteries, ciliary beating of ependyma, and movements of head, spine and respiration.

Real plate — Circulation of CSF

 Fig 15.17 — Circulation of cerebrospinal fluid (IB Singh — Textbook of Human Neuroanatomy, p.250)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a flow diagram of CSF circulation with these exact labelled steps, in sequence:

- ▶ Lateral ventricle (choroid plexus) — right and left
- ▶ Interventricular foramen (of Monro)
- ▶ Third ventricle (choroid plexus)
- ▶ Cerebral aqueduct (of Sylvius)
- ▶ Fourth ventricle (choroid plexus)
- ▶ Median aperture (foramen of Magendie) + paired lateral apertures (foramina of Luschka)
- ▶ Cerebellomedullary cistern / pontine cistern
- ▶ Ascent through tentorial notch → subarachnoid space over cerebral hemispheres (also: descent around spinal cord/cauda equina → lumbar cistern)
- ▶ Arachnoid villi / arachnoid granulations
- ▶ Superior sagittal sinus → confluence of sinuses → transverse/sigmoid sinus → internal jugular vein

4. Biochemistry / composition of CSF

- ▶ **Physical characters**: clear, colourless, slightly alkaline fluid; specific gravity 1.003–1.008; virtually cell-free — normal cell count 0–3 (up to 5) lymphocytes/mm³.
- ▶ **Composition compared with plasma** (values collated from Snell, Vishram Singh and IB Singh — minor numerical variation exists between textbook editions and is given here as ranges):

Parameter	CSF	Blood plasma
Protein	15–45 mg/dL (mainly albumin; much lower than plasma)	~600–700 mg/dL
Glucose	40–85 mg/dL (about half to two-thirds of blood glucose)	~100 mg/dL
Chloride	120–130 mEq/L (slightly higher than plasma)	~100 mEq/L
Calcium	~2.5 mEq/L (lower than plasma)	~4.5 mEq/L
Cells	0–3 lymphocytes/mm ³	—

- ▶ **Pressure:** by lumbar spinal tap in the lateral recumbent position, normal CSF pressure is **60–150 mm of water** (supine 50–200 mm H₂O, rising to 200–250 mm H₂O sitting). Raised by straining, coughing, or jugular compression (basis of Queckenstedt's test).
- ▶ **Blood–CSF barrier:** choroidal capillary endothelium (fenestrated) + its basement membrane + choroidal epithelium (modified ependyma) joined by apical tight junctions — permits largely one-way, selective passage of substances from blood to CSF.
- ▶ **Clinical correlate:** antibodies/most protein-bound drugs cannot cross the intact barrier, so **CNS infections are often severe and antibiotic choice is limited**. Conversely, there is **no CSF–brain barrier** — an intrathecal drug diffuses freely into brain extracellular space, the rationale for intrathecal chemotherapy/anaesthesia and antibiotics in resistant meningitis.

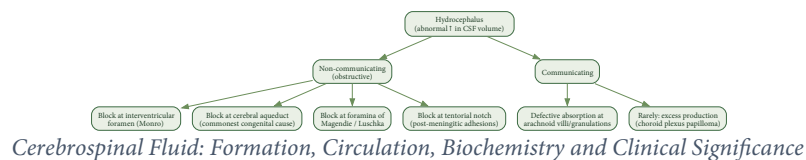
5. Functions of CSF

- ▶ **Mechanical protection** — fluid cushion/shock absorber between CNS and surrounding bone; brain and CSF share similar specific gravity so the brain effectively "floats," its net weight falling from ~1500 g in air to ~50 g in CSF.
- ▶ **Buoyancy/support**, maintaining uniform pressure on neural structures, and **volume-pressure buffering** (Monro–Kellie relationship — CSF drainage adjusts to changes in cerebral blood volume).
- ▶ **Nutritive role and removal of metabolites** from the CNS; a stable chemical/homeostatic medium for the brain's extracellular environment.
- ▶ **Pathway for neurohumoral signalling** — e.g. pineal secretions are thought to reach the pituitary via third-ventricle CSF.

Applied / Clinical anatomy

- ▶ **CSF withdrawal:** *Lumbar puncture* (commonest) — needle in the midline between L3–L4 or L4–L5 spinous processes (back flexed, sitting or left lateral position); safe because the adult spinal cord ends at the **lower border of L1** (L3 in a newborn), so at/below L3–L4 the needle traverses only the roomy, cord-free **lumbar cistern** (cauda equina + filum terminale). *Cisternal puncture* — into the cerebellomedullary cistern through the posterior atlanto-occipital membrane, when lumbar puncture is difficult (e.g. young child). *Ventricular puncture* — direct lateral-ventricle access via the fontanelle in infants.

- ▶ **Queckenstedt's sign:** jugular compression raises cerebral venous pressure and normally produces a prompt manometric CSF pressure rise; failure of this rise (**positive test**) indicates a spinal subarachnoid block.
- ▶ **Hydrocephalus** — abnormal CSF accumulation from excessive production (rare; choroid plexus tumour), circulatory obstruction (commonest cause overall) or defective absorption at arachnoid villi (e.g. post-meningitic). **Non-communicating (obstructive):** block within the ventricular system; **aqueductal stenosis is the commonest cause of congenital hydrocephalus** (Monro block → one/both lateral ventricles; aqueductal block → lateral + third ventricles; Magendie/Luschka block → all four ventricles). **Communicating:** free flow into subarachnoid space but defective absorption, usually post-meningitic arachnoid-villi blockage; age-related granulation degeneration underlies **normal-pressure hydrocephalus**. Infant features: disproportionate head enlargement, frontal bossing, separated sutures, tense fontanelle, dilated scalp veins, "setting-sun" eyes, "cracked-pot" percussion note.



- ▶ **Papilloedema:** the subarachnoid space extends around the optic nerve to the back of the eyeball; raised CSF pressure transmitted along this sleeve compresses the thin-walled retinal vein, causing venous congestion and disc oedema — characteristically **bilateral**.
- ▶ **Froin's syndrome:** below a complete spinal block, trapped CSF shows markedly raised protein (spontaneous coagulation), xanthochromia, and a non-rising Queckenstedt response.
- ▶ **CSF fistulae:** cribriform plate (ethmoid) fracture → **CSF rhinorrhoea** (often with anosmia); petrous temporal bone fracture with torn tympanic membrane → **CSF otorrhoea**. Both risk ascending meningitis.
- ▶ **CSF changes in disease:** bacterial meningitis — turbid, high protein, low glucose, neutrophilic pleocytosis; TB/viral meningitis — clear, lymphocytic, glucose usually preserved in viral disease; subarachnoid haemorrhage — blood-stained, later xanthochromic; multiple sclerosis — raised gamma-globulin.
- ▶ **Recent advance (beyond core anatomy texts):** the **glymphatic system** — perivascular CSF–interstitial exchange via astrocytic aquaporin-4 channels, proposed to clear neuronal metabolic waste (amyloid- β clearance/neurodegeneration research) — an evolving concept offered as awareness, not yet in standard gross-anatomy texts.

High-yield exam pointers

- ▶ CSF is **actively secreted** (not filtered) by choroid plexus epithelium; production is **not pressure-autoregulated**.
- ▶ 80–90% formed in **lateral ventricles**; total volume ~150 mL, ~25–30 mL intraventricular; produced ~500 mL/day; turnover ~5 hours.
- ▶ Pathway: lateral ventricle → foramen of Monro → 3rd ventricle → aqueduct of Sylvius → 4th ventricle → foramina of Magendie/Luschka → subarachnoid cisterns → arachnoid villi → superior sagittal sinus.

- ▶ CSF vs plasma: **low protein**, **~half glucose**, **higher chloride**, **lower calcium**; specific gravity 1.003–1.008; 0–3 lymphocytes/mm³.
- ▶ Normal lumbar CSF pressure (lateral recumbent): **60–150 mm H₂O**.
- ▶ Blood–CSF barrier present (no antibodies in CSF → serious CNS infections); **no CSF–brain barrier** (basis of intrathecal therapy).
- ▶ Aqueductal stenosis = commonest cause of congenital (non-communicating) hydrocephalus; arachnoid villi blockage after meningitis = commonest cause of communicating hydrocephalus.
- ▶ Lumbar puncture site: L3–L4/L4–L5 (adult cord ends at lower border of L1; L3 in a newborn — go lower in children).
- ▶ Cribriform plate fracture → CSF rhinorrhoea; petrous temporal fracture → CSF otorrhoea.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; Vishram Singh Textbook of Anatomy Vol. 3 (4e — lumbar puncture level, lumbar cistern volume); BD Chaurasia Human Anatomy Vol 3–4 (8e — cisterns, blood–CSF/CSF–brain barrier points); AK Datta Human Anatomy Vol 2 (Head & Neck — CSF rhinorrhoea via cribriform plate fracture). Coverage note: Gray's 41e (Ch. 18, Ventricular system and subarachnoid space) covers formation, circulation and absorption in detail but is thin on a numerical biochemistry/composition table; those figures were drawn from Snell, Vishram Singh and IB Singh, whose editions show minor numerical variation (reported here as ranges) — this is normal cross-textbook variability, not a factual conflict.



IV Ventricle

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction — The **fourth ventricle** is the CSF-filled cavity of the hindbrain, lying **dorsal to the pons and the rostral (open) half of the medulla oblongata** and **ventral to the cerebellum**, in the posterior cranial fossa. In sagittal section it is **tent-shaped**, and in horizontal section it is **rhomboidal (diamond/lozenge-shaped)** — hence its floor is called the **rhomboid fossa**. It is continuous rostrally with the **cerebral aqueduct** of the midbrain and caudally with the **central canal** of the medulla and spinal cord, and it communicates with the subarachnoid space through three apertures in its roof. Its floor is one of the most clinically important surfaces in neuroanatomy, carrying the nuclei of cranial nerves V–XII and the vital cardiorespiratory centres.

1. Situation, shape and extent

- ▶ Occupies the posterior cranial fossa between the pons/medulla in front and the cerebellum behind; it is **widest at the pontomedullary junction**, where a **lateral recess** on each side extends to the lateral border of the brainstem.
- ▶ Lined throughout by **ependyma**; possesses two **lateral boundaries**, a **floor**, a **roof**, **four angles** and **five recesses**.

- Communicates **rostrally** with the third ventricle via the cerebral aqueduct and **caudally** with the spinal subarachnoid space via the central canal.

2. Lateral boundaries

- **Superolaterally** — the two **superior cerebellar peduncles**, converging as they pass toward the inferior colliculi.
- **Inferolaterally** — the **gracile and cuneate tubercles** (overlying the dorsal column nuclei) together with the **inferior cerebellar peduncles**.

3. Floor — rhomboid fossa (*calamus scriptorius*)

- Formed by the **dorsal surface of the closed (lower) pons** (upper triangular part) and the **dorsal surface of the open (upper) medulla** (lower triangular part), joined at the pontomedullary junction by an **intermediate part** that is prolonged laterally over the inferior cerebellar peduncle to form the floor of the lateral recess; this strip carries transverse fibre bundles, the **striae medullares**, running from the arcuate nucleus to the opposite cerebellum.
- Structural layers, superficial to deep: **ependyma** → **subependymal neuroglia** → **grey matter** containing the cranial nerve nuclei.
- A **median sulcus** splits the floor into symmetrical halves; each half is further divided by the **sulcus limitans** into a medial **medial eminence** and a lateral **vestibular area** (overlying the vestibular nuclear complex; partly pontine, partly medullary).
- The sulcus limitans widens above into the **superior fovea** and below into the **inferior fovea**. Just cranial to the superior fovea a bluish-grey patch, the **locus coeruleus**, marks pigmented noradrenergic neurons of the **substantia ferruginea** (reticular formation; implicated in paradoxical/REM sleep).
- Opposite the superior fovea, the medial eminence bears the **facial colliculus**, produced by the **internal genu of the facial nerve** looping around the underlying **abducens nucleus**.
- From the inferior fovea an oblique groove runs to the median sulcus, dividing the medullary medial eminence into the **hypoglossal triangle** (medial, over the hypoglossal nucleus) and the **vagal triangle** (lateral, over the dorsal motor nucleus of the vagus).
- The **funiculus separans**, a narrow ependymal ridge, crosses below the vagal triangle and is separated from the **gracile tubercle** by the small **area postrema** — a chemoreceptor patch that lacks a blood–brain barrier.
- The inferolateral margins of the floor are marked by the **taenia**; the two taeniae meet inferiorly at the **obex**. The tapering lowest part of the floor resembles a pen-nib — the **calamus scriptorius**.

Surface landmark	Structure/nucleus deep to it
Facial colliculus	Abducens nucleus (VI) + looping facial (VII) fibres
Locus coeruleus	Noradrenergic nucleus (substantia ferruginea)
Vestibular area	Vestibular nuclear complex (VIII)
Hypoglossal triangle	Hypoglossal nucleus (XII)
Vagal triangle	Dorsal motor nucleus of vagus (X)

Surface landmark	Structure/nucleus deep to it
Area postrema	Chemoreceptor trigger zone — no blood–brain barrier
Striae medullares	Arcuate-nucleus fibres to opposite cerebellum

□ Fig 10.16 — The rhomboid fossa or floor of the fourth ventricle. (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.386)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Posterior view of the brainstem with the cerebellum removed, showing the floor of the fourth ventricle. Label: **superior cerebellar peduncle** and **inferior cerebellar peduncle** (lateral boundaries) — **median sulcus** — **sulcus limitans** with **superior fovea** and **inferior fovea** — **facial colliculus** and **locus coeruleus** on the **medial eminence** — **vestibular area** — **hypoglossal triangle** and **vagal triangle** — **striae medullares** — **funiculus separans** and **area postrema** — **gracile tubercle / cuneate tubercle** — **taenia converging** at the **obex**.

4. Roof

- ▶ **Diamond-shaped**, divisible into superior and inferior parts, its apex projecting into the white core of the cerebellum.
- ▶ **Superior part** — the two converging **superior cerebellar peduncles** together with the **superior medullary velum**, a thin nervous sheet stretched between them and covered dorsally by the **lingula** of the superior vermis.
- ▶ **Inferior part** — largely an exceedingly thin sheet devoid of nervous tissue, formed by ventricular **ependyma** and the **tela choroidea** (a double fold of pia mater); the **inferior medullary velum** forms a small part of the roof lateral to the cerebellar nodule.
- ▶ Just caudal to the nodule, the continuity of this thin sheet is broken by the **median aperture (foramen of Magendie)**, opening the ventricle into the **cerebellomedullary cistern (cisterna magna)**.
- ▶ *Developmental note:* the foramen of Magendie forms when a transient membranous structure, **Blake's pouch**, perforates into the fourth ventricle at about the **9th fetal week**; persistence of this membrane causes cystic obstruction of the median outlet.

5. Angles, recesses and communications

- ▶ **Four angles:** a **superior angle**, continuous with the cerebral aqueduct; an **inferior angle**, continuous with the central canal (marked by the obex); and two **lateral angles**, one toward each inferior cerebellar peduncle.
- ▶ **Five recesses:** paired **lateral recesses** (between the inferior cerebellar peduncle ventrally and the peduncle of the flocculus dorsally, reaching the medial part of the flocculus); a single **median dorsal recess** (extending dorsally into the white core of the cerebellum, above the nodule); and paired **lateral dorsal recesses** (one on each side of the median dorsal recess, cranial to the inferior medullary velum).
- ▶ **Communications:** superiorly with the cerebral aqueduct, inferiorly with the central canal, and — through the roof — with the subarachnoid space via the single **median aperture (foramen of**

Magendie) and the paired **lateral apertures (foramina of Luschka)**, the latter situated at the ends of the lateral recesses, partly occupied by protruding choroid plexus.

6. Tela choroidea, choroid plexus and CSF circulation

- ▶ The **tela choroidea** is a double layer of pia mater occupying the interval between the cerebellum and the lower ventricular roof; its posterior layer covers the inferior vermis and, on reaching the nodule, is reflected forward into direct contact with the ependyma.
- ▶ The **choroid plexus** of the fourth ventricle is **T-shaped**: paired **vertical limbs** flank the midline and reach the median aperture (projecting through it into the subarachnoid space), while paired **horizontal limbs** extend into the lateral recesses and reach the lateral apertures. It is supplied by the **posterior inferior cerebellar arteries**; its mean thickness in children is about **2.5 mm**.
- ▶ **CSF circulation**: lateral ventricles → **interventricular foramen (of Monro)** → third ventricle → **cerebral aqueduct** → fourth ventricle → **foramen of Magendie** (single, median) and **foramina of Luschka** (paired, lateral) → cisterna magna/subarachnoid space → **arachnoid granulations** → superior sagittal sinus, completing the outflow of "used" CSF.

Recent advances

- ▶ **Rhomboid-fossa morphometry for safe brainstem surgery**: a 45-brainstem cadaveric study measured the rhomboid fossa ($\approx 34.7 \times 22.6$ mm) and facial colliculus (≈ 4.3 mm), refining the supra-/infra-facial "safe-entry" triangles used to approach intrinsic brainstem lesions through the ventricular floor without damaging cranial nerve nuclei (Erturk et al, *World Neurosurgery* 2024) [PMID 39181240].
- ▶ **Molecular subgrouping of posterior-fossa ependymoma**: a 412-case series confirms that ependymomas of the fourth-ventricular floor/roof stratify into prognostically distinct **PFA** (poorer outcome, needs adjuvant radiotherapy) and **PFB** (favourable, surgery often curative) methylation subgroups, now built into WHO CNS5 grading (Wang et al, *Neurosurgery* 2024) [PMID 38529997].
- ▶ **Prenatal differentiation of Blake's pouch cyst from Dandy-Walker malformation**: refined fetal MRI criteria now better distinguish the benign **Blake's pouch cyst** (normal vermis, a transient posterior outpouching) from true **Dandy-Walker malformation** (vermian hypoplasia with posterior-fossa enlargement), improving prenatal counselling (Pomar et al, *Ultrasound Obstet Gynecol* 2025) [DOI 10.1002/uog.29239].
- ▶ **Far-lateral safe-entry zones near the obex**: cadaveric mapping of safe-entry corridors around the obex/calamus-scriptorius region now complements the standard telovelar exposure for far-lateral approaches to lower-brainstem lesions (Cavalcanti et al, *Neurosurgical Review* 2026) [DOI 10.1007/s10143-026-04171-7].

(According to PubMed/journal indexing.)

Applied / Clinical anatomy

- ▶ **Vital centres**: respiratory, cardiovascular and vasomotor centres lie in the floor near the vagal triangle; injury here — classically the dens of a fractured atlas striking the floor, as in judicial hanging — is rapidly fatal.

- ▶ **Area postrema:** the chemoreceptor trigger zone for vomiting, stimulated by circulating emetics as it lacks a blood–brain barrier; with the solitary and dorsal vagal nuclei it forms the "dorsal vagal complex".
- ▶ **Obstructive (non-communicating) hydrocephalus:** blockage of the Magendie/Luschka apertures by tumour or post-meningitic exudate dilates the whole ventricular system, with early rise in intracranial pressure — headache, vomiting, papilloedema; contrast **communicating hydrocephalus**, where CSF reaches the subarachnoid space freely but reabsorption at the arachnoid granulations fails.
- ▶ **Medulloblastoma:** commonest tumour here, from primitive neuroectodermal cells of the cerebellar vermis, mostly in children; highly malignant, it gives cerebellar signs or compresses the floor centres, causing cardiac irregularities, tachycardia and irregular respiration.
- ▶ **Ependymoma:** arises from ependymal cells lining the ventricle; may invade the cerebellum and narrow the cavity (see Recent advances — PFA/PFB subgroups).
- ▶ **Arnold–Chiari malformation:** downward herniation of medulla and cerebellar tonsils through the foramen magnum obstructs CSF outflow through the roof apertures, producing hydrocephalus.
- ▶ **Dandy–Walker syndrome:** hydrocephalus from blockage of the median/lateral apertures, with predominant posterior-fossa enlargement and an abnormal cerebellum.
- ▶ **Cisternal (suboccipital) puncture:** CSF can be sampled from the cisterna magna through the posterior atlanto-occipital membrane, an alternative when lumbar puncture is unsuitable.

High-yield exam pointers

- ▶ Fourth ventricle = cavity of the hindbrain; **tent-shaped** in sagittal section, **rhomboidal** in horizontal section; between the cerebral aqueduct above and the central canal below.
- ▶ Lateral boundaries: **superior cerebellar peduncle** (above) + **gracile/cuneate tubercles and inferior cerebellar peduncle** (below).
- ▶ Floor = **rhomboid fossa:** median sulcus + sulcus limitans define the **facial colliculus (VI/VII)**, **vestibular area (VIII)**, **hypoglossal (XII)** and **vagal (X)** triangles, **locus coeruleus** and **area postrema** (no BBB).
- ▶ Roof: **superior medullary velum + superior cerebellar peduncles** above; **inferior medullary velum + tela choroidea** below, pierced by the **foramen of Magendie** (via Blake's pouch, week 9).
- ▶ **3 openings** into the subarachnoid space (1 median foramen of Magendie + 2 lateral foramina of Luschka); **5 recesses** (2 lateral, 1 median dorsal, 2 lateral dorsal); **4 angles**.
- ▶ Choroid plexus is **T-shaped**, supplied by the **posterior inferior cerebellar arteries**.
- ▶ **Obex** = fusion of the two taeniae at the inferior angle; **calamus scriptorius** = pen-nib-shaped lowest part of the floor.
- ▶ Clinically: vital-centre injury near the vagal triangle is fatal; area postrema drives vomiting (CTZ); medulloblastoma and ependymoma are the classic space-occupying lesions; blocked apertures cause non-communicating hydrocephalus (Arnold–Chiari, Dandy–Walker).

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; BD Chaurasia Human Anatomy Vol 3-4 8e; Vishram Singh Clinical Neuroanatomy 4e; Snell Clinical Neuroanatomy 7e; IB Singh Human Embryology (CBME 2021).



Lateral ventricle

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction The lateral ventricles are a pair of C-shaped, CSF-filled cavities, one within each cerebral hemisphere, derived from the lumen of the embryonic telencephalic vesicles. Each is customarily divided into an anterior (frontal), a central part or body, an atrium (trigone), a posterior (occipital) horn and an inferior (temporal) horn. Each lateral ventricle communicates with the third ventricle through the interventricular foramen (of Monro) and is the principal site of CSF production via its choroid plexus. Its C-shaped profile mirrors the growth of the caudate nucleus and fornix, which follow the same curvature as the expanding hemisphere.

1. Parts and boundaries

Part	Extent	Roof	Floor / medial relations	Distinguishing feature
Anterior (frontal) horn	Frontal lobe; from genu/rostrum of corpus callosum in front to the interventricular foramen behind	Trunk (genu) of corpus callosum	Head of caudate nucleus (bulk of floor); rostrum of corpus callosum near the midline	Medial wall = septum pellucidum (common to both ventricles); no choroid plexus here
Central part (body)	Parietal lobe; interventricular foramen to splenium of corpus callosum	Trunk of corpus callosum	Superior surface of thalamus medially, body of caudate nucleus laterally, separated by the groove carrying the stria terminalis and thalamostriate vein	Medial wall = septum pellucidum + body of fornix; choroid fissure (between fornix and thalamus) transmits the choroid plexus
Atrium (trigone)	Parieto-occipital region; confluence of body, posterior and inferior horns	—	Collateral trigone	Most dilated part; choroid plexus here is largest (glomus)

Part	Extent	Roof	Floor / medial relations	Distinguishing feature
Posterior (occipital) horn	Occipital lobe	Tapetum of corpus callosum	Medial wall shows two elevations: bulb (forceps major fibres) above, calcar avis (calcarine sulcus) below	Tapetum forms both roof and lateral wall; asymmetry between the two sides is common
Inferior (temporal) horn	Largest compartment; curves around the pulvinar of thalamus into the temporal lobe, ending ~2.5 cm from the temporal pole near the uncus	Tapetum + tail of caudate nucleus + stria terminalis (both end at the amygdala anteriorly)	Floor = hippocampus (covered by the white-matter sheet, the alveus , converging medially as the fimbria) + collateral eminence laterally	Choroid fissure lies here between fimbria and stria terminalis; overlies the hippocampus

2. Communications

- ▶ Each lateral ventricle opens into the third ventricle through the **interventricular foramen of Monro**, bounded by the **column of the fornix anteriorly** and the **anterior end of the thalamus posteriorly**.
- ▶ The two lateral ventricles do not communicate directly with each other; they are linked only indirectly through the midline third ventricle.
- ▶ Through the foramen, the choroid plexus of one lateral ventricle is continuous across the roof of the third ventricle with that of the opposite side.

3. Choroid plexus of the lateral ventricle

- ▶ Formed where the vascular pia mater (tela choroidea) is invaginated into the ventricle along the **choroid fissure** — the C-shaped gap between the fornix (above) and the thalamus (below) in the body, and between the fimbria (below) and stria terminalis/tail of caudate (above) in the inferior horn.
- ▶ **Extent:** runs from the interventricular foramen, through the body, curves around the thalamus (pulvinar) into the inferior horn as far as the hippocampus; **absent in the anterior and posterior horns**.
- ▶ **Arterial supply:**
 - Choroid plexus of the **body and atrium** — medial and lateral **posterior choroidal arteries** (branches of the posterior cerebral artery), continuing anteriorly from the third-ventricle plexus through the upper choroid fissure.
 - Choroid plexus of the **inferior horn** — **anterior choroidal artery** (branch of the internal carotid artery), entering through the lower part of the choroid fissure.
 - In the atrium, the two supplies anastomose, forming the **glomus choroideum**.

- ▶ Structurally the plexus is a tuft of fenestrated capillaries covered by cuboidal choroid epithelium (modified ependyma) resting on a basement membrane — the anatomical basis of the blood–CSF barrier.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

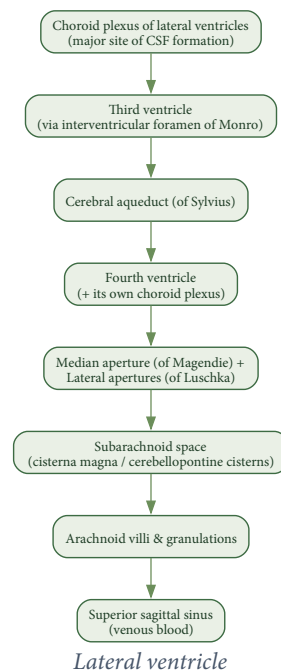
□ Fig 24.2 — Parts of the lateral ventricle (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.440)

Reproduce the C-shaped ventricle in lateral view and label: **anterior (frontal) horn**, **body (central part)**, **atrium/trigone**, **posterior (occipital) horn**, **inferior (temporal) horn**, **interventricular foramen (of Monro)**. On a supplementary coronal section through the body, additionally label: **corpus callosum (roof)**, **septum pellucidum**, **body of fornix**, **choroid plexus**, **thalamus**, **head/tail of caudate nucleus**, **stria terminalis**, **thalamostriate vein**, **hippocampus (in the inferior horn)**, **amygdala**.

4. Development

- ▶ The lateral ventricles are the cavities of the **telencephalic vesicles**, the paired lateral outpocketings of the prosencephalon that appear in the fifth week of development.
- ▶ Each telencephalic cavity communicates with the diencephalic cavity (future third ventricle) through the **interventricular foramen of Monro**.
- ▶ The floor of the hemisphere bulges into the ventricular lumen from the fifth–sixth week as the rapidly proliferating, striated **corpus striatum** (future caudate + lentiform nuclei).
- ▶ Where the thin hemisphere wall abuts the roof of the diencephalon, neuroblasts fail to develop; here a single layer of ependyma covered by vascular mesenchyme invaginates along the choroid fissure to form the **choroid plexus** of each lateral ventricle.
- ▶ Immediately above the choroid fissure, the hemisphere wall thickens to form the **hippocampus**; with differential growth of the frontal, parietal, occipital and temporal poles, the hemisphere — and with it the caudate nucleus, fornix and ventricle — assumes the definitive **C-shaped** configuration, producing the anterior, posterior and inferior horns.
- ▶ Failure of the midline structures to develop (e.g. absence of the septum pellucidum, or agenesis of the corpus callosum) is reflected in ventricular anomalies such as a persistent **cavum septum pellucidum** or "bat-wing" ventricles.

5. CSF formation and circulation



- **Volume/production:** total CSF $\approx$ 140 mL, of which $\approx$ 25 mL lies within the ventricles; $\approx$ 500 mL is produced per day (complete turnover several times daily); about 80–90% is produced by the lateral-ventricle plexuses.
- **Pressure** (lumbar subarachnoid space): 50–200 mm H₂O supine; 200–250 mm H₂O sitting.
- **Composition** (vs plasma): protein 20–40 mg% (vs $\approx$ 600 mg%), glucose 40–60 mg% (vs $\approx$ 100 mg%), chloride 120 mEq/L (vs 100 mEq/L), calcium 2.5 mEq/L (vs 4.5 mEq/L) — low protein, high chloride relative to plasma.
- **Blood–CSF barrier:** capillary endothelium $\rightarrow$ its basement membrane $\rightarrow$ basement membrane of choroid plexus $\rightarrow$ choroid plexus cells (tight junctions), permitting selective, one-way passage from blood to CSF.

Applied / Clinical anatomy

- **Hydrocephalus:** obstruction at the interventricular foramen dilates one (unilateral block) or both (bilateral block) lateral ventricles; obstruction of the aqueduct dilates both lateral ventricles plus the third ventricle; obstruction/atresia of the fourth-ventricle apertures dilates the entire ventricular system. Defective CSF absorption at the arachnoid granulations produces communicating hydrocephalus without ventricular obstruction.
- **Colloid cyst of the third ventricle,** sitting at the roof near the foramen of Monro, may intermittently block one or both foramina, causing positional headache with sudden loss of consciousness ("drop attacks").
- **Choroid plexus tumours** (papilloma, rarely carcinoma) most often arise in the atrium in children, presenting with hydrocephalus from CSF overproduction/obstruction; meningiomas of the trigone arise from the tela choroidea/stroma of the choroid plexus in adults.

- ▶ **Intraventricular haemorrhage:** in preterm neonates, haemorrhage from the fragile subependymal germinal matrix (near the caudate head, floor of the frontal horn) may rupture into the lateral ventricle.
- ▶ **Ventricular access:** the frontal horn is the standard, anatomically consistent target for a ventricular catheter (external ventricular drain / ventriculo-peritoneal shunt) because of its constant relation to the head of caudate nucleus and its safe distance from the choroid plexus and major veins.
- ▶ **Imaging:** the C-shaped ventricle is well shown on sagittal MRI (Fig. 18.3, Gray's Anatomy) with the atrium as the widest point; asymmetry of the atria/occipital horns (colpocephaly) is a recognised normal variant but exaggerated asymmetry may indicate mass effect or dysgenesis of the corpus callosum.
- ▶ **Cavum septum pellucidum:** a normal fetal/neonatal finding (present in virtually all fetuses under 36 weeks, falling to a few percent by later childhood); it does not communicate with the ventricular system.

High-yield exam pointers

- ▶ Four parts: anterior horn, body, atrium (trigone), posterior horn, inferior horn — C-shaped, mirrors caudate nucleus and fornix.
- ▶ Choroid plexus absent in the anterior and posterior horns; present in body, atrium and inferior horn.
- ▶ Interventricular foramen of Monro — bounded by column of fornix (front) and anterior thalamus (behind); only communication with the third ventricle.
- ▶ Arterial supply of choroid plexus: anterior choroidal artery (inferior horn) + posterior choroidal arteries (body/atrium) — anastomose at the glomus in the atrium.
- ▶ Developmental origin: cavity of the telencephalic vesicle; choroid plexus forms where the hemisphere wall fails to develop neuroblasts along the choroid fissure.
- ▶ CSF facts to reproduce verbatim: ~140 mL total, ~500 mL/day produced, lumbar pressure 50–200 mm H₂O (supine).
- ▶ Obstruction level determines the pattern of ventricular dilatation in hydrocephalus — a favourite applied-anatomy question.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; BD Chaurasia — Human Anatomy Vol 3–4, 8e; IB Singh — Textbook of Anatomy Vol 3, 6e; Vishram Singh — Clinical Neuroanatomy 4e; Langman's Medical Embryology (Sadler) 14e.



Lateral ventricle of brain

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction The lateral ventricles are two C-shaped cavities, one within the telencephalic part of each cerebral hemisphere, derived from the cavity of the embryonic cerebral (telencephalic) vesicle and lined throughout by ependyma. Each is described in four continuous parts — an **anterior (frontal) horn**, a **central part (body)**, a **posterior (occipital) horn** and an **inferior (temporal) horn** — which meet at the **atrium (trigone)**. Each lateral ventricle communicates with the midline third ventricle through the **interventricular foramen of Monro** and, except in the anterior horn, its wall carries a vascular **choroid plexus** that secretes cerebrospinal fluid (CSF). The C-shape mirrors the developmental expansion of the frontal, parietal and occipital regions of the hemisphere, which carries the temporal lobe inferiorly and anteriorly, so that the caudate nucleus and fornix in its wall adopt the same curved course.

Parts, extent and boundaries

Part	Extent	Roof	Floor / lateral wall	Medial wall	Special features
Anterior (frontal) horn	Frontal lobe; anterior to the interventricular foramen; closed in front by genu and rostrum of corpus callosum	Anterior part of the trunk of corpus callosum	Head of caudate nucleus (rounded, bulges into cavity)	Septum pellucidum (common to both ventricles)	No choroid plexus enters this horn
Central part (body)	Parietal lobe; from interventricular foramen to splenium of corpus callosum; triangular in cross-section	Trunk of corpus callosum	Thalamus (medially) and caudate nucleus (laterally), separated by the groove for stria terminalis and the thalamostriate vein	Septum pellucidum above, body of fornix below; choroid fissure lies between fornix and thalamus	Choroid plexus enters through the choroid fissure
Atrium (trigone/collateral trigone)	Site of confluence of body, posterior and inferior horns, deep in the parietal lobe	—	—	—	Largest, most dilatable compartment; contains the glomus choroideum (bulky choroid plexus tuft, frequently calcified — a CT/plain-film landmark)

Part	Extent	Roof	Floor / lateral wall	Medial wall	Special features
Posterior (occipital) horn	Occipital lobe; diamond/square in outline, often asymmetrical between sides	Tapetum of corpus callosum (also forms lateral wall)	—	Bulb of the posterior horn (produced by forceps major) above; calcar avis (infolded calcarine sulcus) below	Usually no choroid plexus ; the most variable/rudimentary horn — asymmetry here is a common normal imaging variant
Inferior (temporal) horn	Largest single compartment; curves round the pulvinar of the thalamus into the temporal lobe, ending ~2.5 cm from the temporal pole near the uncus	Tapetum, tail of caudate nucleus and stria terminalis (which end at the amygdala anteriorly)	Hippocampus medially, with the alveus and fimbria on its ventricular surface; collateral eminence (from the collateral sulcus) laterally	—	Choroid plexus enters through the inferior choroid fissure, between fimbria and stria terminalis

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 24.2 — Parts of the lateral ventricle (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.440)

Reproduce a lateral (sagittal projection) view of the C-shaped ventricular system with these labels:

- ▶ Anterior (frontal) horn — in frontal lobe
- ▶ Body (central part) — in parietal lobe
- ▶ Atrium/trigone — confluence point
- ▶ Posterior (occipital) horn — in occipital lobe
- ▶ Inferior (temporal) horn — in temporal lobe, curving to the uncus
- ▶ Interventricular foramen (of Monro) — joining anterior horn/body to third ventricle
- ▶ Third ventricle, cerebral aqueduct, fourth ventricle (drawn in continuity to show the whole system)

Communications

- ▶ Each lateral ventricle opens into the **third ventricle** through the **interventricular foramen of Monro**, bounded by the **column of the fornix anteriorly** and the **anterior end of the thalamus posteriorly**.

- ▶ The two lateral ventricles have **no direct communication with each other**; they communicate only indirectly across the midline through the third ventricle (and the choroid plexus is likewise continuous across the foramen).
- ▶ There is **no direct opening into the subarachnoid space** from the lateral ventricle — CSF must first traverse the third ventricle, cerebral aqueduct and fourth ventricle before reaching the subarachnoid cisterns.

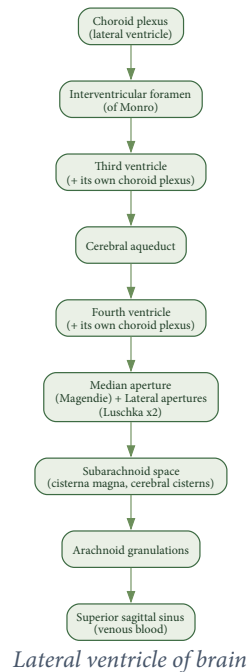
Choroid plexus of the lateral ventricle

Site	Artery of supply	Remarks
Anterior horn	—	Choroid plexus absent
Body (central part)	Medial and lateral posterior choroidal arteries (branches of the posterior cerebral artery), continuing from the third-ventricle plexus through the choroid fissure	Plexus lies in the choroid fissure, between fornix (above) and thalamus (below)
Atrium (trigone)	Anastomosis of anterior and posterior choroidal arteries	Forms the bulky glomus choroideum
Inferior (temporal) horn	Anterior choroidal artery (a slender, preterminal branch of the internal carotid artery), entering via the inferior part of the choroid fissure	Covers the hippocampus; the same artery also supplies parts of the optic tract, posterior limb of internal capsule and choroid plexus — vulnerable to ischaemia
Posterior horn	—	Choroid plexus normally does not extend into this horn

Venous drainage of the plexus is via the **superior and inferior choroidal veins**, which join the **thalamostriate** and **septal veins** at the interventricular foramen to form the **internal cerebral vein**; the two internal cerebral veins unite behind the pineal to form the **great cerebral vein (of Galen)**, which drains into the straight sinus.

CSF formation and circulation through the ventricular system

- ▶ CSF is secreted continuously by the choroid plexuses of the lateral, third and fourth ventricles, and passes: lateral ventricle → interventricular foramen → third ventricle → cerebral aqueduct → fourth ventricle → median aperture (of Magendie) and paired lateral apertures (of Luschka) → subarachnoid space (cisterna magna and cerebellopontine angle) → over the cerebral convexities → absorbed at **arachnoid granulations** into the superior sagittal sinus.
- ▶ Total CSF volume in the adult is **140–270 ml**, of which only about **25 ml** lies within the ventricles; CSF is secreted at **0.2–0.7 ml/minute** ($\approx 600\text{--}700\text{ ml/day}$), so the entire volume is renewed roughly **four times a day**.



Applied / Clinical anatomy

- ▶ **Obstructive (non-communicating) hydrocephalus** — the site of block dictates the pattern of ventricular dilatation: obstruction at the **interventricular foramen** dilates that lateral ventricle alone (or both, if bilateral); obstruction of the **cerebral aqueduct** (e.g., congenital aqueductal stenosis) dilates **both lateral ventricles and the third ventricle**; obstruction/congenital absence of the **fourth-ventricle apertures** dilates the **entire ventricular system**.
- ▶ **Colloid cyst of the third ventricle** — a mobile, choroid-plexus-attached cyst at the anterior end of the third ventricle can act as a ball valve, intermittently blocking one interventricular foramen; classically produces a **positional headache** (worse on head movement) with signs of raised intracranial pressure, and can be excised surgically.
- ▶ **Arnold–Chiari malformation** — cerebellar tonsils and medulla herniate through the foramen magnum, blocking the fourth-ventricle apertures; leads to internal hydrocephalus with dilatation of all ventricles and is frequently associated with **syringomyelia**.
- ▶ **Communicating hydrocephalus** — ventricular and subarachnoid spaces remain in continuity, but CSF absorption at the arachnoid granulations is impaired (e.g., after meningitis or subarachnoid haemorrhage); all ventricles, including the lateral ventricles, dilate together.
- ▶ **Hydrocephalus ex vacuo** — the ventricles (including the lateral ventricles) enlarge passively to fill space left by cerebral atrophy/tissue loss; CSF pressure and head size remain normal, distinguishing it from true hydrocephalus.
- ▶ **Choroid plexus papilloma/carcinoma** — a neoplasm of the choroid-plexus epithelium; when it arises in the lateral ventricle (its most frequent site in children) it may cause hydrocephalus both by CSF overproduction and by obstruction.
- ▶ **Anterior choroidal artery occlusion** — because this vessel supplies the inferior-horn choroid plexus together with the posterior limb of the internal capsule, optic tract and part of the thalamus, its infarction can combine contralateral hemiplegia, hemisensory loss and homonymous hemianopia.

- ▶ **Ventricular/CSF sampling and shunting** — CSF can be sampled by lumbar or cisternal puncture; in obstructive hydrocephalus, CSF diversion is achieved surgically by a **ventriculoperitoneal shunt** or by **endoscopic third ventriculostomy** (an endoscope is passed through the interventricular foramen into the third ventricle to fenestrate its floor).
- ▶ **Radiological correlation** — the lateral ventricles (especially the frontal horns and atria) are the standard CT/MRI landmarks for assessing midline shift, generalised or focal dilatation, and periventricular pathology; mild size asymmetry between the two posterior/occipital horns is a recognised normal variant.
- ▶ **Monro–Kellie doctrine** — since the cranial vault is a rigid, near-fixed-volume box (brain + CSF + blood), a chronic increase in one ventricular compartment is compensated by a reciprocal decrease in the others before intracranial pressure rises sharply.

High-yield exam pointers

- ▶ Each lateral ventricle has **4 parts** (anterior, central/body, posterior, inferior horns) meeting at the **atrium/trigone**; overall it is C-shaped.
- ▶ **No choroid plexus** in the anterior horn (and normally none in the posterior horn).
- ▶ Communicates with the third ventricle via the **interventricular foramen of Monro** — bounded by column of fornix (anterior) and anterior thalamus (posterior).
- ▶ Choroid plexus of the **body** = posterior choroidal arteries; of the **inferior horn** = anterior choroidal artery; of the **atrium** = anastomosis of both.
- ▶ Venous drainage converges at the foramen of Monro to form the **internal cerebral vein** → great cerebral vein of Galen.
- ▶ Total CSF ≈ 140–270 ml (ventricular component ≈ 25 ml); secretion ≈ 600–700 ml/day, turned over ~4×/day.
- ▶ Site of block determines the hydrocephalus pattern: foramen of Monro → one/both lateral ventricles; aqueduct → lateral + third; fourth-ventricle apertures → whole system.
- ▶ Colloid cyst of the third ventricle classically causes **positional headache** by intermittently blocking the foramen of Monro.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; IB Singh — Textbook of Anatomy Vol 3 (6e); BD Chaurasia — Human Anatomy Vol 3-4 (8e); Snell — Clinical Neuroanatomy (7e); Vishram Singh — Clinical Neuroanatomy (4e); Moore — The Developing Human (9e).



Modifications of spinal pia mater

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction The spinal pia mater is the innermost, vascular meningeal layer that closely invests the surface of the spinal cord and dips into its median fissures. Compared with cerebral pia, it is thicker, firmer and less vascular. At four specific sites its collagenous substance becomes locally condensed and specialised into structures with distinct names and mechanical or vascular functions — the **ligamenta denticulata**, the **linea splendens**, the **subarachnoid septum**, and the **filum terminale**. Together these "modifications of pia mater" suspend the cord centrally within the dural sac, escort vessels into the cord substance, and provide important surgical landmarks.

1. Basic organisation of spinal pia mater

- ▶ Two layers: an outer **epi-pia**, carrying the larger blood vessels, and an inner **pia-intima** (**pia-glia**), applied directly to nervous tissue.
- ▶ Between the two layers lie small vessels and cleft-like spaces that communicate with the subarachnoid space (the subpial "space").
- ▶ The subpial collagenous layer is thicker here than over the brain, and is continuous with the collagenous core of the ligamentum denticulatum.
- ▶ Pia closely invests the cord surface and is carried into the ventral (anterior) median fissure.
- ▶ Below the conus medullaris, pia is prolonged as the filum terminale.

2. Ligamenta denticulata (dentate/denticulate ligaments)

- ▶ Paired, flat, ribbon-like sheets of pia running the length of the cord on each side, in the coronal plane, between the ventral and dorsal nerve roots.
- ▶ Medial border is continuous with the subpial tissue of the cord; lateral border gives off **21 triangular, tooth-like processes** on each side.
- ▶ Each process pierces the arachnoid mater and fixes to the inner surface of the dura, midway between the exit points of two adjacent spinal nerves.
- ▶ **First process:** at the level of the foramen magnum — it crosses behind the vertebral artery and attaches to dura just above the foramen-magnum rim, immediately behind the hypoglossal nerve; the accessory nerve ascends along its posterior aspect.
- ▶ **Last process:** a narrow, oblique band descending from the conus medullaris, attaching between the exiting twelfth thoracic and first lumbar spinal nerves.
- ▶ Function: anchors/suspends the spinal cord centrally within the subarachnoid space and limits excessive cord movement during vertebral column motion (documented cine-radiographically).

3. Linea splendens

- ▶ A median, longitudinal, glistening band formed where pia thickens at the mouth of the anterior (ventral) median fissure as it folds inward.
- ▶ Runs the length of the cord along the anterior median fissure.
- ▶ Branches of the anterior spinal artery pierce the linea splendens to enter and supply the substance of the cord — it is therefore a vascular as well as a mechanical landmark.

4. Subarachnoid septum and posterior median attachment

- ▶ Posteriorly, pia mater is adherent to the **posterior median septum** of the spinal cord.
- ▶ It is also connected to the arachnoid mater by a **fenestrated (perforated) pial septum** in the midsagittal plane — the subarachnoid septum.
- ▶ This partitions the posterior part of the subarachnoid space while its fenestrations allow free movement of CSF across it.

5. Filum terminale

A delicate, thread-like prolongation of pia (with a central neuroglial/ependymal core) that continues from the tip of the conus medullaris to the dorsum of the first coccygeal segment, about 20 cm in total.

Feature	Filum terminale internum	Filum terminale externum
Length	~15 cm	~5 cm
Location	Within the dural sac, surrounded by extensions of dura/arachnoid and a capacious CSF-filled subarachnoid space	Outside the dural sac — begins where dura narrows at the lower border of S2
Relations	Central canal of the cord continues into its upper 5–6 mm; lowest cauda equina roots adhere to its upper part; its CSF cistern is the site of election for lumbar puncture	Fuses with the investing dura, pierces/traverses the sacral hiatus, and attaches to the periosteum on the dorsum of the first coccygeal vertebra

6. Intermediate (accessory) layer of leptomeninges — Gray's 41e

- ▶ A further, extensive, lace-like layer of leptomeninges lies between the well-defined arachnoid and pia, concentrated dorsally and ventrally.
- ▶ It is focally condensed into discontinuous **dorsal, dorsolateral and ventral ligaments of the spinal cord**, structurally similar to cranial arachnoid trabeculae (a collagenous core coated by leptomeningeal cells).
- ▶ Proposed function: acts as a baffle damping CSF pulsation waves within the vertebral canal; its fibrosis underlies chronic arachnoiditis.

□ Fig 11.3 — *Ligamentum denticulatum* (BD Chaurasia — *Human Anatomy* Vol 3-4 — 8e, p.227)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A longitudinal view of the exposed spinal cord (dura reflected) labelled with:

- ▶ Dura mater (cut and reflected) and arachnoid mater (outer layer + intermediate layer)
- ▶ Pia mater covering the cord
- ▶ Ligamentum denticulatum with its triangular dentate processes fixed to dura
- ▶ Ventral nerve root and dorsal root ganglion (processes passing between them)
- ▶ Linea splendens along the anterior median fissure
- ▶ Subarachnoid septum and posterior median septum (posterior aspect)
- ▶ Conus medullaris continuing as filum terminale internum (within dural sac, to S2) and filum terminale externum (fused to dura, through sacral hiatus to coccyx)

Applied / Clinical anatomy

- ▶ **Cordotomy landmark:** to relieve intractable pain, a knife is passed about 3 mm deep into the cord immediately anterior to the ligamentum denticulatum and swept forward — this severs the lateral spinothalamic (anterolateral) tract while sparing the pyramidal tract that lies posterior to the ligament.
- ▶ **Posterior fossa/craniovertebral surgery landmark:** the highest denticulate process, attached just above the foramen magnum behind the hypoglossal nerve, lies immediately anterior to the ascending accessory nerve and posterior to the vertebral artery — a useful orientation point during foramen magnum decompression.
- ▶ **Vascular landmark:** the linea splendens marks the course of the anterior spinal artery on the cord surface; its sulcal branches are the vessels compromised in anterior spinal artery (anterior cord) syndrome.
- ▶ **Lumbar puncture:** the wide subarachnoid cistern around the filum terminale internum, below the termination of the cord, is the safe site of election for CSF sampling/spinal anaesthesia (needle passed between L3–L4 or L4–L5, displacing the free-floating cauda equina roots and filum without injury).
- ▶ **Tethered cord syndrome:** an abnormally short, thickened (>2 mm wide) or fatty filum terminale (sometimes with an associated intradural lipoma) fixes the conus medullaris below its normal lower border of L1; traction reduces cord blood flow and produces back pain, motor/sensory deficits and perineal disturbance. MRI shows a low-lying conus with a thickened filum.
- ▶ May coexist with other dysraphic anomalies — spina bifida, diastematomyelia.
- ▶ The filum terminale is an occasional site of origin of **spinal ependymoma**, seen on MRI as a mass just below the conus medullaris, sometimes adherent to the filum at surgery.

High-yield exam pointers

- ▶ Four principal modifications of spinal pia mater: **ligamenta denticulata, linea splendens, subarachnoid septum, filum terminale.**

- ▶ Ligamenta denticulata = 21 tooth-like processes on each side; first process at the foramen magnum, last between T12 and L1 nerve roots; function is to anchor the cord centrally in the subarachnoid space.
- ▶ Linea splendens = glistening pial thickening at the anterior median fissure; pierced by branches of the anterior spinal artery.
- ▶ Subarachnoid septum = fenestrated pial septum linking pia to arachnoid posteriorly, in addition to pia's attachment to the cord's own posterior median septum.
- ▶ Filum terminale $\approx$ 20 cm total = internum (15 cm, within dural sac, to lower border of S2) + externum (5 cm, fused to dura, through sacral hiatus to first coccygeal segment).
- ▶ Spinal pia itself is two-layered: outer epi-pia (vessels) and inner pia-intima/pia-glia (glial contact).
- ▶ Denticulate ligament is the operative landmark for anterolateral cordotomy (knife anterior to ligament).
- ▶ Gray's 41e additionally describes an intermediate leptomeningeal layer forming dorsal/dorsolateral/ventral cord ligaments, proposed to baffle CSF pulsations.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3-4 8e; Vishram Singh Textbook of Anatomy Vol 3 4e and Clinical Neuroanatomy 4e; IB Singh Textbook of Anatomy Vol 3 6e and Textbook of Human Neuroanatomy.



Piamater

Asked in: Paper IV Nov 2017 — RGUHS MD/MS Anatomy

Definition / Introduction The **pia mater** ("tender mother") is the innermost of the three meninges enveloping the brain and spinal cord. It is a thin, delicate, highly vascular membrane that closely and faithfully invests the neural surface, dipping into every sulcus, fissure and groove — unlike the arachnoid, which bridges over them. Together with the arachnoid mater, the pia forms the **leptomeninges** (Gk. *lepto* = thin), as opposed to the tough outer **pachymeninx** (dura mater). The pia carries the blood vessels of the CNS on its surface before they penetrate the neural parenchyma, and its specialised folds and prolongations (denticulate ligaments, filum terminale, tela choroidea, perivascular sheaths) give it important surgical and clinical significance.

1. Structure and histology of the pia mater

- ▶ Composed of a thin sheet of **leptomeningeal (pial) cells**, often only 1–2 cells thick, joined to one another by desmosomes and gap junctions; true tight junctions are scanty, so the pia is not itself a diffusion barrier.
- ▶ Classically (BD Chaurasia) described as **two layers**:
 - **Epi-pia** — outer layer carrying the larger blood vessels.

- **Pia-glia (pia-intima)** — inner layer in direct contact with the glia limitans of the neural tissue.
- Between the two layers lie small vessels and cleft-like spaces that communicate with the subarachnoid space.
- ▶ The pia is separated from the surface of the brain/cord by a microscopic **subpial space**, containing collagen fibrils, fibroblast-like cells and microvessels, and from the neuropil proper by the **glia limitans** (astrocytic end-feet basal lamina).
- ▶ Pia is **avascular in itself but vessel-bearing on its surface** — it does not supply the underlying nervous tissue directly; nutrition of superficial cortex/cord is via vessels running on/through it.

2. Cranial pia mater and its processes

The real dissected plate below shows the cranial pia closely applied to the cerebral surface, with the pial vessels running within the subarachnoid space just external to it.

□ Fig 2.5 — Pia mater covering brain; blood vessels in subarachnoid space (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.440)

- ▶ Over the **cerebral hemispheres** the pia dips into every sulcus and fissure; over the **cerebellum** its relation is less intimate, dipping in only at the larger fissures.
- ▶ **Perivascular (Virchow–Robin) spaces**: as cerebral vessels leave the subarachnoid space to penetrate the brain, they carry a double sleeve of leptomeninges with them — the outer wall from pia, the inner from arachnoid — enclosing a perivascular space; this is now recognised as a **regulatory glio-vascular interface**, not a direct continuation of the subarachnoid space, since the pia is reflected onto the surface of the penetrating vessel and separates the subarachnoid space proper from the subpial/perivascular compartment.
- ▶ **Tela choroidea** of the third and fourth ventricles: formed where the vascular pia becomes apposed to the ependymal roof of the ventricle; invagination of pia + tuft of capillaries into the ventricular cavity produces the **choroid plexus**.
- ▶ **Sheaths for cranial nerves**, most notably the **optic nerve**: the pia adheres closely to the nerve, while arachnoid and dura fuse to form the outer optic nerve sheath; this sheath (and its contained CSF-filled subarachnoid extension) fuses with the sclera posteriorly at the back of the globe — the anatomical basis of papilloedema transmission with raised intracranial pressure.
- ▶ The pia has **no sensory innervation** of its own (unlike the dura), which is why pial/cortical surface manipulation during neurosurgery is relatively painless once dura is opened.



3. Spinal pia mater and its five processes

The spinal pia is thin but **highly vascular**, closely investing the spinal cord and continuous above with the cranial pia at the foramen magnum. Its distinguishing feature (compared with the cranial pia) is a set of named specialisations:

Process	Description	Clinical / surgical significance
Linea splendens	A glistening, thickened pial band along the floor of the anterior median fissure	Anterior spinal artery branches pierce it to reach the cord substance
Ligamenta denticulata	21 paired, triangular, tooth-like pial thickenings extending laterally between the anterior and posterior nerve roots on each side, piercing the arachnoid to attach to the inner dura between successive spinal nerve roots; first tooth at foramen magnum, last tooth between T12 and L1 nerves	Anchor the cord centrally within the subarachnoid CSF cushion; surgical landmark in cordotomy — the anterolateral (spinothalamic/sensory) tract lies in front of the ligament and the corticospinal (motor) tract lies behind it; the forked lowest tooth marks the L1 posterior root, giving the surgeon a reliable level marker
Subarachnoid septum	A midsagittal, fenestrated pial septum connecting the dorsal surface of the cord to the arachnoid	Structural support in the posterior subarachnoid space
Filum terminale internum	~15 cm; continuation of pia from the tip of the conus medullaris, lying within the dural sac; carries a few non-nervous fibrous strands (rudiments of the 2nd–4th coccygeal nerves) in its upper part; central canal extends into it for ~5 mm	Landmark below which lumbar puncture/spinal anaesthesia is safe
Filum terminale externum	~5 cm; the extradural continuation beyond the dural sac (below S2), fused with dura, passing through the sacral hiatus to attach to the dorsum of the first coccygeal vertebra (coccyx)	An abnormally short/thickened filum tethers the cord — tethered cord syndrome

- ▶ Overall the filum terminale is about **20 cm** long, mainly fibrous (pial) tissue.
- ▶ The pia here also carries the **arterial vasocorona**, a pial arterial plexus formed by anastomoses of the anterior and posterior spinal arteries with radicular feeders, from which centripetal branches supply the peripheral cord.

4. Blood supply carried by the pia mater

- ▶ **Anterior spinal artery:** formed in the posterior cranial fossa by union of the right and left anterior spinal branches of the **fourth (V4) part of each vertebral artery**; descends through the foramen magnum in the anterior median fissure, deep to the linea splendens.
- ▶ **Two posterior spinal arteries:** also branches of the V4 segment of the vertebral arteries; each descends as two channels, one in front of and one behind the dorsal nerve roots.
- ▶ **Radicular arteries** (segmental feeders from the aorta/intercostal-lumbar vessels; the largest is the artery of Adamkiewicz) reinforce the anterior spinal system at intervals.

- ▶ All three systems anastomose on the pial surface to form the **arterial vasocorona**, from which perforating branches enter the cord substance.

5. Development of the meninges

- ▶ The meninges arise from the **meninx primitiva**, a condensation of mesenchyme around the neural tube.
- ▶ The **dura mater** is **mesodermal** in origin.
- ▶ The **arachnoid mater** and **pia mater** (the leptomeninges) are **ectodermal**, derived from **neural crest** cells.
- ▶ The pia and arachnoid therefore share a common embryological origin, which explains their continuity (arachnoid trabeculae) and similar cytoarchitecture (leptomeningeal cell sheets).

6. Functional physiology and current concepts

- ▶ The pia is not a passive wrapping: by being reflected from the brain surface onto the walls of penetrating vessels, it creates a **regulatory interface** between the CSF-filled subarachnoid space and the brain interstitium/perivascular space, across which small solutes and metabolites diffuse — a function relevant to CSF–brain exchange and to blood–brain-barrier physiology.
- ▶ This pial-lined **perivascular (Virchow–Robin) pathway** is now recognised as the anatomical basis of peri-arterial CSF influx and interstitial-fluid clearance from the brain (the so-called "glymphatic" pathway), which is of active research interest in ageing, small-vessel disease and neurodegeneration; dilated Virchow–Robin spaces are a recognised MRI finding in these conditions.
- ▶ The pia–ependyma complex (tela choroidea) remains the developmental and functional basis of **choroid plexus** CSF secretion, tying pial vascular biology directly into CSF dynamics and hydrocephalus.

Applied / Clinical anatomy

- ▶ **Lumbar puncture**: performed at L3–L4 (or L2–L3), a level below the conus medullaris (lower border of L1) and below the spinal cord itself, so only the pia-covered filum terminale and cauda equina roots float in the roomy lumbar cistern — the needle traverses skin, ligaments, dura and arachnoid but never risks piercing the cord.
- ▶ **Cordotomy**: ligamentum denticulatum used intra-operatively as the surgical plane separating the anterolateral sensory (spinothalamic) tract in front from the corticospinal motor tract behind, for surgical relief of intractable pain.
- ▶ **Tethered cord syndrome**: a thickened, fatty or shortened filum terminale prevents normal ascent of the cord, producing progressive neurological deficits in the lower limbs and bladder — release ("untethering") of the filum is the surgical treatment.
- ▶ **Subarachnoid haemorrhage**: bleeding (classically from a ruptured berry aneurysm) into the pia-bounded CSF space produces blood-stained/xanthochromic CSF and meningism.
- ▶ **Pyogenic/leptomeningitis**: infection spreads readily through the CSF-filled subarachnoid space because the pia offers no tight-junctional barrier, explaining the rapid, diffuse spread of bacterial meningitis over the whole neuraxis.

- ▶ **Papilloedema:** raised intracranial pressure is transmitted along the pia-arachnoid-lined CSF sheath of the optic nerve to the optic disc, producing swelling visible on fundoscopy.
- ▶ **Spinal anaesthesia / epidural analgesia:** knowledge of the pia–arachnoid–dura relationship and the level of termination of the dural sac (S2) guides safe needle placement.

High-yield exam pointers

- ▶ Pia mater = innermost meninx; with arachnoid forms the **leptomeninges**; ectodermal/neural-crest origin (dura is mesodermal).
- ▶ Two histological layers described: **epi-pia** (vessels) and **pia-glia/pia-intima** (apposed to neural tissue); separated from neuropil by subpial space and glia limitans.
- ▶ Spinal pia gives **five named processes**: linea splendens, ligamenta denticulata (21 pairs), subarachnoid septum, filum terminale internum (15 cm, intradural) and externum (5 cm, extradural, to coccyx).
- ▶ Ligamentum denticulatum = surgical landmark for cordotomy; forked lowest tooth marks L1 posterior root.
- ▶ Cranial pia forms tela choroidea (→ choroid plexus), perivascular (Virchow–Robin) sheaths, and the innermost optic nerve sheath (fuses with sclera).
- ▶ Arterial vasocorona = pial anastomotic plexus of anterior + posterior spinal + radicular arteries.
- ▶ Pia has no sensory nerve supply and (with arachnoid) no tight junctions — key to painless cortical handling and rapid spread of meningitis respectively.
- ▶ Virchow–Robin (perivascular) spaces are pia-lined and are today linked to glymphatic CSF–interstitial clearance.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Labelled transverse section through the spinal cord and its meninges (posterior view emphasis), showing:

- ▶ Vertebral body/vertebral canal (outline)
- ▶ **Dura mater** (single meningeal layer) and epidural space (with internal vertebral venous plexus)
- ▶ **Arachnoid mater** with subdural space external to it
- ▶ **Subarachnoid space** (CSF) with arachnoid trabeculae
- ▶ **Pia mater** closely investing the cord
- ▶ **Linea splendens** along the anterior median fissure
- ▶ **Ligamentum denticulatum** — triangular tooth piercing arachnoid to attach to dura, between two spinal nerve roots
- ▶ Anterior and posterior spinal nerve roots emerging through the dural sleeve
- ▶ Anterior median fissure with anterior spinal artery
- ▶ A second inset: lower end of cord — conus medullaris → filum terminale internum (within dural sac) → dural sac ending at S2 → filum terminale externum → attachment to coccyx, with cauda equina roots surrounding the filum.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3–4 8e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e; Moore's Clinically Oriented Anatomy 9e.



Tela Choroidea (Telachoroidia)

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction The tela choroidea is a two-layered fold of vascular pia mater that lies in direct apposition to the single-layered ependymal lining of the neural tube roof, with no intervening nervous tissue between the two. It occurs at three sites in the adult ventricular system — the medial wall of each lateral ventricle along the choroid fissure, the roof of the third ventricle, and the roof of the inferior (caudal) part of the fourth ventricle. Active vascular proliferation within the tela produces tuft-like invaginations that project into the ventricular cavity to form the **choroid plexus**, the principal secretory source of cerebrospinal fluid (CSF). Because it shares a common embryological origin and structural similarity with the arachnoid mater, the tela choroidea is regarded as a specialised, richly vascular derivative of the pia-arachnoid.

Development

- ▶ The roof plate of the neural tube, at the level of the diencephalon, telencephalon and myelencephalon, consists of a **single layer of ependymal cells externally covered by vascular mesenchyme (the pia mater)**; together the two layers constitute the tela choroidea.
- ▶ **Active proliferation of the vascular mesenchyme** produces a number of sac-like invaginations that project into the underlying ventricular cavity; these tuft-like invaginations form the **choroid plexus**, which secretes CSF.
- ▶ This process occurs independently at three roof-plate sites: the roof of the **myelencephalon** (future fourth ventricle), the roof of the **diencephalon** (future third ventricle), and the medial wall of the **telencephalic vesicle** along the line of the **choroid fissure** (future lateral ventricle).
- ▶ During later development, the pia mater becomes apposed to the ependyma in the roof of the telencephalon and of the fourth ventricle to complete tela formation; the tela choroidea therefore has a common embryological origin and structural affinity with the arachnoid mater.
- ▶ The median aperture (foramen of Magendie) of the fourth ventricle forms when a transient membranous structure, **Blake's pouch**, perforates the tela at about the ninth fetal week; persistence of this membrane produces cystic dilatation and obstruction of the median outlet.

Structure

- ▶ Each tela is a **double (two-layered) fold of pia mater** closely apposed to ependyma, without intervening neural parenchyma.
- ▶ The **stroma (body) of the choroid plexus** consists of numerous fenestrated capillaries embedded in loose vascular connective tissue, separated from the ventricular lumen by a single layer of cuboidal **choroid ependymal (epithelial) cells**.
- ▶ The choroid epithelial cells possess microvillous apical surfaces and interdigitating, folded basal surfaces typical of transporting/secretory cells; **tight (occluding) junctions** between adjacent epithelial cells constitute the **blood–CSF barrier** — the fenestrated capillaries themselves are freely permeable, so the epithelium (not the vessel wall) is the true barrier site.
- ▶ The free, irregular lateral edge of the tela projecting into the ventricle is clinically and descriptively termed the **choroid vascular fringe**, which is the choroid plexus proper.

Tela choroidea of the lateral ventricle

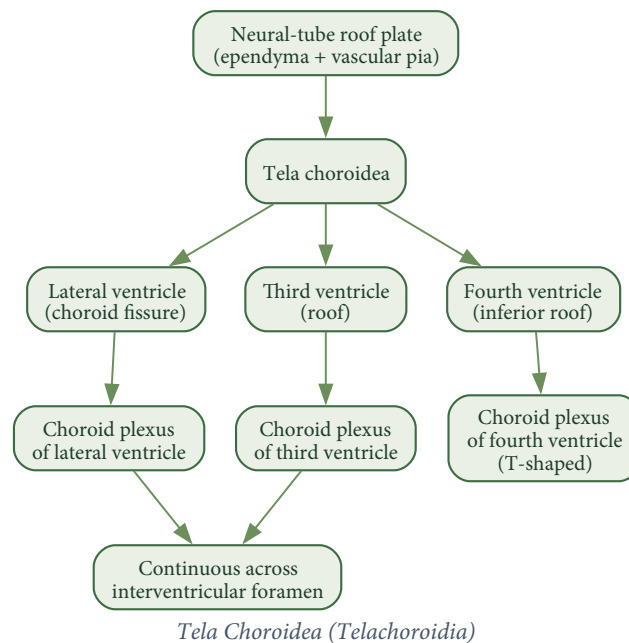
- ▶ Lies in the **choroid fissure**, the cleft between the **fornix superiorly** and the **thalamus inferiorly**, running the length of the body of the lateral ventricle.
- ▶ The choroid plexus formed here extends **anteriorly only as far as the interventricular foramen** (none is present in the frontal/anterior horn); posteriorly it curves around the posterior aspect of the thalamus (pulvinar) to enter the **inferior (temporal) horn** and reach as far as the hippocampus (again, none in the occipital/posterior horn).
- ▶ Through the interventricular foramen, the plexus of each lateral ventricle is **continuous with the plexus of the third ventricle and, across the midline, with that of the opposite lateral ventricle**.

Tela choroidea of the third ventricle

- ▶ Forms the thin **roof of the third ventricle**, lying between the **fornix (body and crura) superiorly** and the **upper surfaces of the two thalami and the roof proper of the third ventricle inferiorly**.
- ▶ Viewed from above it is **triangular**, with a rounded apex directed anteriorly at the **interventricular foramina** (often indented by the two anterior columns of the fornix); its irregular lateral edges bear the vascular fringes that continue laterally as the choroid plexus of each lateral ventricle.
- ▶ Within its substance, the choroid plexus of the third ventricle hangs down as **two longitudinal (anteroposterior) vascular fringes**, one on each side of the midline, supplied chiefly by the anterior choroidal arteries.
- ▶ Posteriorly the tela is reflected over the **pineal gland** to the tectum, separating the pineal from the splenium of the corpus callosum and the internal cerebral/great cerebral veins; it also contributes the roof over the **suprapineal recess**. The tela choroidea usually arises from the ependyma at the superolateral corner of the medial habenular nucleus.
- ▶ If the tela is stripped away, a cleft remains between the splenium of the corpus callosum and the tectal roof — the **transverse (cerebral) fissure** — which transmits the vascular pedicle (roots) of the choroid plexus of the third and lateral ventricles together with the internal cerebral veins.

Tela choroidea of the fourth ventricle

- ▶ Occupies the **roof of the inferior part** of the fourth ventricle, lying between the cerebellum and the ventricular cavity; it is a **double layer of pia mater** whose posterior layer first covers the inferior vermis and, after clothing the nodule, is reflected ventrally and caudally to lie in direct contact with the ependyma.
- ▶ This is distinct from the **superior medullary velum**, which forms the superior part of the roof and — unlike the tela — does contain neural (cerebellar white matter) tissue; the tela choroidea is confined to the **inferior medullary velum**.
- ▶ The resulting choroid plexus is characteristically **T-shaped**: paired vertical (longitudinal) limbs flank the midline and are adherent to the roof, fusing at the superior margin of the **median aperture (foramen of Magendie)**; paired horizontal limbs extend laterally into the **lateral recesses** toward the **lateral apertures (foramina of Luschka)**, through which small ependyma-covered tufts of plexus may protrude into the subarachnoid space of the cerebellopontine angle. Mean plexus thickness in children is about 2.5 mm.



□ Fig 24.5 — Boundaries and recesses of the third ventricle. Note the mode of formation of the tela choroidea (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.442)

Blood supply and CSF physiology

Site of tela / plexus	Arterial supply	Notes
Lateral + third ventricle	Anterior choroidal artery (branch of internal carotid) + choroidal branches of the posterior cerebral artery ; the two anastomose	Drains via a rich venous plexus into a single choroidal vein → internal cerebral vein
Fourth ventricle	(Postero-)inferior cerebellar arteries	Plexus thickness ~2.5 mm in children

- ▶ CSF is secreted actively by the choroid plexuses of the lateral, third and fourth ventricles (ependymal fluid and brain extracellular fluid contribute additionally, though their quantitative share is unclear).
- ▶ Total adult CSF volume ranges from **140–270 mL**; the ventricular system itself holds only about **25 mL**. CSF is produced at **0.2–0.7 mL/minute** (**≈600–700 mL/day**), so the entire CSF volume is replaced roughly **four times a day**.
- ▶ CSF flows from lateral ventricle → interventricular foramen → third ventricle → cerebral aqueduct → fourth ventricle → median/lateral apertures → subarachnoid space, and is ultimately reabsorbed into the venous system.

Applied / Clinical anatomy

- ▶ **Colloid cyst of the third ventricle**: arises from tela-choroidea/paraphyseal remnants near the interventricular foramina; being mobile and suspended from the choroid plexus, it acts as a ball valve, intermittently blocking one or both foramina of Monro — producing classic **positional headache aggravated by head movement**, with risk of acute obstructive hydrocephalus.

- ▶ **Choroid plexus papilloma:** tumour of the choroid plexus epithelium; commonest intraventricular tumour of infancy (lateral ventricle in children, fourth ventricle in adults), causing hydrocephalus by CSF overproduction and/or obstruction.
- ▶ **Physiological calcification** of the choroid plexus (glomus) and pineal gland is the **most frequent incidental intracranial calcification** on CT/plain skull films; lateral displacement of this calcification is a classic sign of midline shift from a space-occupying lesion.
- ▶ **Surgical corridor:** the transchoroidal (velum interpositum) approach splits the tela along the choroid fissure to reach the third ventricle for pineal/thalamic lesions while sparing the fornix and internal cerebral veins.
- ▶ **Aqueduct/foramen obstruction:** proximity of the tela and its plexus to the interventricular foramina and fourth-ventricle outlets means tumours or adhesions here readily cause non-communicating hydrocephalus.
- ▶ **Blood–CSF barrier relevance:** the tight-junctioned choroid epithelium limits CSF penetration of many antibiotics/chemotherapeutic agents — relevant to treating meningitis and CNS tumours.
- ▶ Persistence of **Blake's pouch** at the median aperture causes cystic CSF-outflow obstruction, part of the Dandy–Walker spectrum.

High-yield exam pointers

- ▶ Tela choroidea = **two-layered vascular pia mater directly apposed to ependyma**, no intervening neural tissue, at **three sites**: lateral ventricle (choroid fissure, between fornix and thalamus), third ventricle roof, and fourth ventricle inferior roof.
- ▶ Vascular invagination of the tela → **choroid plexus**, the chief source of CSF; epithelium (not capillary wall) is the blood–CSF barrier.
- ▶ Lateral-ventricle plexus is **continuous through the interventricular foramen** with the third-ventricle plexus and with the opposite side; **absent in the frontal and occipital horns and in the aqueduct**.
- ▶ Fourth-ventricle plexus is **T-shaped** (vertical limbs at midline fusing near the foramen of Magendie; horizontal limbs toward the foramina of Luschka); the **superior medullary velum**, unlike the tela, contains neural tissue.
- ▶ Removing the third-ventricle tela leaves the **transverse (cerebral) fissure**, carrying the choroidal vascular pedicle and internal cerebral veins.
- ▶ Arterial supply: **anterior choroidal artery + choroidal branches of PCA** (lateral/third ventricle); **inferior cerebellar arteries** (fourth ventricle).
- ▶ Adult CSF volume **140–270 mL**, ventricular volume **~25 mL**, production **600–700 mL/day**, turnover **~4×/day** (Gray's Anatomy 41e).
- ▶ **Colloid cyst of the third ventricle** — classic ball-valve, positional-headache vignette arising from the tela near the interventricular foramen.
- ▶ Choroid-plexus and pineal calcification are the **commonest incidental intracranial CT calcifications** and a radiological landmark for midline shift.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Sagittal (median) section through the diencephalon/third ventricle showing (label all): corpus callosum, septum pellucidum, fornix (body, column, crus), interventricular foramen, anterior commissure, lamina terminalis, optic recess, optic chiasma, infundibulum/infundibular recess, hypophysis cerebri, tuber cinereum, mammillary body, posterior perforated substance, tegmentum, aqueduct, tectum (superior/inferior colliculi), posterior commissure, pineal recess, pineal body, suprapineal recess, habenular commissure, interthalamic adhesion (connexus), hypothalamic sulcus, and — running along the roof between fornix and thalamus — the **tela choroidea**. A supplementary coronal inset through the body of a lateral ventricle should show the fornix above, thalamus below, the choroid fissure between them containing the tela choroidea, and the choroid plexus projecting into the ventricular cavity.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Langman's Medical Embryology (Sadler) 14e; Snell Clinical Neuroanatomy 7e; BD Chaurasia Human Anatomy Vol 3–4 8e; IB Singh Textbook of Anatomy Vol 3 6e; Vishram Singh Clinical Neuroanatomy 4e.

Coverage note: The tela choroidea is a niche structural topic given only brief, scattered treatment in standard texts (a few paragraphs each within the ventricular-system/CNS chapters cited above) rather than a dedicated chapter; the answer above consolidates every verbatim-critical fact (boundaries, shape, blood supply, CSF figures, applied points) that is explicitly stated across these sources — no values or classifications have been invented.

**Third ventricle**

Asked in: Paper IV Nov 2017 — RGUHS MD/MS Anatomy

Definition / Introduction The third ventricle is the median, slit-like cavity of the diencephalon, situated between the two thalami and continuous rostrally, on each side, with the lateral ventricle and caudally, in the midline, with the fourth ventricle. It is lined throughout by ciliated ependyma, is traversed by the interthalamic adhesion, and its thin ependymal roof carries a vascular tela choroidea from which the choroid plexus of the third ventricle is suspended. Being narrow, it is a common site of obstruction to CSF flow, making it a high-yield topic for both gross and applied (radiological) anatomy.

Development

- ▶ The ventricular system develops from the persisting lumen of the embryonic neural tube.
- ▶ The third ventricle represents the cavity of the diencephalic vesicle, except for the small area **in front of the interventricular foramen**, which is derived from the median (unpaired) part of the telencephalon.

- ▶ The two thalami, developing from the lateral walls of the diencephalon, grow medially and usually fuse across the midline as the **interthalamic adhesion (massa intermedia)**, which then traverses the ventricular cavity.
- ▶ In early fetal life the neurohypophysis contains a cavity continuous with the third ventricle, reflecting the diencephalic origin of the infundibulum; this cavity is normally obliterated later.
- ▶ The third ventricle is reported to be larger in infants with trisomy 21 than in normal controls — a developmental correlate occasionally quoted in imaging literature.

Boundaries

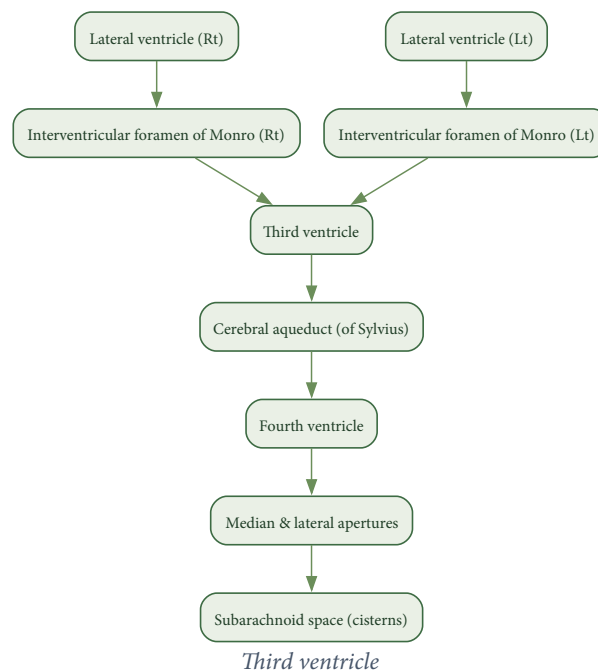
Wall	Constituent structures
Anterior wall	Below: lamina terminalis (extends from optic chiasma to rostrum of corpus callosum, the rostral end of the embryonic neural tube). Above it: diverging anterior columns of the fornix and the transversely running anterior commissure
Posterior wall	Pineal body; posterior commissure (in the lower lamina of the pineal stalk); habenular commissure at the root of the pineal stalk; commencement of the cerebral aqueduct below
Roof	Ependyma stretched across the upper margins of the two thalami, covered externally by the tela choroidea and its choroid plexus; the body of the fornix lies immediately above the roof
Floor (front to back)	Optic chiasma → tuber cinereum → infundibulum (pituitary stalk) → mammillary bodies → posterior perforated substance → tegmentum of the midbrain. All of these except the optic chiasma and the midbrain tegmentum lie in the interpeduncular fossa
Lateral wall (each side)	Above the hypothalamic sulcus: medial surface of the anterior two-thirds of the thalamus. Below the sulcus: hypothalamus. The hypothalamic sulcus runs from the interventricular foramen to the upper end of the cerebral aqueduct and marks the thalamo-hypothalamic boundary

- ▶ The **interthalamic adhesion** is a band of grey matter connecting the two thalami across the cavity; it is present in the great majority of humans and is, on average, larger in women.
- ▶ The two lateral walls are normally closely apposed, so in a coronal section the ventricle appears as a narrow **median vertical slit**.

Communications

- ▶ **Anterosuperiorly**, on each side: the **interventricular foramen (of Monro)** — bounded in front by the column of the fornix and behind by the anterior tubercle (pole) of the thalamus — opens into the body of the lateral ventricle of that side.

- **Posteroinferiorly, in the midline: the cerebral aqueduct (of Sylvius)** — a narrow tube, 1–2 mm in diameter, running through the dorsal part of the midbrain surrounded by the periaqueductal (central) grey matter — leads into the fourth ventricle.



Recesses

The irregular outline of the cavity is due to five diverticula (recesses):

Recess	Site / extent
Optic (chiasmatic) recess	Angular recess at the junction of the anterior wall and the floor, just above/behind the optic chiasma
Infundibular recess	Deep, tunnel-shaped; extends downward through the tuber cinereum into the infundibulum (pituitary stalk)
Anterior recess (vulva of the ventricle)	Triangular; lies in front of the interventricular foramen and behind the anterior commissure, between the diverging columns of the fornix
Pineal recess	Extends posteriorly into the pineal stalk, between its superior lamina (carrying the habenular commissure) and inferior lamina (carrying the posterior commissure)
Suprapineal recess	A capacious blind pouch extending posteriorly above the pineal stalk and below the tela choroidea

Tela choroidea, choroid plexus and blood supply

- The **tela choroidea** of the third ventricle is a triangular, two-layered fold of vascular pia mater lying beneath the body of the fornix; it invaginates the ependymal roof, and the **choroid plexus** hangs down from it as two longitudinal (anteroposterior) vascular fringes, one on each side of the midline.

- ▶ This plexus is continuous, through the interventricular foramen, with the choroid plexus of each lateral ventricle.
- ▶ **Arterial supply:** a single vessel from the **anterior choroidal artery** (branch of the internal carotid artery) together with several **medial and lateral posterior choroidal arteries** (branches of the posterior cerebral artery); the two sets anastomose to some extent.
- ▶ **Venous drainage:** capillaries drain into choroidal veins; at the foramen of Monro the **thalamostriate vein** converges with the (**anterior**) **septal vein** to form the **internal cerebral vein** of each side. The paired internal cerebral veins pass backward in the tela choroidea and, together with the **basal veins (of Rosenthal)**, unite below the splenium of the corpus callosum to form the **great cerebral vein (of Galen)**, which drains into the straight sinus.
- ▶ Functionally the choroid plexus epithelium (with its tight junctions) forms part of the **blood–CSF barrier** and is the principal site of CSF secretion into the third ventricle.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

embed: ![Fig 11.14 — Boundaries and recesses of third ventricle as seen in sagittal section (Vishram Singh — Clinical Neuroanatomy — 4e, p.425)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/82ba8a45498ce76e.jpg)

Reproduce a mid-sagittal outline of the third ventricle and label:

- ▶ Lamina terminalis, anterior commissure, column of fornix
- ▶ Interventricular foramen (of Monro), anterior recess (vulva)
- ▶ Hypothalamic sulcus, interthalamic adhesion
- ▶ Optic recess, optic chiasma, infundibular recess, infundibulum, tuber cinereum
- ▶ Mammillary body, posterior perforated substance, midbrain tegmentum
- ▶ Cerebral aqueduct, periaqueductal grey matter
- ▶ Posterior commissure, pineal body, pineal recess, habenular commissure
- ▶ Suprapineal recess, tela choroidea with choroid plexus, body of fornix

Applied / Clinical anatomy

- ▶ **Obstructive (non-communicating) hydrocephalus:** the third ventricle is narrow and readily obstructed by tumours, congenital stenosis, or clot. Obstruction causes raised intracranial pressure in adults and hydrocephalus (with cranial enlargement) in infants whose sutures are unfused.
- ▶ **Radiological localisation:** on CT/MRI the normal third ventricle appears as a narrow, vertical midline shadow (slit). Symmetrical dilatation of both lateral ventricles with a normal third ventricle localises the block to the interventricular foramina (unilateral lateral-ventricle dilatation if only one foramen is blocked); dilatation of both lateral ventricles **and** the third ventricle, with a normal fourth ventricle, localises the block to the cerebral aqueduct.
- ▶ **Colloid cyst of the third ventricle** — the classic exam vignette: a smooth, ball-like cyst suspended from the choroid plexus/tela choroidea near the roof of the ventricle at, or just behind, the foramen of Monro. Because it is mobile, it can act as a ball-valve at the foramen with changes in

head posture, producing intermittent, posture-related headache with acute rises in intracranial pressure (and, on imaging, a small opaque mass at the anterior part of the ventricle); an expanding cyst may also compress the thalamus/internal capsule, producing contralateral limb weakness or numbness. Treatment is surgical (endoscopic or microsurgical) excision.

- ▶ **Primary aqueductal stenosis** is an important cause of congenital obstructive hydrocephalus and is a recognised feature of neurofibromatosis type 1 (von Recklinghausen disease) in children, though genetic factors independent of neurofibromatosis also contribute.
- ▶ **Hypothalamic floor lesions/tumours** (craniopharyngioma, glioma) can produce diabetes insipidus, obesity, disturbances of sleep and temperature regulation, and hyperglycaemia/glycosuria, reflecting the hypothalamic contribution to the ventricular floor.
- ▶ **Endoscopic third ventriculostomy (ETV)**: obstructive hydrocephalus (e.g. from aqueductal stenosis) can be treated by fenestrating the thin floor of the third ventricle in the midline — the ideal site is midway between the dorsum sellae and the basilar artery, near the infundibular recess — creating a direct communication between the ventricle and the interpeduncular/prepontine subarachnoid cistern that bypasses the blocked aqueduct.
- ▶ **Cistern of the lamina terminalis**, an extension of the interpeduncular cistern immediately below the anterior wall, contains the anterior communicating artery; aneurysmal rupture here may cause intraventricular haemorrhage through the thin lamina terminalis.
- ▶ **Pineal-region masses** compressing the posterior wall and aqueduct produce obstructive hydrocephalus together with an upgaze/vertical-gaze palsy (from pressure on the tectal/pretectal region) — the anatomical basis of the Parinaud (dorsal midbrain) syndrome.

High-yield exam pointers

- ▶ Median, unpaired, ependyma-lined cavity of the diencephalon; part of it (anterior to the interventricular foramen) is telencephalic in origin.
- ▶ Communicates anterosuperiorly with each lateral ventricle via the **interventricular foramen (of Monro)**, and posteroinferiorly with the fourth ventricle via the **cerebral aqueduct**.
- ▶ Five named recesses — **optic, infundibular, anterior (vulva), pineal, suprapineal** — a favourite "list" question.
- ▶ **Interthalamic adhesion (massa intermedia)** crosses the cavity connecting the two thalami; present in most humans, larger in females.
- ▶ Floor, front to back: optic chiasma → tuber cinereum/infundibulum → mammillary bodies → posterior perforated substance → midbrain tegmentum.
- ▶ Choroid plexus continuous with that of the lateral ventricles at the foramen of Monro; supplied by the anterior choroidal artery + medial/lateral posterior choroidal arteries; drained via the internal cerebral veins into the great cerebral vein of Galen.
- ▶ Classic clinical correlate: **colloid cyst of the third ventricle** — ball-valve obstruction at the foramen of Monro causing postural, intermittent headache.
- ▶ ETV fenestration site: floor of the ventricle, midline, midway between dorsum sellae and basilar artery.
- ▶ Pattern of ventricular dilatation on CT/MRI localises the level of CSF-pathway obstruction.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; BD Chaurasia Human Anatomy Vol 3–4 8e; Vishram Singh Textbook of Anatomy Vol 3 4e and Clinical Neuroanatomy 4e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e.



Sensory, motor & special-sense pathways



Describe the auditory pathway

Asked in: Paper IV 02-Jun-2025 · Paper IV 04-Aug-2021 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction — The auditory pathway is the chain of neurons that carries impulses generated by the hair cells of the organ of Corti, in response to sound-induced vibration of the basilar membrane, from the cochlea to the primary auditory cortex. It is conventionally described as a **four-neuron relay** — spiral ganglion → cochlear nuclear complex → superior olivary complex/nucleus of the lateral lemniscus → medial geniculate body — with an obligatory reflex station at the **inferior colliculus**. Its most distinctive feature is **extensive bilateral crossing at multiple levels** (trapezoid body, dorsal acoustic stria, commissure of Probst, inferior collicular commissure, corpus callosum), so that each cochlea is represented in **both** cerebral hemispheres — unlike any other sensory pathway. This bilaterality has direct clinical importance: a unilateral lesion anywhere central to the cochlear nuclei never produces complete deafness.

1. Receptor and first-order neuron

- ▶ The **organ of Corti**, the receptor epithelium for hearing, sits on the basilar membrane within the cochlear duct; its hair cells are excited when sound-induced vibration bends their stereocilia against the tectorial membrane, generating a receptor potential and, in the afferent cochlear nerve fibres synapsing on the hair cell bases, action potentials.
- ▶ **First-order neurons** are bipolar cells whose bodies lie in the **spiral (cochlear) ganglion**, coiled within the bony modiolus of the cochlea (like the olfactory and optic first-order cells, and unlike other cranial sensory nerves).
- ▶ Their peripheral processes contact the hair cells of the organ of Corti; their central processes form the **cochlear nerve**, which joins the vestibular nerve as the vestibulocochlear nerve (CN VIII) and enters the brainstem at the **cerebellopontine angle**, at the pontomedullary junction.
- ▶ On entry, each fibre **bifurcates** to terminate in the dorsal and the ventral cochlear nuclei.

2. Second-order neurons — cochlear nuclear complex

- ▶ The **dorsal and ventral cochlear nuclei** lie on the surface of the inferior cerebellar peduncle at the pontomedullary junction; their cells constitute the **second-order neurons**.
- ▶ Neurons are arranged **tonotopically** — high frequencies represented basally, low frequencies apically — a spatial map that is preserved at every subsequent relay up to the cortex.

- ▶ **Dorsal cochlear nucleus** → axons cross via the **dorsal acoustic stria** directly to the **contralateral inferior colliculus** (largely bypassing the superior olivary complex).
- ▶ **Ventral cochlear nucleus** → axons form the **trapezoid body** (or the intermediate acoustic stria) and relay in the **superior olivary complex**, the **nuclei of the lateral lemniscus**, or pass directly to the inferior colliculus.

3. Third-order neurons — superior olivary complex and formation of the lateral lemniscus

Structure	Location	Input	Function
Trapezoid body	Transverse fibre mass in ventral pontine tegmentum	Crossing axons of both ventral cochlear nuclei	Principal decussation site of the ascending pathway
Nucleus of the trapezoid body	Scattered cell groups within the trapezoid body	Ventral cochlear nucleus	Relay station for some crossing fibres before joining the lateral lemniscus
Superior olivary complex (dominated by the medial superior olivary nucleus)	Dorsal to trapezoid body	Bilateral input from both ventral cochlear nuclei	Sound localisation — the medial nucleus computes interaural <i>time</i> differences; the lateral superior olivary nucleus contributes to interaural <i>intensity</i> differences
Nucleus of the lateral lemniscus	Cell groups embedded within the lemniscus itself	Bilateral cochlear-nucleus afferents	Additional relay before the midbrain

- ▶ Third-order axons — from the superior olivary complex, the trapezoid nucleus and the nucleus of the lateral lemniscus — ascend as the **lateral lemniscus**, the principal ascending auditory tract, running through the lateral pontine tegmentum close to the brainstem surface.
- ▶ Because both crossed and uncrossed fibres contribute, **each lateral lemniscus carries impulses originating in both cochleae**.

4. Midbrain relay — inferior colliculus (the auditory reflex centre)

- ▶ The **inferior colliculus** comprises a **central nucleus** (receiving the bulk of lemniscal fibres and projecting to the ventral division of the medial geniculate body) and **dorsal and external cortices** (integrating auditory with somatosensory/visual input and feeding back to the cochlear nuclei and superior olivary complex via olivocochlear efferents).
- ▶ Most lateral lemniscus fibres bypass the inferior colliculus and go **directly** to the medial geniculate body; a smaller set relays here for **reflex** purposes.
- ▶ Fibres of the inferior colliculus reach the medial geniculate body via the **brachium of the inferior colliculus**.

- ▶ Connections also run from the **nucleus of the lateral lemniscus** to the **deep part of the superior colliculus**, coordinating **auditory–visual reflexes** (e.g., reflex turning of the eyes and head towards a sudden sound, mediated onward via the tectospinal tract).
- ▶ The two inferior colliculi are interconnected by a commissure, contributing further to bilaterality.

5. Fourth-order neurons — medial geniculate body and the auditory radiation

- ▶ The **medial geniculate body** (MGB) of the thalamus is the **final relay station**. Its **ventral division** receives the main lemniscal/collicular input and is reciprocally connected with the primary auditory cortex; the **medial and dorsal divisions** integrate collicular cortical and auditory-cortical feedback respectively.
- ▶ Fourth-order axons from the MGB form the **auditory radiation**, which passes through the **sublentiform part of the internal capsule** to reach the **primary auditory cortex** — the **anterior and posterior transverse temporal gyri** (Heschl's gyri), buried in the lateral sulcus on the posterior part of the superior temporal gyrus, corresponding to **Brodmann areas 41 and 42**.
- ▶ The tonotopic map is preserved in the cortex; **secondary (belt)** auditory areas surround the primary cortex, with **parabelt** auditory association cortex beyond that, where basic acoustic features are progressively integrated into "auditory objects."

6. Bilaterality and interhemispheric connections

- ▶ Decussation occurs at several levels: the **trapezoid body**, the **dorsal acoustic stria**, the **commissure of Probst** (interconnecting the two nuclei of the lateral lemniscus), and the **commissure of the inferior colliculi**.
- ▶ The **posterior third of the corpus callosum** carries interhemispheric fibres linking the primary and secondary auditory cortices of the two sides.
- ▶ Consequently, input from **each cochlea projects to both cerebral hemispheres**, though with contralateral dominance at every level above the cochlear nuclei.

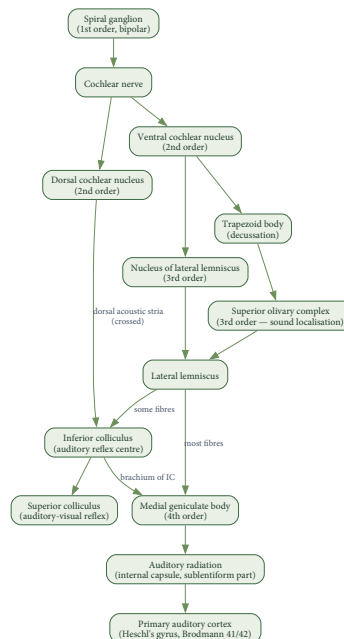
7. Efferent (descending) auditory pathway

- ▶ A parallel **olivocochlear system** runs centrifugally from the superior olivary complex back to the cochlea, within the cochlear nerve.
- ▶ **Lateral olivocochlear efferents** arise near the lateral superior olivary nucleus, are mostly **uncrossed**, and synapse on the **afferent dendrites beneath the inner hair cells**, modulating afferent transmission.
- ▶ **Medial olivocochlear efferents** arise near the medial superior olivary nucleus, are mostly **crossed**, and synapse **directly on the outer hair cells**; their activity **inhibits cochlear responses** to sound and is thought to protect the cochlea and sharpen frequency selectivity (the "cochlear amplifier").

□ Fig 7.16 — The auditory pathway (IB Singh — Textbook of Human Neuroanatomy, p.133)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A schematic coronal series from medulla to cortex, labelling: spiral ganglion → cochlear nerve, dorsal cochlear nucleus and ventral cochlear nucleus, trapezoid body and dorsal nucleus of the trapezoid body, superior olivary nucleus, lateral lemniscus and nucleus of the lateral lemniscus, inferior colliculus, brachium of the inferior colliculus, medial geniculate body, auditory radiation, and primary auditory area (Brodmann 41, 42 / Heschl's gyrus). Use arrows to show crossed (majority) and uncrossed fibres at the trapezoid body level.



Describe the auditory pathway

Applied / Clinical anatomy

- **Conductive hearing loss** results from disorders of the external/middle-ear sound-conducting mechanism — tympanic membrane perforation, ossicular chain disruption, otosclerosis, or middle-ear effusion ("glue ear").
- **Sensorineural hearing loss** results from damage to the hair cells, the cochlear nerve, or the central pathway — e.g., aminoglycoside/noise-induced hair-cell loss, **presbycusis** (age-related loss beginning at the high-frequency, basal end of the cochlea), or **Ménière's disease** (endolymphatic hydrops presenting with fluctuating hearing loss, tinnitus and vertigo).
- **Rinne and Weber tuning-fork tests** clinically distinguish conductive from sensorineural loss at the bedside — a routine extension of this pathway's anatomy into clinical examination.
- **Vestibular schwannoma (acoustic neuroma)** arising from the cochlear/vestibular nerve at the cerebellopontine angle compresses CN VIII (and often adjacent CN V and VII), producing ipsilateral sensorineural deafness, tinnitus and imbalance.
- Because of the pathway's rich bilaterality, **unilateral lesions of the organ of Corti, cochlear nerve, or cochlear nuclei cause ipsilateral hearing loss**, whereas **unilateral lesions of the lateral lemniscus, medial geniculate body, or auditory cortex produce only mild diminution of hearing**.

bilaterally (more marked contralaterally); **only bilateral temporal-lobe lesions cause complete cortical deafness.**

- ▶ The **efferent olivocochlear bundle** is exploited clinically as **contralateral suppression of otoacoustic emissions**, a test of brainstem olivocochlear reflex integrity.
- ▶ **Auditory brainstem implants**, which place stimulating electrodes directly into the cochlear nucleus via a retrosigmoid approach, restore some hearing in patients with neurofibromatosis type 2 or cochlear-nerve aplasia, where a cochlear implant cannot be used because the cochlear nerve itself is absent or destroyed.

High-yield exam pointers

- ▶ Four-neuron relay: **spiral ganglion (1st) → cochlear nuclei (2nd) → superior olivary complex/nucleus of lateral lemniscus (3rd, forms lateral lemniscus) → medial geniculate body (4th, forms auditory radiation).**
- ▶ **Inferior colliculus** = midbrain relay and **centre for auditory reflexes**; most lemniscal fibres bypass it en route to the MGB.
- ▶ Primary auditory cortex = **Heschl's transverse temporal gyri**, posterior superior temporal gyrus, **Brodmann areas 41 and 42.**
- ▶ **Superior olivary complex** (medial nucleus) is the principal site for **binaural sound localisation** via interaural time and intensity differences.
- ▶ Multiple decussation sites: **trapezoid body, dorsal acoustic stria, commissure of Probst, commissure of inferior colliculi, posterior corpus callosum** — hearing has the richest bilateral representation of any sensory modality.
- ▶ Peripheral lesions (organ of Corti/cochlear nerve/cochlear nuclei) → **ipsilateral** deafness; central lesions → only mild **bilateral** diminution; only **bilateral cortical** lesions abolish hearing.
- ▶ Efferent **olivocochlear system** (lateral = uncrossed, to afferent dendrites; medial = crossed, to outer hair cells) modulates/protects cochlear output.
- ▶ Tonotopic organisation is preserved from cochlea to cortex at every relay station.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e.



Medial lemniscus

Asked in: Paper IV May 2010 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction — The **medial lemniscus** is a compact, flattened band of second-order sensory axons forming the brainstem component of the **dorsal column–medial lemniscus (DCML) system** (the posterior column–medial lemniscus pathway), the principal route for **conscious proprioception, vibration sense, discriminative touch and two-point discrimination** from the trunk and limbs to the cortex. It is formed by decussated internal arcuate fibres in the lower (closed) medulla, ascends through the medulla, pons and midbrain near the median raphe, and relays in the **ventral posterolateral (VPL) nucleus of the thalamus** before projecting to the somatosensory cortex. Because it changes shape, position and companions at every brainstem level, it is a favourite RGUHS short-note testing both the pathway and cross-sectional neuroanatomy together.

1. Formation of the medial lemniscus

- ▶ **First-order neurons:** cell bodies in the dorsal root ganglia; their central processes enter the spinal cord through the **medial division of the dorsal root** and ascend **uncrossed (ipsilateral)** in the posterior white column — as the **fasciculus gracilis** (from below mid-thoracic/T6 level — lower limb and trunk) and the **fasciculus cuneatus** (from above T6 — upper limb and upper trunk).
- ▶ These first-order fibres terminate on **second-order neurons** in the **nucleus gracilis** and **nucleus cuneatus**, situated in the dorsal part of the **lower (closed) medulla**.
- ▶ The axons of these second-order neurons curve ventrolaterally around the central grey matter, then ventromedially between the spinal trigeminal tract/nucleus and the central grey matter, as the **internal arcuate fibres**.
- ▶ The internal arcuate fibres of the two sides cross the midline as the **sensory (lemniscal) decussation**, located dorsal to the pyramids and ventral to the central grey matter — this crossing is what makes all sensations carried by this pathway **contralateral** to the side of the body from the point of decussation onward.
- ▶ Immediately after crossing, the fibres turn cranially and ascend as the **medial lemniscus** through the medulla, pons and midbrain to end in the thalamus — hence the pathway's fuller name, the **dorsal column–medial lemniscus system**.

2. Course and level-wise position in the brainstem

The shape, orientation and neighbours of the medial lemniscus change strikingly from medulla to midbrain — a point repeatedly tested in cross-sectional questions.

Level	Position / shape	Key relations
Lower (closed) medulla , at the sensory decussation	Flattened, near-vertical band close to the median raphe, just above the crossing internal arcuate fibres	Pyramid lies ventral to it; medial longitudinal fasciculus and tectospinal tract lie dorsal to it; within the lemniscus, gracile (leg) fibres lie ventral and cuneate (arm) fibres lie dorsal

Level	Position / shape	Key relations
Mid-olivary medulla	Expanded and more prominent anteriorly; fibres progressively re-sort — gracile fibres migrate laterally, cuneate fibres migrate medially	Trigeminal lemniscus and spinal lemniscus lie lateral to it; fibres of the anterior spinothalamic tract join the medial lemniscus, while the spinotectal tract runs with the spinal lemniscus
Pons	Lies in the most anterior (ventral) part of the tegmentum, a little lateral to the median raphe	Joined medially by second-order fibres from the principal (main) sensory nucleus of the trigeminal nerve , forming the trigeminal lemniscus ; somatotopically arranged with C1–S4 segments sequentially medial to lateral ; the facial nucleus lies posterior to its lateral part
Midbrain	Ascends as a compact bundle dorsal (posterior) to the substantia nigra	Medial-most of the three lemnisci — medial lemniscus, trigeminal lemniscus and spinal lemniscus lie in that order from medial to lateral (the auditory lateral lemniscus lies still more laterally and merges with the inferior colliculus); at the level of the red nucleus the whole bundle is displaced further laterally

3. Companion lemnisci and termination

- ▶ From pontine levels upward, the medial lemniscus ascends as part of a compact tegmental bundle together with the **trigeminal lemniscus** (crossed fibres from the trigeminal sensory nuclei, carrying face sensation) and the **spinal lemniscus** (fused anterior and lateral spinothalamic tracts, carrying crude touch, pain and temperature from the trunk/limbs) — the three remain anatomically distinct and end in different thalamic nuclei even though they travel together.
- ▶ The medial lemniscus (together with the spinal lemniscus) terminates by relaying on **third-order neurons in the ventral posterolateral (VPL) nucleus of the thalamus** — the body/limb representation.
- ▶ The trigeminal lemniscus, in contrast, ends in the **ventral posteromedial (VPM) nucleus** of the thalamus — the face representation; some gustatory fibres travelling with the medial lemniscus also end in the most medial part of VPM.
- ▶ Third-order thalamocortical axons from VPL/VPM pass through the **posterior limb of the internal capsule and corona radiata** to reach the **primary somatosensory cortex (postcentral gyrus, Brodmann areas 3, 1, 2)**, preserving somatotopy (the sensory homunculus).

4. Functions (modalities carried)

- ▶ **Conscious (discriminative) proprioception** — joint position and movement sense

- ▶ **Vibration sense**
- ▶ **Fine (discriminative) touch, two-point discrimination**
- ▶ **Stereognosis and graphesthesia** (dependent on cortical processing of this input)
- ▶ Carries these modalities from the **trunk and limbs**; the equivalent input from the **face** travels via the trigeminal lemniscus, not the medial lemniscus proper.

5. Blood supply

- ▶ **Medulla**: paramedian branches of the **vertebral artery** and the **anterior spinal artery**.
- ▶ **Pons**: paramedian and short circumferential branches of the **basilar artery**.
- ▶ **Midbrain**: paramedian branches of the **posterior cerebral artery** (interpeduncular branches).
- ▶ Because the medial lemniscus lies close to the midline at all levels, it is characteristically involved in **paramedian brainstem vascular syndromes** rather than the more laterally placed infarcts.

□ Fig 20.10 — Scheme to show the main features of the posterior column–medial lemniscus pathway (IB Singh — *Textbook of Anatomy Vol 3 — 6e, p.383*)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the dorsal column–medial lemniscus pathway as a schematic (spinal cord → medulla → pons/midbrain → thalamus → cortex), labelling in sequence: **dorsal root ganglion** (first-order neuron) with peripheral receptor; **fasciculus gracilis** (leg/trunk, medial) and **fasciculus cuneatus** (arm, lateral) ascending ipsilaterally; **nucleus gracilis/cuneatus** (second-order neuron) in the lower medulla; **internal arcuate fibres** curving ventromedially; **sensory (lemniscal) decussation** in the midline; **medial lemniscus** ascending through medulla, pons and midbrain (mark its changing position at each level per the table above); **VPL nucleus of thalamus** (third-order neuron); **posterior limb of internal capsule** and **corona radiata**; **postcentral gyrus** (areas 3, 1, 2).

Recent advances

- ▶ **Tractography-guided sparing of the medial lemniscus in MRgFUS thalamotomy**: direct MRI-based targeting (FGATIR sequences) and preoperative diffusion-tensor tractography of the pyramidal tract, medial lemniscus and dentatorubrothalamic tract now allow a personalised lesion "sweet spot" for essential-tremor/Parkinson's thalamotomy, reducing impingement on the medial lemniscus/internal capsule and acute sensory/weakness complications (Cahill et al, *J Neurosurg* 2026 [DOI](<https://doi.org/10.3171/2026.2.JNS252280>); Shalem et al, *Brain Commun* 2026 [DOI](<https://doi.org/10.1093/braincomms/fcag170>)).
- ▶ **Intraoperative electrophysiological mapping of the medial lemniscus** through the biopsy cannula during stereotactic brainstem biopsy is a novel feasibility approach detecting real-time proximity to the medial lemniscus and corticospinal/corticonuclear tracts, allowing trajectory adjustment to reduce new neurological deficit (Lapteva et al, *J Neurooncol* 2026 [DOI](<https://doi.org/10.1007/s11060-026-05609-0>)).
- ▶ **Evoked potentials as a tract-specific functional readout**: in postoperative Brown-Séquard syndrome after cervical spine surgery, combined motor and somatosensory evoked potentials specifically localised dysfunction to the corticospinal and dorsal column–medial lemniscus

pathways, supporting tract-level recovery monitoring (Lee et al, *Am J Phys Med Rehabil* 2026) [DOI](<https://doi.org/10.1097/PHM.0000000000003030>).

- ▶ **Low-cost physical teaching model for the DCML pathway:** an inexpensive, multisensory physical model of the dorsal column–medial lemniscus tract improved learners' understanding versus conventional 2-D illustrations (D'Alessandro et al, *Anat Sci Educ* 2026) [DOI](<https://doi.org/10.1002/ase.70272>).
- ▶ **DTI correlate of central pain:** high-resolution DTI in Chiari malformation type I showed elevated fractional anisotropy in the medial lemniscus and cerebellar peduncles correlating with pain severity, implicating this tract in central sensitisation (Houston et al, *Cerebellum* 2026) [DOI](<https://doi.org/10.1007/s12311-026-01991-7>).

(According to PubMed.)

Applied / Clinical anatomy

- ▶ **Medial medullary syndrome (Dejerine's anterior bulbar syndrome)** — occlusion of paramedian branches of the vertebral artery/anterior spinal artery destroys the **pyramid** (contralateral hemiplegia), the **hypoglossal nucleus/nerve** (ipsilateral LMN tongue paralysis, deviating to the side of the lesion on protrusion) and the **medial lemniscus** (contralateral loss of vibration, proprioception and tactile discrimination) — a classic "crossed"/alternating brainstem syndrome and the standard comparison-pair with the lateral medullary (Wallenberg) syndrome, in which the medial lemniscus (and pyramid, hypoglossal nucleus) are characteristically spared.
- ▶ **Localising value of ipsilateral vs contralateral sensory loss:** because the decussation occurs low in the medulla, a lesion of the **posterior column below this level** (e.g. cord compression, tabes dorsalis, subacute combined degeneration) causes **ipsilateral** loss of proprioception/vibration, whereas a lesion of the **medial lemniscus above the decussation** (medulla, pons, midbrain or thalamus) causes **contralateral** loss — a key bedside/viva discriminator for localising the level of a lesion.
- ▶ **Benedikt syndrome** — a midbrain vascular lesion (paramedian branches of the posterior cerebral artery) damaging the **red nucleus** and **medial lemniscus** together with the emerging oculomotor fibres, producing ipsilateral CN III palsy with contralateral hemianaesthesia and involuntary movements (tremor/chorea) of the opposite limbs — contrasted with **Weber syndrome**, in which only the crus cerebri (motor fibres) is involved.
- ▶ **Lateral pontine infarcts** (short circumferential branches of the basilar artery) can involve the trigeminal nerve, medial lemniscus and middle cerebellar peduncle together, producing contralateral hemianaesthesia with ipsilateral facial sensory loss and ataxia.
- ▶ **Thalamic (VPL) infarction** produces the **Dejerine–Roussy thalamic pain syndrome** — initial contralateral hemianaesthesia followed, after weeks to months, by spontaneous burning pain/dysaesthesia on the same side.
- ▶ **Bedside testing:** vibration sense (tuning fork), joint-position sense, two-point discrimination and the **Romberg test** (positive — swaying with eyes closed, steady with eyes open — indicates a proprioceptive/DCML rather than a cerebellar deficit) assess the integrity of this pathway, e.g. in diabetic neuropathy, tabes dorsalis and subacute combined degeneration of the cord.

- ▶ **Radiological correlate:** the medial lemniscus is a key paramedian landmark on axial MRI/CT at medullary, pontine and midbrain levels; diffusion tensor tractography now permits its direct visualisation for planning thalamotomy, deep brain stimulation and brainstem biopsy so that it can be spared.

High-yield exam pointers

- ▶ Second-order sensory fibres of the **DCML (dorsal column–medial lemniscus) pathway**; formed by **internal arcuate fibres** decussating in the **lower (closed) medulla** as the sensory (lemniscal) **decussation**.
- ▶ Carries **conscious proprioception, vibration, fine touch and two-point discrimination** from the trunk/limbs (equivalent facial pathway = trigeminal lemniscus, via VPM).
- ▶ Relays in the **VPL nucleus of thalamus**; third-order fibres pass through the **posterior limb of internal capsule** to the **postcentral gyrus (areas 3, 1, 2)**.
- ▶ Position changes at each level: **flattened vertical band near the median raphe in the medulla** → **ventral tegmental band in the pons (joined by the trigeminal lemniscus)** → **a bundle dorsal to the substantia nigra in the midbrain**, always medial-most of the three lemnisci.
- ▶ Somatotopy: leg fibres initially ventral/medial, arm fibres dorsal, reorganising to a **cervical-medial to sacral-lateral** arrangement by pontine level.
- ▶ **Medial medullary (Dejerine) syndrome** = pyramid + hypoglossal nucleus + medial lemniscus (contrast with lateral medullary/Wallenberg syndrome, where it is spared).
- ▶ Lesion **below** the sensory decussation → ipsilateral loss; lesion **above** it (including the medial lemniscus itself) → contralateral loss — the key localising principle.
- ▶ Tested clinically by vibration sense, joint position sense, two-point discrimination and the **Romberg test**.
- ▶ A recurrently asked RGUHS Paper IV short note — always be ready to draw the pathway and its brainstem cross-sections.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Anatomy Vol 3 6e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3–4 8e.



Describe the pyramidal tract in detail

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

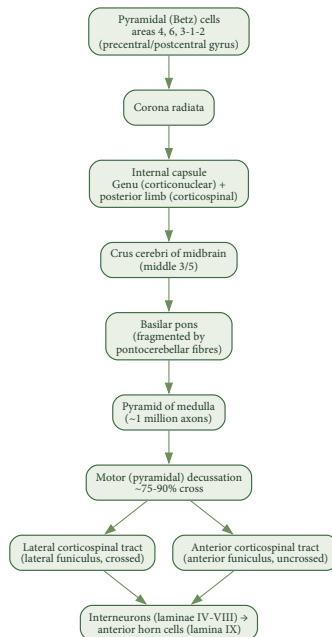
Definition / Introduction The **pyramidal tract** is the principal upper-motor-neuron pathway for voluntary movement, comprising the **corticospinal tract** (cortex to spinal cord anterior horn cells) and the **corticonuclear (corticobulbar) tract** (cortex to cranial nerve motor nuclei). It is named for the medullary **pyramid**, the ventral swelling formed by these fibres in the lower medulla. Each pyramid contains about **one million axons**, mostly small, myelinated, and slow-conducting, with only a small minority — the largest-diameter, fastest fibres — arising from the giant **Betz cells** of area 4. The tract provides speed, precision and agility to skilled voluntary movement, especially of the digits, and its interruption anywhere in its course produces an **upper motor neuron (UMN)** pattern of paralysis.

1. Origin

- ▶ Fibres arise from **pyramidal cells in the fifth layer of the cerebral cortex**, classically taught as roughly one-third each from:
 - the **primary motor cortex (area 4)** — includes the giant pyramidal cells of **Betz**;
 - the **premotor and supplementary motor cortex (area 6)**;
 - the **postcentral gyrus/parietal cortex (areas 3, 1, 2, and area 5)** — these fibres do not control movement but regulate ascending sensory (proprioceptive) input, terminating on the nucleus gracilis, nucleus cuneatus and substantia gelatinosa.
- ▶ Because the **precentral gyrus** is somatotopically organised (the **motor homunculus**), the face is represented inferolaterally and the leg superiorly/on the medial surface of the hemisphere.
- ▶ The fibres arising from the motor and premotor cortex constitute the **corticospinal** component (destined for spinal anterior horn cells); those accompanying them but ending on cranial nerve motor nuclei constitute the **corticonuclear (corticobulbar)** component.

2. Course

- ▶ Fibres converge from the cortex into the **corona radiata**, then pass through the **internal capsule** — corticonuclear fibres in the **genu**, corticospinal fibres in the **anterior two-thirds of the posterior limb** (somatotopically arranged: cervical fibres near the genu, lower-limb fibres more posterior).
- ▶ They descend through the **middle three-fifths of the crus cerebri** of the midbrain (cervical fibres medial, leg fibres lateral; corticonuclear fibres lie just medial to the corticospinal fibres).
- ▶ On entering the **basilar part of the pons**, the compact tract is broken up into numerous smaller bundles by the transversely running **pontocerebellar fibres** and pontine nuclei.
- ▶ The bundles regroup near the ventral surface of the **upper medulla** to form the pyramid, giving the tract its alternative name.
- ▶ Corticonuclear fibres leave at successive brainstem levels (midbrain, pons, medulla) to cross and synapse — directly or via interneurons — with the **motor nuclei of the cranial nerves**.



Describe the pyramidal tract in detail

3. Decussation and spinal divisions

- ▶ Just above the spinomedullary junction, the majority of fibres (commonly cited as ~75-90%, most texts state ~75-80%) cross the midline in the **motor (pyramidal) decussation** and continue caudally as the **lateral corticospinal tract**.
- ▶ The remainder continue **uncrossed** as the **anterior (ventral) corticospinal tract**; most of these eventually cross segmentally through the **anterior white commissure** before terminating, while a small residual component remains permanently uncrossed, contributing to **bilateral cortical control of neck and trunk musculature**.
- ▶ Lesions of the corticospinal tract **above** the decussation produce **contralateral** paralysis; lesions **below** the decussation (i.e., in the spinal cord) produce **ipsilateral** paralysis.

Feature	Lateral corticospinal tract	Anterior (ventral) corticospinal tract
Crossing	Crossed in the medulla (majority of fibres)	Initially uncrossed; crosses segmentally in the anterior white commissure
Location in cord	Lateral funiculus (lateral white column)	Anterior funiculus, close to the ventral median fissure
Extent	Descends the entire length of the cord to sacral segments	Diminishes progressively; usually disappears by mid-thoracic level
Function	Fine, skilled movements of distal limb muscles (hands, fingers, feet)	Bilateral control of axial/proximal trunk musculature

4. Corticonuclear (corticobulbar) tract

- ▶ Fibres run with the corticospinal tract (genu of the internal capsule; medial part of the crus cerebri) and leave at multiple brainstem levels.

- ▶ Most **cross** to synapse (directly or via interneurons) with contralateral cranial nerve motor nuclei; many nuclei also receive a **bilateral (ipsilateral + contralateral)** supply — the exceptions of major clinical importance are the part of the **facial nucleus supplying the lower face** and the **hypoglossal nucleus (genioglossus)**, which receive predominantly **crossed (contralateral)** innervation only.
- ▶ This asymmetry explains why a **UMN (supranuclear) facial palsy spares the forehead** (bilaterally innervated) while an **LMN facial palsy** (e.g., Bell's palsy) paralyzes the entire half of the face.

5. Termination

- ▶ Both divisions terminate in the **spinal grey matter**, chiefly via **internuncial (interneurons) in laminae IV-VIII** at the base of the dorsal and ventral grey columns, which relay to **alpha and some gamma motor neurons**.
- ▶ A smaller proportion of the largest, fastest-conducting fibres **synapse directly** on anterior horn cells (lamina IX) — particularly those controlling the small distal muscles of the hand and foot, conferring maximal speed and precision for skilled digital movement.
- ▶ Termination is somatotopically graded: the tract diminishes in size as it descends, fibres peeling off to synapse at each successive spinal level.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce a **diagrammatic parasagittal/coronal** scheme of the course of the corticospinal tract, labelling in sequence:

- ▶ Pyramidal (Betz) cells in the precentral gyrus (motor cortex, area 4) with the motor homunculus.
- ▶ **Corona radiata** → **internal capsule** (mark genu vs posterior limb).
- ▶ **Crus cerebri** of the midbrain (middle three-fifths).
- ▶ **Basilar pons**, showing fragmentation by transverse pontocerebellar fibres.
- ▶ **Pyramid** on the ventral medulla.
- ▶ **Decussation of the pyramids** at the spinomedullary junction.
- ▶ A cross-section of the spinal cord showing the **lateral corticospinal tract** (lateral funiculus) and **anterior corticospinal tract** (anterior funiculus), with termination on anterior horn cells.

 Fig 20.10 — Pyramidal tracts (corticospinal tract is shown in red and corticobulbar in blue) (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.891)

6. Arterial supply along the course of the tract

Because the pyramidal tract is frequently involved in cerebrovascular disease, its blood supply at each level is high-yield:

Level	Principal supply
Motor cortex/corona radiata	Middle cerebral artery (cortical branches; the medial "leg area" via the anterior cerebral artery)

Level	Principal supply
Internal capsule	Lateral (lenticulostriate) striate branches of the middle cerebral artery (posterior limb); anterior choroidal artery (retrolenticular part); recurrent artery of Heubner (a branch of the anterior cerebral artery, genu/anterior limb)
Midbrain (crus cerebri)	Branches of the posterior cerebral, posterior communicating and superior cerebellar arteries
Pons	Paramedian and short circumferential branches of the basilar artery
Medulla (pyramid)	Anterior spinal artery and branches of the vertebral artery
Spinal cord (corticospinal tracts)	Anterior spinal artery (via sulcal/sulcocommissural branches, ventral two-thirds of the cord)

Applied / Clinical anatomy

- **Upper vs lower motor neuron lesion** — a cardinal exam comparison:

Feature	UMN lesion (pyramidal tract)	LMN lesion
Tone	Spastic (hypertonia)	Flaccid (hypotonia)
Deep tendon reflexes	Exaggerated, clonus	Diminished/absent
Muscle bulk	Little/no atrophy (disuse only)	Marked atrophy, fasciculations
Plantar response	Babinski sign present (extensor)	Normal (flexor) or absent
Superficial abdominal/cremasteric reflexes	Absent	Preserved (unless the reflex arc itself is interrupted)
Fine skilled movement	Lost (especially distal)	Lost, with weakness of the specific muscle

- **Babinski sign** is physiologically present up to the end of the first year of life, because the corticospinal tract is not yet fully myelinated.
- **Capsular hemiplegia**: because corticospinal, corticonuclear and thalamocortical fibres are extremely tightly packed in the internal capsule, even a small lesion here (classically rupture of a **lenticulostriate/lateral striate branch of the middle cerebral artery**, eponymously **Charcot's artery of cerebral haemorrhage**) produces a dense, roughly equal contralateral hemiplegia of face, arm and leg, unlike a cortical lesion which tends to affect one body part predominantly (per the homunculus). Thrombosis of **Heubner's recurrent artery** (a branch of the anterior cerebral artery supplying the anterior limb/genu region) characteristically causes a contralateral upper-limb monoplegia.
- **Alternating (crossed) hemiplegia**: a unilateral brainstem lesion damaging the corticospinal/corticonuclear tract together with a cranial nerve nucleus or nerve at that level produces **ipsilateral cranial nerve palsy with contralateral hemiplegia** — it precisely localises the level of a brainstem lesion (e.g., midbrain, pons, medulla).

- ▶ **Site-of-lesion rule:** lesions above the pyramidal decussation cause contralateral paralysis; lesions at or below the decussation (spinal cord) cause ipsilateral paralysis.
- ▶ **Wallerian degeneration:** a corticospinal tract lesion (e.g., capsular infarct) leads to predictable anterograde degeneration of the distal axon, visible on MRI/DTI within the pyramid and cord — used to assess lesion severity and prognosticate recovery.

Recent advances

According to PubMed:

- ▶ Diffusion tensor imaging shows that **Wallerian (secondary) degeneration of the corticospinal tract** after stroke follows a predictable time course, with early diffusion changes detectable within days and conventional T2/FLAIR signal change emerging over subsequent weeks — informing prognostic MRI protocols after capsular/pontine infarcts (Zedde M et al., *J Clin Med* 2024;13(7):1969).
- ▶ Genetic depletion of **lipin1** in corticospinal motor neurons markedly enhances axon regeneration after experimental spinal cord injury by coordinating mTOR/STAT3 and lipid-metabolism signalling, identifying a novel druggable target for promoting corticospinal tract regrowth (Chen W et al., *Proc Natl Acad Sci USA* 2024;121(39):e2404395121, PMID 39292743).
- ▶ **TMS-evoked motor evoked potentials (MEPs)** are increasingly used to directly assess residual corticospinal tract conduction after stroke, with presence/absence and latency of ipsilesional MEPs guiding individualised neurorehabilitation prescription (Kumar S et al., *Front Hum Neurosci* 2024;18:1408818, PMID 39290568).
- ▶ A 2026 scoping review synthesising neurophysiological (MEP) and structural imaging (CST lesion load, fractional anisotropy) biomarkers concludes that combining these measures improves prediction of post-stroke motor recovery and may help personalise rehabilitation planning (Cieřlik B et al., *Appl Sci* 2026;16(1):317).

High-yield exam pointers

- ▶ Pyramidal tract = **corticospinal tract** (to spinal cord) + **corticonuclear/corticobulbar tract** (to cranial nerve motor nuclei); named for the medullary pyramid, ~1 million axons per side.
- ▶ Internal capsule: corticonuclear in the **genu**, corticospinal in the **anterior two-thirds of the posterior limb**.
- ▶ Midbrain: **middle three-fifths of the crus cerebri**; pons: fragmented by pontocerebellar fibres; medulla: reforms as the pyramid.
- ▶ ~75-90% **cross at the motor (pyramidal) decussation** → **lateral corticospinal tract** (whole cord length, distal limb movement); uncrossed fibres → **anterior corticospinal tract** (disappears by mid-thoracic level, axial muscles, crosses segmentally).
- ▶ Termination: mostly via interneurons (laminae IV-VIII); a small direct projection to anterior horn cells (lamina IX) subserves fine digital movement.
- ▶ Lesion above decussation → **contralateral** paralysis; lesion below (cord) → **ipsilateral** paralysis.
- ▶ UMN lesion signs: spasticity, hyperreflexia, **Babinski sign**, absent superficial (abdominal/cremasteric) reflexes, no significant wasting.

- ▶ **Lenticulostriate artery rupture** → **capsular hemiplegia**; unilateral brainstem lesion → **alternating (crossed) hemiplegia**.
- ▶ UMN facial palsy spares the forehead (bilateral corticonuclear supply to upper face); LMN facial palsy paralyses the whole half of the face.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Anatomy Vol 3 6e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3-4 8e.



Describe the Spinothalamic tracts in detail

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction The **spinothalamic tracts** are the principal ascending sensory pathways of the spinal cord that convey **pain, temperature, crude (non-discriminative) touch and pressure** from the trunk and limbs to the thalamus. They comprise two components — the **lateral spinothalamic tract** (pain and temperature) and the **anterior (ventral) spinothalamic tract** (crude touch and pressure) — which lie side by side in the cord and are together termed the **anterolateral system**. Each is a classical **three-neuron, mostly crossed** pathway: a first-order neuron in the dorsal root ganglion, a second-order neuron in the posterior grey column that decussates and ascends as the tract proper, and a third-order neuron in the thalamus that relays to the somatosensory cortex. Because the second-order fibres cross early and ascend contralaterally, unilateral cord lesions and cordotomy produce sensory loss on the **opposite side of the body**, a fact of major clinical importance.

1. First-order neuron and receptors

- ▶ **Receptors:** free nerve endings (pain, temperature — via A δ and C fibres) and less specialised cutaneous receptors (crude touch, pressure).
- ▶ **Cell body:** unipolar neuron in the **posterior (dorsal) root ganglion**.
- ▶ **Central process:** enters the spinal cord through the **lateral division of the posterior nerve root**, ascends or descends 1–2 segments in the **dorsolateral tract (fasciculus)** of Lissauer, and then synapses with the second-order neuron in the posterior grey column of the **same or an adjoining segment**.

2. Second-order neuron — site of origin (Rexed laminae)

The cell bodies of origin of the spinothalamic tracts are distributed through several **Rexed laminae** of the spinal grey matter, with a broadly different emphasis for the two components:

Component	Principal laminae of origin	Modality
Lateral spinothalamic tract	Lamina I (marginal zone/nucleus posteromarginalis) and laminae IV–VIII, greatest concentration in laminae VI and VII; relay through the substantia gelatinosa (lamina II)	Pain, temperature
Anterior (ventral) spinothalamic tract	Mainly laminae VII and VIII (ventral grey column)	Crude touch, pressure

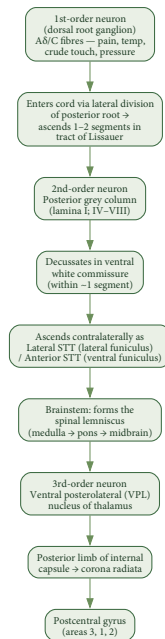
- ▶ Lamina I cells (apical dorsal-horn cells) project directly and prominently to the thalamus and respond maximally to noxious stimuli.
- ▶ There is marked **convergence** of different afferent modalities on to individual tract cells — receptive-field specificity comparable to the dorsal-column system is absent.

3. Decussation

- ▶ Axons of the second-order neurons cross to the **opposite side within the ventral (anterior) white commissure**, just anterior to the central canal.
- ▶ **Pain and temperature fibres cross promptly**, typically within about **one spinal segment** of entry; other modalities may ascend several segments obliquely before crossing.
- ▶ Fibres reach their final position in the contralateral white column a few segments above their entry level — the basis of the surgical rule that a **cordotomy is placed several segments below** the desired analgesic level.
- ▶ A small proportion (~10%, mostly upper cervical) remains **uncrossed**.

4. Course in the spinal cord and somatotopic lamination

- ▶ The **lateral spinothalamic tract** occupies the **lateral funiculus**, medial to the ventral spinocerebellar tract.
- ▶ The **anterior (ventral) spinothalamic tract** lies in the **ventral (anterior) funiculus**, medial to the exit of the ventral nerve roots and dorsal to the vestibulospinal tract, which it overlaps.
- ▶ Both tracts are **segmentally laminated**: fibres that cross at any level join the deep (medial) aspect of fibres that have already crossed from lower levels, so that in the anterolateral system, **sacral fibres come to lie most laterally (outermost) and cervical fibres most medially (innermost)** — the reverse of the lamination in the posterior white column (dorsal-column–medial-lemniscus system), where sacral fibres lie medial and cervical fibres lateral.



Describe the Spinothalamic tracts in detail

5. Course through the brainstem

On reaching the lower brainstem the ventral and lateral components separate: fibres of the **anterior spinothalamic tract** join the **medial lemniscus**, while fibres of the **lateral spinothalamic tract** continue as the **spinal lemniscus**.

Level	Position / relations
Medulla	The spinal lemniscus (anterolateral system) lies in the ventrolateral medulla , together with the spinocerebellar, spinotectal, vestibulospinal and rubrospinal tracts; it is limited dorsally by the spinal tract and nucleus of the trigeminal nerve — the region infarcted in lateral medullary (Wallenberg) syndrome
Pons	Lies in the ventral pontine tegmentum, lateral to the medial lemniscus; here it is joined by the trigeminal lemniscus (crossed fibres from the contralateral spinal trigeminal nucleus, carrying pain/temperature from the face) — together forming a transverse band, medial-to-lateral: medial lemniscus, trigeminal lemniscus, anterolateral system, lateral lemniscus
Midbrain	The spinal lemniscus lies dorsolateral to the medial lemniscus, curving as a band dorsomedial to the substantia nigra; fibres are further somatotopically arranged — lower-limb (pain/temperature) fibres lie dorsal , trunk and upper-limb fibres more ventral

- Somatotopy is preserved throughout the medulla and pons.

- ▶ Both the spinal and medial lemnisci ascend together to end predominantly in the **ventral posterolateral (VPL) nucleus** of the thalamus, with additional projections to the **centrolateral intralaminar nucleus**.
- ▶ Collaterals (**spinoreticular fibres**) leave the tract to terminate in the **brainstem reticular formation**, mediating arousal and the diffuse, poorly localised, affective component of pain.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce a **transverse section of the spinal cord** in the mid-cervical region, showing:

- ▶ Grey matter (H-shaped) with posterior, lateral and anterior grey columns and the **posterior root/dorsal root ganglion** entering laterally.
- ▶ **Lateral spinothalamic tract** in the lateral white column (medial to the ventral spinocerebellar tract) and **anterior spinothalamic tract** in the anterior white column (medial to exiting ventral roots).
- ▶ Second-order fibres **crossing obliquely through the ventral (anterior) white commissure**, anterior to the central canal.
- ▶ Somatotopic lamination arrows: **sacral fibres lateral, cervical fibres medial** within the anterolateral system.
- ▶ Label pain/temperature vs light-touch/pressure fibre streams (as in the figure below).

□ Fig 4.13 — Transverse section of the spinal cord showing the origin of the main ascending sensory tracts (Snell — *Clinical Neuroanatomy* — 7e, p.165)

6. Termination — third-order neuron and further connections

- ▶ Third-order neurons lie chiefly in the **ventral posterolateral (VPL) nucleus of the thalamus**; a smaller contingent of fibres, especially from deeper (laminae VII–VIII) neurons, projects to the **centrolateral intralaminar nucleus**.
- ▶ Thalamocortical axons from VPL pass through the **posterior limb of the internal capsule** and the **corona radiata** to reach the **postcentral gyrus** (**primary somatosensory cortex, Brodmann areas 3, 1, 2**) in a somatotopically organised manner (the sensory homunculus), conveying the discriminative aspects of pain — its intensity and localisation.
- ▶ Projections to the **intralaminar nuclei** and, via spinoreticular collaterals, to the **reticular formation and hypothalamus/limbic structures**, subserve the diffuse arousal and affective-emotional component of pain rather than its precise localisation.

7. Functions carried

Tract	Modality
Lateral spinothalamic tract	Pain and temperature
Anterior (ventral) spinothalamic tract	Crude (non-discriminative) touch and pressure

Discriminative (fine) touch, vibration, and conscious proprioception are **not** carried by the spinothalamic system — they ascend instead in the **fasciculus gracilis and fasciculus cuneatus** (dorsal-column–medial-lemniscus pathway), a distinction that underlies the classic dissociated sensory losses seen clinically.

Applied / Clinical anatomy

- ▶ **Brown-Séquard syndrome** (spinal cord hemisection, e.g. stab injury, fracture-dislocation): produces **contralateral loss of pain and temperature sensation beginning 1–2 segments below the level of the lesion** (because decussating fibres entering at the lesion level are still crossing), together with **ipsilateral spastic paresis and loss of proprioception/vibration/fine touch** — the classic dissociated hemi-cord picture.
- ▶ **Syringomyelia**: gliosis and cavitation expanding from the central canal interrupt the **decussating second-order fibres in the anterior grey and white commissure** at the level of the lesion (typically cervical), producing a **bilateral, segmental ("cape-like") loss of pain and temperature with preservation of touch and proprioception** (dorsal columns spared) — the hallmark dissociated sensory loss.
- ▶ **Clinical significance of segmental lamination**: because sacral fibres lie most peripherally (laterally) in the anterolateral tract, **external (extramedullary) compression** of the cord (e.g. extradural tumour) characteristically causes loss of pain/temperature **first in the sacral dermatomes**, spreading upward as compression increases — in contrast to an **intramedullary (central) lesion**, which characteristically **sparing the sacral segments** ("sacral sparing") because the peripherally placed sacral fibres are affected last.
- ▶ **Anterolateral cordotomy**: surgical (open or percutaneous CT/radiofrequency-guided) division of the anterolateral quadrant for intractable pain (e.g. terminal malignancy); the cut is made a few segments **below** the desired analgesic level because ascending fibres cross obliquely before settling into the tract.
- ▶ **Lateral medullary (Wallenberg) syndrome**: occlusion of the posterior inferior cerebellar artery (or vertebral artery) infarcts the ventrolateral medulla, damaging both the **spinal lemniscus** and the **spinal trigeminal tract/nucleus**, producing **contralateral loss of pain/temperature over the body together with ipsilateral loss over the face** — a classic crossed sensory deficit.
- ▶ **Central post-stroke (thalamic) pain**: infarction or haemorrhage involving the VPL nucleus or its spinothalamic afferents can produce delayed, severe contralateral dysaesthesia and allodynia (Dejerine-Roussy/thalamic pain syndrome).
- ▶ Because discriminative touch and proprioception travel separately in the dorsal columns, **tabes dorsalis** and posterior-column lesions leave pain and temperature intact, while spinothalamic lesions leave joint position sense and vibration intact — testing both modalities together localises the level and side of a cord lesion clinically.

Recent advances

According to PubMed:

- ▶ A 2025 review synthesising a century of cordotomy data confirms the human spinothalamic tract decussates within about two segments of cord entry and is somatotopically arranged, lower-limb fibres dorsolateral and upper-body fibres ventromedial; DTI of cordotomy lesions shows higher mean diffusivity correlates with better postoperative pain relief, a candidate imaging biomarker for surgical planning (Allam et al., *Brain Communications* 2025;7(3):fcf237) [DOI](<https://doi.org/10.1093/braincomms/fcaf237>).

- ▶ Deep single-nucleus RNA sequencing of Phox2a-lineage neurons has identified **five molecularly distinct classes of anterolateral-system (spinothalamic) neurons** — three in laminae I–III, two in deeper laminae — refining the classical laminar model of spinothalamic cell origin (Bell et al., *Proc Natl Acad Sci USA* 2024;121(23):e2314213121) [DOI](https://doi.org/10.1073/pnas.2314213121).
- ▶ Spinal-cord DTI in chronic neck and shoulder pain shows localised fractional-anisotropy reduction and raised mean diffusivity in specific cervical spinothalamic-tract segments, correlating with pain intensity, duration and psychological distress, supporting DTI as an objective marker of ascending nociceptive-pathway injury (Qiu et al., *Front Neurosci* 2025;19:1460881, PMID 40012685; Qiu et al., *Front Neurosci* 2025;18:1485045, PMID 39834699).
- ▶ Diffusion tensor tractography can visualise spinothalamic tract disruption (reduced tract volume, partial fibre loss) underlying **central post-stroke pain**, supporting its use as a diagnostic adjunct after thalamic/brainstem stroke (Djojoseputro et al., *Postep Psychiatr Neurol* 2025;34(1):44-53, PMID 40376283).

High-yield exam pointers

- ▶ **Anterolateral system** = lateral spinothalamic tract (pain, temperature) + anterior/ventral spinothalamic tract (crude touch, pressure); a classic **3-neuron pathway**.
- ▶ 2nd-order neuron cell bodies mainly in **lamina I** and **laminae IV–VIII** (lateral STT) or **laminae VII–VIII** (anterior STT); crosses in the **ventral white commissure**.
- ▶ Somatotopic lamination in the cord: **sacral fibres lateral**, **cervical fibres medial** (opposite of the dorsal columns) — basis of sacral sparing vs sacral-first loss in intramedullary vs extramedullary lesions.
- ▶ In the brainstem the tract becomes the **spinal lemniscus**; joined by the crossed **trigeminal lemniscus** for facial pain/temperature; both terminate mainly in the **VPL nucleus of thalamus** (plus centrolateral intralaminar nucleus).
- ▶ Third-order fibres reach the **postcentral gyrus** (areas 3, 1, 2) via the **posterior limb of the internal capsule**.
- ▶ **Brown-Séquard syndrome** — contralateral pain/temperature loss 1–2 segments below an ipsilateral hemisection.
- ▶ **Syringomyelia** — bilateral, segmental "cape-like" dissociated sensory loss from destruction of decussating fibres at the central canal.
- ▶ **Anterolateral cordotomy** is performed a few segments below the desired analgesic level because crossing fibres ascend obliquely before settling in the tract.
- ▶ **Wallenberg (lateral medullary) syndrome** — crossed sensory loss (contralateral body, ipsilateral face) from combined spinal lemniscus + spinal trigeminal tract infarction.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Human Neuroanatomy.



Give an account of nerve pathways involved in conduction of somatic pain. Discuss its clinical significance

Asked in: Paper IV Oct 2008 — RGUHS MD/MS Anatomy

Definition / Introduction Somatic pain is the noxious sensation arising from free nerve endings in skin, muscle, tendon, joint and periosteum, distinct from visceral pain arising from internal organs. It is conducted centrally by a three-neuron chain — the **anterolateral (spinothalamic) system** for the trunk and limbs, and the **trigeminothalamic pathway** for the face and oral cavity — culminating in the postcentral gyrus, cingulate and insular cortices. Two functionally distinct components exist: a fast, precisely-localised **neospinothalamic** component and a slow, poorly-localised, multisynaptic **paleospinothalamic** component. Knowledge of this pathway underlies the localisation of spinal cord lesions and the rationale of surgical and pharmacological pain relief.

1. Peripheral reception and conducting fibres

- ▶ **Receptors:** pain and thermal receptors are unencapsulated **free nerve endings**; they show little or no adaptation, allowing persistent tissue-damaging stimuli to remain signalled.
- ▶ **Two fibre types** carry nociceptive impulses from the periphery:
 - **A-delta fibres** — thinly myelinated, fast-conducting (6–30 m/sec) → mediate **fast, sharp, pricking, well-localised** pain (e.g., a pinprick), felt within ~0.1 second of the stimulus.
 - **C fibres** — unmyelinated, slow-conducting (0.5–2.0 m/sec) → mediate **slow, dull, burning, aching, poorly-localised** pain, felt after ~1 second and outlasting the stimulus.
- ▶ Chemical mediators sensitising or exciting free nerve endings include **bradykinin, histamine, serotonin, K⁺ ions, lactic acid and prostaglandins**; **substance P** lowers the pain threshold and is also the principal neurotransmitter released by C fibres centrally, while **glutamate** is the fast neurotransmitter of both A-delta and C fibres at their central synapse.

2. First-order neuron and its entry into the spinal cord

- ▶ Cell bodies of the first-order neurons lie in the **dorsal (posterior) root ganglion**.
- ▶ Their central processes enter through the **lateral division of the dorsal root**, reach the tip of the posterior grey column and bifurcate into short ascending and descending branches that run for one or two (up to several, for touch) segments as the **posterolateral tract (fasciculus) of Lissauer**.
- ▶ These fibres terminate by synapsing on second-order neurons in the posterior grey horn, principally in the **substantia gelatinosa** (Rexed lamina II), using glutamate and substance P as neurotransmitters.

3. Ascending pathways — the anterolateral (spinothalamic) system

The axons of the second-order neurons **decussate obliquely** in the anterior grey and white commissures (crossing over 1–3 segments above their level of entry) and ascend in the contralateral anterolateral white column. Classically two components are described, now often grouped together as the **anterolateral system**:

Feature	Lateral spinothalamic tract (neospinothalamic)	Anterior spinothalamic tract (component of paleospinothalamic system)
Modality carried	Pain and temperature	Crude/light touch and pressure
Fibres	Fast A-delta	Predominantly C-fibre relayed multisynaptically
Decussation	Within 1 segment, obliquely	Over several segments, obliquely
Course in brainstem	Joins spinal lemniscus with spinotectal tract; lies between inferior olivary nucleus and spinal trigeminal nucleus in medulla; lateral to medial lemniscus in midbrain tegmentum	Joins the medial lemniscus in the pons
Thalamic relay	Ventral posterolateral (VPL) nucleus — third-order neuron	VPL nucleus
Cortical projection	Through posterior limb of internal capsule and corona radiata to postcentral gyrus (areas 3, 1, 2), somatotopically organised (leg medial, face/hand lateral, inverted map)	Postcentral gyrus
Clinical character	Fast, sharp, well-localised pain	Crude touch (fine touch survives via posterior columns)

- ▶ Collateral branches of the ascending fibres are given off at every level to:
 - the **reticular formation** (spinoreticular tract) — activates the entire nervous system, maintains wakefulness, and mediates the affective/arousal component of pain;
 - the **superior colliculus of the midbrain** (spinotectal tract) — mediates spinovisual (turning the eyes/head toward a painful stimulus) reflexes;
 - the **inferior olivary nucleus** (spino-olivary tract) — indirect route to the cerebellum.
- ▶ This multisynaptic, phylogenetically older route — via reticular formation, periaqueductal grey and non-specific (intralaminar) thalamic nuclei to the **cingulate gyrus** (affective-emotional interpretation) and **insular cortex** (autonomic/visceral interpretation of pain) — is the **paleospinothalamic system** and is responsible for conducting **slow, burning, diffuse, poorly-localised** pain; it explains why deep/visceral pain (e.g., osteoarthritis of the hip) cannot be pinpointed the way a pinprick can.

- ▶ **Segmental lamination** within the tract: sacral fibres are added most laterally, cervical fibres most medially (opposite of the lemniscal system in the posterior columns) — clinically important, as extrinsic cord compression classically causes sacral sparing to be lost last, or first depending on the lesion's plane.

4. Trigeminal pathway for pain from the face and head

Pain, temperature and crude touch from the face, forehead, cornea, oral and nasal mucosa are carried by an exactly analogous three-neuron chain, the **ventral trigeminothalamic tract**:

- ▶ **First-order neuron**: cell body in the **trigeminal (Gasserian) ganglion**; central fibres descend as the **spinal tract of the trigeminal nerve** to synapse in the **spinal nucleus of the trigeminal nerve** (its pars caudalis is the principal pain/temperature relay, continuous with the substantia gelatinosa of the upper cervical cord).
- ▶ **Second-order neuron**: axons cross the midline and ascend as the **ventral trigeminothalamic tract**, closely applied to the medial lemniscus, to relay in the contralateral **ventral posteromedial (VPM) nucleus** of the thalamus.
- ▶ **Third-order neuron**: from VPM through the posterior limb of the internal capsule to the face area of the **postcentral gyrus** (areas 3, 1, 2).
- ▶ (Fine touch/pressure from the face travels instead in the **dorsal trigeminothalamic tract** via the principal sensory nucleus, largely uncrossed, to the ipsilateral VPM — the facial counterpart of the posterior-column system.)

□ Fig 3.13 — Spinothalamic pathways (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.458)

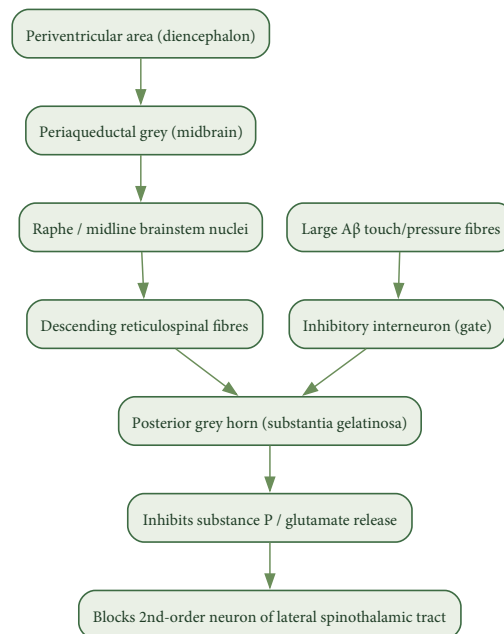
DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A transverse section series (spinal cord → medulla → pons → midbrain → thalamus → cerebrum) with the pain pathway labelled at each level:

- ▶ **First-order neuron** — dorsal root ganglion → posterolateral tract of Lissauer → substantia gelatinosa (posterior grey horn)
- ▶ **Second-order neuron** — decussation in anterior white/grey commissure → **lateral spinothalamic tract** in contralateral anterolateral white column
- ▶ Brainstem course — joins spinotectal tract to form the **spinal lemniscus**; medulla (between inferior olive and spinal trigeminal nucleus) → pons → midbrain tegmentum (lateral to medial lemniscus)
- ▶ **Third-order neuron** — relay in **ventral posterolateral (VPL) nucleus** of thalamus → posterior limb of internal capsule → corona radiata → **postcentral gyrus** (areas 3, 1, 2)
- ▶ Collaterals labelled to reticular formation (spinoreticular) and superior colliculus (spinotectal)
- ▶ Alongside, the **trigeminothalamic limb**: trigeminal ganglion → spinal nucleus of V → cross → VPM nucleus → postcentral gyrus (face area)

5. Central modulation of pain

- ▶ **Gate-control theory** (Melzack and Wall): large, myelinated, fast A β afferents carrying non-painful touch/pressure activate inhibitory interneurons in the substantia gelatinosa that "close the gate" on transmission from small pain fibres (A δ /C) to the projection neuron — the physiological basis of relief by massage, rubbing an injury, TENS and acupuncture.
- ▶ **Descending analgesic (endogenous opioid) system**: stimulation of the **periventricular area of the diencephalon**, the **periaqueductal grey matter of the midbrain** and midline brainstem (raphe) nuclei activates descending **reticulospinal fibres** that synapse on posterior-horn pain-transmission cells; **enkephalins, endorphins and serotonin** here inhibit release of substance P/glutamate from the primary afferent terminal, suppressing both fast pricking and slow burning pain — the rationale for opioid analgesics acting at spinal and supraspinal sites.



Give an account of nerve pathways involved in conduction of somatic pain. Discuss its clinical significance

Applied / Clinical anatomy

- ▶ **Lateral spinothalamic tract lesion:** contralateral loss of pain and temperature 1–2 segments below the level of a cord lesion; the patient fails to respond to pinprick or distinguish hot/cold, while fine touch, vibration and proprioception (posterior columns) are preserved.
- ▶ **Brown-Séquard syndrome** (hemisection of the cord — trauma, stab wound, tumour): ipsilateral spastic paraplegia and loss of posterior-column modalities below the lesion, ipsilateral LMN signs/anaesthesia at the lesion level, but **contralateral loss of pain and temperature** 2–3 segments below the lesion (because the crossed lateral spinothalamic fibres of the *opposite* side are cut).
- ▶ **Syringomyelia:** cavitation around the central canal (commonly cervical) interrupts the decussating fibres in the anterior white/grey commissure **bilaterally**, giving a characteristic **"cape" or "shawl"-distribution dissociated sensory loss** — pain and temperature lost, but tactile discrimination, vibration and proprioception preserved (posterior columns spared); patients present with painless burns of the fingers.
- ▶ **Tabes dorsalis** (neurosyphilis): destroys the posterior roots, causing lightning pains, loss of deep pain (calf/Achilles compression), sensory ataxia and areflexia — a useful contrast lesion for the pain pathway question.
- ▶ **Surgical relief of intractable pain:** **posterior rhizotomy** divides the dorsal root; **anterolateral cordotomy** (commonly performed in the cervical or upper thoracic cord) divides the lateral spinothalamic tract in the anterolateral quadrant — effective because pain fibres cross low and ascend contralaterally 2–3 segments higher than their level of entry, so the cut must be made a few segments above the desired analgesic level.
- ▶ **Thalamic syndrome (Dejerine–Roussy):** infarction of the thalamogeniculate branch of the posterior cerebral artery (involving VPL) causes contralateral pansensory loss followed, on recovery, by severe, spontaneous, intractable **thalamic pain** ("anaesthesia dolorosa") disproportionate to the stimulus, with transient hemiparesis and homonymous hemianopia.

- ▶ **Referred pain:** visceral (and some somatic) afferents converge on the same second-order neurons as cutaneous afferents of the corresponding dermatome, so visceral pain is felt in the somatic distribution of that spinal segment (e.g., cardiac pain referred to the left arm/chest wall, dental pain referred along other branches of the trigeminal nerve, dural pain of the anterior/posterior cranial fossa referred to the forehead/occiput via ophthalmic V₁/upper cervical nerves).
- ▶ **Pharmacological correlates:** NSAIDs act by reducing prostaglandin synthesis at the free nerve ending; local anaesthetics block peripheral nerve conduction; opioids act on receptors in the posterior grey horn and brainstem analgesic centres; intrathecal/epidural morphine exploits the spinal site of action for chronic cancer pain.

High-yield exam pointers

- ▶ Pain/temperature = **lateral spinothalamic tract**; crude touch/pressure = **anterior spinothalamic tract**; together = the **anterolateral system**.
- ▶ Three-neuron chain: dorsal root ganglion (1st) → substantia gelatinosa/posterior horn (2nd, crosses) → **VPL** of thalamus (3rd) → postcentral gyrus.
- ▶ Decussation occurs in the **anterior white/grey commissure**, 1–3 segments above the level of entry — the anatomical basis for cordotomy level selection.
- ▶ Face pain travels by an exactly parallel route: trigeminal ganglion → spinal nucleus of V → cross → **VPM** → postcentral gyrus (face area).
- ▶ A-delta = fast/sharp/localised pain; C fibres = slow/burning/diffuse pain; substance P and glutamate are the key neurotransmitters.
- ▶ Syringomyelia = bilateral, dissociated (pain/temperature lost, touch spared), "cape" distribution — due to commissural fibre involvement.
- ▶ Brown-Séquard = contralateral pain/temperature loss + ipsilateral posterior-column and corticospinal loss.
- ▶ Gate-control theory and the descending PAG–raphe–enkephalin system are the two physiological mechanisms of pain modulation.
- ▶ Cordotomy divides the anterolateral quadrant; Dejerine–Roussy (thalamic) syndrome follows VPL infarction (thalamogeniculate artery).

SOURCE & COVERAGE

Snell — Clinical Neuroanatomy (7e); BD Chaurasia — Human Anatomy Vol 3–4 (8e); Vishram Singh — Clinical Neuroanatomy (4e); IB Singh — Textbook of Human Neuroanatomy; Gray's Anatomy (Standring) 41e.



Optic radiation

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction The optic radiation (geniculocalcarine tract) is the fourth-order (thalamocortical) limb of the visual pathway, carrying visual impulses from the lateral geniculate body (LGB) of the thalamus to the primary visual cortex (area 17) in the walls of the calcarine sulcus of the occipital lobe. It is the final relay of the retino-geniculo-cortical pathway (retina → optic nerve → optic chiasma → optic tract → LGB → optic radiation → visual cortex). Because it has an unusually long, curved intracranial course — through the internal capsule and then around the temporal horn/atrium of the lateral ventricle before reaching the occipital pole — it is frequently damaged by capsular strokes, temporal-lobe tumours and temporal-lobe epilepsy surgery, each producing a characteristic and localisable contralateral visual field defect. This makes it a high-yield structure for both gross/neuroanatomy and applied questions.

1. Origin

- ▶ Arises from the principal projection neurones of the six-layered **lateral geniculate body (LGB)**, the thalamic relay nucleus of the visual pathway; a smaller contribution of fibres also arises from the **pulvinar**.
- ▶ Because the LGB itself receives crossed fibres from the contralateral nasal hemiretina and uncrossed fibres from the ipsilateral temporal hemiretina (via the optic tract), every optic radiation carries information from the **contralateral half of the binocular visual field** only.

2. Course and relations

- ▶ Fibres leave the LGB and first traverse the **retrolentiform (retrolenticular) part of the internal capsule**, together with the posterior thalamic radiation; the lowest fibres additionally pass through the **sublentiform (sublenticular) part** of the internal capsule.
- ▶ Beyond the internal capsule the fibres enter the **sagittal stratum** of the temporal lobe, arching over the roof of the **inferior (temporal) horn** and the **atrium** of the lateral ventricle.
- ▶ Within the sagittal stratum the optic radiation lies along the depths of the superior and middle temporal gyri, about 2 cm from the brain surface — inferior to the vertical part of the superior longitudinal fasciculus, and always superior to the inferior temporal sulcus; it lies deep to the auditory radiation, and the **tapetum of the corpus callosum** lies directly beneath it, separating it from the ventricular ependyma.
- ▶ The fibres then sweep posteriorly through parietal and occipital white matter, passing superior and inferior to the posterior (occipital) horn as part of the posterior thalamic peduncle, to reach **both lips of the calcarine sulcus**.
- ▶ On coronal section the tract appears flat anteriorly and comma-shaped posteriorly.

3. The three functional bundles — Meyer's loop

The optic radiation is not a single homogeneous sheet; on the basis of its course and the retinal quadrant each part represents, it is described in three bundles:

Bundle	Course	Retinal fibres / field represented	Effect of an isolated lesion
Anterior bundle (Meyer's loop)	Fibres from the lower retinal quadrant sweep forward and downward, looping around the tip of the temporal (inferior) horn into the temporal lobe, before turning sharply backward to the occipital lobe	Lower retinal quadrant = upper (superior) field of vision	Temporal-lobe lesion → contralateral superior quadrantanopia ("pie in the sky")
Central bundle	Shortest, most direct course — through the retrolentiform internal capsule and sagittal stratum straight back to the central/posterior calcarine cortex	Central/macular retina	Macular field defect, often with sparing due to dual cortical supply
Posterior (parietal) bundle	Passes more directly backward, above the atrium and posterior horn, through parietal white matter	Upper retinal quadrant = lower (inferior) field of vision	Parietal-lobe lesion → contralateral inferior quadrantanopia ("pie on the floor")

- **Meyer's loop** is the clinically most important of the three: it is formed by fibres arising from the lateral part of the LGB, and its anterior-most fibres reach the region of the anterior temporal peduncle (though remaining lateral to it) before curving back — this places it close to the temporal pole, at direct risk during anterior temporal lobectomy.

□ Fig 7.12 — Meyer's loop (IB Singh — *Textbook of Human Neuroanatomy*, p.130)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Sketch a horizontal (axial) schematic of the visual pathway from the LGB to the occipital pole and label:

- ▶ **Lateral geniculate body (LGB)** — origin.
- ▶ **Retrolentiform and sublenticular parts of the internal capsule** — first relation.
- ▶ **Sagittal stratum**, arching over the **temporal (inferior) horn** and **atrium** of the lateral ventricle, with the **tapetum** labelled just deep to it.
- ▶ Three labelled bundles diverging from the main tract: **anterior bundle (Meyer's loop)** curving forward around the temporal horn; **central bundle** running directly back; **posterior (parietal) bundle** passing above the atrium.
- ▶ Termination at the **calcarine sulcus**, with **cuneus** labelled above (upper lip) and **lingual gyrus** labelled below (lower lip), surrounded by **area 17 (striate cortex)**, flanked by **areas 18 and 19 (visual association cortex)**.
- ▶ Mark the **occipital pole** as the site of macular representation.

4. Termination — visual cortex and retinotopic organisation

- ▶ Terminates in the **primary (striate) visual cortex, area 17**, which occupies the upper and lower lips and depths of the posterior calcarine sulcus and extends onto the **cuneus** (above) and **lingual gyrus** (below); it is surrounded by the visual association cortex (**areas 18 and 19**).
- ▶ Termination is in strict **point-to-point (retinotopic) fashion**: the **superior retinal quadrants** (representing the **inferior** half of the visual field) project to the cortex **above** the calcarine sulcus (cuneus); the **inferior retinal quadrants** (representing the **superior** half of the visual field) project to the cortex **below** the calcarine sulcus (lingual gyrus).
- ▶ The **peripheral retina** projects to the more **anterior** cortex; the **macula** occupies a disproportionately large area at the **occipital pole** — the anatomical basis of "macular sparing" seen with posterior cerebral artery infarcts (the pole has additional collateral supply from the middle cerebral artery).
- ▶ Fibres terminate mainly in **lamina IVA and IVC** of the six-layered striate cortex, whose layer IV bears the stria of Gennari (hence "striate" cortex).

5. Blood supply

- ▶ **Internal capsular part (retrolenticular/sublenticular)**: chiefly the **anterior choroidal artery**, a slender branch of the internal carotid artery — classically remembered as the "**artery of cerebral thrombosis**" because of its long, narrow subarachnoid course; contributions also come from the lateral striate (lenticulostriate) branches of the **middle cerebral artery** and from thalamogeniculate/posterolateral central branches of the **posterior cerebral artery**.
- ▶ **Temporal, parietal and occipital white-matter part, and the striate cortex itself**: the **calcarine branch of the posterior cerebral artery (PCA)**; the occipital pole additionally receives collateral supply from the **middle cerebral artery**, which is why macular vision is often spared in PCA-territory infarcts.

Applied / Clinical anatomy

- **Localising visual field defects** (classic teaching figure, lesion sites 1–8):

Site of lesion	Visual field defect
1. Optic nerve (complete)	Total (monocular) blindness of that eye
2. Central optic chiasma (e.g. pituitary tumour)	Bitemporal (heteronymous) hemianopia
3. Lateral chiasma, one side (e.g. ICA aneurysm)	Ipsilateral nasal hemianopia
4/5. Optic tract or entire optic radiation (complete)	Contralateral homonymous hemianopia
6. Upper lip of calcarine sulcus (cuneus)	Contralateral inferior quadrantanopia
7. Lower lip of calcarine sulcus (lingual gyrus)	Contralateral superior quadrantanopia
8. Meyer's loop (temporal lobe)	Contralateral superior quadrantanopia ("pie in the sky")
Occipital pole (complete, PCA territory)	Contralateral homonymous hemianopia with macular sparing (dual MCA collateral supply)

- **Vascular lesions:** a deep (capsular) stroke involving the anterior choroidal artery or lenticulostriate branches of the MCA produces a dense **contralateral homonymous hemianopia**, often accompanied by contralateral hemiplegia and hemianaesthesia because the corticospinal and thalamocortical sensory fibres run alongside the radiation in the internal capsule. **PCA occlusion** classically spares the macula because of MCA collateral flow to the occipital pole.
- **Temporal lobectomy** (e.g. for drug-resistant temporal-lobe epilepsy) risks transecting **Meyer's loop** as it sweeps around the temporal horn, producing a predictable **contralateral superior quadrantanopia** — the single most important applied fact examiners look for.
- **Parietal lobe surgery/tumours** involving the posterior bundle instead produce a **contralateral inferior quadrantanopia**.
- Radiologically, the optic radiation and Meyer's loop can be identified on cross-sectional/MR imaging as they run through the temporal horn region, relevant to pre-operative planning.

Recent advances

- Modern microsurgical/neuroimaging studies (Párraga et al 2012, cited in Gray's Anatomy 41e, using fibre dissection and 3-dimensional reconstruction) have refined the classical description of the three bundles and confirmed the close, variable relationship of Meyer's loop to the temporal pole — informing safer resection margins in anterior temporal lobectomy.
- **Diffusion tensor imaging (DTI) tractography** is now used pre-operatively in epilepsy and tumour surgery to individually map the course of the optic radiation and Meyer's loop, allowing the surgeon to tailor the corticectomy and reduce the incidence of post-operative superior quadrantanopia — a direct clinical application of the classical gross anatomy described above.
- Intra-operative subcortical stimulation mapping is increasingly used as an adjunct to DTI to confirm the radiation's course in real time during temporal and parietal lobe resections.

High-yield exam pointers

- ▶ Optic radiation = **geniculocalcarine tract**: LGB → area 17 (striate cortex) around the calcarine sulcus.
- ▶ Passes through the **retrolentiform** ($\pm$ **sublentiform**) **part of the internal capsule**, then the **sagittal stratum** around the temporal horn/atrium.
- ▶ **Three bundles**: anterior (**Meyer's loop** — upper field, loops through temporal lobe), central (macula), posterior/parietal (lower field).
- ▶ **Meyer's loop lesion** (temporal lobe) → **contralateral superior quadrantanopia** ("pie in the sky"); **parietal lesion** → **contralateral inferior quadrantanopia**.
- ▶ Retinotopy: cortex **above** calcarine sulcus (cuneus) = inferior visual field; **below** (lingual gyrus) = superior visual field; macula → occipital pole.
- ▶ Complete lesion of optic tract, radiation, or visual cortex → **contralateral homonymous hemianopia**; PCA infarcts classically show **macular sparing**.
- ▶ Blood supply: anterior choroidal artery (internal capsular part) + calcarine branch of PCA (cortical part); occipital pole has MCA collateral.
- ▶ Anterior temporal lobectomy is the classic surgical hazard to Meyer's loop.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh Textbook of Human Neuroanatomy; Vishram Singh Clinical Neuroanatomy 4e; Snell Clinical Neuroanatomy 7e.



Taste pathway

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction The taste (gustatory) pathway carries chemosensory information from taste buds in the tongue, soft palate, epiglottis and pharynx to the gustatory cortex. Functionally it is classified as a **special visceral afferent (SVA)** pathway — unlike vision and audition, which are special somatic afferent — and is subserved by three cranial nerves: the **facial (VII)**, **glossopharyngeal (IX)** and **vagus (X)**. It is a classical **three-neuron relay**: a first-order (ganglionic) neuron from the receptor to the brainstem, a second-order neuron in the **nucleus of the solitary tract (NTS)** that decussates and ascends to the thalamus, and a third-order thalamocortical neuron ending in the inferior postcentral gyrus and insula. Collateral connections to the hypothalamus, limbic system and salivatory nuclei mediate the autonomic and reflex components of taste.

Taste buds — the peripheral receptor

- ▶ **Taste buds** are microscopic, barrel/oval-shaped intra-epithelial chemoreceptor organs; there are about **10,000 taste buds** in the adult, sited in the epithelium of the tongue, soft palate and pharynx.

- Each bud contains two cell types: **gustatory (receptor) cells**, which bear microvilli projecting through a **gustatory pore** and are in synaptic contact with afferent nerve fibres, and non-innervated **supporting (sustentacular) cells**.
- On the tongue, taste buds are carried chiefly on the **fungiform papillae** (anterior two-thirds), the **circumvallate (vallate) papillae** (10–12 in number, arranged in a V in front of the sulcus terminalis, each bearing the largest number of taste buds), and the **foliate papillae** (postero-lateral tongue); **filiform papillae carry no taste buds** and are purely mechanical.
- The classical "tongue map" of four exclusive zones (sweet-tip, salt-anterolateral, sour-posterolateral, bitter-back) is now known to be an oversimplification — receptor cells for all taste qualities are represented, with varying sensitivity, over most of the tongue; bitter thresholds are the lowest (most sensitive), a plausible protective adaptation against ingesting toxic alkaloids.

First-order (primary) neurons — three afferent limbs

Region tasted	Peripheral nerve route	Ganglion (1st-order cell body)
Anterior two-thirds of tongue (excluding vallate papillae), floor of mouth	Lingual nerve → chorda tympani → facial nerve	Geniculate ganglion (facial nerve)
Soft palate	Greater petrosal nerve → pterygopalatine fossa → palatine nerves	Geniculate ganglion (facial nerve)
Posterior one-third of tongue, including circumvallate papillae	Glossopharyngeal nerve	Inferior (petrous) ganglion of IX
Valleculae	Internal laryngeal branch of superior laryngeal nerve → vagus	Inferior (nodose) ganglion of X
Epiglottis and pharynx	Internal laryngeal branch of vagus	Inferior (nodose) ganglion of X

- In every limb the **peripheral process** of the ganglion cell reaches the taste bud, while the **central process** enters the brainstem and terminates in the **rostral (upper) part of the nucleus of the solitary tract**, which is therefore also called the **gustatory nucleus**.
- **Embryological correlation** (mirrors pharyngeal-arch origin of the tongue): the anterior two-thirds (1st-arch derivative) is supplied by the lingual/chorda tympani route; the posterior one-third (3rd-arch derivative) by the glossopharyngeal nerve; the posteriormost part and epiglottis (4th-arch derivative) by the vagus — "nerve supply follows development."

□ Fig 10.4 — Taste pathway (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.594)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the three peripheral limbs converging on the nucleus of the solitary tract, then continuing centrally, and label:

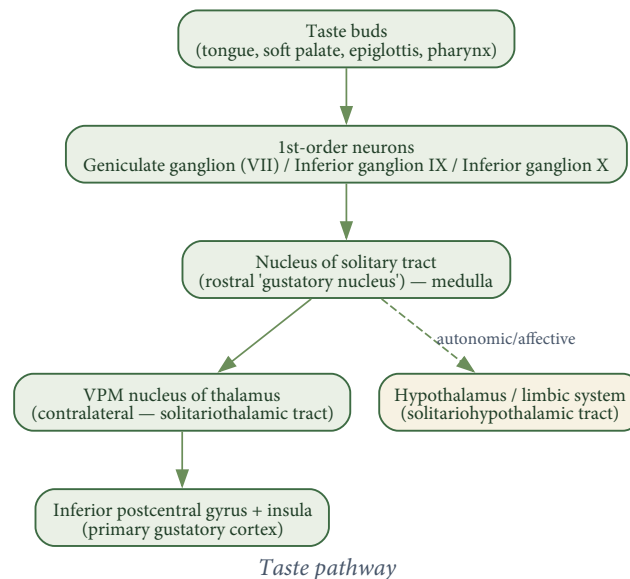
- ▶ **Taste receptors:** anterior 2/3 tongue + oral cavity; soft palate; posterior 1/3 tongue + vallate papillae; valleculae/epiglottis/pharynx.
- ▶ **Nerves:** lingual nerve → **chorda tympani** → facial (VII); greater petrosal nerve → facial (VII); **glossopharyngeal** (IX); internal laryngeal branch of **vagus** (X).
- ▶ **Ganglia:** **geniculate ganglion** (VII); **inferior/petrous ganglion** (IX); **inferior/nodose ganglion** (X).
- ▶ **Nucleus of the solitary tract (gustatory nucleus)** in the medulla — mark the point of **decussation** of second-order fibres.
- ▶ **Solitariothalamic tract** (with trigeminal/medial lemniscus) → **ventral posteromedial (VPM) nucleus of thalamus**, contralateral side.
- ▶ **Posterior limb of internal capsule** → **inferior part of postcentral gyrus and insula** (primary gustatory cortex).
- ▶ **Side branch: solitariohypothalamic tract** → hypothalamus/limbic system (autonomic reactions to taste).

Second-order neurons — the nucleus of the solitary tract

- ▶ The **nucleus solitarius** lies lateral/ventrolateral to the dorsal vagal nucleus in the medulla, closely applied to the **tractus solitarius**, which carries the incoming gustatory (and other visceral) fibres from VII, IX and X.
- ▶ Termination shows a **viscerotopic (rostrocaudal) pattern**: fibres from the anterior two-thirds of the tongue and palate (chorda tympani/greater petrosal) end in the extreme rostral part of the solitary complex; fibres from the circumvallate/foliate papillae and pharynx (glossopharyngeal) are distributed rostral to the obex; fibres from the larynx/epiglottis (vagus) end more caudally and laterally — the rostral pole overall constitutes the **gustatory nucleus**.
- ▶ **Second-order gustatory axons** arising here take two principal routes:
 - The **solitariothalamic tract**, whose fibres **cross the midline (decussate)** and ascend grouped with the trigeminal lemniscus/medial lemniscus to terminate in the most medial part of the contralateral **ventral posteromedial (VPM) nucleus of the thalamus** (a region sometimes termed the accessory arcuate nucleus).
 - The **solitariohypothalamic tract**, carrying gustatory/visceral information to the hypothalamus and limbic system, mediating autonomic and affective responses to taste (e.g. salivation, satiety-related reactions).
- ▶ The nucleus solitarius also sends fibres to the **reticular formation**, to the **general visceral efferent (parasympathetic secretomotor) cranial-nerve nuclei**, and, via a solitariospinal projection, to **autonomic (intermediolateral) grey column neurons** of the spinal cord.

Third-order neurons — thalamocortical projection

- ▶ Tertiary gustatory axons arise from the **VPM nucleus of the thalamus** and radiate through the **posterior limb of the internal capsule** to reach the **inferior part of the postcentral gyrus** and the overlying **insula** — together constituting the **primary gustatory cortex**.
- ▶ Some authorities (Barr and Kiernan) place the true gustatory area more precisely in the **inferior part of the parietal lobe**, just posterior to the general (somatosensory) representation of the mouth in the postcentral gyrus.
- ▶ Ascending fibres that instead terminate in the hypothalamus link into the **limbic system**, providing the anatomical substrate by which taste evokes emotional/autonomic (appetitive or aversive) reactions, independent of conscious cortical perception.



Applied / Clinical anatomy

- ▶ Lesions anywhere along the pathway (peripheral nerve, ganglion, NTS, VPM or cortex) can cause **ageusia** (loss of taste), **hypogeusia** (diminished taste) or **dysgeusia** (distorted taste).
- ▶ **Chorda tympani injury** (middle-ear surgery, temporal bone fracture, or as part of a lower motor neuron facial palsy) abolishes taste over the **ipsilateral anterior two-thirds of the tongue**, often with associated loss of submandibular/sublingual salivary secretion.
- ▶ **Referred otalgia**: lesions of the posterior one-third of the tongue, tonsil or pharynx (carried by IX/X) frequently present as ear pain, because the same nerves (via the tympanic branch of IX and auricular branch of X) also supply cutaneous sensation to the ear — a clinically important example of referred pain.
- ▶ **Gustatory–salivary reflex**: taste afferents relayed through the NTS activate the **superior salivatory nucleus** (facial nerve — secretomotor to submandibular, sublingual, nasal and palatine glands) and the **inferior salivatory nucleus** (glossopharyngeal nerve — secretomotor to the parotid via the otic ganglion), explaining reflex salivation on tasting food.
- ▶ The NTS also relays the **afferent limb of swallowing** (via the glossopharyngeal nerve) onward to the nucleus ambiguus, which supplies the motor pattern for the pharyngeal stage of deglutition — clinically relevant to dysphagia after lower brainstem lesions.

- ▶ **Electrogustometry** and regional taste testing (localised sweet/sour/salt/bitter solutions) are used clinically to localise a lesion to a specific cranial nerve (e.g. distinguishing a chorda tympani lesion from a glossopharyngeal one in a patient with facial palsy or a skull-base tumour).
- ▶ Loss of smell (anosmia) is frequently misreported by patients as "loss of taste," because retronasal olfaction contributes heavily to flavour perception even though the gustatory pathway proper is intact.

Recent advances

- ▶ **Molecular basis of transduction:** sweet, umami and bitter tastes are detected by two families of G-protein-coupled receptors — **T1Rs** (sweet/umami, as heterodimers T1R1+T1R3 and T1R2+T1R3) and **T2Rs** (bitter) — coupled to gustducin-mediated intracellular signalling; this GPCR framework has become the standard molecular model of taste sensing (Cygankiewicz et al., *Crit Rev Food Sci Nutr* 2014, [DOI](https://doi.org/10.1080/10408398.2011.606929)).
- ▶ **Ectopic/extra-oral taste receptors:** T1R and T2R family receptors are now recognised outside the tongue — in the gut, airway epithelium, and even testis/spermatozoa — raising interest in their non-gustatory chemosensory roles (Li F, *Mol Hum Reprod* 2013, [DOI](https://doi.org/10.1093/molehr/gat009)).
- ▶ **Species-specific circuit organisation:** contemporary optogenetic/chemogenetic circuit-mapping in mice shows an **obligatory relay in the parabrachial nucleus (PBN) of the pons** between the NTS and the gustatory thalamus, modulating taste responses according to internal state (hunger, sodium appetite) — in contrast to the more direct solitario-thalamic projection classically described in primates/humans, underscoring a genuine species difference relevant when extrapolating rodent taste-circuit data (Nakajima K-I, *Physiol Rep* 2024, [DOI](https://doi.org/10.14814/phy2.70106)).
- ▶ **Localisation of the human primary gustatory cortex remains debated:** fMRI studies implicate the **anterior insula and frontal operculum**, whereas gustatory event-related potentials/magnetic fields localise early responses to the **posterior insula/parietal-operculum transition** — refining (rather than overturning) the classical "inferior postcentral gyrus + insula" teaching (Iannilli et al., *Neuroscience* 2014, [DOI](https://doi.org/10.1016/j.neuroscience.2014.05.017)).
- ▶ **COVID-19-associated gustatory dysfunction:** SARS-CoV-2 directly infects chemosensory cells — taste bud/fungiform papilla cells express the viral entry factors **ACE2, TMPRSS2 and furin**, and infection alters expression of taste-transduction genes, providing a peripheral mechanistic explanation for the ageusia/dysgeusia widely reported in COVID-19 (Scotto et al., *Life* 2022, [DOI](https://doi.org/10.3390/life12050690); Donadoni et al., *J Neurovirol* 2023, [DOI](https://doi.org/10.1007/s13365-023-01117-3)).

High-yield exam pointers

- ▶ Taste = **special visceral afferent**; carried by **VII (chorda tympani, greater petrosal)**, **IX and X**, in that antero-posterior order along the tongue/pharynx.
- ▶ 1st-order cell bodies: **geniculate ganglion (VII)**, **inferior/petrous ganglion (IX)**, **inferior/nodose ganglion (X)** — all end in the **rostral nucleus of the solitary tract (gustatory nucleus)**.

- ▶ 2nd-order fibres **decussate** and ascend as the **solitariothalamic tract** (with trigeminal/medial lemniscus) to the **contralateral VPM nucleus of thalamus**; a parallel **solitariohypothalamic tract** reaches the limbic system.
- ▶ 3rd-order fibres go from VPM, via the **posterior limb of internal capsule**, to the **inferior postcentral gyrus and insula** (primary gustatory cortex).
- ▶ Nerve supply mirrors pharyngeal-arch development: **1st arch** → VII (**anterior 2/3**); **3rd arch** → IX (**posterior 1/3**); **4th arch** → X (**epiglottis/posteriormost tongue**).
- ▶ Chorda tympani lesion → ipsilateral loss of taste, anterior two-thirds of tongue ± reduced submandibular/sublingual salivation.
- ▶ NTS is the integrative hub — it also relays swallowing (to nucleus ambiguus) and gustatory-salivary reflexes (to superior/inferior salivatory nuclei).
- ▶ Lesion anywhere in the pathway → ageusia/hypogeusia/dysgeusia; the "four-zone tongue map" is an outdated oversimplification.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh Textbook of Human Neuroanatomy; BD Chaurasia Human Anatomy Vol 3–4 8e (text and figure); Vishram Singh Clinical Neuroanatomy 4e; Snell Clinical Neuroanatomy 7e. Recent-advances citations from PubMed as linked above.



Trigeminal Lemniscus

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction — The trigeminal lemniscus (= trigeminothalamic tract) is the compact bundle of second- and third-order sensory fibres that carries general somatic sensations — touch, pressure, pain and temperature — from the face, scalp, cornea/conjunctiva, and the oral and nasal cavities to the thalamus. It is formed chiefly by axons of the principal (chief/main) sensory nucleus and the spinal nucleus of the trigeminal nerve that decussate and ascend through the brainstem alongside the medial and spinal lemnisci, relaying in the ventral posteromedial (VPM) nucleus of the thalamus before projecting to the face area of the postcentral gyrus. It is thus the trigeminal (facial) counterpart of the medial lemniscus (dorsal column pathway) and spinal lemniscus (spinothalamic pathway) for the body.

1. Formation and origin

- ▶ **First-order neurons:** pseudounipolar cells in the **trigeminal (Gasserian/semilunar) ganglion**. Peripheral processes travel in the ophthalmic, maxillary and mandibular divisions; central processes form the large **sensory root** entering the pons, about half of which bifurcate into ascending and descending branches.
- ▶ **Ascending branches** terminate in the **principal (chief) sensory nucleus** — situated in the dorsolateral pontine tegmentum, lateral to the motor nucleus — which subserves **touch/pressure**.

- **Descending branches** form the **spinal tract of the trigeminal nerve** and terminate in the subjacent **spinal nucleus of the trigeminal nerve**, which extends from the pons down to the C2 spinal segment and subserves **pain and temperature**. The spinal nucleus is subdivided craniocaudally into **pars rostralis**, **pars interpolaris** and **pars caudalis**; fibres of the ophthalmic division end most caudally (pars caudalis), maxillary fibres in the pars interpolaris, and mandibular fibres most rostrally (pars rostralis) — a laminated ("onion-skin") somatotopy. A small general-somatic-afferent component from the facial, glossopharyngeal and vagus nerves (external ear, posterior tongue, pharynx, larynx) also joins the spinal tract/nucleus.
- **Second-order neurons**: cell bodies in the principal sensory nucleus and spinal nucleus. Their axons **cross the midline** and ascend as the **trigeminal lemniscus**, to relay in the **VPM nucleus of the thalamus**.
- **Proprioceptive component**: the **mesencephalic nucleus** of the trigeminal nerve — the only site in the CNS containing cell bodies of first-order sensory neurons — carries proprioception from the muscles of mastication, the temporomandibular joint and teeth. Most of this relays monosynaptically onto the trigeminal **motor** nucleus (jaw-jerk/stretch reflex); some central processes instead relay in the reticular formation, from which fibres ascend in a more dorsally placed bundle (the **dorsal trigeminal lemniscus**) to the VPM nucleus.

2. Ventral and dorsal trigeminothalamic components

Two components of the pathway are described, and either name may appear in an exam key:

Feature	Ventral trigeminothalamic tract ("trigeminal lemniscus" proper)	Dorsal trigeminothalamic tract ("dorsal trigeminal lemniscus")
Modality carried	Pain and temperature (and some crude touch)	Tactile discrimination and pressure
2nd-order station	Spinal nucleus of trigeminal nerve	Principal (chief) sensory nucleus of trigeminal nerve
Decussation	Crosses the midline	Predominantly uncrossed; a smaller crossed component is also described
Thalamic relay	Contralateral VPM nucleus	Ipsilateral VPM nucleus
Cortical projection	Contralateral postcentral gyrus (areas 3, 1, 2)	Mainly ipsilateral postcentral gyrus (areas 3, 1, 2)

3. Course and relations in the brainstem

Once formed, the trigeminal lemniscus ascends through the tegmentum of the medulla, pons and midbrain in constant company with the medial lemniscus and the spinal lemniscus (anterolateral/spinothalamic system). From medial to lateral, the classical order of the four lemnisci in cross-section is: **medial lemniscus** → **trigeminal lemniscus** → **spinal lemniscus** → **lateral lemniscus** (mnemonic "MTSL").

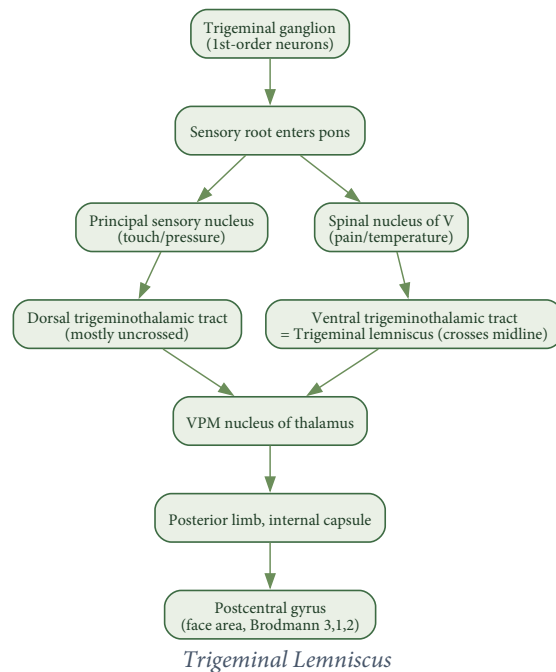
Level	Relations of the trigeminal lemniscus
Medulla oblongata	Lies among the ascending lemnisci of the tegmentum, just crossed and beginning its ascent, medial to the spinal lemniscus
Pons	In the ventral tegmentum; lies a little lateral to the medial lemniscus (which is joined medially by fibres from the principal sensory nucleus); the anterolateral system (spinal lemniscus) and the lateral lemniscus with its nucleus lie further dorsolaterally
Midbrain	Same medial-to-lateral sequence persists — medial lemniscus most medial, trigeminal lemniscus next, then spinal lemniscus, with the lateral lemniscus most lateral/dorsal, close to the periaqueductal grey matter and the mesencephalic nucleus of V

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 5.25 — Transverse sections of the midbrain. A: At the level of the inferior colliculus. B: At the level of the superior colliculus (Snell — *Clinical Neuroanatomy* — 7e, p.233)

Reproduce a transverse section of the midbrain (level of inferior/superior colliculus) and label, from medial to lateral in the tegmentum:

- ▶ Central grey matter (periaqueductal grey) and cerebral aqueduct
- ▶ Mesencephalic nucleus of the trigeminal nerve (dorsolateral, beside the aqueduct)
- ▶ Medial lemniscus (most medial)
- ▶ **Trigeminal lemniscus** (immediately lateral to medial lemniscus)
- ▶ Spinal lemniscus (anterolateral system)
- ▶ Lateral lemniscus (most lateral/dorsal)
- ▶ Medial longitudinal fasciculus, reticular formation
- ▶ Substantia nigra, crus cerebri (ventral) and tectum/colliculus (dorsal) as landmarks of the tegmentum



4. Termination and third-order projection

The trigeminal lemniscus ends in the **ventral posteromedial (VPM) nucleus** of the thalamus — the thalamic relay dedicated to the head and face, just as the ventral posterolateral (VPL) nucleus relays medial-lemniscal and spinothalamic input from the trunk and limbs. Third-order neurons arising in the VPM nucleus project through the **posterior limb of the internal capsule** to the **postcentral gyrus** (Brodmann areas 3, 1 and 2), terminating in its most inferolateral part, the **face area** of the somatosensory homunculus (near the lateral/Sylvian fissure). VPM and VPL together form a continuous, somatotopically ordered thalamic relay for the entire body surface.

5. Modalities and functional summary

- ▶ **Touch and pressure** — from principal sensory nucleus, via dorsal trigeminothalamic tract.
- ▶ **Pain and temperature** — from spinal nucleus (pars caudalis especially, an important nociceptive relay/"pain gate"), via ventral trigeminothalamic tract (trigeminal lemniscus proper).
- ▶ **Proprioception** (mastication muscles, TMJ, teeth) — via mesencephalic nucleus; mainly a reflex arc onto the motor nucleus of V (jaw-jerk), with a smaller component reaching VPM through the reticular formation.
- ▶ Together these carry sensation from the face, scalp, cornea and conjunctiva, teeth, oral cavity and anterior two-thirds of the tongue (general sensation only), and the nasal mucosa.

Applied / Clinical anatomy

- ▶ **Site of lesion determines the pattern of facial sensory loss** — a favourite viva correlate:
 - Lesion of the trigeminal nerve, ganglion, or its nuclei (**before decussation**) → **ipsilateral** facial sensory loss.
 - Lesion of the trigeminal lemniscus **after** it has crossed (e.g., a high pontine or midbrain lesion) → **contralateral** facial sensory loss, together with contralateral body sensory loss

(spinothalamic tract, already crossed) — a "clean," uniform contralateral hemianesthesia including the face.

- **Lateral medullary (Wallenberg) syndrome** — occlusion of the posterior inferior cerebellar artery damages the spinal nucleus/tract of V (still uncrossed at this level) together with the already-crossed spinal lemniscus (spinothalamic tract): this produces **ipsilateral facial analgesia and thermoanaesthesia** combined with **contralateral loss of pain and temperature over the trunk and limbs** — the classic "crossed"/alternating sensory loss that demonstrates the decussation of the trigeminal lemniscus.
- **Medial medullary syndrome** spares facial sensation (spinal nucleus of V is dorsolateral, outside the infarct territory) but produces contralateral loss of position sense and tactile discrimination of the body (medial lemniscus involvement) — a useful contrast.
- ▶ **Trigeminal neuralgia (tic douloureux)** — paroxysmal lancinating facial pain, usually from vascular compression of the nerve root/ganglion rather than the central pathway; distinguishing the level of the lesion (nerve/ganglion vs. central lemniscal pathway) is a common applied question.
- ▶ **Thalamic (VPM) lesions** may produce contralateral facial dysaesthesia/hyperpathia (thalamic pain syndrome).
- ▶ **Cortical (postcentral gyrus face-area) lesions** impair fine tactile discrimination on the face while crude pain sensation is relatively spared, owing to its more diffuse, bilateral cortical representation.

High-yield exam pointers

- ▶ Trigeminal lemniscus = crossed, second-order **trigeminothalamic tract** formed by the principal sensory nucleus (touch) and spinal nucleus (pain/temperature) of the trigeminal nerve.
- ▶ Also termed the **ventral trigeminothalamic tract**; the **dorsal trigeminothalamic tract** is the largely uncrossed touch/pressure component relaying to the ipsilateral VPM.
- ▶ Brainstem order of lemnisci, medial to lateral: **Medial – Trigeminal – Spinal – Lateral** ("MTSL").
- ▶ Relays in the **VPM nucleus of thalamus** (VPM = face, VPL = trunk/limbs).
- ▶ Third-order fibres pass through the **posterior limb of the internal capsule** to the **face area of the postcentral gyrus** (areas 3, 1, 2).
- ▶ The **mesencephalic nucleus** of V is the only CNS site containing first-order sensory neuron cell bodies (proprioception, jaw-jerk reflex).
- ▶ **Wallenberg's (lateral medullary) syndrome** is the classic clinico-anatomical correlate: ipsilateral facial + contralateral body pain-temperature loss.
- ▶ Spinal nucleus of V is somatotopically laminated: ophthalmic → pars caudalis, maxillary → pars interpolaris, mandibular → pars rostralis.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3–4 8e.



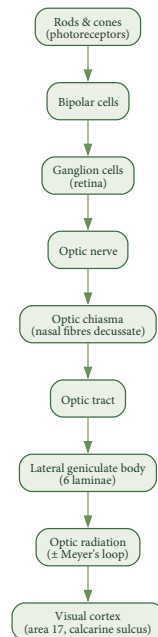
Visual pathway and the defects produced in lesions in its pathway

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction. The visual pathway is the chain of neurons that conducts photic impulses from the photoreceptors of the retina to the primary visual (striate) cortex, comprising the **retina, optic nerve, optic chiasma, optic tract, lateral geniculate body (LGB) and optic radiation**. Throughout its course the pathway maintains a strict **retinotopic organisation**, so that the site of a lesion can be localised clinically from the pattern of visual field loss charted on perimetry. Because nasal retinal fibres decussate at the chiasma while temporal fibres remain uncrossed, lesions anterior to the chiasma give unilateral (monocular) defects, lesions of the chiasma give bilateral heteronymous defects, and lesions posterior to the chiasma give contralateral homonymous defects.

1. Neurons of the visual pathway

- ▶ **Four neurons** conduct the visual impulse to the cortex (Snell):
- ▶ **Rods and cones** — specialised photoreceptor neurons of the retina.
- ▶ **Bipolar cells** — connect rods/cones to ganglion cells.
- ▶ **Ganglion cells** — their axons pass to the LGB, forming the **optic nerve**.
- ▶ **Neurons of the lateral geniculate body** — their axons pass to the visual cortex, forming the **optic radiation**.



Visual pathway and the defects produced in lesions in its pathway

2. Retina, optic nerve and optic chiasma — the decussation pattern

- ▶ **Retina:** rods (~100 million, peripheral, dim-light/movement vision) and cones (~7 million, concentrated centrally, colour/acuity). The **macula lutea** with its central **fovea centralis** (cones only) is the area of most distinct vision; the **optic disc**, medial to the macula, contains no photoreceptors and is the **blind spot**.
- ▶ **Optic nerve:** formed by axons of retinal ganglion cells, converging on the optic disc; myelinated by **oligodendrocytes** (not Schwann cells), since it is a CNS tract rather than a true peripheral nerve. It leaves the orbit through the **optic canal** to unite with its fellow and form the chiasma.
- ▶ **Optic chiasma:** lies at the junction of the anterior wall and floor of the third ventricle.
 - Fibres from the **nasal (medial) half of each retina**, including the nasal half of the macula, **cross** the midline to enter the **opposite** optic tract.
 - Fibres from the **temporal (lateral) half of each retina** remain **uncrossed**, continuing in the tract of the **same** side.
 - Each optic tract therefore carries fibres from the temporal half of the ipsilateral retina plus the nasal half of the contralateral retina — together representing the **contralateral half of the visual field**.

3. Optic tract, lateral geniculate body and optic radiation

- ▶ **Optic tract:** emerges from the chiasma and winds posterolaterally around the cerebral peduncle. Most fibres (~90%) terminate in the LGB; a smaller **extrageniculate** contingent (~10%) leaves the tract before the LGB — some to the **pretectal nucleus** and **superior colliculus** (subserving the light and visual-body reflexes), others to the **suprachiasmatic nucleus** of the hypothalamus (circadian entrainment).
- ▶ **Lateral geniculate body:** a small oval projection from the **pulvinar of the thalamus**, made up of **six cellular laminae**. Crossed (contralateral, nasal-retina) fibres end in laminae **1, 4 and 6**; uncrossed (ipsilateral, temporal-retina) fibres end in laminae **2, 3 and 5**. Laminae 1–2 are

magnocellular, laminae 3–6 **parvocellular**. A strict point-to-point retinotopic map of the entire contralateral visual field is re-established here.

- ▶ **Optic radiation (geniculocalcarine tract)**: axons of LGB neurons pass through the **retrolentiform (retrolenticular) part of the internal capsule** to the visual cortex. Fibres from the **inferior retinal quadrants** (representing the **superior** visual field) sweep forward and downward into the temporal lobe, curving around the atrium and inferior horn of the lateral ventricle, before turning back to the occipital lobe — this detour is **Meyer's loop**.

4. Visual cortex and retinotopic mapping

- ▶ The optic radiation terminates in the **primary visual (striate) cortex, area 17 (V1)**, occupying the upper and lower lips (banks) of the **calcarine sulcus** on the medial occipital lobe.
- ▶ **Retinotopy**: lower retinal quadrants (upper visual field) project **above** the calcarine sulcus; upper retinal quadrants (lower visual field) project **below** it.
- ▶ The **macula** is represented **posteriorly**, occupying a disproportionately large cortical area (reflecting the high density of foveal ganglion cells); it has a **dual arterial supply** — the **posterior cerebral artery** and cortical branches of the **middle cerebral artery** — which is the anatomical basis of **macular sparing** in occipital vascular lesions. The **peripheral retina** is represented **anteriorly**.
- ▶ The visual (association) cortex, **areas 18 and 19**, surrounds area 17 and is responsible for further processing — recognition of objects and colour perception.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 11.24 — Visual field defects associated with lesions of the optic pathways (Snell — Clinical Neuroanatomy — 7e, p.379)

Reproduce a superior view of the visual pathway (as in the figure above / Fig. 11-2), labelling in sequence:

- ▶ Both eyeballs, with **nasal** and **temporal retinal halves** shaded differently, and the **macula**
- ▶ **Optic nerve** of each side
- ▶ **Optic chiasma** — show only the **nasal (crossing) fibres** decussating; temporal fibres uncrossed
- ▶ **Optic tract** of each side, winding around the cerebral peduncle
- ▶ **Lateral geniculate body** of each side (mark the six laminae)
- ▶ **Optic radiation**, with **Meyer's loop** looping into the temporal lobe
- ▶ **Visual cortex** (areas 17/18/19) on the medial occipital lobe, in the calcarine sulcus
- ▶ Number 7 **lesion sites** along the pathway (1 = peripheral optic-nerve fibres, 2 = complete optic nerve, 3 = lateral chiasma, 4 = mid-chiasma, 5 = optic tract, 6 = optic radiation, 7 = visual cortex) and draw, alongside, the corresponding **left- and right-eye visual-field wedge diagrams** for each level, as in the figure above.

5. Visual field defects according to site of lesion

Site of lesion	Field defect produced	Distinguishing feature	Typical cause
Branch of central retinal artery	Altitudinal hemianopia (upper or lower field loss, one eye)	Sharp horizontal border	Branch retinal artery occlusion
Optic nerve, peripheral fibres (at disc)	Peripheral/ circumferential field constriction, arcuate scotoma		Glaucoma — raised IOP compresses peripheral fibres curving into the disc
Optic nerve, complete section	Total blindness of that eye (amblyopia)	Unilateral; direct light reflex lost, consensual preserved	Trauma, glioma, complete optic neuritis
Optic nerve, partial (retrobulbar)	Circumferential blindness / central scotoma		Retrobulbar optic neuritis, hysteria
Optic chiasma, lateral angle (uncrossed fibres)	Nasal hemianopia (unilateral)		Perichiasmal adhesions, calcified internal carotid artery
Optic chiasma, mid-part (crossing fibres)	Bitemporal hemianopia (heteronymous), "tunnel vision"; often begins as upper temporal quadrantanopia	Bilateral; respects the vertical midline	Pituitary adenoma (compresses from below), craniopharyngioma

Site of lesion	Field defect produced	Distinguishing feature	Typical cause
Optic tract	Contralateral homonymous hemianopia , markedly incongruous	Vertical midline split; pupillary light reflex may be lost on stimulating the blind hemifield (extrageniculate pretectal fibres interrupted)	Basal tumours, trauma
Lateral geniculate body	Contralateral homonymous hemianopia		Thalamic infarct
Optic radiation — Meyer's loop (temporal lobe)	Contralateral superior homonymous quadrantanopia ("pie in the sky")		Temporal lobectomy, temporal lobe tumour
Optic radiation — parietal fibres	Contralateral inferior homonymous quadrantanopia		Parietal lobe lesion
Visual cortex, unilateral complete	Contralateral homonymous hemianopia with macular sparing	Congruous; pupillary reflex normal	Posterior cerebral artery occlusion
Visual cortex, bilateral (occipital poles)	Cortical blindness	Pupillary light reflex preserved (reflex arc bypasses cortex)	Bilateral posterior cerebral artery occlusion

Applied / Clinical anatomy

- **Perimetry** (field charting) is the principal clinical method of localising a lesion along the pathway, since the shape of the defect corresponds to the retinotopic map disrupted.
- **Pituitary adenoma** is the classic cause of **bitemporal hemianopia** — it expands upward from the sella and compresses the inferior, decussating fibres of the chiasma first, so field loss classically begins in the **upper temporal quadrants** before progressing to complete bitemporal hemianopia; a suprasellar mass (e.g., craniopharyngioma) compressing from above tends to affect the lower quadrants first.
- **Incongruity** (dissimilarity between the field defects of the two eyes) is a localising clue: it is most marked in **optic tract** lesions, less obvious in **optic radiation** lesions, and usually absent in **cortical** lesions.
- **Macular sparing** in an otherwise complete homonymous hemianopia points to a **vascular (cortical)** lesion, owing to the macula's dual supply from the posterior cerebral and middle cerebral arteries; a **compressive** lesion (tumour) nearer the chiasma or tract generally does **not** spare the macula.

- ▶ **Glaucoma** selectively damages peripheral nerve-fibre bundles as they curve into the lamina cribrosa, producing early **arcuate scotomas** and peripheral field constriction while central vision is preserved until late.
- ▶ Because pupillary light-reflex fibres are **extrageniculate** (leaving the optic tract for the pretectal nucleus before reaching the LGB), an **optic tract** lesion can abolish the pupillary response to light shone in the blind hemifield, whereas lesions of the **optic radiation or visual cortex** leave pupillary reflexes intact — a useful bedside sign distinguishing pre- from post-geniculate lesions.
- ▶ **Bilateral occipital (calcarine) infarction** produces **cortical blindness** with pupillary light reflexes fully preserved, since the reflex arc (retina → pretectal nucleus → Edinger-Westphal nucleus) bypasses the visual cortex entirely.

High-yield exam pointers

- ▶ Four neurons: **rods/cones** → **bipolar cells** → **ganglion cells (optic nerve)** → **LGB neurons (optic radiation)** → **visual cortex**.
- ▶ At the chiasma: **nasal** retinal fibres **cross**; **temporal** fibres remain **uncrossed** — each optic tract represents the **contralateral half** of the visual field.
- ▶ LGB = **6 laminae**; crossed fibres → 1, 4, 6; uncrossed fibres → 2, 3, 5; laminae 1–2 magnocellular, 3–6 parvocellular.
- ▶ Optic radiation runs in the **retrolentiform internal capsule**; its inferior fibres form **Meyer's loop** through the temporal lobe.
- ▶ Visual cortex = **area 17**, in the **calcarine sulcus**; macula represented **posteriorly** with a large, dually-vascularised area.
- ▶ **Bitemporal hemianopia** = **chiasmal lesion** (classically pituitary tumour); **homonymous hemianopia** = **retrochiasmal lesion**.
- ▶ **Macular sparing** → **cortical (vascular) lesion**; **no macular sparing** → **compressive/tract lesion**.
- ▶ **Incongruity grades the lesion**: tract (most incongruous) → radiation → cortex (congruous, macular sparing).
- ▶ **Meyer's loop lesion** → **superior quadrantanopia** ("pie in the sky"); parietal radiation lesion → **inferior quadrantanopia**.

SOURCE & COVERAGE

Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; Gray's Anatomy (Standring) 41e.



Radiological & cross-sectional anatomy



CT Scan

Asked in: Paper IV May 2010 · Paper IV Apr 2008 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

Computed tomography (CT), also called computerised axial tomography (CAT) scanning, is a radiological imaging technique in which a rotating X-ray source and an array of detectors generate cross-sectional ("tomographic") images of the body by measuring the differential attenuation of X-rays as they pass through tissues of varying density. A computer converts this attenuation data into a matrix of picture elements (pixels)/volume elements (voxels), each assigned a radiodensity value expressed in **Hounsfield units (HU)**. CT was invented and introduced into clinical practice by **Godfrey N. Hounsfield in 1970** (Hounsfield and Allan Cormack shared the 1979 Nobel Prize in Physiology or Medicine for this work). Because CT images correlate almost exactly with the appearance of anatomical cross-sections, CT has become the backbone of modern radiological/cross-sectional anatomy teaching and of clinical practice across every organ system.

Principle and technique of image formation

- ▶ The X-ray tube and the detector array rotate together, in a fixed relationship, around the long axis of the body within the gantry of the scanner.
- ▶ A fan-shaped beam of X-rays is sent through the body part from many different angular positions during each rotation; detectors placed on the opposite side of the body measure the amount of radiation transmitted through that horizontal section.
- ▶ These multiple, overlapping radial absorption measurements are compared and processed by a computer, which calculates the **radiodensity of each voxel** in the chosen plane.
- ▶ The radiodensity of a voxel depends on the proportion of air, water, fat or bone within it; tissues of high absorption (bone) appear relatively **radiopaque (white)** and tissues of low absorption (air) appear **radiolucent (black)** — the same convention as a plain radiograph.
- ▶ Because information is gathered for the whole volume of the part scanned, the computer can reconstruct "**slices**"/**tomograms in any plane** (axial, coronal, sagittal or oblique) and even three-dimensional images — **multiplanar reconstruction (MPR)**.
- ▶ **Viewing convention:** axial CT (and MRI) images are always viewed as though the observer is standing at the foot of a supine patient looking cranially (an inferior view); coronal images are viewed as if the patient is facing the observer; sagittal images are viewed as if the observer is standing at the patient's left side.

□ Fig 1.53 — Technique for producing CT scan. A. The X-ray tube rotates around the person in the CT scanner and sends a fan-shaped beam of X-rays through the upper abdomen from a variety of angles. X-ray detectors on the opposite side of the body measure the amount of radiation that passes through a horizontal section. B. A computer reconstructs the images from several scans, and a CT scan is produced. C. As well as 2D "slices," scans can be compiled by the computer to generate a 3D reconstructed image. (Moore — Clinically Oriented Anatomy — 9e, p.195)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple block diagram of the CT scanner and the imaging chain, labelled exactly:

- ▶ **Gantry** enclosing the **X-ray tube** and the opposing **detector array**, both rotating around the **axis of rotation** (long axis of the patient)
- ▶ **Fan-shaped X-ray beam** passing through the body part
- ▶ **Patient table** (moves the patient longitudinally through the gantry)
- ▶ **Computer/console** receiving detector signals and reconstructing the image
- ▶ The reconstructed **axial "slice"** displayed as a cross-sectional grey-scale image, oriented as viewed from the patient's feet

Hounsfield scale, attenuation and windowing

- ▶ Each pixel's mean X-ray attenuation is compared with that of water and displayed on the **Hounsfield scale**, where water = 0 HU by definition.

Tissue	Approximate attenuation (HU)
Air	about –1000
Fat	about –100
Water (reference)	0
Soft tissue (muscle, viscera)	+20 to +70
Bone	greater than +400

- ▶ Because the HU range vastly exceeds the number of grey shades the human eye can distinguish, the operator selects a display "**window**" (a chosen width and level/centre) so that only the HU range of interest is spread across the visible grey scale — a narrow soft-tissue window for brain/abdominal viscera, and wider lung and bone windows to display aerated lung and cortical bone without losing detail at the extremes.
- ▶ This windowing step is why the same raw CT dataset can be displayed as a "lung window," "bone window" or "soft-tissue window" image without re-scanning the patient.

Evolution of CT technology

- ▶ **Conventional CT (CCT)**: an early movable X-ray tube and single detector row acquire one slice at a time; the tube rotates in an arc, the table then increments before the next slice is obtained.
- ▶ **Spiral/helical CT (SCT)**: the patient/table moves continuously and longitudinally while the X-ray tube rotates continuously, so the beam traces a **spiral (helical) path** through the organ. This continuous volumetric acquisition allows images to be viewed from any angle, unwanted overlying structures to be removed by computer manipulation, and the display to be improved by colour coding.
- ▶ **Modern multislice/multidetector helical CT (MDCT)**: multiple detector rows acquire several slices per rotation in sub-second times; whole-body imaging from the skull base to the thighs can be completed within a single breath-hold of a few seconds. Fast scan times permit **dynamic**

imaging of arteries and veins at different phases after intravenous contrast injection, and continuous data acquisition allows routine **multiplanar reconstruction (MPR)** in sagittal and coronal planes.

Advantages, limitations and comparison with allied modalities

Feature	CT	Plain radiograph	Ultrasonography	MRI
Uses ionising radiation	Yes	Yes	No	No
Cross-sectional/tomographic image	Yes	No (2D projection with overlap)	Yes (real-time)	Yes
Soft-tissue contrast	Moderate	Poor	Moderate (operator-dependent)	Excellent
Best for	Bone, lung, acute haemorrhage, trauma, calcification	Screening skeletal/chest survey	First-line for pregnancy, biliary/renal tract, vascular Doppler	Brain/spinal cord, joints, soft-tissue tumours
Scan time	Seconds	Instant	Real-time	Minutes
Safe with pacemakers/ferromagnetic implants	Yes	Yes	Yes	No (absolute contraindication for many devices)

- **Advantages:** rapid acquisition (life-saving in trauma/critically ill patients); excellent spatial resolution for bone, lung parenchyma and acute haemorrhage; permits 3-D/MPR reconstruction and CT angiography; safe to use in patients with pacemakers or metallic implants (unlike MRI); more widely available and less costly than MRI.
- **Limitations:** uses **ionising radiation**, so cumulative dose and stochastic cancer risk must be considered, particularly with repeated scanning or in children; **inferior soft-tissue contrast** compared with MRI; requires **iodinated contrast media** for vascular/luminal studies, with attendant risk of contrast-induced nephropathy or anaphylactoid reaction; prone to **beam-hardening artefact** from metallic implants/dental work and to motion artefact.

Contrast media used with CT

- **Radiopaque (positive) contrast media:** salts of heavy metals (barium sulphate) and organic iodide preparations. Aqueous iodinated contrast is injected intravenously to opacify blood vessels and enhance solid organs/lesions (CT angiography, contrast-enhanced abdominal/thoracic CT), or given orally/rectally to opacify the gastrointestinal lumen.
- **Radiolucent (negative) contrast:** air/gas, occasionally used to distend a viscus (e.g. colon on CT colonography).
- **Functions of contrast media:** (1) delineation of normal structures such as the GIT, biliary tree, urinary tract and blood vessels; (2) **lesion enhancement**, distinguishing a focal mass from surrounding normal parenchyma by its differing enhancement pattern.

- ▶ A good contrast medium should be non-toxic, reasonably radiopaque, easily administrable and readily available.

Recent advances in CT imaging

- ▶ **Photon-counting detector CT (PCD-CT):** the first clinical PCD-CT system became available in 2021, converting X-ray energy directly into an electrical signal photon-by-photon (a "one-step" process) rather than the older two-step scintillation-detection method. This eliminates electronic noise, improves spatial resolution (sub-millimetre) and iodine signal-to-noise ratio, and provides native energy-resolved (spectral) imaging without a dual-source setup, allowing lower radiation and contrast doses (Rajendran et al, *Radiology* 2022) [PMID: 34904876]; (McCollough et al, *Eur Radiol* 2023) [PMID: 37020069].
- ▶ **Expanding clinical applications of PCD-CT:** a 2025 updated review documents growing use of photon-counting CT across cardiovascular, thoracic, abdominal, musculoskeletal, neuro- and paediatric imaging, exploiting its high spatial resolution and reduced metal-artefact/radiation profile (van der Bie et al, *Eur J Radiol* 2025) [PMID: 40516505].
- ▶ **Deep-learning image reconstruction (DLR):** AI-trained reconstruction algorithms are progressively replacing filtered back-projection and model-based iterative reconstruction, producing diagnostic-quality images from lower-dose acquisitions faster than iterative methods, and are being combined with spectral photon-counting data for further dose reduction (Koetzier et al, *Radiology* 2023) [PMID: 36719287].
- ▶ **CT coronary angiography (CTCA) as a first-line investigation:** contemporary international guidance now supports CTCA as the first-line test for stable chest pain given its high negative predictive value for excluding obstructive coronary artery disease, and its ability to guide preventive therapy (Ihdayhid et al, *Heart Lung Circ* 2023) [PMID: 36610819].

(According to PubMed; DOIs: [10.1148/radiol.212579](https://doi.org/10.1148/radiol.212579), [10.1007/s00330-023-09596-y](https://doi.org/10.1007/s00330-023-09596-y), [10.1016/j.ejrad.2025.112189](https://doi.org/10.1016/j.ejrad.2025.112189), [10.1148/radiol.221257](https://doi.org/10.1148/radiol.221257), [10.1016/j.hlc.2022.12.003](https://doi.org/10.1016/j.hlc.2022.12.003).)

Applied / Clinical anatomy

- ▶ **Cross-sectional anatomy teaching:** axial CT images of the thorax and abdomen are routinely paired with cadaveric transverse sections at defined vertebral levels (e.g. the fifth, fourth and third thoracic vertebral levels) to teach the disposition of the great vessels, oesophagus, trachea and mediastinal structures — the single most direct application of CT to gross/radiological anatomy.
- ▶ **Trauma imaging:** whole-body CT ("pan-scan") is the investigation of choice in the haemodynamically stable polytrauma patient, rapidly detecting intracranial/intra-abdominal haemorrhage, solid-organ (splenic, hepatic, renal) injury and complex fractures.
- ▶ **CT angiography (CTA):** non-invasive, contrast-enhanced volumetric imaging of arteries and veins (cerebral, pulmonary, coronary, peripheral) has replaced conventional catheter angiography for most diagnostic indications.

- ▶ **Oncology:** CT is central to tumour detection, TNM staging, monitoring treatment response, and radiotherapy treatment-planning ("simulation CT").
- ▶ **Image-guided intervention:** CT guides percutaneous biopsy, abscess drainage and ablation procedures with precise anatomical localisation.
- ▶ **Specialised studies:** CT urography (urinary tract), CT colonography ("virtual colonoscopy"), and high-resolution CT of the temporal bone/paranasal sinuses/lung parenchyma.
- ▶ **Radiation-sensitive groups:** because of ionising radiation, ultrasonography or MRI are preferred over CT in pregnancy and in children wherever diagnostically adequate.

High-yield exam pointers

- ▶ CT invented/introduced clinically by **Godfrey Hounsfield (1970)**; Hounsfield and Cormack shared the **1979 Nobel Prize**.
- ▶ Principle: X-ray tube and detector rotate around the body; computer calculates the **radiodensity of each voxel** and reconstructs a cross-sectional slice.
- ▶ **Hounsfield unit (HU)** scale (water = 0 reference): air ≈ -1000 , fat ≈ -100 , soft tissue +20 to +70, bone $> +400$.
- ▶ **Windowing** (width + level) lets the same dataset be displayed as lung, bone or soft-tissue window images.
- ▶ Evolution: conventional (step-and-shoot) CT $\rightarrow$ spiral/helical CT (continuous table + gantry motion) $\rightarrow$ multidetector/multislice CT (MDCT) — sub-second, single-breath-hold whole-body scans with multiplanar reconstruction (MPR).
- ▶ Viewing convention: axial images viewed as if standing at the patient's feet; coronal as if patient facing you; sagittal as if standing at the patient's left.
- ▶ Advantages over MRI: faster, cheaper, safe with pacemakers/metal implants, better for bone/lung/acute bleed; key disadvantage: **ionising radiation** and poorer soft-tissue contrast.
- ▶ Iodinated contrast media (IV) opacify vessels/organs for CT angiography and lesion enhancement; barium/iodinated agents opacify the GI lumen.
- ▶ Recent advance to name: **photon-counting detector CT** with **deep-learning reconstruction**, enabling higher resolution at lower radiation dose.

SOURCE & COVERAGE

Moore's Clinically Oriented Anatomy 9e; Gray's Anatomy (Standring) 41e; Vishram Singh — General Anatomy 4e; BD Chaurasia — Human Anatomy Vol 1 8e. Recent-advances citations are from PubMed (2022–2025) per the answer-bank's recency-enrichment method.



Contrast X-rays

Asked in: Paper IV Oct 2010 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

Contrast radiography (special/contrast X-rays) is a radiographic technique in which a substance whose permeability to X-rays differs from that of the surrounding tissue — a **contrast medium** — is introduced into a hollow organ, cavity, duct or blood vessel to increase the natural radiodensity difference between it and its surroundings. Plain films cannot separate adjacent soft tissues of similar density (bowel loops, ducts, vessels), so these structures remain "radiologically silent"; a contrast medium renders their lumen, contour, calibre and patency visible. The technique, developed as an extension of Roentgen's 1895 discovery of X-rays, underlies most of "radiological (imaging) anatomy" and gives rise to a family of named studies — barium meal, angiogram, myelogram, sialogram, hysterosalpingogram, and others — each called a "**-gram**" and each visualising a specific organ system.

1. Principle and rationale

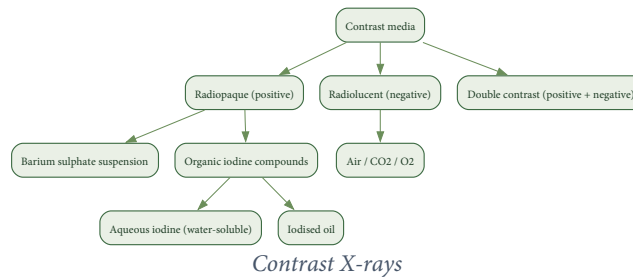
- ▶ On a plain radiograph only four basic densities are distinguished — **air/gas** (radiolucent, black), **fat, soft tissue/water**, and **bone/metal/calcalcification** (radiopaque, white); structures of similar density lying adjacent to one another cannot be told apart.
- ▶ A contrast medium alters the radiodensity of the **lumen** of a hollow viscus/duct/vessel relative to its wall and surrounding parenchyma, so its interior outline, calibre and any filling defect can be assessed.
- ▶ Contrast media are also used for **lesion enhancement** — increasing the density difference between a focal lesion (e.g. a mass in the liver, a renal calculus) and the normal surrounding parenchyma of a solid organ, aiding detection of the lesion itself rather than a hollow lumen.
- ▶ The picture obtained is named by adding the Greek suffix "**-gram**" (gramme = mark) to the structure studied — angiogram, pyelogram, cholecystogram, myelogram, bronchogram, and so on.

2. Classification of contrast media

Type	Examples	Chief use
Radiopaque (positive)	Salts of heavy metals — barium sulphate suspension/emulsion	Gastrointestinal tract (swallow/meal/follow-through/enema)
	Organic iodine compounds — aqueous (water-soluble, ionic/non-ionic)	Biliary passage, urinary tract, blood vessels
	Organic iodine compounds — iodised oil	Bronchial tree, genital passage (uterus/tubes)
Radiolucent (negative)	Air, CO₂, O₂ and other gases	Body cavities — cerebral ventricles (historical pneumoencephalography), serous cavities

Type	Examples	Chief use
Double contrast	Barium + air/gas insufflation	Mucosal-relief studies of stomach and colon — barium coats the mucosa as a thin film after the organ is distended with air

Criteria for an ideal contrast medium: (1) non-toxic, (2) adequately radiopaque or radiolucent, (3) easily administrable, (4) easily available/economical, and (5) rapidly excreted/non-irritant to the mucosa it contacts.



3. Techniques of contrast/special radiography

- **Static contrast radiography:** a single (or few) exposure(s) taken after the contrast medium has filled/coated the structure — used for most named "-grams" below.
- **Fluoroscopy:** the contrast-filled part is viewed **live** under a fluorescent screen/image intensifier, so movement can be studied — e.g. swallowing, peristalsis, or blood flow.
- **Cineradiography:** the fluoroscopic image is recorded on cine film, capturing a moving sequence (e.g. deglutition) for repeated review.
- **Digital subtraction angiography (DSA):** dilute contrast is injected into an artery; a computer digitally **subtracts** the pre-injection ("mask") image from the post-injection image, eliminating overlying bone/soft tissue so only the contrast-filled vessel remains — the preferred method to study a named artery's course, branches and disease.
- **Tomography** (precursor of CT): the X-ray tube and film move in opposite directions during exposure, blurring structures outside one focal plane to produce a single "cut"/section image.

4. Named contrast studies and the structures they visualise

Study ("-gram")	Contrast route	Structure demonstrated
Barium swallow	Oral	Oesophagus
Barium meal	Oral	Stomach and duodenum
Barium follow-through / small-bowel enema	Oral / via tube	Jejunum, ileum
Barium enema	Per rectum	Colon and rectum
Angiography / arteriography	Intra-arterial injection	Arteries
Venography	Intravenous injection	Veins
Lymphangiography	Injected into a lymphatic vessel	Lymphatic vessels

Study ("-gram")	Contrast route	Structure demonstrated
Lymphadenography	As above, delayed films	Lymph nodes
Pyelography — descending (intravenous) or ascending (retrograde)	IV injection, or via a ureteric catheter	Renal calyces, pelvis and ureter
Cystography	Catheter into bladder	Urinary bladder
Cholecystography / cholangiography	Oral or IV	Gall bladder / biliary tree
Hysterosalpingography (HSG)	Cannula through the cervix	Uterine cavity and uterine (fallopian) tubes
Myelography	Intrathecal, via lumbar puncture	Subarachnoid space around the spinal cord and nerve roots
Sialography	Cannula into the duct orifice	Parotid or submandibular salivary duct system
Bronchography	Instilled into the bronchial tree	Bronchi (largely historical)
Arthrography	Intra-articular injection	Joint cavity

5. Interpretation of representative contrast radiographs

- **Barium meal:** taken with the patient erect; the stomach casts a "J"-shaped shadow with a lucent air bubble in the fundus, an **incisura angularis** at the junction of the pylorus and lesser curvature, and a narrow pyloric canal; the first part of the duodenum shows a triangular "**duodenal cap**", and the rest of the duodenum has a floccular mucosal pattern. Mucosal filling defects indicate a lesion; a peptic ulcer produces an "**ulcer crater**" in the stomach or duodenal wall.
- **Barium enema:** demonstrates the characteristic **sacculations (haustrations)** of the colonic wall; the rectum has a wider calibre than the colon, and the vermiform appendix may fill from the base of the caecum. Used to assess the colon for carcinoma, diverticulosis and the extent of inflammatory bowel disease.
- **Intravenous pyelogram (IVP):** the standard method to visualise the urinary tract, showing the calyces, ureter and bladder; radiopaque calculi in the pelvicalyceal system, ureter or bladder are seen as dense shadows. Chief indications: haematuria, dysuria, loin pain.
- **Hysterosalpingogram:** contrast (classically an oil-based agent such as lipiodol) is injected via a cervical cannula; it outlines the uterine cavity and fallopian tubes, and free spill into the peritoneal cavity through the tubal (fimbrial) ostia confirms **tubal patency** — the key investigation in the work-up of female infertility.
- **Cerebral angiography:** contrast injected into the common carotid or vertebral artery shows, in sequence, the **arterial, capillary and venous phases** of transit, mapping the normal vascular pattern and any stenosis/occlusion/aneurysm.

□ Fig 64.7 — Double contrast barium meal films. A, In the erect position, the stoma (Gray's Anatomy — Standing — 41e, p.1545)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled outline of the stomach and duodenum as seen on a barium meal film (erect position), with these exact labels:

- ▶ **Fundus** with lucent gastric **air bubble**
- ▶ **"J"-shaped body** of the stomach
- ▶ **Incisura angularis** (angular notch) at the junction of pylorus and lesser curvature
- ▶ **Pyloric canal** (narrow, at the gastroduodenal junction)
- ▶ **Duodenal cap** — triangular shadow of the first part of the duodenum
- ▶ Floccular mucosal pattern of the remaining duodenum
- ▶ An **ulcer crater** marked at the lesser curvature/duodenal cap to show a filling defect

Recent advances in contrast radiography

- ▶ **Photon-counting CT (PCCT):** semiconductor detectors convert individual X-ray photons directly to electrical signal, giving markedly higher spatial resolution (~0.25 mm), lower noise and spectral (multi-energy) capability — of direct relevance to contrast X-rays, it can **reduce both radiation and contrast-medium dose** while yielding virtual monoenergetic/non-contrast images and iodine maps from one acquisition (Douek et al, *Radiology* 2023) [PMID: 37787672].
- ▶ **Deep-learning image reconstruction (DLIR/DLR) for dose reduction:** DLIR with low-tube-voltage protocols lets coronary/whole-body CT angiography use substantially lower iodinated-contrast volumes and radiation dose than conventional reconstruction while preserving vessel signal/contrast-to-noise (Li et al, *Eur J Radiol* 2023 [PMID: 36804314]; Shen et al, *Eur Radiol* 2025 [PMID: 40411550]).
- ▶ **Next-generation gadolinium-based agents:** high-relaxivity macrocyclic agents such as gadopicles permit a lower administered gadolinium dose without loss of image quality (Bendszus et al, *J Magn Reson Imaging* 2024) [PMID: 38226697]; an updated safety review confirms nephrogenic systemic fibrosis is now rare with modern agents, while trace brain/organ gadolinium deposition remains of uncertain clinical significance (Starekova et al, *AJR* 2023) [PMID: 37850581].
- ▶ **Contrast-induced acute kidney injury (CI-AKI) prevention:** current reviews emphasise adequate peri-procedural hydration, the lowest feasible contrast volume, withholding metformin/NSAIDs around contrast administration in at-risk patients, and risk stratification (e.g. Mehran score) by pre-existing renal impairment, diabetes, dehydration and cardiac failure (Li & Wang, *BMC Nephrology* 2024) [PMID: 38649939].

(According to PubMed; DOIs: [10.1148/radiol.222432](https://doi.org/10.1148/radiol.222432), [10.1016/j.ejrad.2023.110736](https://doi.org/10.1016/j.ejrad.2023.110736), [10.1007/s00330-025-11681-3](https://doi.org/10.1007/s00330-025-11681-3), [10.1002/jmri.29181](https://doi.org/10.1002/jmri.29181), [10.2214/AJR.23.30036](https://doi.org/10.2214/AJR.23.30036), [10.1186/s12882-024-03570-6](https://doi.org/10.1186/s12882-024-03570-6).)

Applied / Clinical anatomy

- ▶ **Indications, by study:** barium studies for dysphagia, peptic ulcer, tumour, obstruction; IVP/pyelography for haematuria, renal colic, calculi; HSG for female infertility work-up (tubal patency, uterine anomalies), timed to the early-to-mid follicular phase (days 7–10) to avoid an early pregnancy/endometritis; myelography when MRI is contraindicated or unavailable, for disc prolapse/cord compression/tumour; sialography for recurrent sialadenitis or sialolithiasis; arthrography for internal joint derangement.
- ▶ **Barium-specific precautions:** contraindicated if bowel **perforation** is suspected — extravasated barium causes chemical/granulomatous **barium peritonitis**; a water-soluble iodinated agent is substituted instead. Aspiration into the airway can occur if swallowing is incoordinated.
- ▶ **Iodinated-contrast reactions:** idiosyncratic (anaphylactoid) reactions ranging from mild urticaria/nausea to bronchospasm, laryngeal oedema and anaphylactic shock — risk is lower with modern low-osmolar/iso-osmolar non-ionic agents than older high-osmolar ionic media; contrast-induced acute kidney injury is the other major systemic complication (see Recent advances).
- ▶ **DSA in clinical practice:** the standard technique for mapping cerebral, coronary and peripheral vascular disease before endovascular/surgical intervention, since subtraction removes overlying bone that would otherwise obscure a small-calibre vessel.
- ▶ **Superseded by cross-sectional imaging:** pneumoencephalography, ventriculography, cranial myelography and plain bronchography are now largely obsolete, replaced by CT/MRI/modern DSA; spinal myelography, HSG, cholangiography and sialography retain specific clinical niches.

High-yield exam pointers

- ▶ Two basic categories of contrast medium: **radiopaque** (barium sulphate, organic iodine compounds) and **radiolucent** (air/gases); **double contrast** = both combined.
- ▶ Criteria of an ideal contrast medium: non-toxic, adequately radiopaque/radiolucent, easily administrable, easily available.
- ▶ **"-gram"** suffix names the resulting picture: angiogram, pyelogram, myelogram, sialogram, cholangiogram.
- ▶ Pyelography is **descending (IV)** or **ascending (retrograde, via ureteric catheter)**.
- ▶ **Barium meal** landmarks: "J"-shaped stomach, incisura angularis, pyloric canal, duodenal cap.
- ▶ HSG confirms tubal patency by peritoneal spill of contrast through the fimbrial ostia — key infertility investigation.
- ▶ **Myelography** = intrathecal contrast via lumbar puncture, for the subarachnoid space/spinal cord/nerve roots.
- ▶ **DSA** = digital subtraction of pre- from post-contrast images to remove bone/soft-tissue background and isolate the vessel.
- ▶ Barium is contraindicated in suspected **perforation** (risk of barium peritonitis) — use water-soluble contrast instead.
- ▶ Fluoroscopy gives **real-time/dynamic** images; cineradiography **records** the fluoroscopic sequence on film.

SOURCE & COVERAGE

Vishram Singh — General Anatomy 4e; IB Singh — Textbook of Anatomy Vol 1, 2 and 3 (6e); AK Datta — Human Anatomy Vol 2 (Head & Neck); BD Chaurasia — Human Anatomy Vol 2 and Vol 3–4 (8e); Moore's Clinically Oriented Anatomy 9e; IB Singh — Textbook of Human Neuroanatomy; Gray's Anatomy (Standring) 41e.

Coverage note: adverse-reaction and contrast-induced-nephropathy detail is standard radiology-adjacent teaching rather than a topic elaborated at length in the anatomy corpus itself; it is stated here at the level universally taught alongside "Contrast X-rays" in Indian PG anatomy texts, and cross-checked against the Recent-advances literature above (PubMed, 2023–2025) for currency.



Cross sectional anatomy at the level of L1 vertebra (labeled diagram only)

Asked in: Paper IV Oct 2009 · Paper IV May 2009 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

A transverse (axial) section through the body of the first lumbar (L1) vertebra is one of the four "landmark" cross-sectional levels used to teach the disposition of the upper abdominal viscera (the others being T10, T12 and L3–L4), and it corresponds closely to the **transpyloric plane (plane of Addison)** — a horizontal surface plane lying midway between the suprasternal notch and the pubic symphysis. This level is deliberately chosen because an extraordinary number of clinically important structures cluster here: the pylorus, the neck of the pancreas, the origins of the coeliac trunk and superior mesenteric artery, the renal hila, the cisterna chyli, and the termination of the spinal cord. A single labelled diagram at this level therefore tests the candidate's grasp of vertebral, muscular, vascular, visceral and neural anatomy simultaneously, and is routinely correlated with axial CT/MRI images in radiology teaching.

Level of section and its relation to the transpyloric plane

Vertebral level	Key viscera at this level (Gray's Table 43.3)
T10 / upper T11	Lower border of lung; cardia of stomach; upper border of kidney
T12–L1 space / mid-L1 body	Lowest level of pleura; pylorus; transpyloric plane; hilum of left kidney; origin of renal arteries and superior mesenteric artery; neck of pancreas; spinal cord termination
L1–L2 space / mid-L2 body	Head of pancreas; duodenojejunal flexure
L2–L3 space / mid-L3 body	Lower border of kidney

- ▶ The transpyloric plane posteriorly intersects the lower half of the body of L1, the L1/L2 intervertebral disc, or the upper half of L2 (it sits slightly higher in males than females); anteriorly it crosses the ninth costal cartilage at the linea semilunaris.
- ▶ Because the vertebral body of L1 has vertical height, a "section at L1" in practice spans a short cranio-caudal range — its **upper part corresponds to the classic transpyloric-plane landmarks**, while its **lower part (approaching the L1–L2 disc) corresponds to the level most often illustrated in cross-sectional atlases, where the renal hila, renal vessels and origin of the superior mesenteric vein are the dominant features**. Both sub-levels are described below so that the single diagram can be labelled comprehensively.

Vertebral column and vertebral (spinal) canal

- ▶ The **body of L1** is kidney-shaped in section, larger transversely than antero-posteriorly, with a pair of short, stout **pedicles** continuing back into the **laminae**, a single midline **spinous process**, and a **transverse process** on each side (site of origin of slips of psoas major and, more laterally, quadratus lumborum).
- ▶ The **vertebral (spinal) canal** lies posterior to the body and contains, from without in: **epidural fat and the internal vertebral venous plexus**, the **dura mater** enclosing the **thecal sac** (arachnoid mater and CSF), and within the thecal sac either the tapering tip of the **conus medullaris** or the beginning of the **cauda equina** — the adult spinal cord terminates, on average, at the middle third of the body of L1 (range: middle third of T11 to middle third of L3), so a section through L1 very often catches the conus/cauda equina transition.
- ▶ **Ligaments**: anterior longitudinal ligament on the front of the body, posterior longitudinal ligament on its posterior surface within the canal, and ligamentum flavum linking adjacent laminae.

Posterior abdominal wall — muscles, great vessels and lymphatics

- ▶ **Psoas major** bulges on each side from the lateral aspect of the vertebral body/transverse process (it takes fleshy slips from the bodies, discs and transverse processes of T12–L5); the **sympathetic trunk with its lumbar ganglia** runs along its medial border, on the antero-lateral surface of the vertebral body.
- ▶ **Quadratus lumborum** lies posterolateral to psoas major, and the **erector spinae** mass lies further posteriorly, flanking the spinous process; the tip of the **12th rib** may be cut if the section is high enough.
- ▶ The **right and left crura of the diaphragm** are cut as paired muscular pillars applied to the front and sides of the vertebral body — the broader right crus arises from the upper three lumbar vertebral bodies/discs (L1–L3) and the left crus from the upper two (L1–L2), so both crura are present at this level, flanking the aorta.
- ▶ In the midline anterior to the vertebral body lies the **abdominal aorta**, with the **inferior vena cava** immediately to its right. To the right of the aorta, in order, are the IVC, the **right crus**, and (in the upper part of the level) the **cisterna chyli and azygos vein**; to the left of the aorta lie the **left crus and the pancreas**.

- The **cisterna chyli**, the dilated lower end of the thoracic duct (about 5–7 cm long), lies in front of the L1–L2 vertebral bodies immediately to the right of the aorta, overlapped by the right crus — it receives the paired lumbar lymphatic trunks and the intestinal lymphatic trunk.
- The **coeliac trunk** arises from the front of the aorta just above this level (T12/L1); the **superior mesenteric artery** arises from the aorta at L1, close to the transpyloric plane; the **renal arteries** arise a little lower, most commonly at the lower border of L1 to the upper border of L2.

Anterior (visceral) structures at the level of L1

Upper part of L1 (transpyloric plane)	Lower part of L1 / L1–L2 junction (renal-hilar level)
Pylorus of stomach (inconstant — a supine/gravity-dependent finding)	Coils of jejunum/ileum occupying most of the peritoneal cavity; liver reduced to a small area on the right
Fundus of the gallbladder, near the tip of the right 9th costal cartilage	Hila of both kidneys with the renal vessels — the dominant feature of this level
Neck of the pancreas, anterior to the union of the splenic and superior mesenteric veins forming the portal vein	Uncinate process of the pancreas , wrapped behind the superior mesenteric vessels
First part of the duodenum (duodenal cap)	Origin/confluence of the superior mesenteric artery and vein
Left lobe of liver anteriorly; right lobe smaller here than at T10/T12	Second (descending) part of duodenum, related to the head of pancreas medially and the right kidney posteriorly
Lower pole of spleen / tail of pancreas may still be cut on the left in some individuals	Left renal vein crossing anterior to the aorta, just below the origin of the SMA, to reach the IVC

□ Fig 5.104 — Transverse magnetic resonance images (MRIs) of abdomen. A. Level of T1 (Moore — Clinically Oriented Anatomy — 9e, p.926)

(Panel B of this Moore plate is captioned "Level of L1–L2 vertebra and renal vessels and hilum" — the actual radiological cross-section at the level asked.)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw one transverse (inferior-view) outline of the trunk at the L1 level and label exactly:

- ▶ **Body of L1 vertebra** (pedicle, lamina, spinous process, transverse process)
- ▶ **Vertebral canal**: thecal sac containing conus medullaris/cauda equina, epidural fat
- ▶ **Abdominal aorta** (midline, slightly left) and **inferior vena cava** (to its right)
- ▶ **Right crus and left crus of diaphragm** flanking the vertebral body
- ▶ **Cisterna chyli and azygos vein**, behind the right crus, to the right of the aorta
- ▶ **Right kidney and left kidney**, each with its **hilum, renal artery and renal vein**
- ▶ **Uncinate process of pancreas / neck of pancreas**, with the **splenic vein–superior mesenteric vein confluence (portal vein origin)**
- ▶ **Second part of duodenum** (right) and **stomach/first part of duodenum** if the cut is high
- ▶ **Liver** (right, reduced) and **spleen/tail of pancreas** (left, if cut is high)
- ▶ **Psoas major** (both sides, sympathetic trunk on its medial border) and **quadratus lumborum** (posterolateral to psoas)
- ▶ **Erector spinae** mass posteriorly; **12th rib** tip if present
- ▶ **Abdominal wall muscle layers** anterolaterally: external oblique, internal oblique, transversus abdominis

Applied / Clinical anatomy

- ▶ **Transpyloric plane as a surface landmark**: because the pylorus, fundus of gallbladder, DJ flexure, hila of the kidneys, neck of pancreas and origin of the SMA all cluster at the L1 level, this plane is used clinically to localise these structures on examination and on cross-sectional imaging.
- ▶ **Lumbar puncture / spinal anaesthesia safety**: since the spinal cord (conus medullaris) usually ends at the level of L1, LP and spinal anaesthesia are performed lower down, at the L3–L4 or L4–L5 interspace (below Tuffier's/the supracristal line), to avoid cord injury — the L1-level section is the anatomical basis for this safety margin.
- ▶ **PCNL and retroperitoneal access**: the note that the pleura may descend to the T12/L1 level is directly relevant to percutaneous nephrolithotomy and posterior renal/adrenal surgical approaches, where a supracostal (11th/12th rib) puncture risks pleural transgression.
- ▶ **Vascular surgery**: because the renal arteries arise just below the SMA near the L1/L2 level, this is the key landmark distinguishing a **suprarenal from an infrarenal abdominal aortic aneurysm**, which determines the feasibility of standard endovascular repair.
- ▶ **Radiology correlation**: axial CT/MRI at this level is the standard slice used to assess pancreatic-neck/uncinate-process pathology, renal hilar masses and calculi, and retroperitoneal (para-aortic) lymphadenopathy.
- ▶ **Psoas abscess**: tuberculous caries of the L1 vertebral body can track down within the psoas sheath (seen flanking the vertebral body at this level) to present as a swelling below the inguinal ligament.

- ▶ **Cisterna chyli and lymphatic leaks:** its position anterior to L1–L2, behind the right crus, is relevant to iatrogenic chyle leak/chylous ascites during retroperitoneal (para-aortic) lymph node dissection or aortic surgery.

High-yield exam pointers

- ▶ L1 vertebral level ≈ **transpyloric plane (plane of Addison)** — midway between the suprasternal notch and the pubic symphysis.
- ▶ **Spinal cord (conus medullaris) terminates, on average, at the mid-third of L1** — hence lumbar puncture is performed at L3–L4/L4–L5, well below this level.
- ▶ Cranio-caudal order of major branches near this level, from above downwards: **coeliac trunk (T12/L1)**, then the **superior mesenteric artery (L1)**, then the **renal arteries (lower L1–upper L2)**.
- ▶ **Renal hila** lie approximately at the L1/L2 level, the left slightly higher than the right.
- ▶ **Cisterna chyli** lies in front of the L1–L2 vertebral bodies, to the right of the aorta, deep to the right crus of the diaphragm.
- ▶ **Both crura of the diaphragm** are cut at L1 — right crus from L1–L3, left crus from L1–L2 vertebral bodies.
- ▶ **Neck of the pancreas** lies in the transpyloric plane, anterior to the confluence of the splenic and superior mesenteric veins that forms the **portal vein**.
- ▶ **Psoas major** (origin T12–L5) and **quadratus lumborum** flank the vertebral body; the **sympathetic trunk** runs along the medial border of psoas.
- ▶ The **pleura may extend down to the T12/L1 level posteriorly** — relevant to supracostal renal punctures.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; IB Singh — Textbook of Anatomy Vol 2 6e; BD Chaurasia — Human Anatomy Vol 2 8e.



Functional MRI

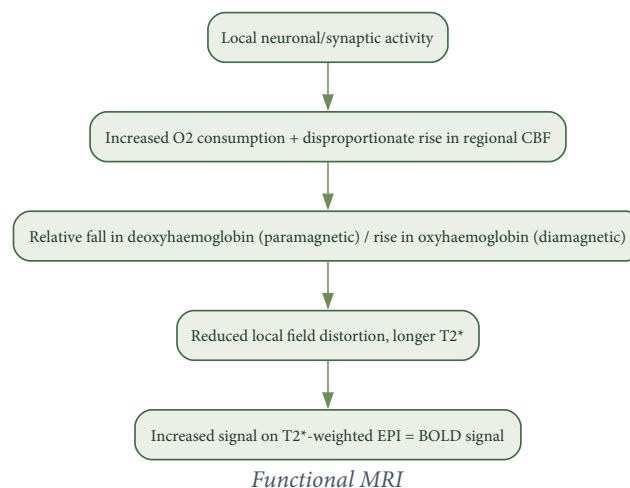
Asked in: Paper IV 14-Jul-2023 · Paper IV Nov 2017 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

Functional magnetic resonance imaging (fMRI) is a non-invasive neuroimaging technique that maps regional neuronal activity in the living brain by detecting the haemodynamic changes that accompany neural firing, rather than imaging structure directly. It exploits the **blood oxygenation level-dependent (BOLD)** contrast generated by the differing magnetic properties of oxy- and deoxy-haemoglobin. Unlike CT/PET, fMRI requires no ionising radiation or radiotracer, and unlike diffusion tensor imaging (DTI), which maps white-matter tract anatomy at rest, fMRI maps functional activity, either evoked by a task or occurring spontaneously ("resting state"). It has become indispensable in neuroanatomy research, cognitive neuroscience and presurgical planning.

Principle: the BOLD signal and neurovascular coupling

- ▶ **Neurovascular coupling:** increased neuronal/synaptic activity in a cortical region raises local oxygen demand; the vascular response overcompensates, producing a disproportionate **increase in regional cerebral blood flow (rCBF)** relative to the rise in oxygen extraction.
- ▶ Net result: the ratio of oxygenated to deoxygenated haemoglobin in the activated region's capillaries and draining veins **increases** (i.e. relative deoxyhaemoglobin falls).
- ▶ **Magnetic basis:** oxyhaemoglobin is **diamagnetic**; deoxyhaemoglobin is **paramagnetic**. Paramagnetic deoxyhaemoglobin distorts the local magnetic field and shortens T_2/T_2 relaxation, *reducing MR signal*; a fall in deoxyhaemoglobin therefore produces a local increase in signal intensity on T_2 -weighted images — the BOLD signal.
- ▶ Because blood oxygenation tracks the level of neural activity, comparing BOLD signal during an "active" epoch with a "control/rest" epoch localises the brain regions engaged by that activity.
- ▶ **Acquisition:** rapid T_2 -weighted gradient-echo echo-planar imaging (EPI)** sequences are used to acquire whole-brain volumes every 1–3 seconds; typical clinical spatial resolution is 2–4 mm (sub-millimetre, isotropic resolution achievable at ultra-high field ≥ 7 T).
- ▶ The BOLD response is an indirect, delayed (peaking ~4–6 s after neuronal onset) haemodynamic proxy for neural activity, not a direct measure of electrical firing.



Task-based vs resting-state fMRI

Feature	Task-based (activation) fMRI	Resting-state fMRI
Paradigm	Subject performs a motor/sensory/cognitive task in alternating "on/off" (block) or single-trial (event-related) epochs	Subject lies quietly, eyes open/closed, performing no explicit task
What is mapped	Cortex directly activated by the specific task	Spontaneous, low-frequency (<0.1 Hz) synchronous fluctuations defining intrinsic functional-connectivity networks

Feature	Task-based (activation) fMRI	Resting-state fMRI
Key finding	Localises eloquent cortex for that task (e.g. finger tapping → motor cortex)	Reveals networks such as the default mode network (DMN) — active during quiet repose, "deactivating" during externally-directed tasks (Biswal et al 1995; Raichle et al 2001)
Clinical use	Presurgical mapping in cooperative patients	Presurgical mapping in patients unable to cooperate (children, sedated, aphasic, paretic patients)
Limitation	Requires task compliance, is confounded by performance variability	Networks still being standardised; more sensitive to physiological noise (respiration, cardiac pulsation)

Functional neuroanatomy demonstrated by fMRI

Function tested	Typical paradigm	Cortical area localised
Motor	Finger/foot tapping, tongue movement, lip pursing	Precentral gyrus (primary motor cortex); the hand representation lies at a characteristic protrusion of the precentral gyrus corresponding to the middle genu of the central sulcus , at the distal end of the superior frontal sulcus — clinically termed the " hand knob " (Yousry et al 1997)
Sensory	Tactile/vibratory stimulation	Postcentral gyrus (primary somatosensory cortex)
Expressive language	Silent word generation, antonym generation	Broca's area (opercular and triangular parts of the inferior frontal gyrus)
Receptive language	Text reading vs symbol discrimination; true/false statements vs symbol matching	Wernicke's area (posterior superior temporal gyrus/temporo-parietal junction)
Vision	Passive viewing/reading of text	Primary visual cortex (calcarine cortex, occipital lobe)
Resting/intrinsic network	No task (resting state)	Default mode network — posterior cingulate cortex/retrosplenial cortex, precuneus, ventromedial and dorsomedial prefrontal cortex, inferior parietal lobule, lateral temporal cortex, hippocampal formation

Rhyme, semantic and category-fluency language tasks each activate overlapping but distinct combinations of the middle frontal gyrus, opercular/triangular/orbital parts of the inferior frontal gyrus,

superior temporal sulcus and superior occipital gyrus of the (usually left, language-dominant) hemisphere.

□ Fig 3.1 — default mode network: a surface projection of regions more active during passive/resting task states than during active tasks, and a topography of regions functionally coupled to the posterior cingulate, dorsomedial prefrontal cortex and hippocampal formation (Gray's Anatomy — Standring — 41e, p.564)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Lateral surface projection of the default mode network (label exactly, per the plate above):

- ▶ PFC (prefrontal cortex) and dMPFC (dorsomedial prefrontal cortex)
- ▶ vMPFC (ventromedial prefrontal cortex)
- ▶ pCC/Rsp (posterior cingulate cortex/retrosplenial cortex)
- ▶ Precuneus
- ▶ IPL (inferior parietal lobule)
- ▶ LTC (lateral temporal cortex)
- ▶ Ins (insula)
- ▶ HF+ (hippocampal formation)

A second simple lateral-brain outline is worth sketching for eloquent-cortex mapping, labelling: central sulcus, precentral gyrus with the "hand knob" (motor hand area), postcentral gyrus, inferior frontal gyrus (opercular/triangular parts = Broca's area), posterior superior temporal gyrus (Wernicke's area), lateral (Sylvian) fissure, and calcarine sulcus (primary visual cortex).

fMRI compared with other imaging modalities

Modality	What it images	Radiation/tracer	Spatial resolution	Temporal resolution
fMRI (BOLD)	Haemodynamic surrogate of neural activity	None	~2–4 mm (sub-mm at ≥7 T)	Seconds
PET	Regional metabolism/receptor binding (e.g. FDG)	Radiotracer, ionising	~4–6 mm	Minutes
DTI/tractography	Structural white-matter fibre orientation (at rest, no task)	None	~2 mm	N/A (structural)
EEG/MEG	Direct electrical/magnetic neuronal signal	None	Poor (cm)	Milliseconds

Modality	What it images	Radiation/tracer	Spatial resolution	Temporal resolution
Intraoperative electrocortical stimulation / Wada (intracarotid amytal) test	Direct cortical stimulation mapping / hemispheric language-memory lateralisation	Invasive	High	Real-time

Recent advances in fMRI

- ▶ **Ultra-high-field (≥ 7 T) fMRI with AI-assisted post-processing:** sub-millimetre BOLD mapping improves delineation of resection margins for presurgical planning; AI is being used for denoising, artefact removal and generating super-resolution fMRI maps that can feed directly into robot-assisted neurosurgical navigation systems (Seghier, *Eur Radiol Exp* 2024) [PMID: 38945979].
- ▶ **Resting-state fMRI standardisation for neuro-oncology:** growing evidence supports resting-state fMRI as a substitute for task-based fMRI in patients (children, sedated, aphasic or paretic) unable to cooperate with active paradigms, aiding tailored glioma resection while preserving eloquent functional networks (Sparacia et al, *Brain Sci* 2021) [PMID: 34942915].
- ▶ **fMRI replacing the Wada (intracarotid amytal) test:** non-invasive fMRI language/memory lateralisation is increasingly used in place of the invasive Wada test in presurgical epilepsy work-up, though concordance/discordance between the two remains an active area of study, particularly in paediatric epilepsy with atypical hemispheric organisation (Ailion et al, *Clin Neuropsychol* 2023) [PMID: 37985747].
- ▶ **Simultaneous EEG-fMRI:** combining scalp EEG with BOLD imaging localises the haemodynamic correlates of interictal epileptiform discharges, implicating networks such as the thalamus and default mode network in generalized and focal epilepsy, and informing surgical planning (Ikemoto et al, *Epilepsia* 2022) [PMID: 35822919].
- ▶ **Network-guided neuromodulation:** fMRI-derived functional and structural connectivity maps are being combined with diffusion imaging to select and target deep-brain/responsive neurostimulation sites (e.g. anterior and centromedian thalamic nuclei) in drug-resistant epilepsy (Piper et al, *Brain* 2022) [PMID: 35771657].

(According to PubMed; DOIs: [10.1186/s41747-024-00472-y](<https://doi.org/10.1186/s41747-024-00472-y>), [10.3390/brainsci11121613](<https://doi.org/10.3390/brainsci11121613>), [10.1080/13854046.2023.2281708](<https://doi.org/10.1080/13854046.2023.2281708>), [10.1111/epi.17364](<https://doi.org/10.1111/epi.17364>), [10.1093/brain/awac234](<https://doi.org/10.1093/brain/awac234>).)

Applied / Clinical anatomy

- ▶ **Presurgical mapping:** fMRI is the primary non-invasive tool to localise eloquent motor, sensory, language and visual cortex relative to a tumour or epileptogenic focus before neurosurgical resection, minimising post-operative neurological/cognitive deficit.

- ▶ **Cerebral lateralisation:** fMRI (with PET) has replaced much of the older commissurotomy/"split-brain" literature for studying hemispheric dominance — the left hemisphere is typically dominant for language, mathematics and analytical thought, the right for spatial/holistic processing; lateralisation is less marked in left-handers and in women.
- ▶ **Default mode network as a disease biomarker:** DMN connectivity changes discriminate Alzheimer's disease from dementia with Lewy bodies, track cognitive decline in Alzheimer's disease, are disrupted in Parkinson's disease even before structural change is evident, and grade the depth of disorders of consciousness (vegetative state vs minimally conscious state vs emergence from minimal consciousness).
- ▶ **Psychiatric and developmental correlates:** altered resting-state/DMN connectivity has been reported in schizophrenia, major depressive disorder and autism spectrum disorder, though these remain research rather than routine diagnostic applications.
- ▶ **Safety profile:** being radiation- and contrast-free (in BOLD mode), fMRI is repeatable and suited to paediatric and longitudinal study, though standard MRI contraindications (ferromagnetic implants, pacemakers) apply.
- ▶ **Limitation to remember:** BOLD is a haemodynamic surrogate, so it can be confounded by vascular pathology (e.g. tumour neovascularity, stenosis) causing "neurovascular uncoupling" and false localisation — a key reason intraoperative electrocortical stimulation remains the gold standard for final confirmation.

High-yield exam pointers

- ▶ fMRI is based on the **BOLD** effect: paramagnetic deoxyhaemoglobin vs diamagnetic oxyhaemoglobin.
- ▶ Sequence used: $*T2^*$ -weighted gradient-echo EPI**.
- ▶ Two broad paradigms: **task-based** (block/event-related) and **resting-state**.
- ▶ Motor hand area = protrusion of precentral gyrus at the **middle genu of the central sulcus** ("hand knob").
- ▶ Language mapping: **Broca's area** (expressive, inferior frontal gyrus) and **Wernicke's area** (receptive, posterior superior temporal gyrus).
- ▶ **Default mode network** = posterior cingulate/precuneus + ventromedial prefrontal cortex + inferior parietal lobule, active at rest, suppressed during externally-directed tasks (Raichle et al 2001).
- ▶ Main clinical use: **presurgical mapping** of eloquent cortex in epilepsy/tumour surgery, and increasingly replacing the invasive Wada test.
- ▶ No ionising radiation, unlike PET; complementary to DTI (structure) and EEG/MEG (millisecond electrical timing).
- ▶ Key limitation: indirect, delayed, vascular-dependent signal — vulnerable to neurovascular uncoupling near tumours/vascular lesions.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Weir & Abrahams — Imaging Atlas of Human Anatomy 6e; IB Singh — Textbook of Human Neuroanatomy.

Coverage note: the spec's assigned specialty text (Moore's Clinically Oriented Anatomy 9e) does not carry a dedicated fMRI passage in the indexed chapters; grounding for imaging principle and clinical paradigms was drawn instead from Weir & Abrahams' dedicated "Functional imaging (fMRI and DTI)" chapter and from Gray's Anatomy 41e (Cerebral hemispheres chapter and the "Resting human brain/default mode network" commentary), cross-checked against IB Singh's Neuroanatomy for the lateralisation point. Recent-advances citations are from PubMed (2021–2024) per the answer-bank's recency-enrichment method.



MRI

Asked in: Paper IV 17-Apr-2026 · Paper IV Sep 2007 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction Magnetic resonance imaging (MRI) is a non-invasive, non-ionizing cross-sectional imaging technique that generates high-resolution images of soft tissue by exploiting the behaviour of mobile hydrogen protons (in fat, water and other soft tissues) when a patient is placed in a powerful static magnetic field and pulsed with radiofrequency (RF) energy. Unlike computed tomography (CT), MRI uses no X-rays, carries no recognised biological hazard from the magnetic field itself, and gives markedly better soft-tissue differentiation. Because the sections it generates closely resemble true anatomical sections, MRI is central both to clinical diagnosis and to the teaching of cross-sectional/radiological anatomy.

1. Principle of magnetic resonance imaging

- ▶ The **hydrogen nucleus (proton)** behaves like a tiny spinning bar magnet. Free protons in body tissues, when placed in the scanner's strong static magnetic field, become **aligned** with or against the field, producing a small net magnetic vector.
- ▶ RF energy delivered through coils (built into the scanner or applied to specific body parts) generates a **second magnetic field perpendicular to the static field**, which "flips" the aligned protons away from equilibrium — i.e., **excites** them — when broadcast at the resonant (Larmor) frequency (≈ 46.3 MHz for hydrogen in a typical clinical field).
- ▶ When the RF pulse is switched off, the excited protons **relax** back to their original equilibrium position, releasing the absorbed RF energy as a measurable signal that is picked up by the receiving antenna/coil around the patient.
- ▶ This signal is amplified, digitised and **spatially encoded** (using additional gradient magnetic fields) by an array processor and reconstructed by computer into a matrix of picture elements — the MR image.
- ▶ Tissue **signal intensity** depends on three proton properties of the region being imaged: **proton density**, **T1 relaxation** (longitudinal/spin-lattice relaxation) time, and **T2 relaxation**

(transverse/spin-spin relaxation) time — giving rise to proton-density-, T1- and T2-weighted images respectively.

- Tissues rich in mobile protons (fat, water) emit strong signals; tissues poor in mobile protons (cortical bone, air) emit little or no signal. Fast-moving protons, as in flowing blood, tend to move out of the imaging slice before they can relax and emit their signal — hence flowing blood typically appears black (a "flow void"), especially on T1-weighted images.

2. MR image weighting and pulse sequences

The same tissue can look very different depending on how the RF pulses are timed and received — this is called "weighting" the image.

Sequence	CSF / fluid	Fat	Typical role
T1-weighted	Low signal (dark)	High signal (bright)	Best depicts anatomical detail — nicknamed the "anatomy weighting" among radiologists who teach anatomy
T2-weighted	High signal (bright)	High signal (bright)	Shows fluid/oedema clearly — the "pathology weighting"
Proton-density	Intermediate	Intermediate	Good tissue contrast, e.g. joint imaging
STIR / T2 fat-sat (T2FS)	High signal	Suppressed (dark)	Very sensitive for soft-tissue or bone-marrow oedema of inflammation/tumour
T1 fat-sat + gadolinium (T1FS)	—	Suppressed	Exquisitely highlights hypervascularity (tumour, inflammation, blood–brain-barrier breakdown)

- **Metallic artefact reduction sequences (MARS)** are used to image periprosthetic soft tissue after joint replacement or other orthopaedic metalwork, minimising the local artefact produced by "MRI-friendly" implants.

3. MRI equipment and magnet types

Magnet type	Field strength	Technology	Use
Routine high-field system	3–7 Tesla (T)	Superconducting electromagnet immersed in liquid helium	Standard whole-body clinical/research scanning
Open magnet	0.2–0.75 T	Permanent magnet	Claustrophobic patients
Limb/extremity scanner	0.2–0.75 T	Permanent magnet	Peripheral joint imaging

Magnet type	Field strength	Technology	Use
(for comparison) Earth's magnetic field	30–60 μ T	—	—

- Higher field strength gives greater spatial resolution and contrast; 8-T research systems now image live human brain microvasculature in detail comparable with histological sections.
- Computers attached to the scanner can reconstruct data in **any plane** — transverse, sagittal, coronal or oblique — and generate three-dimensional reconstructions, without repositioning the patient.

4. Advantages and limitations of MRI

Advantages

- No ionising radiation; no recognised biological hazard from the static magnetic field.
- Superior soft-tissue contrast/differentiation compared with CT and ultrasound.
- True multiplanar and 3-D imaging from a single acquisition.
- Fast, gated sequences now allow real-time imaging of moving structures such as the beating heart and flowing blood, overcoming the motion artefact that limited early scanners.
- Can be extended to give functional, metabolic and microstructural information (see below), not just anatomical detail.

Limitations

- Expensive equipment and long scan times relative to CT/ultrasound.
- Cortical bone, calcification and air (lungs, bowel gas) give little or no signal, so plain radiography/CT remain better for these.
- Absolutely contraindicated in patients with certain implants (see Safety, below).
- Requires patient co-operation/stillness for optimal image quality; claustrophobia limits use of closed high-field magnets.

5. Newer / advanced MRI-based techniques



- **Functional MRI (fMRI)** exploits the differing magnetic properties of oxygenated (diamagnetic) versus deoxygenated (paramagnetic) haemoglobin (the BOLD signal) to map neuronal activity in real time — used for pre-surgical localisation of eloquent cortex.
- **MR spectroscopy (MRS)** displays the chemical-shift resonance spectrum of a chosen brain volume; peaks for metabolites such as N-acetylaspartate, choline and lactate help evaluate multiple sclerosis, stroke, schizophrenia and brain tumours.
- **Diffusion tensor imaging (DTI)** and **high angular resolution diffusion imaging (HARDI)** measure the anisotropic (directional) diffusion of water along white-matter fibre bundles (the myelin sheath and axon bundles act as diffusion barriers); this data is used to reconstruct **MR tractography (MRT)**, a 3-D model of neural tracts used for pre-operative mapping of pathways such as the pyramidal tract. Diffusion MRI was first introduced in 1985.

- ▶ **Molecular MRI (mMRI)** uses biomarkers that alter the image according to molecular/biochemical change in the target tissue, aiding early disease detection.
- ▶ **MR angiography/venography (MRA/MRV)** images blood vessels non-invasively, often without contrast (time-of-flight technique); **MR cholangiopancreatography (MRCP)** is now the standard non-invasive method for imaging the biliary tree and pancreatic duct, largely replacing diagnostic ERCP.

6. Safety, hazards and contraindications

- ▶ MRI itself has **no recognised biological hazard**, since it uses no ionising radiation.
- ▶ **Absolute contraindications** (high risk of death or blindness): cardiac pacemakers or other implanted electro-inductive devices, ferromagnetic intracranial aneurysm clips, certain cardiac valve replacements, and intraocular metallic foreign bodies.
- ▶ Many extracranial vascular clips and orthopaedic prostheses are now "**MRI-friendly**" but may still cause local artefact (reduced with newer/MARS sequences).
- ▶ Loose metallic objects, "MR-unfriendly" anaesthetic equipment and credit cards must be kept out of the scanner room — ferromagnetic objects can become dangerous projectiles.

Applied / Clinical anatomy

□ Fig 16.13 — MRI of the head (Vishram Singh — *General Anatomy* — 4e, p.676)

- ▶ **CNS:** MRI is the modality of choice for the brain and spinal cord — demonstrating ventricles, midbrain, cerebral hemispheres, demyelination (T2/FLAIR hyperintensity in multiple sclerosis), infarcts (diffusion-weighted imaging), and tumours (contrast enhancement); DTI/MR tractography is used for pre-surgical mapping of white-matter tracts.
- ▶ **Joints:** T1-weighted coronal MRI clearly depicts the ligaments and menisci of the knee joint and other joints; MARS sequences image periprosthetic soft tissue after joint replacement.
- ▶ **Pelvis:** T2-weighted MR images through the pelvis demonstrate normal female pelvic anatomy (uterus, cervix, ovaries, rectum) and are used in staging pelvic malignancy.
- ▶ **Thorax:** MRI better delineates mediastinal soft-tissue lesions, lymph nodes and lung-root structures than CT, and reconstructed MR angiograms display the heart and great vessels; breast MRI (with dedicated breast coils) further characterises lesions detected on mammography/ultrasound.
- ▶ **Abdomen:** MRI gives superior soft-tissue differentiation of the liver and its relationship to retroperitoneal structures; MRA is used for abdominal vascular studies, and MRCP has become the standard non-invasive study of the biliary and pancreatic ductal system.
- ▶ **Vascular system:** MR angiography/venography (e.g., of the dural venous sinuses) provides non-invasive vascular anatomy without the need for catheter contrast injection.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

An axial (horizontal) MR section through the head at the level of the midbrain — label:

- ▶ Nasal cavity
- ▶ Eyeball
- ▶ Midbrain
- ▶ Cerebral hemisphere

High-yield exam pointers

- ▶ MRI produces images by exciting hydrogen protons with RF pulses in a strong static magnetic field, then detecting the RF signal released as protons "relax" — no ionising radiation is used.
- ▶ Signal intensity is governed by proton density, T1 relaxation and T2 relaxation, giving proton-density-, T1- ("anatomy weighting") and T2- ("pathology weighting") images.
- ▶ Routine clinical/research (high-field) magnets: 3–7 T (superconducting); open/limb magnets: 0.2–0.75 T (permanent).
- ▶ STIR/T2-fat-sat sequences highlight marrow/soft-tissue oedema; gadolinium-enhanced T1-fat-sat sequences highlight hypervascular/inflamed tissue.
- ▶ Absolute contraindications: cardiac pacemakers, ferromagnetic aneurysm clips, certain valve replacements, intraocular metallic foreign bodies.
- ▶ Newer techniques: fMRI (BOLD-based functional mapping), MRS (metabolite spectrum), DTI/MR tractography (white-matter tracking), MRA/MRV (vascular imaging), MRCP (biliary/pancreatic ducts).
- ▶ MRI gives superior soft-tissue contrast and true multiplanar imaging compared with CT, but poorly depicts cortical bone, calcification and air-containing structures.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e — Commentary 7.1, "Technical aspects and applications of diagnostic radiology"; Moore's Clinically Oriented Anatomy 9e; Vishram Singh — General Anatomy 4e (figure); IB Singh — Textbook of Human Neuroanatomy.

**PET scan**

Asked in: Paper IV May 2018 · Paper IV May 2011 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

Positron emission tomography (PET) is a nuclear medicine radionuclide imaging technique that produces cross-sectional (tomographic) images depicting the **metabolic, physiological or biochemical activity** of an organ — such as blood flow, oxygen use or glucose metabolism — rather than its static structure. A biologically active molecule labelled with a short-lived, positron-emitting radioisotope (most commonly the glucose analogue **¹⁸F-fluorodeoxyglucose, ¹⁸F-FDG**) is injected intravenously; after an uptake interval, the tracer's positron emissions are converted, via annihilation with tissue

electrons, into paired gamma photons that are captured in coincidence by a detector ring and reconstructed by computer into a three-dimensional map of tracer distribution. PET is used chiefly to diagnose malignancy and evaluate tumour staging, and to study brain, heart and other organ function; because it reveals metabolic and functional derangement at the cellular level very early — well before CT or MRI can detect the structural change that eventually follows — it is now almost always acquired fused with CT or MRI (PET-CT/PET-MRI) for combined functional-anatomical localisation.

1. Principle: positron emission and coincidence detection

- ▶ A **positron-emitting radionuclide** (e.g. ^{18}F fluorine, ^{11}C carbon) is chemically incorporated into a biologically active molecule and injected into the blood; over roughly an hour the tracer becomes concentrated in the tissue of interest in proportion to that tissue's metabolic activity.
- ▶ On decay, the isotope emits a **positron** — a positively charged particle of the same mass and charge magnitude as an electron. The positron travels only a **few millimetres** before colliding with a free tissue electron, and the two undergo mutual **annihilation**, their combined rest mass converting into a **pair of gamma photons moving in exactly opposite directions** ($\approx 180^\circ$ apart, each of ≈ 511 keV, the electron/positron rest-mass energy).
- ▶ A ring of detectors surrounding the patient registers only those photon pairs arriving **simultaneously** at two opposing detectors — **coincidence detection** — which localises the annihilation event along the line joining the two detectors, without requiring a mechanical (lead) collimator.
- ▶ A computer accepts only such coincident events and reconstructs the spatial distribution of tracer activity into tomographic sections, displayed as the whole organ or in cross section; because acquisition can be dynamic, time-activity (functional) curves for an organ can also be generated.
- ▶ The short half-life of PET isotopes is the chief practical constraint: close access to a **cyclotron** for on-site isotope generation determines where a PET scanner can feasibly be sited.

□ Fig 16.11 — Positron emission tomography (PET): schematic of tracer injection, uptake, positron-electron annihilation, coincidence detection and computer image reconstruction (Vishram Singh — *General Anatomy* — 4e, p.671)

□ Fig 1.27 — Axial (horizontal) PET scan of a normal brain after injection of ^{18}F -fluorodeoxyglucose; regions of active cortical metabolism appear as "hot" (yellow) areas, with the lateral ventricles also outlined (Snell — *Clinical Neuroanatomy* — 7e, p.47)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple boxes-and-arrows schematic of PET image formation, labelled exactly:

- ▶ Cyclotron → production of a short-lived positron-emitting isotope (e.g. ^{18}F)
- ▶ Radiotracer (e.g. ^{18}F -FDG) synthesis and intravenous injection
- ▶ Uptake into the target tissue (proportional to local metabolic/glucose activity)
- ▶ Positron emission → travels a few mm → **annihilation** with a tissue electron
- ▶ Two 511 keV gamma photons emitted 180° apart
- ▶ Detector ring (scintillation crystals + photomultipliers) around the patient — **coincidence circuit**
- ▶ Computer image-reconstruction console
- ▶ Reconstructed tomographic PET image — "hot" (increased uptake) vs "cold" (reduced uptake) areas
- ▶ Fusion with a co-registered CT or MRI section (PET-CT / PET-MRI)

2. Radiopharmaceuticals (tracers) used in PET

Radioisotope	Approximate half-life	Typical radiopharmaceutical	Principal use
^{11}C Carbon	~20 minutes	^{11}C -labelled ligands	Neuroreceptor/blood-flow research (short-lived, on-site cyclotron essential)
^{13}N Nitrogen	~10 minutes	^{13}N -ammonia	Myocardial perfusion imaging
^{15}O Oxygen	~2 minutes	^{15}O -water/ $^{15}\text{O}_2$	Cerebral blood flow and oxygen-extraction studies
^{18}F Fluorine	~110 minutes	^{18}F -FDG (2-deoxy-2- ^{18}F fluoro-D-glucose)	Commonest clinical tracer — oncology, brain, cardiac studies
^{68}Ga Gallium	~68 minutes	^{68}Ga -DOTATATE; ^{68}Ga -PSMA	Neuroendocrine tumour and prostate cancer imaging (theranostic tracers)

- ▶ ^{18}F -FDG, a glucose analogue, is taken up by metabolically active tissue and concentrates in proportion to the local rate of glucose utilisation; **malignant cells characteristically metabolise glucose at a much greater rate than normal cells**, which is the biochemical basis of oncological FDG-PET imaging.
- ▶ A key interpretive pitfall is that normal **brown adipose tissue** (neck, supraclavicular fossa, axilla, mediastinum, para-vertebral region) also shows increased ^{18}F -FDG uptake — especially in lean, young patients during cold weather — and can be mistaken for malignancy unless recognised.

3. PET compared with SPECT, CT and MRI

Feature	PET	SPECT	CT	MRI
Emission/energy source	Positron emitter → 2 coincident 511 keV photons	Single gamma-photon emitter (^{99m}Tc , ^{123}I)	External X-ray beam	Radiofrequency pulses in a magnetic field
Collimation	None needed (electronic coincidence)	Lead collimator required	—	—
What is shown	Metabolic/physiological function	Function, using longer-lived tracers	Anatomical density (Hounsfield scale)	Anatomical/soft-tissue detail
Isotope half-life & tracers	Very short (minutes–~2 h); cyclotron-produced	Longer-lasting tracers	—	—
Resolution/cost/time	Higher resolution, costlier	Lower resolution, cheaper, longer scan time	Fast, high spatial resolution	Slower, ~two-thirds costlier than CT; best soft-tissue contrast
Ionising radiation	Yes	Yes	Yes	No
Disease detection	Detects metabolic/functional change earliest	Functional	Detects change only after structural change	Detects change before gross structural change, but without PET's metabolic specificity

4. PET-CT and PET-MRI: fusion (multimodality) imaging

- ▶ PET images alone have poor intrinsic spatial resolution and lack anatomical landmarks, making precise localisation of an abnormal focus difficult.
- ▶ Modern scanners therefore combine PET with CT (**PET-CT**) or MRI (**PET-MRI**) in a single gantry, fusing/co-registering the functional PET data with the anatomical CT or MR section — the same "spatial sequence imaging" principle used to combine SPECT with CT.
- ▶ In PET-CT, the co-acquired CT data are additionally used for **attenuation correction** of the PET signal (correcting for photon absorption by overlying tissue), obtained in a single patient sitting.
- ▶ **PET-MRI** adds MRI's superior soft-tissue contrast to PET's functional data while avoiding the extra radiation dose of a CT component — an advantage in neuro-oncological and paediatric studies, and for repeated/longitudinal imaging, and is increasingly used for neuroendocrine-tumour staging with ^{68}Ga -DOTA-peptide tracers.

5. Recent advances in PET imaging

- ▶ **Total-body PET/CT** with ultra-long axial field-of-view scanners (uEXPLORER, PennPET Explorer, Biograph Vision Quadra, spanning ~1–2 m gantries) gives a marked increase in system sensitivity, enabling shorter scan times, reduced injected activity, delayed/dynamic whole-body

imaging, and simultaneous multi-organ kinetic modelling in a single acquisition (Ng et al, *Semin Nucl Med* 2022) [PMID: 35272853].

- ▶ **PSMA PET/CT** is now a guideline-endorsed standard (joint EANM/SNMMI Procedure Guideline/Standard 2.0, 2023) for primary staging, detection of biochemical recurrence and treatment selection in prostate cancer, and underlies the PSMA-theranostic pairing with ¹⁷⁷Lu-PSMA-617 radioligand therapy (Fendler et al, *Eur J Nucl Med Mol Imaging* 2023) [PMID: 36604326].
- ▶ **Revised (2024) biological diagnostic and staging criteria for Alzheimer's disease** place amyloid PET (and increasingly tau PET) among the "Core" biomarkers sufficient on their own to establish an AD diagnosis and stage disease severity, marking a shift from purely syndromic clinical diagnosis toward biomarker-defined disease (Jack et al, *Alzheimers Dement* 2024) [PMID: 38934362].
- ▶ **Simultaneous PET/MRI** hybrid systems are maturing for neuroendocrine-neoplasm imaging with ⁶⁸Ga-DOTA-peptides, offering superior soft-tissue contrast, motion correction, and higher lesion-detection and lesion-classification accuracy than PET/CT (Ambrosini et al, *J Comput Assist Tomogr* 2024) [PMID: 38518197].
- ▶ **Theranostics** — pairing a diagnostic PET radiotracer with a therapeutic radionuclide that targets the same molecule, e.g. ⁶⁸Ga-DOTATATE (diagnostic)/¹⁷⁷Lu-DOTATATE (therapeutic) for neuroendocrine tumours, and ⁶⁸Ga-PSMA/¹⁷⁷Lu-PSMA for prostate cancer — exemplifies the "see-and-treat" paradigm now central to precision oncology, increasingly supported by AI-assisted dosimetry and radiomics (Gandhi et al, *Med Oncol* 2025) [PMID: 41006727].

(According to PubMed; DOIs:
 [10.1053/j.semnuclmed.2022.01.002](https://doi.org/10.1053/j.semnuclmed.2022.01.002),
 [10.1007/s00259-022-06089-w](https://doi.org/10.1007/s00259-022-06089-w), [10.1002/alz.13859]
 (https://doi.org/10.1002/alz.13859),
 [10.1097/RCT.0000000000001594](https://doi.org/10.1097/RCT.0000000000001594), [10.1007/s12032-025-03061-0](https://doi.org/10.1007/s12032-025-03061-0).)

Applied / Clinical anatomy

- ▶ **Oncology (commonest use)**: whole-body ¹⁸F-FDG PET-CT is used to diagnose malignancy and to evaluate tumour **staging**, restaging and treatment response, exploiting malignant cells' disproportionately high glucose uptake.
- ▶ **Neurology — brain tumours**: FDG uptake is markedly increased in high-grade/malignant gliomas, seen as a focal hypermetabolic "hot" area on axial or coronal PET, distinguishing viable tumour from surrounding brain and from post-treatment change.
- ▶ **Neurology — epilepsy, movement disorders, dementia, schizophrenia**: PET has been used to study the distribution and activity of neurotransmitters, variations in oxygen utilisation and cerebral blood flow, and has been successfully applied in the evaluation of patients with brain tumours, movement disorders, seizures and schizophrenia; interictal hypometabolism helps localise an epileptogenic focus, and a temporo-parietal hypometabolic pattern is characteristic of Alzheimer's disease.

- ▶ **Cardiology:** PET is used to study the metabolic activity of the heart, in addition to the brain and other organs, helping distinguish viable (hibernating) from infarcted myocardium.
- ▶ **Genitourinary/endocrine oncology:** target-specific tracers — $^{68}\text{Ga}/^{18}\text{F}$ -PSMA for prostate cancer and ^{68}Ga -DOTATATE for somatostatin-receptor-positive neuroendocrine tumours — are now guideline-standard alternatives to generic FDG imaging, and permit direct "see-and-treat" theranostic pairing.
- ▶ **Key interpretive pitfall:** physiological uptake of ^{18}F -FDG by activated brown adipose tissue in the neck, supraclavicular fossa, axilla and mediastinum can mimic malignancy and cause a false-positive report if not recognised, particularly in lean or young patients scanned in cold weather.
- ▶ **Practical/logistic correlate:** because PET isotopes (^{11}C , ^{13}N , ^{15}O , ^{18}F) have very short half-lives, a PET facility requires on-site or nearby cyclotron access, which determines the feasible location of a scanner and adds to cost relative to SPECT.

High-yield exam pointers

- ▶ PET images **function/metabolism**, not structure: **positron emission** → **annihilation with a tissue electron** → **two coincident 511 keV gamma photons emitted 180° apart** → **detector-ring coincidence detection** → **computer image reconstruction**.
- ▶ Commonest tracer: ^{18}F -FDG (a glucose analogue); other PET isotopes — ^{11}C (~20 min), ^{13}N (~10 min), ^{15}O (~2 min), ^{18}F (~110 min) — are **cyclotron-produced with very short half-lives**.
- ▶ No lead collimator is needed (unlike SPECT) — coincidence detection localises the event electronically, giving PET higher resolution than SPECT.
- ▶ PET detects metabolic/functional change **earlier** than CT/MRI, which show only established structural change.
- ▶ **"Hot"** areas = increased tracer uptake (tumour, active cortex); **"cold"** areas = reduced uptake (infarct, necrosis, cyst).
- ▶ Because PET alone has poor anatomical resolution, it is routinely fused with CT or MRI (**PET-CT/PET-MRI**) for combined functional-anatomical localisation; the CT component also provides attenuation correction.
- ▶ Principal clinical uses: oncological staging (commonest), epilepsy-focus localisation, dementia work-up, brain-tumour evaluation, cardiac viability assessment.
- ▶ Classic pitfall: physiological brown-fat FDG uptake can mimic malignancy.
- ▶ Newer frontiers: **total-body (long axial field-of-view) PET**, and **theranostic** tracer pairs (PSMA, DOTATATE) linking diagnostic PET to matched radionuclide therapy.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; BD Chaurasia — Human Anatomy Vol 3-4 8e; Vishram Singh — General Anatomy 4e; Snell — Clinical Neuroanatomy 7e; Ross Histology — A Text and Atlas 7e. Recent-advances citations are from PubMed (2022–2025) per the answer-bank's recency-enrichment method.



PET scanning

Asked in: Paper IV Nov 2018 · Paper IV Nov 2017 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction Positron emission tomography (PET) is a nuclear medicine (radioisotope) imaging technique that produces cross-sectional (tomographic) images of the **physiological, metabolic and biochemical activity** of an organ, rather than its static structure. A biologically active molecule labelled with a short-lived, positron-emitting radioisotope (most commonly the glucose analogue ^{18}F -FDG) is injected intravenously; the emitted positrons annihilate with tissue electrons to generate paired gamma photons that are picked up in **coincidence** by a ring of detectors surrounding the patient and reconstructed by computer into a three-dimensional map of tracer concentration. Because functional/metabolic derangement in a tumour, an ischaemic myocardium or a degenerating neuron typically precedes gross structural change, PET can detect disease **earlier** than purely anatomical modalities such as CT or MRI, with which it is now routinely fused (PET-CT, PET-MRI) to superimpose function on anatomy.

1. Principle: positron emission and annihilation coincidence detection

- ▶ A **positron-emitting radionuclide** (e.g. ^{18}F fluorine, ^{11}C carbon) decays by emitting a **positron** — a positively charged particle with the same mass and magnitude of charge as an electron.
- ▶ The positron travels only a **few millimetres** through tissue before colliding with a free electron; this collision causes mutual **annihilation** of both particles, converting their mass into energy released as a **pair of gamma photons that travel in exactly opposite directions** ($\approx 180^\circ$ apart, each carrying 511 keV — the electron/positron rest-mass energy).
- ▶ Detectors arranged in a **ring gantry** around the patient register only those photon pairs that arrive **simultaneously** at two opposing detectors — **annihilation coincidence detection** — which localises the annihilation event along the line joining the two detectors without need for a mechanical collimator.
- ▶ A computer accepts only such coincident events and reconstructs the spatial distribution of tracer activity into transverse tomographic sections, viewable as the whole organ or in cross section.
- ▶ This differs fundamentally from **single photon emission computed tomography (SPECT)**, which uses single-gamma-emitting isotopes (e.g. $^{99\text{m}}\text{Tc}$, ^{123}I) detected by a rotating gamma camera fitted with a lead collimator — PET's collimator-free coincidence detection gives it substantially higher sensitivity and spatial resolution than SPECT.

2. Radiopharmaceuticals (tracers) used in PET

- ▶ PET isotopes are cyclotron-produced and have **extremely short half-lives**, which limits the feasible location of a PET scanner to sites with (or close to) a cyclotron.

Radioisotope	Approximate half-life
^{11}C Carbon	~20 minutes
^{13}N Nitrogen	~10 minutes
^{15}O Oxygen	~2 minutes

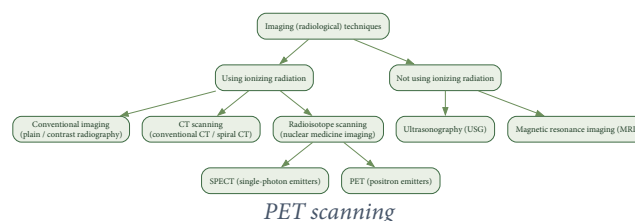
Radioisotope	Approximate half-life
¹⁸ F-Fluorine	~110 minutes

- ▶ The radioisotope is chemically incorporated into a biologically active molecule of known metabolic behaviour and injected intravenously; after an uptake interval it becomes concentrated in the tissue of interest.
- ▶ ¹⁸F-FDG (2-deoxy-2-[fluorine-18]fluoro-D-glucose) is the tracer used in the great majority of clinical PET studies. It is a glucose analogue taken up by glucose transporters and phosphorylated by hexokinase like glucose, but — unlike glucose — it is **not further metabolised** and remains trapped intracellularly as FDG-6-phosphate, so its accumulation is proportional to the tissue's rate of glycolysis.
- ▶ **Malignant cells characteristically show markedly increased glucose metabolism (aerobic glycolysis)** compared with normal cells, so they take up disproportionately more ¹⁸F-FDG — the biochemical basis of oncological FDG-PET imaging.
- ▶ Other tracers reflect other physiological processes — e.g. radiolabelled water/ammonia for regional blood flow, and receptor-specific ligands (somatostatin-receptor and prostate-specific membrane antigen analogues) discussed under Recent advances below.

3. PET scanner: instrumentation and image acquisition

- ▶ The radiotracer is administered intravenously (occasionally by inhalation or ingestion, depending on the study) and an uptake period is allowed to elapse.
- ▶ The patient lies on a table that moves through a **ring gantry of scintillation-crystal detectors** coupled to photomultiplier tubes; only simultaneously-detected (coincident) photon pairs are accepted by the coincidence circuitry.
- ▶ A computer converts these signals into images that can be displayed as the **whole organ or in cross section**, and — because PET is a functional study — can also be acquired dynamically to plot a time-activity curve of organ function.
- ▶ On the image, areas of increased tracer uptake ("**hot areas**") correspond to increased metabolism, blood flow or neuronal activity (e.g. an active tumour, activated cortex); areas of reduced uptake ("**cold areas**") correspond to reduced perfusion or necrosis (e.g. an infarct, a cyst).
- ▶ PET reveals such **metabolic and functional changes at the cellular level very early**, often well before CT or MRI can detect the structural changes that eventually follow.

4. Classification of imaging techniques and PET vs other modalities



Feature	PET	SPECT	CT	MRI
Emission type	Positron → 2 coincident 511 keV photons	Single gamma photon	X-rays (transmitted)	RF signal (no ionizing radiation)
Collimation	None (electronic coincidence)	Lead collimator required	—	—
What it shows	Metabolic/physiological function	Function (longer-lived tracer)	Structural/anatomical detail	Structural + some functional detail
Typical tracer/agent	^{18}F -FDG, ^{11}C , ^{13}N , ^{15}O	$^{99\text{m}}\text{Tc}$, ^{123}I	Iodinated contrast	Gadolinium contrast
Cost/time/resolution	Costlier, higher resolution	Cheaper, longer scan time, lower resolution	Fast, high spatial resolution	Slower, best soft-tissue contrast
Radiation	Ionizing	Ionizing	Ionizing	None

5. PET–CT and PET–MRI: multimodality (fusion) imaging

- ▶ PET images alone have **poor intrinsic spatial/anatomical resolution** and provide no anatomical landmarks, making precise localisation of an abnormal focus difficult.
- ▶ Modern PET scanners are therefore integrated with CT (PET–CT) or MRI (PET–MRI) in a single gantry: the functional PET data are **fused/co-registered** with the anatomical CT or MR image (spatial-sequence imaging, comparable to how SPECT is combined with CT), so an area of abnormal tracer uptake can be pinpointed to a precise anatomical structure.
- ▶ In PET–CT, the co-acquired CT dataset is additionally used for **attenuation correction** of the PET signal (correcting for photon absorption by overlying tissue) as well as for anatomical localisation — both obtained in one patient sitting.
- ▶ PET–MRI combines the superior soft-tissue contrast of MRI with PET's functional information while avoiding the added ionizing-radiation dose of a CT component — advantageous in neuro-oncological and paediatric imaging, and for repeated/longitudinal studies.

6. Recent advances in PET imaging

- ▶ **Total-body PET with ultra-long axial field of view** (e.g. the uEXPLORER-type scanner) images the entire body simultaneously with markedly higher sensitivity; deep-learning post-processing can now generate **CT-free attenuation-corrected total-body PET images**, cutting the extra radiation dose from a redundant CT acquisition while preserving quantitative accuracy of standardised uptake values (Li et al, *Eur Radiol* 2024) [PMID: 38355987], and can also **upgrade shorter-axial-FOV PET scanners** toward total-body-PET-equivalent image quality using a 3-D U-Net, controlling cost (Huang et al, *Eur J Nucl Med Mol Imaging* 2023) [PMID: 37672046].
- ▶ **AI-assisted PET/SPECT interpretation in Alzheimer's disease**: deep-learning and radiomic tools are being layered onto amyloid, tau and FDG-metabolic PET/SPECT biomarkers to improve diagnostic classification, automated quantification, image reconstruction/denoising and prognostic (conversion/decline) modelling beyond classical visual reads and SUVR thresholds,

addressing reader variability and cross-scanner heterogeneity (Tsougos et al, *Ann Nucl Med* 2026) [PMID: 41886174].

- **Theranostics — paired diagnostic/therapeutic radioligands** targeting the same molecular receptor exemplify the "see-and-treat" precision-oncology paradigm: ^{68}Ga -DOTATATE PET (diagnostic) paired with ^{177}Lu -DOTATATE (therapeutic) for neuroendocrine tumours, and ^{68}Ga -PSMA PET paired with ^{177}Lu -PSMA therapy for prostate cancer, now integrated with PET/CT, SPECT/CT and hybrid PET/MRI for dosimetry and adaptive treatment planning (Gandhi et al, *Med Oncol* 2025) [PMID: 41006727].
- **Novel receptor-targeted tracers beyond PSMA:** a first-in-human head-to-head study of a neurotensin-receptor-1 (NTSR1)-targeted PET tracer against established ^{68}Ga -PSMA-617 in prostate cancer found PSMA-PET superior pre-treatment, but the NTSR1 tracer showed rising sensitivity after androgen-deprivation therapy — reflecting the trend toward **stage-adapted, receptor-driven** molecular imaging (He et al, *Ann Med* 2026) [PMID: 42304982].

(According to PubMed; DOIs: [10.1007/s00330-024-10647-1](https://doi.org/10.1007/s00330-024-10647-1), [10.1007/s00259-023-06422-x](https://doi.org/10.1007/s00259-023-06422-x), [10.1007/s12149-026-02194-0](https://doi.org/10.1007/s12149-026-02194-0), [10.1007/s12032-025-03061-0](https://doi.org/10.1007/s12032-025-03061-0), [10.1080/07853890.2026.2678019](https://doi.org/10.1080/07853890.2026.2678019).)

Applied / Clinical anatomy

□ Fig 16.11 — Positron emission tomography (PET) (Vishram Singh — *General Anatomy* — 4e, p.671)

- **Oncology:** FDG-PET (usually as PET-CT) is used to diagnose malignancy and to evaluate **tumour staging**, exploiting the increased glycolytic activity of malignant cells relative to surrounding normal tissue.
- **Cardiology:** PET assesses **myocardial viability and blood flow**, distinguishing hibernating (viable) from infarcted (non-viable) myocardium by comparing perfusion and metabolic tracer patterns.
- **Neurology:** PET maps regional cerebral **blood flow and neuronal/metabolic activity**, and — together with SPECT — shows characteristic **hypometabolism patterns in Alzheimer's disease** and other dementias, aiding earlier and more objective diagnosis when combined with AI-based quantification.
- **Psychiatry/functional neuroanatomy:** PET studies have demonstrated **abnormal corpus striatal activity in obsessive-compulsive disorder**, and PET (alongside fMRI) has been used to map the cortical/subcortical circuitry underlying complex volitional functions such as swallowing.
- **Theranostic oncology:** PET with somatostatin-receptor or PSMA-targeted tracers both stages disease and selects patients for matched radionuclide therapy (neuroendocrine tumours, prostate cancer) in a single "see-and-treat" pathway.
- **Limitations to remember:** PET needs **cyclotron-produced, extremely short-half-life isotopes**, restricting scanner location and raising cost; it uses **ionizing radiation**; and its spatial resolution is coarser than CT/MRI — hence routine fusion (PET-CT/PET-MRI) imaging.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple schematic of PET image formation — label:

- ▶ Peripheral vein — site of radiotracer (e.g. ^{18}F -FDG) injection
- ▶ Target tissue with increased tracer uptake (e.g. tumour / metabolically active neurons)
- ▶ Site of positron emission and annihilation with a tissue electron
- ▶ Two 511 keV gamma photons emitted at 180° to each other
- ▶ Ring gantry of scintillation detectors around the patient (coincidence detection)
- ▶ Coincidence circuit → computer image-reconstruction console
- ▶ Reconstructed tomographic PET image, fused with a co-registered CT/MRI section

High-yield exam pointers

- ▶ PET images **function/metabolism**, not structure — based on **positron emission → annihilation → 2 coincident 511 keV gamma photons detected 180° apart**, needing no collimator (unlike SPECT).
- ▶ Standard tracer: ^{18}F -FDG (glucose analogue, trapped as FDG-6-phosphate); PET isotopes (^{11}C , ^{13}N , ^{15}O , ^{18}F) are **cyclotron-produced with very short half-lives** (minutes to ~110 min for ^{18}F).
- ▶ Classification: radioisotope/nuclear medicine scanning (an ionizing-radiation technique) splits into **SPECT** (single photon, collimated) and **PET** (positron, coincidence-detected).
- ▶ PET detects metabolic/functional change **earlier** than CT/MRI, which detect established structural change.
- ▶ **"Hot" areas** = increased uptake (tumour, active cortex); **"cold" areas** = reduced uptake (infarct, cyst/necrosis).
- ▶ Fusion imaging — **PET-CT** (CT also gives attenuation correction) and **PET-MRI** — overcomes PET's poor intrinsic anatomical resolution.
- ▶ Recent advances: **total-body PET** with AI/deep-learning attenuation correction, **AI-assisted Alzheimer's-disease PET/SPECT** interpretation, and **theranostics** (^{68}Ga -DOTATATE/ ^{177}Lu -DOTATATE; ^{68}Ga -PSMA/ ^{177}Lu -PSMA) linking diagnostic PET to matched radionuclide therapy.
- ▶ Key clinical uses: oncological staging, myocardial viability, dementia/hypometabolism imaging, presurgical/functional-neuroanatomy mapping (with fMRI).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; BD Chaurasia Human Anatomy Vol 3-4 8e; Vishram Singh General Anatomy 4e; Vishram Singh Clinical Neuroanatomy 4e; Snell Clinical Neuroanatomy 7e; Ross Histology — A Text and Atlas 7e; Weir & Abrahams — Imaging Atlas of Human Anatomy 6e. Recent-advances citations per PubMed (2023–2026), method as per the answer-bank's recency-enrichment protocol.

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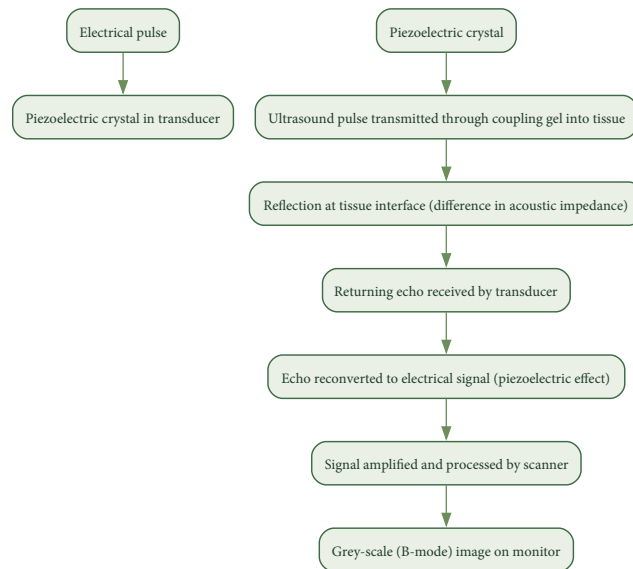
Ultra sound

Asked in: Paper IV May 2011 · Paper IV May 2010 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction Ultrasonography (USG/US) is a non-invasive, real-time medical imaging technique that uses high-frequency mechanical sound waves — not any part of the electromagnetic spectrum — to visualize soft tissues, vessels and the developing fetus. A piezoelectric transducer generates pulses of sound above 20 kHz that are transmitted into the body; differences in acoustic impedance at tissue interfaces reflect a fraction of the beam back as an "echo," which the same transducer detects and converts into a cross-sectional, grey-scale image. Because it uses no ionizing radiation, is portable, low-cost and gives real-time images including blood flow (Doppler), ultrasound is one of the four principal modalities of radiological/cross-sectional anatomy alongside plain radiography, CT and MRI.

1. Principle of ultrasound image generation

- ▶ Ultrasound imaging is unique among the imaging modalities in that it does **not depend on electromagnetic wave forms**; it uses high-frequency, longitudinal sound waves and their interaction with biological tissue.
- ▶ Sound oscillations above 20 kHz (inaudible to the human ear) are termed ultrasonic; diagnostic imaging typically uses frequencies in the range of roughly **2–20 MHz**.
- ▶ The sound pulse is generated (and subsequently detected) by a **piezoelectric crystal** housed in the transducer/probe — the crystal deforms and emits an ultrasound pulse on electrical stimulation, and conversely generates an electrical signal when struck by a returning echo.
- ▶ A **water-based coupling gel** is applied between the transducer and skin to eliminate the air gap (air reflects almost all incident sound) and allow efficient transmission of the beam into the body.
- ▶ Within the tissues, the beam undergoes **attenuation** — a progressive loss of energy from absorption, reflection and refraction — which reduces signal intensity with increasing depth.
- ▶ At any interface between tissues of differing **acoustic impedance**, part of the beam is reflected back toward the transducer as an echo; the sound wave travels through soft tissue at an average velocity of about **1500 m/s**.
- ▶ The returning echo vibrates the transducer, regenerating an electrical pulse whose **amplitude** (echo strength) and **time delay** (depth) are processed by the scanner and displayed as varying shades of grey, producing the final image.



Ultra sound

2. Modes of ultrasound display

Mode	Principle	Typical use
A-mode (amplitude)	Echoes along a single scan line displayed as spikes of varying amplitude/depth (one-dimensional)	Largely historical — distance/biometric measurements
B-mode (brightness)	A two-dimensional cross-section is built as the transducer/beam is swept across an area; echo strength is coded as brightness (grey scale)	Standard anatomical (grey-scale) imaging
Real-time imaging	Repetitive B-mode frames generated in rapid sequence	Live, moving images — e.g. fetal cardiac activity, moving structures
M-mode (motion)	A single scan line is sampled repeatedly and displayed against time, recording the motion of a reflector	Cardiac valve motion; diaphragmatic excursion studies
Doppler mode (duplex/colour)	Frequency shift between the emitted wave and its echo, produced by moving reflectors (red cells), is measured and colour-coded	Blood flow velocity and direction

- **2D and 3D/4D imaging:** a 2D image is a single sectional "slice"; acquiring a series of adjacent 2D slices by sweeping/rotating the transducer allows computer reconstruction of **3D images** (4D adds real-time motion).

3. Ultrasound appearance of tissues (echogenicity)

Appearance	Screen colour	Behaviour of the beam	Example tissue
Hyperechoic	White/bright	Strongly reflects the beam	Fat-containing tissue; cartilage (ultrasound penetrates and reflects strongly off cartilage)
Hypoechoic	Grey	Weak/partial reflection	Muscle (connective tissue, by contrast, tends to be relatively more hyperechoic)
Anechoic	Black	Beam passes through with no reflection	Clear fluid — amniotic fluid, bile, urine, vessel lumen
Acoustic shadowing	Black band posterior to the reflector	Gas does not transmit an echo at all	Bowel gas; also seen posterior to bone/calculi

4. Probe frequency, penetration and scanning approach

Probe frequency	Depth of penetration	Image resolution	Typical application
High (10–15 MHz)	Superficial, 2–4 cm	Best resolution	Thyroid, testis, superficial soft-tissue masses
Mid (5–10 MHz)	5–6 cm	Intermediate	Abdominal wall, paediatric abdomen
Low (2–5 MHz)	~10 cm	Lower resolution, best penetration	Deep abdominal and pelvic organs in adults

- **Transabdominal scanning** is performed across the anterior abdominal wall; for pelvic organs, a **fully distended urinary bladder** acts as an acoustic window, transmitting sound with minimal attenuation to the posteriorly placed viscera and displacing gas-filled bowel loops out of the pelvis.
- **Transvaginal (endovaginal) sonography** positions the transducer closer to the organ of interest (e.g. the ovary), avoiding intervening fat and gas and giving higher-resolution images; an analogous **transrectal** approach is used for prostate imaging.
- **Endoscopic ultrasound (EUS)** combines an endoscope with a high-frequency transducer at its tip, allowing high-resolution imaging (and image-guided FNAC) of mediastinal, oesophageal, biliary and pancreatic lesions from within the lumen — an angular approach not possible from the body surface.

5. Doppler ultrasonography

- Doppler ultrasonography visualizes vessels and assesses **vascular status/circulation**; unlike grey-scale imaging, the echo signal used is not from the vessel wall but from **moving red blood cells** in the lumen.

- ▶ The frequency shift between the transmitted wave and its echo (the Doppler effect) calculates flow **velocity**; flow is superimposed in colour on the grey-scale image (colour Doppler) and can also be measured in **duplex mode**.
- ▶ Convention (not universally standardized): **BART** — Blue Away, Red Toward the probe.
- ▶ Pulsed Doppler renders flow as an audible pulsing sound, useful for measuring velocity at a specific point (e.g. umbilical or uterine artery).

6. Advantages, limitations and recent advances

Advantages

- ▶ Non-invasive, portable, relatively inexpensive compared with CT/MRI, and can be performed at the bedside, in the clinic room or the operating theatre.
- ▶ Uses no ionizing radiation — the World Health Organization (1988) declared diagnostic ultrasound safe and capable of providing clinically relevant information about most parts of the body, including the fetus, making it the imaging method of choice in pregnancy.
- ▶ Gives true **real-time** images, so motion of structures (heart valves, fetal movement, peristalsis) and blood flow can be directly observed.
- ▶ Differentiates solid from cystic/fluid-filled masses (e.g. renal or hepatic masses) — a distinction plain radiography cannot make.

Limitations

- ▶ **Highly operator-dependent**, with image quality and interpretation varying between examiners.
- ▶ **Bone reflects nearly all** incident ultrasound and **air/gas conducts it poorly**; USG is of little use for structures surrounded by bone (e.g. brain within the cranial box) or containing air (lungs, bowel loops).
- ▶ Static images are harder to interpret than other modalities; resolution at depth is lower than CT/MRI.

Recent advances

- ▶ **Harmonic imaging** and **ultrasound contrast agents** (stabilized microbubbles) enable non-invasive assessment of myocardial perfusion and improve detection of hepatic/splenic metastases.
- ▶ **Elastography** measures tissue stiffness/strain — cancer may be 5–28 times stiffer than surrounding parenchyma, helping detect/classify breast, thyroid and liver tumours; liver elasticity correlates with cirrhosis score (transient elastography).
- ▶ **3D/4D sonography**, reconstructed from serial 2D slices, is increasingly used in obstetric and cardiac imaging.
- ▶ **Endoscopic ultrasound-guided FNAC (EUS-FNAC)** and image-guided percutaneous biopsy extend ultrasound from a diagnostic to an **interventional** tool.

Applied / Clinical anatomy

□ Fig 1.54 — Technique for producing ultrasound image of upper abdomen. A. The image results from the echo of ultrasound waves from abdominal structures of different densities. B. The image of the right kidney is displayed on a monitor. C. Doppler US shows blood flow to and away from the kidney (Moore — Clinically Oriented Anatomy — 9e, p.196)

Region/system	Representative application
Abdomen	Gallbladder, cystic duct and common bile duct, pancreas, kidneys, spleen and abdominal vessels — USG is now the primary investigation for suspected gallbladder disease, since the liver, kidneys and pancreas can be assessed in the same sitting
Pelvis	Uterus, ovaries and prostate (transabdominal, transvaginal or transrectal approach)
Obstetrics	Confirmation of pregnancy, gestational age, detection of multiple pregnancy, ectopic pregnancy and fetal anomalies; antenatal spine screening at 18–20 weeks assesses the three vertebral ossification centres in axial/coronal/sagittal planes to detect spina bifida and scoliosis
Vascular system	Doppler assessment of the renal, carotid and peripheral arteries/veins; duplex scanning for deep-vein thrombosis
Diaphragm	The posterolateral diaphragm is seen as a thin hypoechoic muscular line between two hyperechoic layers (peritoneum and pleura) that thickens on inspiration — used to detect an atrophic/paralysed diaphragm
Anorectal	Endoanal ultrasound images the internal and external anal sphincters in axial planes for sphincter injury/incontinence assessment
Interventional	USG-guided fine-needle aspiration cytology (FNAC) of superficial and deep organs (e.g. pancreas, thyroid, breast) — real-time, no radiation, angular approach possible, but limited by air/bone obscuration and lower resolution than CT guidance
Prenatal genetics	Ultrasound serves as an ancillary/guide to amniocentesis and chorionic villus sampling

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled schematic of the technique for producing an ultrasound image (as in Fig. 1.54 above) — label:

- ▶ Transducer/probe (with piezoelectric crystal)
- ▶ Coupling gel and skin surface
- ▶ Transmitted ultrasound beam (into abdomen)
- ▶ Tissue interface / organ of interest (e.g. kidney)
- ▶ Reflected echo returning to transducer
- ▶ Cable to scanner/console
- ▶ Monitor displaying the grey-scale cross-sectional image (and a separate Doppler colour-flow panel)

High-yield exam pointers

- ▶ USG uses mechanical sound waves (not electromagnetic radiation) generated by a piezoelectric transducer; diagnostic frequencies are roughly 2–20 MHz.
- ▶ Image formation depends on attenuation and reflection of the beam at interfaces of differing acoustic impedance; sound travels through soft tissue at ~1500 m/s.
- ▶ Modes: A-mode (amplitude), B-mode (brightness/grey-scale), real-time (rapid B-mode), M-mode (motion), Doppler (duplex/colour flow — moving red cells, not vessel wall, generate the signal).
- ▶ Echogenicity: hyperechoic (white — fat, cartilage), hypoechoic (grey — muscle), anechoic (black — fluid); bone and gas produce posterior acoustic shadowing and block the beam.
- ▶ Higher-frequency probes give better resolution but less penetration; lower-frequency probes penetrate deeper with lower resolution.
- ▶ A full urinary bladder or transvaginal approach acts as an acoustic window for pelvic organ imaging.
- ▶ Chief advantages: no ionizing radiation (WHO-declared safe, including in pregnancy), portable, low-cost, real-time; chief limitations: highly operator-dependent, and of no use for air-filled (lung, bowel) or bone-surrounded (brain) structures.
- ▶ Recent advances: harmonic imaging with microbubble contrast agents, elastography (tissue-stiffness imaging), 3D/4D sonography, endoscopic ultrasound-guided FNAC.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e (specialty text, imaging chapter); IB Singh — Textbook of Anatomy Vol 1 6e ("Introduction to Radiological Anatomy"); Vishram Singh — General Anatomy 4e; Sontakke — Textbook of Human Embryology; Gangane — Human Genetics 5e; BD Chaurasia — Human Anatomy Vol 2 8e ("Radiological and Imaging Procedures"); Pranab Dey — Lab Techniques in Histopathology & Cytology 2e (USG-guided FNAC).



Abdominal ultrasound

Asked in: Paper IV Nov 2016 — RGUHS MD/MS Anatomy

Definition / Introduction Abdominal ultrasound (ultrasonography, USG) is a real-time, non-ionizing imaging technique in which a transducer generates high-frequency sound waves (diagnostic range 3.5–20 MHz) that pass into the tissues and are reflected as echoes at every interface between structures of differing acoustic impedance. Because the abdomen contains soft, fluid-filled and hollow viscera lying at reproducible vertebral levels, its cross-sectional and surface anatomy directly determines the scanning windows, patient positioning and image interpretation used at the bedside. It is the first-line modality for the liver, gallbladder, biliary tree, pancreas, spleen, kidneys and great vessels, and underlies techniques such as the FAST scan in trauma.

1. Physical principles of ultrasound imaging

- ▶ A piezo-electric crystal in the transducer converts electrical energy into high-frequency longitudinal sound waves and, on return, converts reflected echoes back into an electrical signal.
- ▶ Image formation depends on **attenuation** (loss of signal from absorption, reflection and refraction in soft tissue) and **reflection** at tissue interfaces; the resulting echotexture depends on tiny differences in acoustic impedance between adjacent tissues.
- ▶ **B-mode (brightness mode)** real-time two-dimensional scanning is the standard clinical mode; **M-mode** records motion of a structure (e.g. a valve) against time.
- ▶ **Doppler ultrasonography**: frequency shift between the emitted wave and its echo from moving red cells is used to calculate velocity and direction of blood flow; in **duplex/colour Doppler**, flow is displayed in colour superimposed on the greyscale B-mode image.
- ▶ **Bone reflects almost all incident ultrasound**, and **air conducts it poorly** — hence adult CNS and aerated lung are not amenable to transabdominal USG, and gas-filled bowel loops degrade image quality.
- ▶ **3D and 4D (real-time 3D) ultrasound** generate volumetric and moving volumetric images respectively.
- ▶ **Endosonography**: miniaturized high-frequency probes introduced through a natural orifice (endoscope, vagina) bring the transducer close to the target organ, giving higher-resolution images of deep structures such as the pancreatobiliary region.

2. Patient preparation and acoustic windows

- **Fasting** for several hours reduces bowel gas and allows gallbladder distension for adequate visualization of the biliary tree.
- Solid, fluid-filled organs act as **acoustic windows**: the liver is used as a window to image the right kidney and gallbladder fossa, and the spleen for the left kidney; a **full urinary bladder** serves as the acoustic window for the pelvic viscera, transmitting sound with minimal attenuation while simultaneously displacing gas-filled bowel out of the pelvis.
- Scanning is performed with the patient supine, and in right/left lateral decubitus and erect positions to shift bowel gas and confirm the mobility of calculi or fluid.
- Graded transducer pressure and deep inspiration (which lowers the liver and diaphragm) are used to improve visualization of upper abdominal viscera.

3. Standard scan planes and their anatomical (vertebral) basis

Ultrasound scanning windows correspond closely to the classical transverse levels used to describe cross-sectional abdominal anatomy.

□ Fig 1.54 — Technique for producing ultrasound image of upper abdomen. A. The image results from the echo of ultrasound waves from abdominal structures of different densities. B. The image of the right kidney is displayed on a monitor. C. Doppler US shows blood flow to and away from the kidney. (Moore — Clinically Oriented Anatomy — 9e, p.196)

Vertebral level	Key structure(s) at that level	Correlate on USG
T12 (just below aortic hiatus)	Coeliac trunk (trifurcates into left gastric, common hepatic and splenic arteries)	Transverse epigastric scan through the "coeliac axis"/"seagull sign"
Transpyloric plane (upper border L1/ L1–L2 disc)	Pylorus, neck of pancreas, hila of both kidneys, fundus of gallbladder (in ~⅓ of supine subjects)	Transverse scan through the pancreas
L1 (1–2 cm below coeliac trunk)	Origin of superior mesenteric artery	Longitudinal/sagittal scan through the aorta
Upper border of L2	Origin of renal arteries	Renal hilar Doppler window
Lower border of L4	Bifurcation of abdominal aorta into common iliac arteries	Lower abdominal aortic scan (screening for aneurysm)

4. Normal sonoanatomy of the abdominal viscera

Organ	Position / surface projection	Sonographic features
Liver	Mapped by three points — right 5th rib/intercostal space in the mid-clavicular line, left 5th intercostal space/6th rib in the mid-clavicular line, and right 10th costal cartilage in the mid-axillary line	Homogeneous, medium-level echotexture; hepatic veins (thin, non-echogenic walls) and portal veins (thicker, echogenic walls) mark the segmental (Couinaud) anatomy used for planning resections

Organ	Position / surface projection	Sonographic features
Gallbladder & biliary tree	Fundus at the tip of the 9th costal cartilage, at the junction of the linea semilunaris with the costal margin, near the transpyloric plane	Anechoic, pear-shaped structure; common bile duct runs anterior to the portal vein in the free edge of the lesser omentum
Pancreas	Head in the duodenal C-loop to the right of L2; neck in the transpyloric plane at the L1/2 disc; body/tail passing obliquely upward-left toward the spleen	Retroperitoneal band anterior to the splenic vein and origin of the SMA; uncinate process lies anterior to the aorta
Spleen	Deep to ribs 9–11 (or 10–12 in about half of subjects); long axis along the 10th/11th rib; normal size approximates the individual's clenched fist	Homogeneous, slightly more echogenic than liver; splenorenal recess used as a FAST window
Kidneys	Left T12–L3/4, right L1–L4 (right ~2 cm lower than left); length ≈11.5 cm (men)/11.0 cm (women); width 5–6 cm; hilum ≈5–6 cm from the midline	Central echogenic renal sinus fat, hypoechoic medullary pyramids, and a thin echogenic capsule; corticomedullary differentiation is a key normal marker
Aorta & IVC	Aorta in the midline/slightly left, IVC to its right	Pulsatile, anechoic tubular structures traced from the diaphragmatic hiatus to the bifurcation

5. Peritoneal recesses and the anatomical basis of the FAST scan

Ultrasound windows for detecting free intraperitoneal fluid are chosen because gravity directs fluid into specific dependent recesses:

- **Hepatorenal pouch (of Morison)** — the potential space between the liver and right kidney; in the supine position this is the **most dependent part of the peritoneal cavity in the upper abdomen**, and the commonest site to detect free fluid or seed peritoneal metastases.
- **Subphrenic spaces** (right and left) — separated by the falciform ligament, which prevents free passage of fluid across the midline anteriorly.
- **Paracolic gutters** — the right gutter is deeper and unobstructed by a phrenicocolic ligament (unlike the left), so it is the preferred route by which fluid ascends from the pelvis to the right subhepatic and subphrenic spaces.
- **Rectovesical pouch (male) / recto-uterine pouch of Douglas (female)** — the most dependent recesses of the pelvis, and the last site to clear and first site to accumulate free peritoneal fluid.

These four recesses form the anatomical basis of the four standard FAST (Focused Assessment with Sonography in Trauma) windows — perihepatic (Morison's pouch), perisplenic, pelvic, and (with the subxiphoid view) pericardial.

6. Newer sonographic techniques

- ▶ **Contrast-enhanced ultrasound (CEUS)** — harmonic imaging combined with stabilized microbubble contrast agents permits non-invasive assessment of organ perfusion and clearly improves detection of focal liver and splenic metastases.
- ▶ **Elastography** — ultrasound is now the commonest technique for generating elastograms (stiffness/strain maps); tumour tissue is 5–28 times stiffer than surrounding normal tissue, and liver elastography correlates with the histological cirrhosis/fibrosis score, offering a non-invasive alternative to biopsy.
- ▶ **3D/4D ultrasound** — volumetric and moving-volumetric reconstruction, first developed for antenatal imaging, is increasingly applied to organ volumetry and vascular mapping in the abdomen.
- ▶ **Endosonography (endoscopic ultrasound, EUS)** — a miniaturized high-frequency probe passed via an endoscope into the stomach/duodenum brings the transducer directly against the pancreas and biliary tree, giving substantially higher resolution than transabdominal scanning.
- ▶ **Point-of-care ultrasound (POCUS)/FAST protocol** — the same acoustic-window and dependent-recess anatomy above is applied for rapid bedside triage of free fluid in trauma and acute abdomen.

Applied / Clinical anatomy

- ▶ **Gallstones** appear as echogenic foci within the gallbladder lumen with posterior acoustic shadowing (because bone/calculi reflect almost all incident ultrasound).
- ▶ **Hepatic segmental (Couinaud) anatomy**, based on the independent branching of the right and left hepatic arteries, ducts and portal vein branches, must be established sonographically (with dye injection or balloon occlusion) before any hepatic resection.
- ▶ **Renal cysts** are a common incidental USG finding; multiple bilateral cysts with enlarged kidneys suggest adult polycystic kidney disease (autosomal dominant).
- ▶ **Hydronephrosis/hydroureter** — dilated pelvicalyceal system and ureter proximal to an obstruction; correlating the ureter's course (crossing the tips of the lumbar transverse processes, then the sacroiliac joint and ischial spine) helps localize the level of obstruction.
- ▶ **Subphrenic abscess** is frequently drained percutaneously under ultrasound guidance, exploiting the same recess anatomy described above.
- ▶ **Abdominal aortic aneurysm** screening is performed at and above the L4 bifurcation level.
- ▶ **FAST scan in blunt abdominal trauma** — Morison's pouch is the single most sensitive window for detecting haemoperitoneum in the supine patient.

High-yield exam pointers

- ▶ USG uses high-frequency (3.5–20 MHz) sound reflected at tissue-impedance interfaces; it is real-time, portable, low-cost, and free of ionizing radiation, but highly operator-dependent.
- ▶ Bone and gas are the two great enemies of transabdominal USG — bone reflects almost all the beam, gas conducts it poorly.
- ▶ Full urinary bladder = acoustic window for the pelvis; liver/spleen = acoustic windows for the ipsilateral kidney.

- ▶ Coeliac trunk — T12; SMA — L1; renal arteries — upper border of L2; aortic bifurcation — lower border of L4 (classic vertical "vascular ladder" tested repeatedly).
- ▶ Gallbladder fundus lies at the tip of the 9th costal cartilage, near the transpyloric plane.
- ▶ Morison's pouch (hepatorenal recess) is the most dependent peritoneal recess in the supine upper abdomen — key to FAST scanning.
- ▶ Right paracolic gutter (deep, unobstructed) > left (shallower, phrenicocolic ligament) for cranial spread of ascitic/peritoneal fluid.
- ▶ Recent advances: contrast-enhanced USG (microbubbles) for liver/splenic lesion detection; elastography for non-invasive liver fibrosis/cirrhosis staging; endosonography (EUS) for pancreatobiliary imaging; 3D/4D reconstruction.
- ▶ Kidney: length ≈11.5 cm (M)/11 cm (F), width 5–6 cm, left kidney normally ~2 cm higher than right — a common numerical short-note.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; IB Singh — Textbook of Anatomy Vol 2 6e; Larsen — Human Embryology 6e. Coverage note: none of the gross-anatomy texts in this library carries a single dedicated "abdominal ultrasound" chapter; the physics, scan-plane/vertebral-level correlations, normal sonoanatomy and recent-advances content above have been assembled from the imaging-anatomy sections scattered through the surface-anatomy, peritoneum, great-vessel and basic-concepts chapters of these texts, cross-checked for internal consistency.



Anatomical basis of C.T. scan procedure and pictures

Asked in: Paper IV May 2007 — RGUHS MD/MS Anatomy

Definition / Introduction Computed tomography (CT), also called computerised axial tomography (CAT) scanning, is a radiological imaging technique that generates cross-sectional ("tomographic") pictures of the body by measuring the differential attenuation of a rotating X-ray beam as it passes through tissues of varying density, and reconstructing this data by computer into a numerical, then visual, image. CT was invented and introduced into clinical use by **Godfrey N. Hounsfield in 1970** (Hounsfield and Allan Cormack shared the 1979 Nobel Prize in Physiology or Medicine for this work). The entire technique — the way the machine is built and operated (the **procedure**), and the way each resulting cross-sectional image is generated and read (the **picture**) — rests directly on normal cross-sectional/topographic anatomy: only a sound knowledge of the relations of structures at a given transverse level allows a CT slice to be correctly interpreted.

1. Physical basis: X-ray attenuation as the anatomical foundation of CT

- ▶ The same fundamental principle underlies plain radiography and CT: substances of different atomic weight and density absorb (attenuate) X-rays to different degrees, producing a differential exposure pattern.

- ▶ The order of increasing X-ray absorption is: **air < fat < water/fluid < soft tissue (muscle, viscera, vessels) < bone < enamel < metal/radiopaque contrast**. Tissues that absorb little appear **radiolucent (dark)**; those absorbing more appear **radiopaque (white)**.
- ▶ CT differs from plain radiography only in *how* this attenuation information is captured and displayed: instead of a single, superimposed 2-D shadow of the whole thickness of the body, CT records attenuation from **many angular projections through one thin slice**, so a computer can calculate the attenuation of every small volume within that slice separately, free of overlap from structures above or below it.
- ▶ Because the anatomical relations at any transverse level are constant and reproducible, this attenuation map corresponds exactly, point for point, to the true cross-sectional anatomy at that level — which is why CT largely replaced older, overlapping-shadow techniques for deep-seated lesions.

2. Procedure: scanning technique and instrumentation

- ▶ The patient lies supine on a motorised table that passes through the **gantry**, a ring-shaped housing containing the X-ray tube and, diametrically opposite it, an array of detectors.
- ▶ The **X-ray tube and detector array rotate together, in a fixed relationship, around the long axis of the patient**; a fan-shaped X-ray beam is sent through the body from many angular positions during each rotation, and the opposing detectors measure the fraction of radiation transmitted through that horizontal section.
- ▶ These multiple overlapping absorption readings are processed by computer, which calculates the radiodensity of each small volume element and reconstructs the corresponding cross-sectional ("axial") slice; because data are gathered for the entire volume scanned, tomograms of **any plane** — axial, coronal, sagittal or oblique — and even 3-D surface images can subsequently be generated (**multiplanar reconstruction, MPR**).
- ▶ Modern gantries permit up to about **25° of tilt**, which is particularly useful in spinal imaging; the patient is usually studied supine, though direct coronal images (prone, neck extended, gantry angled) are occasionally still obtained for cranial/maxillofacial work.
- ▶ For chest, abdomen and pelvis studies, and for complex brain histories, **intravenous iodinated contrast** is generally required to define vascular relationships and separate normal from pathological soft tissue; oral water-soluble contrast is additionally used to opacify the bowel (details under Contrast media, below).

□ Fig 1.53 — Technique for producing CT scan. A. The X-ray tube rotates around the person in the CT scanner and sends a fan-shaped beam of X-rays through the upper abdomen from a variety of angles; X-ray detectors on the opposite side measure the radiation transmitted through the horizontal section. B. A computer reconstructs the images from several scans to produce a transverse CT image of the upper abdomen. C. Scans can also be compiled into a 3-D reconstructed image. (Moore — Clinically Oriented Anatomy — 9e, p.195)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple labelled block diagram of the CT imaging chain:

- ▶ **Gantry** (the ring housing), enclosing the **X-ray tube** and the opposite **detector array**, both shown rotating around the **axis of rotation** (long axis of the supine patient)
- ▶ **Fan-shaped X-ray beam** traversing the body part inside the gantry aperture
- ▶ **Patient couch/table**, shown moving longitudinally into the gantry
- ▶ **Computer/console**, receiving the detector signal and performing image reconstruction
- ▶ The output axial "slice", a grey-scale cross-sectional picture, labelled as viewed from the patient's feet looking towards the head

3. Hounsfield scale and windowing — how numbers become a picture

- ▶ Each picture element (**pixel**, and in three dimensions, **voxel**) is assigned a mean attenuation value that is compared with the attenuation of water and displayed on the **Hounsfield scale**, where water = 0 Hounsfield units (HU) by definition.

Tissue	Approximate attenuation (HU)
Air	about –1000
Fat	about –100
Water (reference)	0
Soft tissue (muscle, viscera)	+20 to +70
Bone	greater than +400

- ▶ The HU range (roughly –1000 to +1000 or more) vastly exceeds the number of grey shades the human eye can distinguish, so the operator selects a display "**window**" — a chosen width and level (centre) — that stretches only the HU range of interest across the visible grey scale: a narrow soft-tissue window for brain or abdominal viscera, and much wider lung and bone windows so aerated lung or cortical bone can be displayed without losing detail at the extremes of the scale.
- ▶ This is why the identical raw dataset from one acquisition can be displayed as a "lung window," "bone window" or "soft-tissue window" picture without re-scanning the patient — the anatomical data are unchanged; only the grey-scale mapping is altered.
- ▶ **Viewing convention:** an axial CT slice is conventionally viewed as though the observer is standing at the patient's feet, looking towards the head — so the patient's right side appears on the observer's left, exactly as in a standard radiograph; coronal reconstructions are viewed as if the patient were facing the observer, and sagittal reconstructions as if the observer stood at the patient's side.

4. Reading CT pictures — cross-sectional correlation at two representative levels

Every CT "picture" is read by matching light/dark areas to the known relations of structures at that vertebral level — the same exercise as interpreting a cadaveric transverse section.

- **Upper abdomen (Fig. 1.53B above)**, around the **transpyloric plane (upper border of L1)** where the pancreatic neck and renal hila lie: liver and gallbladder occupy the right side, stomach lies anteriorly on the left, pancreas crosses the midline anterior to the great vessels, and the aorta/vertebral body lie posteriorly in the midline, flanked by the kidneys.
- **Thorax at the upper part of the T5 vertebra** (manubriosternal junction/angle of Louis, just below the tracheal bifurcation): the section passes through the atria; ascending aorta lies anterior to the pulmonary trunk, descending aorta posterior to it; the principal bronchi lie behind the bifurcating pulmonary trunk and in front of the oesophagus; pulmonary vessels radiate into the aerated (dark) lungs; azygos vein and thoracic duct lie posterior and to the left of the oesophagus.

□ Fig 11.3 — Cross-section (axial section) of thorax obtained by CT scan at the level of the upper part of the T5 vertebra, viewed from the foot end of the patient. The section passes through the upper part of the heart (mainly atria), just below the bifurcation of the trachea. Air-filled areas (lungs, bronchial lumen) appear dark; other structures appear light. DA, descending thoracic aorta; OE, oesophagus; LB, left principal bronchus; RB, right principal bronchus; PV, pulmonary vessels. (IB Singh — Textbook of Anatomy Vol 2 — 6e, p.143)

- In both pictures, the fundamental "reading rule" is identical: **air-containing structures (lung, bowel gas) are darkest; fat is dark grey; soft tissue/viscera and blood-filled chambers are mid-grey to light grey; bone is white** — a direct visual translation of the Hounsfield scale above.

5. Evolution of CT technology

Generation	Key feature
Conventional/step-and-shoot CT (CCT)	A single detector row and a tube that rotates through an arc acquire one slice; the table then increments before the next slice is taken
Spiral/helical CT (SCT)	The table moves continuously and longitudinally while the tube rotates continuously, so the beam traces a spiral path; this continuous volumetric acquisition allows viewing from any angle, computer removal of overlying structures, and colour-coded display
Multidetector/multislice helical CT (MDCT)	Multiple detector rows acquire several slices per rotation in sub-second times; whole-body imaging (skull base to thighs) is possible within one breath-hold, permitting dynamic contrast-timed vascular imaging and routine multiplanar (sagittal/coronal) reconstruction
High-resolution CT (HRCT)	Thin-section acquisition optimised for fine parenchymal detail, e.g. lung interstitium, temporal bone

6. Contrast media used with CT

- **Radiopaque (positive) media:** salts of heavy metals (barium sulphate) and organic iodide preparations; aqueous iodinated contrast is injected intravenously to opacify vessels and enhance solid organs/lesions, or given orally/rectally to opacify the gut lumen.
- **Radiolucent (negative) media:** air/gas, used to distend a viscus.

- **Functions:** (1) delineation of normal structures — the gastrointestinal tract, biliary tree, urinary tract, blood vessels; (2) **lesion enhancement** — distinguishing a focal mass from surrounding normal parenchyma by its differing pattern of contrast uptake.
- A good contrast medium should be non-toxic, reasonably radiopaque or radiolucent, easily administrable and readily available.

7. Advantages, limitations and comparison with allied modalities

Feature	CT	Plain radiograph	Ultrasonography	MRI
Ionising radiation	Yes	Yes	No	No
True cross-sectional image	Yes	No (2-D projection, overlap)	Yes (real-time)	Yes
Soft-tissue contrast	Moderate	Poor	Moderate (operator-dependent)	Excellent
Best for	Bone, lung, acute haemorrhage, trauma, calcification	Skeletal/chest screening	Pregnancy, biliary/renal tract, vascular Doppler	Brain/cord, joints, soft-tissue tumours
Scan time	Seconds	Instant	Real-time	Minutes
Safe with pacemakers/metal implants	Yes	Yes	Yes	No (absolute contraindication for many devices)

- **Advantages:** rapid, life-saving in trauma; excellent for bone, lung parenchyma and acute bleed; permits MPR/3-D reconstruction and CT angiography; usable in patients with pacemakers/metallic implants unlike MRI; wider availability, lower cost than MRI.
- **Limitations:** ionising radiation with cumulative dose/cancer-risk considerations (particularly in children and with repeat scanning); inferior soft-tissue contrast to MRI; iodinated contrast carries a risk of nephropathy/anaphylactoid reaction; susceptible to beam-hardening artefact from metal and to motion artefact.

Recent advances in CT imaging

- **Photon-counting detector CT (PCD-CT)** converts each X-ray photon directly into an electrical signal rather than the older two-step scintillation-detection process, eliminating electronic noise and giving sub-millimetre spatial resolution together with native energy-resolved (spectral) data — a landmark 25-year review of dose-reduction technology places PCD-CT, alongside deep-learning reconstruction, as the most significant recent step in cutting radiation dose while preserving diagnostic image quality (McCollough & Yu, *AJR* 2026) [PMID: 41636571].
- Ultra-high-resolution PCD-CT (0.2 mm slice thickness) has been shown to substantially reduce false-positive "dehiscence" readings of thin bony septa (e.g. the superior semicircular canal roof) caused by partial-volume averaging on conventional CT — bringing radiological prevalence estimates much closer to true cadaveric anatomical prevalence, a direct demonstration of

improved scanner resolution refining anatomical accuracy (Sakaida et al, *Clin Neuroradiol* 2025) [PMID: 41222587].

- ▶ **Dual-energy/spectral CT**, which acquires data at two X-ray energies to generate iodine (material-specific) maps and virtual non-contrast images, is now well established in critical-care imaging — improving detection of pulmonary emboli, distinguishing true haemorrhage from contrast staining, and characterising renal calculi — while reducing contrast dose (Freed et al, *J Crit Care* 2026) [PMID: 41962419].
- ▶ Emerging cone-beam and photon-counting CT protocols are extending high-resolution CT into small, anatomically intricate regions such as the orbit, complementing MRI's superior soft-tissue detail with better bony resolution (Martin, *Radiol Clin North Am* 2026) [PMID: 42230052].

(According to PubMed; DOIs: [10.2214/AJR.25.34450](https://doi.org/10.2214/AJR.25.34450), [10.1007/s00062-025-01591-8](https://doi.org/10.1007/s00062-025-01591-8), [10.1016/j.jcrc.2026.155589](https://doi.org/10.1016/j.jcrc.2026.155589), [10.1016/j.rcl.2026.03.003](https://doi.org/10.1016/j.rcl.2026.03.003).)

Applied / Clinical anatomy

- ▶ **Cross-sectional anatomy teaching:** axial CT images are routinely paired with cadaveric transverse sections at defined vertebral levels (e.g. T4, T5 in the thorax; the transpyloric plane in the abdomen) to teach the disposition of the great vessels, viscera and mediastinal structures — the single most direct application of CT to gross/radiological anatomy, and the basis of every "identify the level and structures" spotter.
- ▶ **Trauma imaging:** whole-body ("pan-scan") CT is the investigation of choice in the stable poly-trauma patient for rapid detection of intracranial/intra-abdominal haemorrhage, solid-organ injury and complex fractures.
- ▶ **CT angiography (CTA):** contrast-enhanced volumetric imaging of arteries and veins (cerebral, pulmonary, coronary, peripheral) has replaced conventional catheter angiography for most diagnostic indications.
- ▶ **Oncology:** CT is central to tumour detection, TNM staging, monitoring treatment response, and radiotherapy treatment-planning ("simulation CT").
- ▶ **Image-guided intervention:** CT guides percutaneous biopsy, abscess drainage and ablation with precise anatomical localisation.
- ▶ **Specialised studies:** HRCT of lung parenchyma or temporal bone, CT urography, CT colonography ("virtual colonoscopy").
- ▶ Because of ionising radiation, ultrasonography or MRI are preferred over CT in pregnancy and in children wherever diagnostically adequate.

High-yield exam pointers

- ▶ CT invented/introduced clinically by **Godfrey Hounsfield (1970)**; shared the **1979 Nobel Prize** with Allan Cormack.
- ▶ Principle: X-ray tube and detector array rotate around the patient in the gantry; a computer calculates the attenuation of each pixel/voxel and reconstructs a cross-sectional slice.

- ▶ **Hounsfield unit (HU)** scale, water = 0; air ≈ -1000 , fat ≈ -100 , soft tissue +20 to +70, bone $> +400$.
- ▶ **Windowing** (width + level) lets one raw dataset be displayed as lung, bone or soft-tissue window pictures.
- ▶ Viewing convention: axial images viewed as if standing at the patient's feet looking towards the head (patient's right = observer's left).
- ▶ Evolution: conventional (step-and-shoot) $\rightarrow$ spiral/helical (continuous table + gantry motion) $\rightarrow$ multidetector/multislice CT (MDCT) — sub-second, single-breath-hold, multiplanar reconstruction (MPR).
- ▶ Thorax CT at T5 (angle of Louis) level classically shows atria, ascending aorta anterior to pulmonary trunk, descending aorta posterior to it, and the just-bifurcated principal bronchi; upper abdomen CT at the transpyloric (L1) level classically shows pancreas, both renal hila, stomach and great vessels.
- ▶ Advantages over MRI: faster, cheaper, pacemaker/metal-implant safe, superior for bone/lung/acute bleed; key disadvantages: ionising radiation, poorer soft-tissue contrast.
- ▶ Iodinated contrast (IV) opacifies vessels/organs for CTA and lesion enhancement; barium/water-soluble agents opacify the gut lumen.
- ▶ Recent advance to name: **photon-counting detector CT** with **deep-learning reconstruction**, giving higher spatial resolution at lower radiation dose.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; Moore's Clinically Oriented Anatomy 9e; Vishram Singh — General Anatomy 4e; IB Singh — Textbook of Anatomy Vol 1 6e and Vol 2 6e. Recent-advances citations are from PubMed (2025–2026).



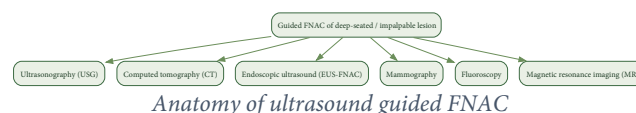
Anatomy of ultrasound guided FNAC

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction — Fine needle aspiration cytology (FNAC) uses a thin (22–25-gauge) needle to aspirate cells from a lesion for cytological diagnosis; it is painless, needs no anaesthesia, and can be done as an office procedure. When the lesion is deep-seated, non-palpable, or lies close to vital structures, real-time **ultrasonography** (USG) is used to localize it and track the needle tip continuously, converting a "blind" pass into an image-guided one. USG-guided FNAC is thus fundamentally an **applied-anatomy** procedure — its safety and diagnostic yield depend entirely on knowing the fascial planes, vessels and nerves the needle must cross to reach each target organ.

1. Physical principle underlying anatomical guidance

USG property	Anatomical relevance
A transducer emits high-frequency sound waves reflected at every tissue interface of differing acoustic impedance (echogenicity)	Reconstructs a real-time cross-sectional (B-mode) image of every soft-tissue plane between skin and lesion
Bone reflects almost all the beam (acoustic shadowing); air conducts it poorly	USG cannot image structures deep to bone or aerated lung — CT/endoscopic-USG substituted at these sites
Colour/power Doppler superimposes real-time blood flow on the 2-D image	Lets the operator trace the carotid sheath, jugular vein, or mediastinal great vessels and pick an avascular track before puncture
Real-time visualization of the needle tip	The chief anatomical advantage over "blind" FNAC — the tip is watched moving through named planes and can be re-angled if it approaches a vessel/nerve



2. Technique — the needle's anatomical path

- ▶ **Equipment:** disposable 22–25-gauge needle (thin-bore for vascular/small structures such as the thyroid or lymph nodes; large-bore for hard, fibrotic or cystic lesions), 10–20 mL syringe with pistol-grip holder, sterile coupling gel, spirit swab.
- ▶ **Approach:** freehand (needle introduced alongside the probe, in or out of the scan plane) or a needle-guide bracket fixed to the transducer — both keep the tip continuously visible.
- ▶ **Steps:** identify the lesion and plan the shortest safe track on USG → clean the skin → introduce the needle with stylet under real-time vision → withdraw stylet → apply negative suction with the syringe → make several to-and-fro passes within the lesion → release suction before withdrawing (prevents aspirating tract structures) → expel the material onto a slide.
- ▶ An **angular (oblique) approach** is possible with USG, unlike a fixed CT gantry — the operator can deliberately steer around a vessel or nerve seen live in the same image.

3. Regional anatomy — thyroid and neck (the classic USG-FNAC site)

- ▶ The gland lies anterior to the neck at the level of C5–T1; the isthmus overlies the 2nd–3rd tracheal rings.
- ▶ **Needle path:** skin → superficial fascia/platysma → investing layer of deep cervical fascia → sternohyoid and sternothyroid (strap muscles) → pretracheal fascia → thyroid lobe/isthmus.
- ▶ **Structures at risk** (deep/posterior relations): the **recurrent laryngeal nerve** and **oesophagus** medially (oesophagus lies closer on the left); the **external branch of the superior laryngeal nerve**, medial to the upper pole near the superior thyroid vessels; the **carotid sheath** (common carotid artery, internal jugular vein, vagus) posterolaterally, overlapped by the gland; the **parathyroid glands** and the lateral thyroid (**Berry's**) ligament along the posterior border; on the left, the **thoracic duct** near the lower posterior border.
- ▶ A **thin-bore needle** is deliberately chosen because the thyroid is a highly vascular organ.
- ▶ **Cervical lymph node FNAC** (thyroid/head-neck malignancy staging): Level I nodes lie in the submandibular triangle; Level II–III nodes lie around the internal jugular vein from skull base to the omohyoid; **Level VI (central compartment)** — the paratracheal, pretracheal and prelaryngeal nodes flanking the trachea/oesophagus along the recurrent laryngeal nerve — is the group most often sampled for thyroid-cancer nodal staging.

□ Fig 8.5 — Deep relations of the thyroid gland (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.174)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Cross-section of the neck at the level of the thyroid isthmus, showing the USG-guided needle track, labelled:

- ▶ Skin and superficial fascia (with platysma)
- ▶ Investing layer of deep cervical fascia
- ▶ Sternohyoid and sternothyroid (strap muscles)
- ▶ Pretracheal fascia
- ▶ Thyroid lobe / isthmus (needle tip in lesion)
- ▶ Trachea (midline)
- ▶ Oesophagus and recurrent laryngeal nerve (posteromedial)
- ▶ Parathyroid glands and Berry's ligament (posterior border)
- ▶ Carotid sheath — common carotid artery, internal jugular vein, vagus nerve (posterolateral)
- ▶ Ultrasound transducer on skin surface, beam directed at the lesion

4. Regional anatomy — breast

- ▶ The breast base extends vertically from the 2nd/3rd to the 6th rib and transversely from the sternal edge to the mid-axillary line; the superolateral quadrant prolongs as the **axillary tail of Spence**.

- **Needle path:** skin → subcutaneous fat → glandular/fibrous parenchyma (site of most lumps) → **retromammary (submammary) space** → deep pectoral fascia → **pectoralis major** → intercostal space/ribs → parietal pleura.
- **Structures at risk:** internal thoracic (mammary) perforators medially, lateral thoracic vessels laterally, axillary vessels/nodes in the upper-outer quadrant, and — if the needle is angled too steeply through the retromammary space — the intercostal neurovascular bundle and the pleura (pneumothorax).
- USG differentiates a **solid** from a **cystic** mass by echogenicity/attenuation, and Doppler shows the blood-flow pattern within a mass — both used to select the aspiration target; FNA is also used to therapeutically drain a symptomatic cyst.

□ Fig 3.14 — Deep relations of the breast (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.176)

5. Regional anatomy — deep/visceral and pelvic sites

Site	Approach & anatomical landmark	Structures at risk
Liver	Intercostal, targeted to the relevant Couinaud segment (I–VIII; segments II–IV form the left hemi-liver, V–VIII the right)	Costodiaphragmatic pleural recess, hepatic veins/IVC near segment I, gallbladder bed
Kidney	Posterior (retroperitoneal) approach below the 12th rib, lateral to erector spinae, through Gerota's (renal) fascia and perinephric fat	Pleura crosses the 12th rib at the lateral border of erector spinae, so the medial part of the kidney lies above the pleural reflection — USG is used to confirm whether the palpable rib is the 11th or 12th before puncture, since mistaking the level opens the pleura
Pancreas	Usually sampled by EUS-FNAC through the posterior gastric/duodenal wall, because the retroperitoneal gland is otherwise obscured by bowel gas on transabdominal USG	Splenic vessels along the body/tail; portal and superior mesenteric vessels near the neck/head
Prostate	Transrectal FNAC — Franzen's needle-guide fixed on the examining index finger is passed per rectum to the lesion, and the FNAC needle–syringe is introduced through the guide	Rectal wall and Denonvilliers' (rectovesical) fascia , which separates rectum from prostate; rectal vessels
Mediastinal/hilar nodes	EBUS-guided transbronchial needle aspiration through the tracheal/bronchial wall (stations 1–4, 7, 10–12), or oesophageal-EUS-FNA for stations 7–9	Great mediastinal vessels — the EBUS probe's power Doppler identifies vessels before the needle passes

6. Advances in image-guided cytological sampling

- ▶ **EBUS-TBNA/EUS-FNA** now sample mediastinal, hilar, oesophageal, biliary and pancreatic lesions in real time under direct endoscopic-ultrasound vision, largely replacing mediastinoscopy for many nodal stations.
- ▶ **Core-needle/mammotome biopsy**, taken under the same USG guidance, is increasingly preferred over FNA in the breast because it preserves tissue architecture and can distinguish in-situ from invasive carcinoma.
- ▶ Material from a single USG-guided pass is now routinely apportioned for ancillary studies — **flow cytometry, microbial culture, molecular/PCR analysis** — extending the diagnostic yield of one anatomical needle track.

Applied / Clinical anatomy

- ▶ **Advantages of USG guidance** (anatomical/safety standpoint): no ionizing radiation, portable/bedside, real-time needle-tip tracking, angular approach possible, economical compared with CT/MRI guidance.
- ▶ **Limitations**: operator-dependent; poor resolution through bone/air; obscured by overlying bowel gas — hence EUS is substituted for the pancreas and deep abdominal lesions behind gut loops.
- ▶ **Complications**, each traceable to the structures crossed: minor haematoma (superficial vessel nick); surgical emphysema (transpleural lung/mediastinal pass); pneumothorax (transpleural breast, kidney or liver passes); recurrent laryngeal nerve injury (an aberrantly deep or posterior thyroid pass); rarely, needle-tract seeding of tumour cells with a thick-bore needle.
- ▶ **Contraindication linked to regional vascularity**: caution in highly vascular organs (thyroid, vascular tumours) in patients with bleeding diatheses (haemophilia, thrombocytopenia) — coagulation parameters are checked before any deep-seated guided FNAC because the needle traverses named vessels at every site above.
- ▶ **Parotid/submandibular gland FNAC** (superficial-organ analogue): the intraparotid facial nerve is isolated surgically during parotidectomy and is likewise the key structure the operator must anatomically respect during a parotid FNAC pass.

High-yield exam pointers

- ▶ USG-guided FNAC = real-time, radiation-free, image-directed placement of a 22–25 G needle; safety depends on site-specific "structures at risk."
- ▶ **Thyroid**: recurrent laryngeal nerve + oesophagus (medial), carotid sheath (posterolateral), Berry's ligament + parathyroids (posterior border), thoracic duct (left lower pole).
- ▶ **Cervical Level VI** (central compartment) nodes flank the trachea/RLN — key nodal target in thyroid cancer FNAC.
- ▶ **Breast**: needle path = skin → parenchyma → retromammary space → pectoralis major → ribs/pleura; angling too deep risks pneumothorax.
- ▶ **Kidney**: posterior approach below the 12th rib; pleura crosses the 12th rib at the lateral border of erector spinae, so the medial kidney lies above the pleura.
- ▶ **Liver**: Couinaud's eight segments define the intercostal needle path.

- ▶ Pancreas/mediastinum: EUS/EBUS-FNA substitutes for transabdominal USG because bowel gas or lung air blocks the beam.
- ▶ Prostate: transrectal FNAC via Franzen's guide; needle crosses rectal wall and Denonvilliers' fascia.
- ▶ A pre-puncture Doppler sweep of the planned track is the single most important anatomical safety step before every guided pass.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; Pranab Dey — Lab Techniques in Histopathology & Cytology 2e; BD Chaurasia Human Anatomy Vol 3–4 8e (figure); Vishram Singh Textbook of Anatomy Vol 1 4e (figure).

Coverage note: neither the spine text (Gray's) nor Moore's carries a single dedicated "USG-guided FNAC" chapter; the procedural/instrument facts above are grounded in Pranab Dey's cytology-techniques text, while every regional/relational anatomical fact (thyroid, breast, kidney, liver, prostate) is grounded in Gray's/Moore's standard descriptive anatomy of each organ.



Ascending and Descending Pyelography

Asked in: Paper IV Oct 2008 — RGUHS MD/MS Anatomy

Definition / Introduction Pyelography (urography) is a contrast radiological technique that outlines the pelvicalyceal system, ureter and urinary bladder by rendering them radio-opaque. It is named **descending (intravenous/excretory) pyelography** when the contrast is injected intravenously and reaches the urinary tract by renal excretion (i.e. the dye "descends" through the kidney into the tract), and **ascending (retrograde/instrumental) pyelography** when the contrast is introduced from below, through a ureteric catheter passed via a cystoscope, and made to "ascend" up the ureter to the renal pelvis. Both techniques exploit the same anatomy of the collecting system but differ in the route of contrast administration, the information yielded, and their clinical indications.

1. Anatomical basis — structures a pyelogram outlines

Structure	Anatomical detail relevant to the pyelogram
Renal pelvis	Funnel-shaped dilatation formed within (or partly outside) the renal sinus; may be predominantly intrarenal or extrarenal — a variation that alters its radiological outline
Major calyces	2–3 in number; each receives several minor calyces
Minor calyces	7–13 in number; each is cup-shaped and indented by one to three renal papillae projecting into it — the basis of the normal "cupped" calyceal appearance on a pyelogram

Structure	Anatomical detail relevant to the pyelogram
Ureter	~25 cm long, retroperitoneal, running from the pelviureteric junction (PUJ) to the trigone of the bladder
Three constrictions of the ureter	(1) at the pelviureteric junction ; (2) at the pelvic brim , where it crosses the iliac vessels; (3) at its oblique passage through the bladder wall . These are the classic sites of calculus impaction and of a "hold-up" of contrast on a pyelogram
Skeletal relations used to read the film	Abdominal ureter runs in line with the tips of the lumbar transverse processes ; pelvic ureter crosses the sacroiliac joint and the anterior border of the greater sciatic notch to reach the ischial spine , then turns medially to end near the level of the pubic tubercle
Urinary bladder	Outlined as an oval or triangular shadow once contrast fills it

2. Descending (intravenous/excretory) pyelography

- ▶ **Principle:** a water-soluble, iodine-based contrast medium is given intravenously; being selectively excreted by the kidney, it renders the calyces, pelvis, ureter and bladder radio-opaque as it is filtered and concentrated.
- ▶ **Preparation:** routine abdominal preparation (bowel emptied of gas/faeces); additionally the patient takes nothing orally and diuretics are withheld for about 8 hours before the study, and the bladder is emptied just before injection of the dye.
- ▶ **Contrast and dose:** 20–40 mL of a warm iodine compound (e.g. urograffin 60%/76%, Conray 420/280) is injected slowly intravenously, taking care not to extravasate it outside the vein as it is an irritant and can cause sloughing.
- ▶ **Exposures:** serial films (excretory pyelograms) are taken at **5, 15 and 30 minutes** after injection; maximum calyceal/pelvic concentration is reached at 15–20 minutes, and by 30 minutes the dye has filled the bladder.
- ▶ **Nature of the test:** intravenous pyelography is both an **anatomical and a physiological (functional) test** — it demonstrates the anatomy of the tract and also gives an indirect assessment of renal excretory function (delayed or absent excretion implies impaired function on that side).

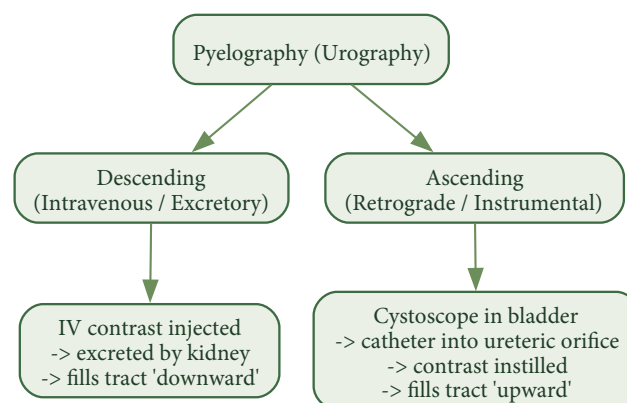
3. Ascending (retrograde/instrumental) pyelography

- ▶ **Principle:** contrast is introduced directly into the ureter/renal pelvis from below, independent of renal excretory function, so it visualises the anatomy of the tract even when the kidney is functioning poorly.
- ▶ **Preparation:** similar patient preparation to descending pyelography.

- **Technique:** a **cystoscope** is passed through the urethra into the bladder; a fine **ureteric catheter** is then guided through the cystoscope into the ureteric orifice and threaded up to the renal pelvis. This is a specialised urological (not anatomical/radiological-department) procedure.
- **Contrast and dose:** through the catheter, 5–10 mL of a sterile 6–8% sodium iodide solution (e.g. Conray 280) is injected.
- **Endpoint and safety:** as the renal pelvis fills to capacity the patient develops loin pain, at which point injection must stop; **general anaesthesia is therefore contraindicated** for this procedure because the patient cannot report pain and the pelvis may be overdistended. If the pelvis accepts **more than 10 mL** of dye before pain appears, hydronephrosis (an already-dilated, capacious pelvis) is suspected.

4. Distinguishing an ascending pyelogram from a descending pyelogram

Feature	Descending (IV/excretory) pyelogram	Ascending (retrograde) pyelogram
Route of contrast	Intravenous injection, excreted by kidney	Direct instillation via ureteric catheter/cystoscope
Dependence on renal function	Depends on adequate renal excretion	Independent of renal function
Sides visualised	Both kidneys/ureters seen together	Usually only one pelvis is outlined at a time
Instrumentation on film	Catheter is not seen	The ureteric catheter (and cystoscope) used to instil the dye is itself visible on the film
Information yielded	Anatomical and functional (physiological)	Anatomical only
Operator	Radiologist	Urologist (specialised, cystoscopic procedure)
Anaesthesia	Not required	General anaesthesia contraindicated (loss of the pain warning of overdistension)



Ascending and Descending Pyelography

5. Reading a normal pyelogram

- ▶ **Minor calyces** appear cup-shaped, the concavity produced by the projecting renal papillae.
- ▶ **Renal pelvis** is funnel-shaped, tapering inferomedially to become the ureter.
- ▶ **Ureter** is traced as a fine radio-opaque line along its bony landmarks (transverse process tips, sacroiliac joint, ischial spine) down to the bladder.
- ▶ **Bladder** fills as an oval or triangular contrast shadow.
- ▶ Because of normal renal rotation, the **posterior calyces lie relatively medial** and the **anterior calyces relatively lateral** — important when interpreting the two-dimensional projection of a three-dimensional collecting system.

embed: ![Fig 36.5 — Intravenous pyelogram (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.538)]
(C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/572ceceee6de2858.jpg)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a labelled schematic of a normal excretory pyelogram and mark:

- ▶ **Renal pelvis** — funnel-shaped, tapering to the ureter
- ▶ **2–3 major calyces**, each dividing into cup-shaped **minor calyces** (indented by renal papillae)
- ▶ **Ureter**, with its **three constrictions** labelled — pelviureteric junction, pelvic brim, and vesical (bladder-wall) segment
- ▶ Ureteric course drawn along the tips of the **lumbar transverse processes**, across the **sacroiliac joint**, to the **ischial spine**
- ▶ **Urinary bladder** outline (oval/triangular) at the lower end
- ▶ For a retrograde pyelogram, additionally mark the **cystoscope in the bladder** and the **ureteric catheter** running up to the renal pelvis (features absent on a descending film)

Applied / Clinical anatomy

- ▶ **Hydronephrosis and hydroureter**: obstruction distal to the renal pelvis causes chronic distension of the pelvicalyceal system and ureter proximal to the block; the normal cupping of the minor calyces by the papillae is obliterated, producing "clubbed" calyces on the pyelogram.
- ▶ **Calculus impaction**: renal/ureteric stones characteristically lodge at the **three anatomical constrictions** (PUJ, pelvic brim, vesical segment), producing a filling defect or a sudden "hold-up" of contrast on the film — the anatomical basis of ureteric colic.
- ▶ **Retrograde pyelography as the fallback investigation**: because it does not depend on renal excretion, retrograde pyelography can outline the tract even when a kidney is poorly functioning or non-visualised on an intravenous study, or when intravenous contrast is relatively contraindicated (e.g. contrast allergy, deranged renal function) — it demonstrates anatomical patency independent of physiology.

- ▶ **Extrarenal vs intrarenal pelvis:** the renal pelvis is variably intrarenal or extrarenal in position; this variation alters its normal radiological outline and must be recognised before a pyelographic appearance is labelled abnormal.
- ▶ **Congenital variation:** pyelography can reveal a **duplex pelvicalyceal system/ureter**, a **pelvic (ectopic) kidney**, or a **horseshoe kidney** — anomalies of the metanephric/ureteric-bud development.
- ▶ **Current practice:** conventional descending pyelography is now largely superseded by **computed tomographic urography (CTU)**, which applies the same excretory principle (intravenous contrast excreted by the kidney) but with cross-sectional imaging; retrograde (ascending) pyelography via cystoscopy remains in use, particularly to define ureteric anatomy precisely before endourological procedures.

High-yield exam pointers

- ▶ Descending = intravenous/excretory pyelography; ascending = retrograde/instrumental pyelography — know both names for each.
- ▶ Descending pyelography is both anatomical AND functional; retrograde pyelography is anatomical ONLY.
- ▶ On a retrograde film, the catheter/cystoscope is visible and usually only one side is studied; on a descending film neither instrument is seen and both sides are studied together.
- ▶ IVP films are taken at 5, 15 and 30 minutes; peak concentration at 15–20 minutes; bladder fills by 30 minutes.
- ▶ Retrograde dye volume is 5–10 mL of 6–8% sodium iodide; pain is the safety endpoint, so general anaesthesia is contraindicated; >10 mL tolerated without pain suggests hydronephrosis.
- ▶ Normal pyelogram: cup-shaped minor calyces (papillary indentation), funnel-shaped pelvis, ureter along transverse processes/SI joint/ischial spine, oval/triangular bladder shadow.
- ▶ Ureter has 2–3 major and 7–13 minor calyces, and three constrictions — PUJ, pelvic brim, vesical segment — the classic stone-impaction sites, clinically correlated on the pyelogram as a hold-up/filling defect.
- ▶ Loss of calyceal cupping with pelvicalyceal/ureteric dilatation = hydronephrosis/hydroureter.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2 8e; IB Singh's Textbook of Anatomy Vol 2 6e; Vishram Singh's General Anatomy 4e; Vishram Singh's Textbook of Anatomy Vol 2 4e.



Bone scan & its applications

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — A bone scan (radionuclide bone scintigraphy) is a nuclear medicine imaging technique in which a bone-seeking radiopharmaceutical, technetium-99m methylene diphosphonate (^{99m}Tc -MDP), is injected intravenously and its distribution in the skeleton is imaged with a gamma camera. Unlike a plain radiograph, which depends on X-rays passed through the body from an external source, nuclear medicine imaging works by detecting radiation emitted from a tracer taken up internally, so the images represent regional bone **physiology** (osteoblastic turnover and vascularity) rather than gross bone mineral density. Because MDP chemisorbs onto hydroxyapatite crystals wherever new bone formation/remodelling is occurring, any process that alters local bone activity — fracture, tumour, infection, or arthritis — produces a focal area of altered tracer uptake, making the scan a highly sensitive (though non-specific) whole-body screen for skeletal disease.

1. Principle and radiopharmaceutical

- ▶ **Tracer:** ^{99m}Tc -MDP (methylene diphosphonate labelled with technetium-99m).
- ▶ **Mechanism:** MDP attaches to hydroxyapatite in bone; altered bone physiology — as in a fracture, metastatic bone disease, or arthritic change — increases biochemical bone (osteoblastic) activity and produces a focal accumulation of MDP, seen as a "**hot spot**" on the scan.
- ▶ **Radioisotope:** ^{99m}Tc is the "workhorse" radioisotope of nuclear medicine — it is eluted from a molybdenum-99/technetium-99m generator kept within the nuclear medicine department (easy, on-site access), has a short half-life (~6 hours) that favours ease of imaging and disposal, and emits gamma rays of an energy suitable for detection by a gamma camera.
- ▶ **Excretion:** the tracer that is not bone-bound is cleared by the kidneys, so the kidneys and bladder are normally visualised on the scan.
- ▶ Nuclear medicine differs fundamentally from radiography/CT: it demonstrates **physiological function**, and its images can be fused with the anatomical detail of CT or MRI (hybrid SPECT-CT/PET-CT), combining function with anatomy.

2. Instrumentation and imaging technique

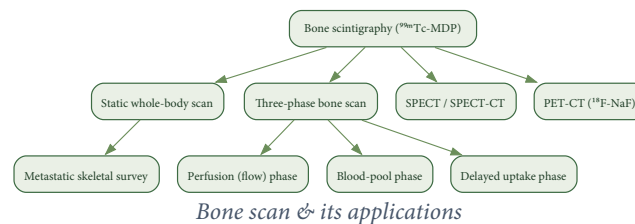
- ▶ Imaging is performed with a **gamma camera**, which detects the emitted gamma photons and can acquire:
 - **Planar (whole-body) scintigraphy** — simultaneous anterior and posterior static views of the entire skeleton (the standard survey image).
 - **SPECT (single-photon emission computed tomography)** — the camera rotates around the patient to generate a tomographic slice-stack, improving localisation in complex regions (spine, hips, facet joints).
 - **SPECT-CT / PET-CT** — spatial (tomographic) nuclear medicine data fused with a concurrent CT scan, combining physiological (tracer) and anatomical (CT) information in a single image set.
- ▶ Radiation dosage from a bone scan is broadly comparable to that of a CT study.

3. Phases of bone scintigraphy

A **multiphasic (three-phase) bone scan** acquires images during three distinct temporal phases after tracer injection — used specifically when regional blood flow and soft-tissue hyperaemia need to be assessed in addition to bone uptake (e.g. infection, avascular necrosis, complex regional pain syndrome):

Phase	Timing (approx.)	What it demonstrates
Perfusion (flow) phase	Dynamic images acquired over the first ~60 seconds after IV injection	Regional arterial blood flow/vascularity
Blood-pool phase	Static image immediately after the flow phase (within a few minutes)	Soft-tissue hyperaemia/capillary blood pool
Delayed uptake (static) phase	2–4 hours after injection	Osteoblastic bone activity — the definitive skeletal image

- ▶ A **fourth phase** (a further static image at ~24 hours) is often added when infection of bone in the presence of overlying soft-tissue disease (e.g. the diabetic foot) needs to be distinguished, since bone activity persists at 24 hours while soft-tissue tracer has cleared.
- ▶ A **static (single delayed-phase) whole-body scan** — omitting the flow/blood-pool phases — is the routine technique for a metastatic skeletal survey.



4. Normal distribution pattern

- ▶ Uptake is normally symmetrical, with the greatest physiological activity at sites of highest bone turnover: growth plates/epiphyses in children and adolescents, sacroiliac joints, sternum, and the axial skeleton.
- ▶ The tracer not fixed to bone is excreted renally, so the **kidneys and urinary bladder** are routinely visualised and serve as an internal check that the study has been performed correctly.
- ▶ Soft-tissue extravasation of tracer at the venous injection site (antecubital fossa) is a common normal-variant artefact.

□ Fig 1.56 — Anterior (A) and posterior (B) whole body views, radionuclide bone sca (Moore — Clinically Oriented Anatomy — 9e, p.199)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label a normal anterior/posterior whole-body bone scan with:

- ▶ Cranium/skull
- ▶ Nose and facial bones
- ▶ Cervical spine
- ▶ Clavicle
- ▶ Acromioclavicular joint
- ▶ Scapula
- ▶ Humeral head
- ▶ Humeral shaft
- ▶ First rib
- ▶ Fifth rib
- ▶ Sternum
- ▶ Thoracic spine
- ▶ Soft-tissue extravasation at the antecubital-fossa injection site
- ▶ Bodies of lumbar spine
- ▶ Third lumbar vertebral body
- ▶ Right kidney
- ▶ Iliac crest
- ▶ Sacrum
- ▶ Urinary bladder
- ▶ Ischial tuberosity
- ▶ Femoral head
- ▶ Greater trochanter of femur
- ▶ Femoral shaft
- ▶ Patella
- ▶ Tibia
- ▶ Ankle
- ▶ Elbow
- ▶ Wrist

5. Applications of bone scan

Indication	Typical scan finding / clinical use
Skeletal metastases (breast, prostate, lung, thyroid, kidney primaries)	Multiple, randomly distributed focal "hot spots"; detects osteoblastic metastatic deposits well before the plain radiograph becomes abnormal, since scintigraphy reflects osteoblastic reaction rather than the gross mineral loss a radiograph needs before a lesion becomes visible
Diffuse metastatic/metabolic bone disease	"Superscan" — markedly increased, diffuse skeletal uptake with faint or absent renal visualisation (seen in extensive skeletal metastases and in metabolic bone disease such as hyperparathyroidism/renal osteodystrophy)
Primary bone tumours (e.g. osteosarcoma, Ewing sarcoma)	Assesses local extent, "skip" lesions, and skeletal metastatic spread
Occult/stress fracture	Focal uptake at the fracture line seen before any radiographic change; classic use in stress fractures of the tibia/metatarsals and in spondylolysis (pars interarticularis)
Osteomyelitis	Three-phase scan positive in all three phases (flow, blood-pool, and delayed) helps differentiate bone infection from overlying cellulitis, which is typically positive only in the early (flow/blood-pool) phases
Avascular necrosis (AVN)	Early: a photopenic "cold spot" from interrupted blood supply; later, a rim of increased peripheral uptake around a persistent central cold area as revascularisation/repair begins ("doughnut sign")
Paget disease of bone	Markedly increased, well-defined tracer uptake conforming to the expanded, deformed bone contour; used to map disease extent and monitor activity
Prosthesis loosening/infection	Aseptic loosening shows uptake localised to the bone-implant interface (typically the distal stem), whereas infection shows diffuse uptake around the whole prosthesis
Non-accidental injury (child abuse)	Detects otherwise clinically occult fractures of differing ages across the skeleton
Reflex sympathetic dystrophy/complex regional pain syndrome	Increased peri-articular uptake in all three phases of a three-phase scan

Applied / Clinical anatomy

- **Greater sensitivity than plain radiography** for early skeletal disease, because the scan reflects reactive osteoblastic bone turnover, not the degree of mineral loss a radiograph requires to show an abnormality — this is the principal reason it is used for an early metastatic skeletal survey and for occult/stress fractures.

- ▶ **Limited specificity:** degenerative joint disease, healing trauma, infection and neoplasm can all appear as non-specific focal uptake, so a positive scan is routinely correlated with plain radiographs, CT/MRI, or resolved with hybrid **SPECT-CT**, which localises an area of abnormal uptake to a precise anatomical structure.
- ▶ **Functional-anatomical fusion:** SPECT-CT/PET-CT combine the physiological information of the tracer study with the anatomical detail of CT, which is of particular value in the spine (facet-joint disease) and pelvis.
- ▶ **Radiation and safety:** overall dosage is comparable to CT; the tracer is renally excreted, so adequate hydration and bladder emptying reduce pelvic-organ dose; the study is generally avoided in pregnancy and interrupted briefly during breastfeeding.
- ▶ **Comparison with bone mineral densitometry (DEXA):** a bone scan is a functional map of bone turnover and must be distinguished from dual-energy X-ray absorptiometry, which quantifies bone mineral density (e.g. for osteoporosis) rather than imaging focal reactive disease.

High-yield exam pointers

- ▶ Radiopharmaceutical: ^{99m}Tc -MDP; mechanism — chemisorption onto hydroxyapatite at sites of increased osteoblastic activity → focal "hot spot".
- ▶ ^{99m}Tc : eluted from a Mo-99/Tc-99m generator, half-life ~6 hours, pure gamma emitter, ideal for gamma-camera imaging.
- ▶ Three phases: perfusion (flow) → blood-pool → delayed uptake; a 4th (24 h) phase aids diagnosis of osteomyelitis.
- ▶ Whole-body static scan is the standard technique for a metastatic skeletal survey.
- ▶ Normal uptake: growth plates in children, sacroiliac joints, sternum, spine; renal/bladder excretion always visualised.
- ▶ Bone scan detects reactive bone change before it is visible on X-ray — high sensitivity, low specificity.
- ▶ Classic named patterns: "superscan" (diffuse metastatic/metabolic disease), "doughnut sign" (healing AVN), "cold spot" (early AVN, infarction).
- ▶ SPECT-CT/PET-CT fuse function with anatomy and are used to resolve equivocal planar findings.
- ▶ Applications span oncology (metastases, primary bone tumours), trauma (occult/stress fracture), infection (osteomyelitis), orthopaedics (prosthesis loosening), and forensic/paediatric practice (non-accidental injury).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; Weir & Abrahams — Imaging Atlas of Human Anatomy 6e.

Coverage note: the RGUHS anatomy library's dedicated gross-anatomy texts (BD Chaurasia, AK Datta) do not carry a discrete nuclear-medicine section; core grounding for the mechanism, instrumentation and phases above is drawn from the imaging-technique passages common to Gray's Anatomy 41e, Moore's Clinically Oriented Anatomy 9e, and Weir & Abrahams' Imaging Atlas, which are essentially concordant. The applications table lists standard, universally-taught clinical indications for bone scintigraphy consistent with this grounding.



Carotid angiogram

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction — A carotid angiogram (carotid angiography) is a contrast radiological/interventional procedure that outlines the internal carotid artery (ICA) and its intracranial branches — and, when the common carotid artery itself is injected, the external carotid artery (ECA) as well — by rapid serial imaging after intra-arterial injection of a radiopaque (iodinated) contrast medium. Its anatomical basis lies in the course and four parts of the ICA, the branches given off at each part, the carotid bifurcation, and the cerebral arterial circle (circle of Willis) that these vessels complete intracranially. It remains the reference standard for demonstrating cerebrovascular occlusion, aneurysm, and the vascular pattern of intracranial space-occupying lesions, and is today most often performed as catheter-based digital subtraction angiography (DSA).

1. Course and parts of the internal carotid artery

- ▶ **Origin:** at the carotid bifurcation, in the carotid triangle of the neck, at about the level of the fourth cervical vertebra (C4); a **carotid sinus** is usually present here.
- ▶ The **cervical part is a branchless vessel** — a key angiographic landmark, since any branch seen arising from the cervical carotid column on a film belongs to the external, not the internal, carotid artery.
- ▶ It ascends within the carotid sheath, in front of the transverse processes of the upper three cervical vertebrae, to the carotid canal in the petrous part of the temporal bone, then enters the cranial cavity.
- ▶ Traditionally divided into **four parts** — **cervical, petrous, cavernous and cerebral**:
 - **Petrous part** — traverses the carotid canal, curving forward and medially above the fibrocartilage plugging the foramen lacerum.
 - **Cavernous part** — passes forward through the cavernous sinus, in the carotid groove on the body of the sphenoid, describing a sinuous, S-shaped course — the **carotid siphon** of angiograms.

- **Cerebral (supraclinoid) part** — pierces the dural roof of the cavernous sinus medial to the anterior clinoid process and ends, lateral to the optic chiasma near the anterior perforated substance, by dividing into its terminal branches.
- **Terminates** by dividing into the **anterior cerebral artery (ACA)** and **middle cerebral artery (MCA)**.

□ Fig 12.16 — Various parts of internal carotid artery (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.246)

2. Branches of the internal carotid artery

Part	Branches
Cervical	None — branchless
Petrous	Caroticotympanic branches; artery of the pterygoid canal
Cavernous	Ophthalmic branch; superior and inferior hypophyseal branches; trigeminal ganglion branch
Cerebral (supraclinoid)	Anterior choroidal branch; posterior communicating branch; terminal division into anterior cerebral artery and middle cerebral artery

The ophthalmic artery classically arises just as the ICA is about to leave the cavernous sinus, medial to the anterior clinoid process (as shown in the figure above); it runs forward into the orbit through the optic canal.

3. External carotid artery and the carotid bifurcation

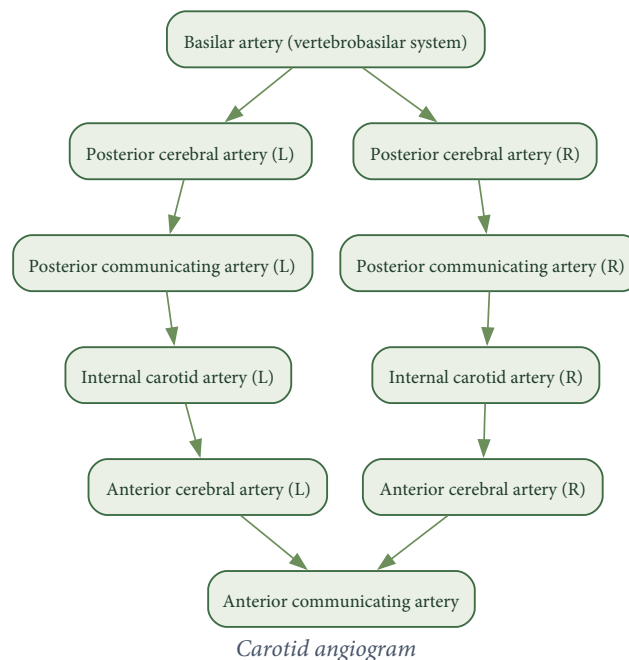
- Classical carotid angiography injects the **common carotid artery**, so both the ICA and ECA opacify on the film and must be told apart.
- The ECA is distinguished on the film by (a) an anteromedial position at its origin, curving back to lie superficial to the ICA near the digastric muscle, and (b) **multiple named branches within the neck**, unlike the branchless cervical ICA.
- The ECA gives **eight branches**: an anterior group — superior thyroid, lingual, facial; a posterior group — occipital, posterior auricular; a medial/ascending branch — ascending pharyngeal; and two terminal branches within the parotid gland — maxillary and superficial temporal.
- The **carotid sinus** (baroreceptor, innervated chiefly by the carotid branch of the glossopharyngeal nerve) and the **carotid body** (chemoreceptor) lie at/near the bifurcation — clinically relevant both to needle placement for direct-puncture angiography and to surgery in this region.

4. Cerebral arterial circle (circle of Willis) — completing the picture intracranially

- A polygonal anastomotic ring in the interpeduncular fossa, linking the two systems supplying the brain — the internal carotid (anterior circulation) and the vertebrobasilar (posterior circulation) systems.
- **Formation**: anterior communicating artery (anterior part) + two anterior cerebral arteries (anterolateral part) + terminations of the two internal carotid arteries (lateral part) + two

posterior communicating arteries (posterolateral links) + terminal bifurcation of the basilar artery into two posterior cerebral arteries (posterior part).

- The **middle cerebral artery does not take part** in the circle of Willis — a frequently tested negative fact.
- **Functional importance:** equalizes arterial pressure between the two cerebral hemispheres and provides collateral flow if a major feeding vessel is blocked.
- **Angiographic correlate:** contrast injected into one carotid system fills the ipsilateral ACA and MCA promptly. Cross-filling of the contralateral ACA (via the anterior communicating artery) or of the posterior cerebral artery (via the posterior communicating artery) is variable in normal individuals — good filling of the posterior cerebral artery from a carotid injection is seen in only about **25% of patients**, reflecting variation in the calibre of the communicating arteries.
- **Berry (saccular) aneurysms** arise on the circle from congenital muscular weakness at arterial junctions; the two classical sites are the **junction of the anterior cerebral and anterior communicating arteries**, and the **bifurcation of the internal carotid artery**. Rupture produces subarachnoid haemorrhage.



5. Technique of carotid (cerebral) angiography

- Introduced in 1927 by Egas Moniz (Nobel Prize, 1949); revolutionized in 1953 by the **Seldinger technique**, which allows a catheter to be advanced without leaving a sharp needle inside the vascular lumen.
- **Classical direct-puncture method:** the common carotid artery is located and fixed at the **carotid tubercle** (anterior tubercle of the transverse process of the sixth cervical vertebra — the tubercle of Chassaignac), and about **10–12 mL of a 30% iodinated contrast medium** (historically pyelocil or diodone) is injected percutaneously. Serial skiagrams are exposed rapidly, at about 1-second intervals. Contrast reaches the cerebral arteries within about 2 seconds (**arterial phase**), the veins by a further 2 seconds (**venous/phlebographic phase**), and the intracranial venous sinuses about

2 seconds after that (**sinogram phase**) — one injection thus yields an arteriogram, a venogram and a sinogram.

- ▶ **Modern catheter method:** under anaesthesia and with the patient supine, a catheter introduced by the Seldinger technique through the femoral (or radial) artery is guided to the common carotid or vertebral artery; both **anteroposterior and lateral projections** are exposed at short (1–2-second, up to 30 frames/second) intervals.
- ▶ **Digital subtraction angiography (DSA):** a pre-contrast "mask" image is electronically subtracted from every subsequent contrast-filled image, leaving only the opacified vessels free of overlying bone and soft tissue; the patient must remain motionless for accurate subtraction. Arterial DSA (dilute contrast injected directly into the artery) gives the sharpest vascular detail of the course, branches and disease of a vessel.
- ▶ **Indications:** intracranial tumours, haematomas, aneurysms and vascular malformations (angiomas); detection of arterial stenosis or occlusion. Because of these safer modern techniques, older methods — pneumoencephalography, ventriculography and myelography — have become obsolete.
- ▶ Conventional catheter cerebral angiography carries a **morbidity of about 0.5–2.5%**, so non-invasive CT/MR angiography and Doppler ultrasound are used first wherever adequate.

6. Normal angiographic anatomy — AP and lateral views

□ Fig 20.21 — Carotid angiogram (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.367)

Landmark	Lateral-view appearance
Cervical ICA	Straight, vertical, branchless column
Carotid siphon (cavernous ICA)	Sigmoid (S-shaped) curve at the skull base — localizes the sella/cavernous sinus region
Ophthalmic artery	Small branch running anteriorly into the orbit, arising at the siphon
Anterior cerebral artery	Curves upward then backward, arching around the genu of the corpus callosum (pericallosal course)
Middle cerebral artery	Passes laterally into the lateral (sylvian) fissure, then fans out over the insula in a candelabra-like branching pattern

On the **AP view**, the ACA appears as a midline vertical shadow — displaced sideways by a space-occupying lesion, an important sign of raised intracranial tension/midline shift — while the MCA branches lie more laterally over the hemisphere convexity.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A lateral skull outline with the carotid angiogram traced and labelled:

- ▶ Cervical part of internal carotid artery (branchless, vertical)
- ▶ Petrous part (within carotid canal)
- ▶ Cavernous part — forming the **carotid siphon** (S-shaped curve)
- ▶ Cerebral (supraclinoid) part, ending in anterior and middle cerebral arteries
- ▶ Ophthalmic artery (arising at the siphon, running into the orbit)
- ▶ Anterior cerebral artery — pericallosal course around the corpus callosum
- ▶ Middle cerebral artery — candelabra branching over the insula (sylvian point)
- ▶ Posterior communicating and anterior choroidal arteries (supraclinoid branches)
- ▶ Circle of Willis at the base, with anterior/posterior communicating arteries and both posterior cerebral arteries
- ▶ Skull vault and sella turcica outline for orientation

Applied / Clinical anatomy

□ Fig 15.12 — Lateral internal carotid angiogram: A, filling defect (narrowing); B, occlusion (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.553)

- ▶ **Atherosclerotic stenosis/occlusion** at the carotid bifurcation is the commonest modern indication for carotid angiography — seen as a **filling defect** (narrowing) or an abrupt **cut-off** (occlusion) of the contrast column. It is a major cause of stroke/transient ischaemic attack, producing contralateral weakness, and of **amaurosis fugax** (a "curtain falling" transient monocular blindness) through ophthalmic-artery hypoperfusion.
- ▶ **Carotid endarterectomy** for a stenotic plaque is performed at the bifurcation; the **hypoglossal nerve**, which crosses both carotid arteries here, and the vagus/superior laryngeal nerves, are at operative risk.
- ▶ **Carotid body tumour (chemodectoma)** arises at the bifurcation and characteristically splay the internal and external carotid arteries apart — a sign best appreciated on angiography; it is a slow-growing, painless swelling that may infiltrate adjacent vessels and nerves.
- ▶ **Carotid sinus syndrome**: hypersensitivity of the carotid sinus baroreceptor (e.g. on head rotation or a tight collar) can provoke bradycardia, hypotension and syncope.
- ▶ **Berry aneurysm rupture** (at the ACA–anterior communicating junction or the ICA bifurcation) causes subarachnoid haemorrhage; angiography (increasingly CT/MR angiography) localizes the sac before clipping or coiling.
- ▶ A **hypoplastic or absent communicating artery** reduces collateral capacity through the circle of Willis and predisposes to watershed (border-zone) infarcts when a major feeding vessel occludes.
- ▶ The same catheter access used for diagnostic DSA now doubles as a therapeutic platform — **balloon angioplasty and stenting** of a stenosed carotid segment.

High-yield exam pointers

- ▶ ICA has 4 parts — cervical (branchless), petrous, cavernous, cerebral — and terminates as ACA + MCA.
- ▶ **Carotid siphon** = the S-shaped cavernous/adjoining part of the ICA, a key lateral-angiogram landmark.
- ▶ The **middle cerebral artery** is NOT part of the circle of Willis.
- ▶ Circle of Willis = 2 ACA + 1 AComm + 2 ICA terminations + 2 PComm + 2 PCA (from basilar bifurcation).
- ▶ **Berry aneurysm**'s two classical sites: ACA–AComm junction; ICA bifurcation — cause of subarachnoid haemorrhage.
- ▶ Carotid bifurcation ≈ C4 vertebral level; carotid tubercle (compression/puncture landmark) = C6 transverse process (Chassaignac's tubercle).
- ▶ Classical technique: contrast into common/internal carotid artery → serial skiagrams give arteriogram (~2 s) → venogram (~4 s) → sinogram (~6 s).
- ▶ DSA = a pre-contrast "mask" image electronically subtracted from contrast images; the patient must stay motionless.
- ▶ Indications: intracranial tumour, haematoma, aneurysm, angioma, and arterial stenosis/occlusion; morbidity ~0.5–2.5%.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3–4 8e; Moore's Clinically Oriented Anatomy 9e; Vishram Singh Textbook of Anatomy Vol 3 4e; Vishram Singh Clinical Neuroanatomy 4e; IB Singh Textbook of Anatomy Vol 3 6e; IB Singh Textbook of Human Neuroanatomy; Snell Clinical Neuroanatomy 7e. Figures: BD Chaurasia Human Anatomy Vol 3–4 8e (Figs 12.16, 20.21); Vishram Singh Clinical Neuroanatomy 4e (Fig 15.12).



Cerebral angiography

Asked in: Paper IV May 2018 — RGUHS MD/MS Anatomy

Definition / Introduction — Cerebral angiography is a radiological technique in which a radiopaque (iodinated) contrast medium is injected into the internal carotid or vertebral arterial system and a rapid series of skiagrams is taken to visualize the arterial, capillary and venous phases of the cerebral circulation. It remains the **gold-standard method of visualizing brain vessels**, used to demonstrate vascular malformations, aneurysms, occlusive vascular disease and the vascular pattern of space-occupying lesions. Its anatomical basis rests entirely on the paired carotid and vertebro-basilar systems and their anastomotic ring, the **circle of Willis**, at the base of the brain.

1. Historical background and basic principle

- ▶ Contrast X-ray cerebral angiography was first described in 1927 by **Egas Moniz**, a physician-neurologist (Moniz was later awarded the Nobel Prize for his work, in 1949).

- ▶ In 1953, the field was revolutionized by the **Seldinger technique**, which allowed catheterization of a vessel without leaving a sharp needle inside the lumen during imaging — the basis of all modern catheter angiography.
- ▶ **Principle:** a radiopaque dye is introduced rapidly into the lumen of the common carotid/internal carotid artery or the vertebral artery (directly or via a catheter); as the dye transits the cerebral circulation, serial skiagrams taken at ~1–2-second intervals in both **antero-posterior and lateral projections** capture, in sequence, the **arterial phase (arteriogram)**, the **capillary flush**, and the **venous/dural-sinus phase (venogram/phlebogram and sinogram)**.
- ▶ Angiography as a discipline has since broadened, with the advent of image-guided minimally invasive treatment, into **interventional (vascular and interventional) radiology**.

2. Anatomical basis — arterial supply of the brain

- ▶ The brain is supplied by two paired systems that anastomose at the base of the brain: the **carotid system** (anterior circulation) and the **vertebro-basilar system** (posterior circulation).

Artery	Origin	Distribution
Internal carotid	Common carotid artery, at the superior border of the thyroid cartilage	Branches to cavernous sinus wall, pituitary gland, trigeminal ganglion; primary supply to the brain
Anterior cerebral	Internal carotid artery	Cerebral hemispheres except occipital lobes
Anterior communicating	Anterior cerebral artery	Completes circle of Willis anteriorly
Middle cerebral	Continuation of internal carotid artery beyond the anterior cerebral	Most of the lateral surface of the cerebral hemisphere
Vertebral	Subclavian artery	Cranial meninges and cerebellum
Basilar	Union of the two vertebral arteries	Brainstem, cerebellum and cerebrum
Posterior cerebral	Terminal branch of the basilar artery	Inferior surface of the hemisphere and occipital lobe
Posterior communicating	Connects internal carotid to posterior cerebral artery	Optic tract, cerebral peduncle, internal capsule, thalamus

- ▶ **Circle of Willis (circulus arteriosus):** a six-sided anastomotic polygon formed around the interpeduncular fossa (lying in the interpeduncular subarachnoid cistern) —
 - **anteriorly** by the anterior communicating artery and the two anterior cerebral arteries;
 - **posteriorly** by the basilar artery bifurcating into the two posterior cerebral arteries;
 - **laterally**, on each side, by the posterior communicating artery linking the internal carotid to the posterior cerebral artery.
- ▶ **Functional significance:** normally there is little or no mixing of blood streams — (a) of the two vertebral arteries within the basilar artery, (b) of the two anterior cerebral arteries across the

anterior communicating artery, and (c) of the internal carotid and posterior cerebral arteries across the posterior communicating artery — so each half of the brain is essentially supplied by the vertebral and internal carotid arteries of that side. If one constituent artery is occluded, however, the circle re-routes flow and provides collateral circulation, functioning like an "arterial traffic circle."

3. Technique of cerebral angiography

- ▶ **Vascular access:** classically, the common carotid artery was punctured **directly and percutaneously** at the carotid tubercle of Chassaignac (anterior tubercle of the transverse process of C6), where the vessel can be pressed against the tubercle deep to the anterior border of sternocleidomastoid. Modern practice uses an **indirect catheter technique** (Seldinger technique) via a remote peripheral artery.
- ▶ **Anatomical catheter routes** to the carotid/vertebral vessels:
 - **Transradial approach:** radial artery → brachial artery → axillary artery → subclavian artery → arch of aorta → desired vessel.
 - **Transfemoral approach:** femoral artery → external iliac artery → common iliac artery → descending aorta → arch of aorta → desired vessel.
 - Once the catheter reaches the arch of aorta it can be selectively steered into any of the three great vessels arising from it, and thence into the common/internal carotid or vertebral artery under fluoroscopic guidance.
- ▶ **Contrast and imaging:** a radiopaque medium (classically ~10–12 mL of 30% pyelocil or diodone; contemporary practice uses safer non-ionic iodinated agents) is injected rapidly, and skiagrams are exposed at close (~1-second) intervals. Injection into the carotid system yields a **carotid angiogram**; injection into the vertebral artery yields a **vertebral angiogram**.
- ▶ **Digital Subtraction Angiography (DSA):** the modern default technique. A pre-contrast "mask" image is taken and electronically subtracted from every subsequent contrast image (2–30 frames/second), so that the computer digitally removes the overlying bone and muscle shadows, leaving only the contrast-filled vessels sharply visible; the patient must remain motionless for optimal subtraction. Low (dilute) concentrations of contrast medium suffice for DSA, and **arterial DSA** — dilute contrast injected directly into the artery to display its course, branches and any disease — is considered the ideal method.

4. Normal angiographic anatomy

- ▶ **Carotid angiogram:** the catheter tip lies in the common/internal carotid artery. The internal carotid artery gives off no branches in the neck; intracranially it gives an **ophthalmic artery** and then terminates by dividing into a smaller **anterior cerebral artery** and a larger **middle cerebral artery** — this absence of cervical branches (in contrast to the external carotid artery, which shows superior thyroid, lingual, facial, occipital, maxillary and superficial temporal branches on the same run) is the key radiological point used to identify the internal carotid artery on a carotid angiogram.

□ Fig 15.12 — Lateral internal carotid angiogram. (A, filling defect=narrowing, B, occlusion=filling defect, ACA=anterior cerebral artery, MCA=middle cerebral artery, PCA=posterior cerebral artery, ECA=external carotid artery.) (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.553)

- ▶ **Vertebral angiogram:** the catheter tip lies in the vertebral artery, which is followed as it ascends, unites with its fellow to form the **basilar artery**, and terminates by bifurcating into the two **posterior cerebral arteries**; the cerebellar branches — **posterior inferior cerebellar (PICA)**, **anterior inferior cerebellar (AICA)** and **superior cerebellar (SCA)** arteries — are also outlined.

□ Fig 15.13 — Lateral vertebral angiogram. (A, filling defect=narrowing, B, occlusion=filling defect, VA=vertebral artery, AICA=anterior inferior cerebellar artery, PICA=posterior inferior cerebellar artery, SCA=superior cerebellar artery.) (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.554)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Base of the brain showing the circle of Willis, labelled:

- ▶ Anterior cerebral artery (right and left)
- ▶ Anterior communicating artery
- ▶ Internal carotid artery (right and left), terminating in ACA + MCA
- ▶ Middle cerebral artery (right and left)
- ▶ Posterior communicating artery (right and left)
- ▶ Posterior cerebral artery (right and left)
- ▶ Basilar artery (formed by union of the two vertebral arteries)
- ▶ Vertebral artery (right and left)
- ▶ Interpeduncular fossa/cistern (site around which the circle is formed)
- ▶ Optic chiasma (anterior relation, for orientation)

5. Applied / Clinical anatomy

- ▶ **Indications:** to demonstrate **aneurysms** and vascular malformations; to evaluate **occlusive vascular disease** (stenosis, thrombosis, embolism) and assess future stroke risk; to localize and characterize the vascularity of **space-occupying lesions** (tumours, haematomas, abscesses); and to plan definitive treatment such as angioplasty, stenting or surgery.
- ▶ **Congenital (berry) aneurysms:** occur mostly on the vessels of the circle of Willis, characteristically **at or near the junction of two of its constituent arteries** — the underlying defect is a congenital deficiency of the tunica media (elastic tissue) at these junctional points, producing a berry-shaped outpouching.
- ▶ **Subarachnoid haemorrhage (SAH)** commonly, though not exclusively, follows rupture of a congenital berry aneurysm in the interpeduncular cistern; because the circle of Willis lies at the base of the brain, SAH characteristically pools at the base of the brain — presenting with sudden severe headache, neck stiffness and loss of consciousness.
- ▶ Distinguish from **Charcot–Bouchard micro-aneurysms** of the lenticulostriate arteries (branches of the middle cerebral artery), whose rupture is the classic cause of hypertensive **intracerebral (not subarachnoid) haemorrhage**.
- ▶ **Complications of the procedure itself:** cerebral angiography is invasive and carries a reported morbidity of 0.5–2.5% (vessel dissection, embolic stroke, access-site haematoma, contrast reaction) — hence CT and MRI are used preferentially wherever they suffice.

- ▶ **Interventional (therapeutic) extension** of the same anatomical access: coil embolization of aneurysms and vascular malformations, balloon angioplasty with stent placement for stenotic segments, and thrombolysis for acute arterial occlusion — all performed through the identical transfemoral/transradial catheter routes used for diagnostic angiography.

6. Recent advances in cerebral vascular imaging

- ▶ **MR angiography (MRA)**: a modification of MRI that visualizes cerebral blood vessels **without injecting any contrast dye**; however, conventional (catheter) angiography is still preferred when fine vascular/branch detail is required.
- ▶ Non-invasive **CT and MR angiography**, along with CT, MRI and PET, have now largely replaced conventional catheter cerebral angiography for routine diagnosis of cerebrovascular disease, offering comparable accuracy with far lower risk and no arterial puncture.
- ▶ Because of these safer modern procedures, the older invasive neuro-investigations — **pneumoencephalography, ventriculography and (for the spine) myelography** — have become obsolete.
- ▶ **Digital Subtraction Angiography (DSA)** remains the technique of choice whenever fine anatomical or haemodynamic detail is required before an intervention (e.g., pre-treatment mapping of an aneurysm or arteriovenous malformation), because mask-subtraction isolates the contrast-filled vessel lumen from all overlying bone and soft tissue.
- ▶ The discipline has broadened from purely diagnostic angiography into **interventional (vascular and interventional) radiology**, in which the same catheter access is used therapeutically — coil embolization, balloon angioplasty/stenting and thrombolysis — converting a diagnostic anatomical pathway into a treatment pathway.

High-yield exam pointers

- ▶ Cerebral angiography = radiopaque dye into carotid/vertebral system + serial skiagrams capturing arterial, capillary and venous phases; gold-standard method of visualizing brain vessels.
- ▶ First described by Egas Moniz (1927); catheter technique revolutionized by Seldinger (1953).
- ▶ Circle of Willis formed by: 2 ACA + anterior communicating artery (anterior); basilar bifurcation into 2 PCA (posterior); posterior communicating artery each side (lateral) — around the interpeduncular fossa.
- ▶ Carotid angiogram shows ICA → ophthalmic artery → ACA (smaller) + MCA (larger); ICA has no cervical branches, unlike ECA — the key point distinguishing them.
- ▶ Vertebral angiogram shows VA → basilar artery → 2 PCA, plus PICA/AICA/SCA.
- ▶ Access routes: transfemoral (femoral → ext. iliac → common iliac → aorta) or transradial (radial → brachial → axillary → subclavian → aorta) via the Seldinger technique.
- ▶ Berry aneurysms occur at junctions of circle-of-Willis vessels (congenital tunica media defect) → classic cause of subarachnoid haemorrhage; Charcot–Bouchard micro-aneurysms of lenticulostriate arteries → intracerebral haemorrhage.
- ▶ Procedure morbidity 0.5–2.5%; CTA/MRA now first-line, with DSA reserved for pre-interventional planning.

- Modern default technique is Digital Subtraction Angiography (DSA): mask image electronically subtracted from contrast images at 2–30 frames/second.

SOURCE & COVERAGE

Vishram Singh — Clinical Neuroanatomy 4e (technique, catheter routes, berry aneurysms, figures); BD Chaurasia — Human Anatomy Vol 3–4 8e (carotid tubercle, contrast dye, DSA, MR angiography, obsolescence of pneumoencephalography/ventriculography/myelography); Snell — Clinical Neuroanatomy 7e (technique, projections, procedure morbidity); Moore's Clinically Oriented Anatomy 9e (arterial supply table, circle of Willis); IB Singh — Textbook of Human Neuroanatomy (angiography phases, DSA); Gray's Anatomy (Standring) 41e (history of angiography — Moniz, Seldinger technique; DSA principle; evolution to interventional radiology).



Color Doppler Scan

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction A **colour Doppler scan** (colour-flow Doppler imaging, CFDI) is a real-time ultrasonographic technique in which colour-coded information about the **direction and relative velocity of moving blood** is superimposed on a conventional two-dimensional grey-scale (B-mode) anatomical image. It works on the **Doppler effect/principle** — the shift in frequency of ultrasound reflected from a moving target (the red blood cells) compared with the frequency transmitted — and needs no ionising radiation and (for routine studies) no contrast agent. Because it displays flowing blood in colour over an anatomically accurate B-mode background (**duplex scanning**), colour Doppler has become central both to teaching radiological/cross-sectional anatomy of vessels and organs and to everyday vascular, obstetric, and visceral imaging.

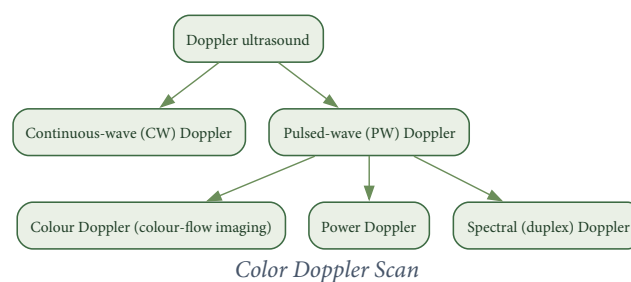
1. Physical principle — the Doppler effect

- The **Doppler effect**: an apparent change in the frequency of a wave when there is relative motion between the source/observer (here, the transducer) and a moving reflector (the **red blood cells** flowing in a vessel) — echo signals in Doppler studies arise from the moving RBCs, not from the static vessel wall.
- The **Doppler-shift equation**: $\Delta f = 2f_0 \cdot v \cdot \cos\theta / c$, where Δf = Doppler frequency shift, f_0 = transmitted frequency, v = velocity of blood flow, θ = **angle of insonation** (angle between the ultrasound beam and the long axis of the vessel/direction of flow), and c = velocity of sound in soft tissue (≈ 1540 m/s).
- **Angle dependency**: accuracy is best when θ is kept below about 60° ; at $\theta = 90^\circ$ (beam perpendicular to flow), $\cos\theta = 0$ and no Doppler shift is recorded even though flow is present — a key source of error/artefact.
- Flow **towards** the transducer raises the returning frequency (positive shift); flow **away** from it lowers the frequency (negative shift) — this directionality is exactly what colour Doppler displays as colour.

- Diagnostic ultrasound (and Doppler) beams are generated by the **piezo-electric** effect in the transducer, typically in the 3.5–20 MHz range.

2. Types of Doppler ultrasound

Mode	Emission	Key feature	Main limitation
Continuous-wave (CW) Doppler	Continuous transmit + continuous receive (two crystals)	Measures very high velocities without aliasing	No depth (range) resolution — cannot localise signal along the beam
Pulsed-wave (PW) Doppler	Short pulses; echoes timed/gated	Range-gating — a defined sample volume at a chosen depth	Limited maximum measurable velocity (Nyquist limit) → aliasing at high velocities
Colour Doppler (colour-flow imaging)	PW-based, multi-gate	Direction + mean velocity colour-coded and overlaid on B-mode image, over a selected region of interest	Angle-dependent; aliasing; cannot show very slow/low-volume flow well
Power Doppler	PW-based	Displays amplitude/power of the Doppler signal rather than frequency shift/direction; far more sensitive to slow, low-volume flow	No directional or velocity information; more motion artefact
Duplex scan	Combines B-mode (anatomy) + colour or spectral Doppler simultaneously	The routine clinical format of every colour Doppler study	—



3. Technique, colour convention and derived indices

- The chosen vessel/organ is first located in **B-mode (grey-scale)**; a **colour box** (region of interest) is then placed over it and the machine switched to colour Doppler mode.
- **Colour convention** — "**BART**": Blue Away, Red Toward — by international convention, flow **towards** the transducer is coded **red**, flow **away** is coded **blue**; brightness/hue intensity within each colour reflects relative velocity, and a mixed, speckled ("mosaic") colour pattern indicates **turbulent flow**.

► **Spectral waveform analysis** (from the same PW gate) allows calculation of:

- **Resistive index (RI)** = (peak systolic velocity – end-diastolic velocity) / peak systolic velocity
- **Pulsatility index (PI)** = (peak systolic velocity – end-diastolic velocity) / mean velocity

— both used to quantify downstream vascular resistance (obstetric, renal, testicular and transplant Doppler).

► **Power Doppler** is typically used as an adjunct when the vessel is small or flow is slow (e.g., detecting minimal residual flow, synovial/tumour neovascularity), because it is far less angle- and flow-dependent than colour Doppler.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled schematic of the colour Doppler principle over a blood vessel, with these exact labels:

- **Ultrasound transducer**, held obliquely so that the **angle of insonation (θ)** is less than 60° to the vessel
- **Incident ultrasound beam** (transmitted frequency, f_0)
- **Blood vessel (lumen)** with **red blood cells** moving with velocity (v) — the actual Doppler-reflecting target
- **Reflected/backscattered echo** (received frequency, $f_0 \pm \Delta f$)
- The **Doppler-shift equation** labelled beside the beam: $\Delta f = 2f_0 v \cos\theta / c$
- A **colour box (region of interest)** superimposed on the B-mode grey-scale background image
- **Colour key**: red = flow toward transducer, blue = flow away ("BART")

□ Fig 76.9 — A colour Doppler scan of the scrotal contents showing normal flow. The linear echogenic band seen centrally represents the mediastinum testis, which is composed of fibrofatty material. (Gray's Anatomy — Standring — 41e, p.1764)

4. Applied regional anatomy — where colour Doppler is used to study anatomy

Region / organ	What colour Doppler shows
Neck — carotid arteries	Direction/velocity of flow across the carotid bifurcation; a monophasic, clamped or absent signal and a mosaic jet indicate stenosis, guiding carotid endarterectomy
Thyroid gland	Vascularity pattern of a nodule (peripheral vs central flow) as part of nodule risk-stratification
Scrotum/testis	Confirms normal intratesticular flow (as in Fig 76.9 above); absent flow is the key sign of testicular torsion (surgical emergency); increased flow with a "bag of worms" pattern in varicocele
Abdomen — liver, portal vein, spleen	Direction of portal flow (hepatopetal vs hepatofugal in portal hypertension), patency of a TIPS shunt, and splenic hilar/splenic-artery flow (splenic imaging, e.g., Fig 70.13 of Gray's Anatomy)

Region / organ	What colour Doppler shows
Kidney/renal transplant	Main renal artery waveform (renal artery stenosis raises peak systolic velocity), resistive index of intrarenal arcuate vessels, and crossing lower-pole vessels in pelvi-ureteric junction (PUJ) obstruction
Obstetrics — uterine, umbilical and fetal middle cerebral arteries	Uterine artery Doppler (raised PI/RI with diastolic notch) screens for pre-eclampsia/placental insufficiency; umbilical artery waveform (absent/reversed end-diastolic flow signals fetal compromise); fetal MCA Doppler detects fetal anaemia
Lower limb veins	Loss of normal respiratory phasicity/compressibility and absence of colour fill in a vein confirms deep vein thrombosis (DVT) ; incompetent valves with reversed flow on Valsalva confirm varicose veins
Heart (Doppler echocardiography)	Valvular stenosis/regurgitation jets, septal-defect shunt flow, and chamber inflow/outflow velocities
Thoracic outlet	A clamped, monophasic subclavian/axillary signal supports cervical-rib/thoracic-outlet compression — now assessed by duplex ultrasonography rather than catheter arteriography

5. Recent advances in colour Doppler / vascular ultrasound imaging

- **Superb/slow-flow microvascular imaging (SMI) and vector-flow imaging:** newer multiparametric platforms add SMI/slow-flow algorithms, vector-flow imaging, elastography and contrast-enhanced ultrasound (CEUS) to conventional colour Doppler, visualising minute low-velocity microvascular flow (intraplaque neovascularity, synovitis, tumour vascularity) missed by standard colour Doppler, and quantifying arterial stiffness (Oktar et al, *Diagn Interv Radiol* 2026) [PMID: 40862366].
- **AI-automated Doppler waveform analysis:** a 2024 convolutional-neural-network workflow automatically classifies feto-placental Doppler images (umbilical artery, MCA, aortic isthmus, ventricular inflow/outflow) and extracts waveforms with only 3.5–6.1% mean error, reducing operator dependency in obstetric Doppler (Aguado et al, *Front Digit Health* 2024) [PMID: 39479252].
- **First-trimester uterine artery Doppler for pre-eclampsia prediction:** recent evidence confirms abnormal uterine artery PI/RI at 11–14 weeks retains strong predictive validity for pre-eclampsia, supporting its place in first-trimester combined screening (Karpagam et al, *Cureus* 2024) [PMID: 39087160].
- **Doppler in anatomy teaching:** a 2025 systematic review documents growing integration of Doppler-capable point-of-care ultrasound into undergraduate anatomy curricula, improving spatial understanding of vascular anatomy, though advanced Doppler modes remain reserved for senior learners (Brunel, Schäfer & Recker, *Ultrasound J* 2025) [PMID: 40773073].

(According to PubMed; DOIs: [10.4274/dir.2025.253448](https://doi.org/10.4274/dir.2025.253448), [10.3389/fdgth.2024.1455767](https://doi.org/10.3389/fdgth.2024.1455767), [10.7759/cureus.63591])

(<https://doi.org/10.7759/cureus.63591>), [10.1186/s13089-025-00443-3](<https://doi.org/10.1186/s13089-025-00443-3>).)

6. Advantages and limitations

Advantages	Limitations
No ionising radiation; safe in pregnancy and for repeated/serial studies	Angle-dependent — accuracy falls as the angle of insonation approaches 90°
Real-time; portable/bedside; combines anatomy (B-mode) and flow (colour) in one pass	Aliasing at velocities exceeding the Nyquist limit (PW/colour modes)
No contrast agent needed for routine studies	Cannot image through bone or aerated lung (poor acoustic window)
Directly shows direction of flow, not just its presence	Highly operator-dependent ; reproducibility varies with technique
Non-invasive alternative to catheter angiography for many vascular questions	Cannot detect very slow/low-volume flow as reliably as power Doppler or contrast-enhanced ultrasound

Applied / Clinical anatomy

- ▶ **Testicular torsion vs epididymo-orchitis:** absent intratesticular colour flow (torsion, surgical emergency) versus increased flow (inflammation) — a classic, high-stakes differential built entirely on Doppler.
- ▶ **Carotid disease:** colour Doppler at the carotid bifurcation screens for stenosis before **carotid endarterectomy**; the operative anatomy it protects (internal/external carotid, vagus, hypoglossal, glossopharyngeal nerves) is the same anatomy the surgeon dissects.
- ▶ **Deep vein thrombosis:** loss of vein compressibility and absent colour fill in the femoral/popliteal veins is the standard non-invasive confirmatory test, replacing venography.
- ▶ **Obstetric surveillance:** uterine artery (pre-eclampsia risk), umbilical artery (placental insufficiency), and fetal MCA (anaemia, e.g. Rh-isoimmunisation) Doppler are routine antenatal applications built on uteroplacental/fetal vascular anatomy.
- ▶ **Portal hypertension:** reversal of normal hepatopetal portal flow to hepatofugal flow, and Doppler assessment of a TIPS shunt or porto-systemic collaterals, are anatomy-based Doppler signs of cirrhotic portal hypertension.
- ▶ **Renal and PUJ anatomy:** identification of a **crossing lower-pole vessel** by colour Doppler is an important pre-operative finding in PUJ obstruction, since an aberrant vessel (rather than an intrinsic stricture) changes the surgical approach.

High-yield exam pointers

- ▶ Colour Doppler = **B-mode (grey-scale) anatomy + colour-coded blood-flow direction/velocity**, based on the **Doppler effect**; echoes arise from moving **red blood cells**, not the vessel wall.
- ▶ Doppler-shift equation: $\Delta f = 2f_0 v \cos\theta / c$ — accuracy best at $\theta < 60^\circ$; no signal at $\theta = 90^\circ$.
- ▶ Colour convention mnemonic — "**BART**": **B**lue **A**way, **R**ed **T**oward.

- ▶ **Types:** **CW Doppler** (no depth resolution, no aliasing) vs **PW/colour Doppler** (range-gated, subject to **aliasing**) vs **power Doppler** (amplitude-based, most sensitive to slow flow, no direction/velocity).
- ▶ **Resistive index (RI)** and **pulsatility index (PI)** quantify downstream resistance — used in obstetric, renal and testicular Doppler.
- ▶ No ionising radiation, real-time, combines with B-mode as "**duplex**" scanning.
- ▶ Classic exam associations: **absent testicular flow = torsion**; **absent/reversed umbilical end-diastolic flow = fetal compromise**; **hepatofugal portal flow = portal hypertension**; **carotid stenosis screening before endarterectomy**; **DVT diagnosis by loss of vein compressibility/colour fill**.
- ▶ Key limitation to state: **angle-dependent and operator-dependent**; cannot penetrate bone/aerated lung.
- ▶ Recent advance to name: **superb/slow-flow microvascular imaging and vector-flow imaging**, and **AI-automated Doppler waveform analysis** in obstetric ultrasound.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; IB Singh — Textbook of Anatomy Vol 1, 6e; Vishram Singh — General Anatomy 4e. Recent-advances citations are from PubMed (2024–2026) per the answer-bank's recency-enrichment method. Coverage note: the library's imaging sections describe the Doppler principle and give real examples (scrotal, splenic, obstetric, carotid Doppler figures) but do not tabulate CW/PW/power-Doppler distinctions or the RI/PI formulae explicitly; these are standard, universally accepted ultrasound-physics points added for completeness.



Computed tomography and its usefulness in learning anatomy

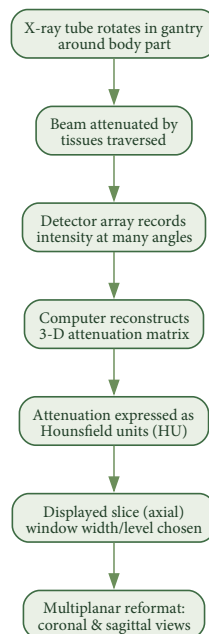
Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction Computed tomography (CT), also called computerised axial tomography (CAT) scanning, is an X-ray-based cross-sectional imaging technique in which a rotating X-ray tube and an array of detectors record the differential attenuation of tissues from many angles around the body; a computer then reconstructs this raw data into a matrix of picture elements, generating thin "slices" or tomograms (Greek *tomos* = cut) through any desired level without the superimposition of structures seen on a plain radiograph. It was invented and introduced into clinical use by the British engineer **Sir Godfrey N. Hounsfield**, working with the physicist **Allan Cormack**, in the early 1970s — an achievement for which the two shared the 1979 Nobel Prize in Physiology or Medicine. Because CT depicts the living body in true cross-section — the very orientation in which topographical anatomy is classically taught, drawn and examined — it has become one of the most important tools for teaching, revising and testing cross-sectional (radiological) anatomy in the modern postgraduate curriculum.

1. Principle and image formation

- ▶ The X-ray tube and an opposing detector array rotate together in a **gantry** around the part of the body being examined, sending a narrow beam of X-rays through it from many projection angles.
- ▶ Each detector records the intensity of the beam after it has been **attenuated** by the tissues it has traversed; these intensity data are entered into a computer as a matrix, and the **radiodensity** (**attenuation coefficient**) at every point in the **three-dimensional volume** is calculated.
- ▶ With a sufficiently narrow beam, sensitive detectors and digital signal-processing, even a small difference in radiodensity is converted into a visible image — so the computed matrix carries information about the *entire* volume scanned, allowing tomograms to be generated at any level.
- ▶ Attenuation is expressed on the **Hounsfield scale (HU)**: water is fixed at 0 HU, air is strongly negative (≈ -1000 HU), and dense cortical bone is strongly positive (up to about +1000 HU or more); **window width/level** settings then select which range of HU is displayed as grey shades, allowing the same raw dataset to be viewed as a "bone window," "lung window" or "soft-tissue window."
- ▶ A comparable convention is used across all cross-sectional modalities to describe brightness and darkness:

Imaging modality	"Bright" shade	"Dark" shade
Plain radiograph	Radiopaque	Radiolucent
Ultrasonography	Hyperechoic	Hypoechoic
CT scan	High attenuation	Low attenuation
MRI	High signal	Low signal
Nuclear medicine (isotope) scan	"Hot" area	"Cold" area



Computed tomography and its usefulness in learning anatomy

2. Technological evolution of CT

- ▶ **Conventional (sequential) CT:** the earliest form; one slice is acquired, the table steps to the next level, and the next slice is acquired — slower and with gaps possible between slices.
- ▶ **Spiral/helical CT (SCT):** the patient (table) moves continuously and longitudinally while the X-ray tube rotates continuously, so the beam traces a spiral path through the region studied; this yields a continuous volumetric dataset that a computer can manipulate to display an image viewable from any angle, with unwanted overlying tissue removed and the result colour-coded if desired.
- ▶ **Multidetector/multislice CT (MDCT) and high-resolution CT (HRCT)** are further refinements built on the spiral principle, acquiring multiple thin, near-isotropic slices per gantry rotation for faster scans and superior 3-D reconstruction.
- ▶ **Multiplanar reconstruction (MPR), 3-D volume rendering, CT angiography and virtual endoscopy** are advanced post-processing applications made possible once the raw data are stored as a volumetric matrix rather than single 2-D slices.

3. Imaging planes and viewing convention

- ▶ The basic CT image is an **axial (transverse/horizontal) slice**, at right angles to the long axis of the body; by convention it is viewed as though the observer were standing at the patient's feet and looking towards the head (so the patient's right is on the viewer's left).
- ▶ With multiplanar reformatting, the same volumetric dataset can be reconstructed as **coronal** (anterior-to-posterior slice, right-to-left extent) and **sagittal** (anterior-to-posterior extent, long-axis slice) images.
- ▶ These are exactly the three cardinal anatomical planes used to describe and draw cadaveric sections — which is precisely why CT integrates so naturally into the teaching of cross-sectional anatomy.

4. Usefulness of computed tomography in learning anatomy

This follows directly from CT's ability to depict true cross-sectional, living anatomy:

- ▶ **Direct correlation with cadaveric cross-sections.** A CT slice and a cadaveric transverse section are made in the same anatomical plane, so standard atlases pair a CT image with a matching cadaveric section at the *same vertebral level* — e.g., thoracic figures place a transverse CT scan of the chest beside a cadaveric section at the third, fourth and fifth thoracic vertebral levels, so the same structures (great vessels, oesophagus, trachea, lungs, pleura, vertebral body) are identified on both.
- ▶ **Demonstrates anatomy in the living state.** A CT scan shows viscera with normal muscle tone, physiological fluid content, gas shadows and gravitational relations that are altered or lost in a fixed, embalmed cadaver lying supine — a truer picture of "living anatomy" than dissection alone gives.
- ▶ **Reinforces three-dimensional spatial relationships.** The same volumetric dataset can be reformatted into axial, coronal and sagittal planes (and 3-D volume-rendered), letting a student mentally rotate a structure rather than memorising one fixed 2-D drawing.
- ▶ **Basis of the modern "radiological/imaging anatomy" curriculum.** With the advent of CT, ultrasonography, MRI and PET through the twentieth century, progressively more importance has been given to radiological anatomy as a formal, examined part of the anatomy course — the very reason this question is asked.
- ▶ **The Visible Human Project.** This digital cross-sectional image library, created by the (US) National Institutes of Health, is explicitly designed to be "highly useful in orienting and associating structures seen in a cadaver in an exact location in a cross-section of the body" — a landmark, cross-sectional-imaging-based tool of twenty-first-century anatomical education.
- ▶ **Teaches applied and surface anatomy together.** Comparing a structure's surface marking with its true depth and level on CT lets the candidate verify clinical surface anatomy against its actual internal position.
- ▶ **Non-invasive, repeatable study of variation.** CT can be performed on living subjects without consuming a scarce cadaveric resource, allowing normal anatomical variants and organ dimensions to be studied across large numbers of individuals.
- ▶ **Supplements dissection where cadavers are scarce.** Volume-rendered 3-D CT reconstructions and CT-derived models give a tangible, manipulable equivalent of dissection for structures difficult to dissect (skull base foramina, temporal bone, complex joints).

□ Fig 4.30 — Divisions of thoracic cavity and lining of pulmonary cavities. A. Transverse CT scan of the thorax with an interpretive line diagram, labelled 1 sternum, 2 vertebral body, 3–6 ribs, 7 right pulmonary cavity, 8 left pulmonary cavity, 9 mediastinum (Moore — *Clinically Oriented Anatomy* — 9e, p.590)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple line diagram of the CT scanner apparatus/principle, labelled with:

- ▶ **X-ray tube** — rotates in the gantry around the patient
- ▶ **Collimator** — narrows the beam before it enters the patient
- ▶ **Patient couch** — moves the patient through the gantry (continuously, in spiral CT)
- ▶ **Detector array** — opposite the tube, records the attenuated beam at each angle
- ▶ **Gantry** — the rotating frame carrying tube and detectors
- ▶ **Computer/image-reconstruction unit** — converts detector data into a Hounsfield-unit matrix
- ▶ **Monitor/display** — shows the reconstructed axial slice (with window width/level control)

Alongside it, draw a labelled axial CT slice at a chosen level (e.g., mid-thorax, as in the figure above) showing sternum, vertebral body, ribs, right and left pulmonary cavities and mediastinum — the CT-to-cadaveric-section correlation is itself the standard exam diagram for this topic.

Applied / Clinical anatomy

- ▶ **Localisation and staging of lesions.** CT's excellent cross-sectional depiction of internal structures makes it very useful for detecting deep-seated lesions, haemorrhage, infarction, fractures and tumours, and for staging malignancy before treatment.
- ▶ **CT angiography** reconstructs the vascular tree from a contrast-enhanced volumetric scan, allowing vascular anatomy and its variations to be studied and planned for surgery without conventional catheter angiography.
- ▶ **Image-guided intervention.** CT-guided biopsy, drainage and ablation procedures rely directly on precise cross-sectional anatomical knowledge of the target organ and the safe needle path past vessels and viscera.
- ▶ **Trauma protocols.** Whole-body CT is now central to the primary survey of the polytrauma patient, rapidly demonstrating solid-organ injury, free fluid/air and skeletal fracture in their correct anatomical planes.
- ▶ **Forensic and growth studies.** CT-based measurement of skeletal and epiphyseal features is increasingly used for age estimation and morphometric research without damaging specimens, extending anatomical variation-study beyond the limits of cadaver availability.
- ▶ **Lower radiation, faster scanning.** Because each slice is acquired in a few seconds, CT is safer than the older, slower tomographic methods it replaced, though its use of ionising radiation still restricts unrestricted use in children and in pregnancy compared with ultrasonography or MRI.

Recent advances relevant to anatomy teaching

- ▶ **Multidetector-row CT (MDCT):** acquires multiple thin, near-isotropic slices per rotation, giving sub-millimetre resolution and markedly superior multiplanar/3-D reconstructions for teaching, compared with older single-slice scanners.

- ▶ **Virtual/digital dissection tables:** touch-screen tables reconstruct segmented CT (and cryosection) datasets into an interactive "virtual cadaver" that students can rotate, slice and peel — supplementing teaching where cadavers are scarce.
- ▶ **CT-based 3-D printing:** CT data of complex regions (skull base, temporal bone, pelvis) can be segmented and printed into low-cost, reusable, hand-held models for repeated hands-on teaching.
- ▶ **Dual-energy/spectral and cone-beam CT:** refine tissue characterisation and reduce radiation dose while retaining the anatomical detail needed for teaching.
- ▶ **Formal curricular integration:** identification of normal structures on CT (and MRI) cross-sections is now an explicit, examined competency in the modern anatomy course.

High-yield exam pointers

- ▶ CT = CAT (computerised axial tomography) scan; invented/introduced clinically by **Godfrey Hounsfield** (with Allan Cormack), early 1970s; both shared the **1979 Nobel Prize**.
- ▶ Principle: rotating X-ray tube + detector array measure attenuation from many angles → computer reconstructs a cross-sectional slice (tomogram); *tomos* = cut/slice.
- ▶ **Hounsfield units:** water = 0 HU, air $\approx$ -1000 HU, dense bone up to $\approx$ +1000 HU; window width/level selects the displayed range.
- ▶ **Spiral/helical CT** = continuous gantry rotation + continuous table movement → volumetric data; MDCT, HRCT, MPR, 3-D rendering and CT angiography are later refinements.
- ▶ Viewing convention: axial slices viewed as if standing at the patient's feet looking towards the head; MPR also derives coronal/sagittal images from the same dataset.
- ▶ **Usefulness in learning anatomy:** true, living cross-sectional anatomy directly correlatable with cadaveric transverse sections at matched vertebral levels; underlies the Visible Human Project; a formally examined "radiological anatomy" component of the PG curriculum.
- ▶ Modern teaching aids from CT data: virtual/digital dissection tables and 3-D-printed models — supplement, not replace, cadaver dissection.
- ▶ Vs plain X-ray: safer, no superimposition, better deep-lesion detail; vs MRI: uses ionising radiation, inferior soft-tissue contrast, but faster and better for bone.

SOURCE & COVERAGE

Vishram Singh — General Anatomy 4e; IB Singh — Textbook of Anatomy Vol 1, 6e; BD Chaurasia — Human Anatomy Vol 1, 8e; Moore's Clinically Oriented Anatomy 9e. Coverage note: Gray's Anatomy (Standing) 41e is organised regionally and does not carry a dedicated section on the pedagogy of imaging/CT in anatomy teaching; the technique, principle and "usefulness in learning anatomy" content above is therefore drawn from the dedicated radiological/imaging-anatomy chapters of the Indian gross-anatomy texts and the imaging-anatomy discussion in Moore, cross-checked for internal consistency.



Coronary arteriograms

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction A **coronary arteriogram** (coronary angiogram) is a fluoroscopic/radiographic image of the coronary arterial tree obtained by selectively injecting radio-opaque contrast into the ostium of the right or left coronary artery through a catheter passed retrogradely from a peripheral artery to the aortic root. It reproduces, on a two-dimensional cine-film, the normal branching pattern, calibre and dominance of the coronary tree, and is the reference standard for localising sites of luminal narrowing. Correct interpretation therefore rests entirely on knowledge of the anatomical origin, course and branches of the two coronary arteries, since every named branch seen on the film is also given a parallel “clinical” name by cardiologists. Non-invasive ECG-gated CT (and, less commonly, MR) coronary angiography now reconstructs the same branching pattern without catheterisation.

1. Technique — how the arteriogram is obtained

- ▶ A catheter is introduced into the **femoral artery** (classical Judkins/Seldinger route) or, increasingly, the **radial artery** in the forearm, and advanced retrogradely up the aorta to the aortic root.
- ▶ Its tip is selectively engaged in turn into the ostium of the right and then the left coronary artery, and a bolus of contrast medium is injected while cine-fluoroscopy records the film.
- ▶ Because the two coronary trees overlap when viewed from directly in front, each artery is filmed in an **oblique projection** chosen to unfold its branches with minimal superimposition — the right coronary artery is conventionally shown in a **left anterior oblique (LAO)** view and the left coronary artery in a **right anterior oblique (RAO)** view.
- ▶ The two resulting films — one per artery, from the same patient — are read together to reconstruct the complete coronary pattern and its dominance.

□ Fig 21.22 — Normal coronary angiogram. (A) Of the right coronary artery, left anterior oblique view; (B) of the left coronary artery, right anterior oblique view (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.855)

2. Right coronary artery (RCA) as seen on the arteriogram

Feature	Detail
Origin	Anterior aortic sinus of the ascending aorta
Course (3 parts)	(i) forward between pulmonary trunk and right auricle → (ii) down the right anterior coronary sulcus to the acute (inferior) margin → (iii) winds onto the diaphragmatic surface, running in the right posterior coronary sulcus to the crux
Branches read on the film	Conal (infundibular) artery ; SA nodal artery (arises from the RCA in ~60% of hearts); right marginal artery running along the acute border to near the apex; posterior interventricular (descending) artery at the crux, giving the AV nodal branch
Termination	Anastomoses with the circumflex branch of the left coronary artery near the crux

3. Left coronary artery (LCA) as seen on the arteriogram

Feature	Detail
Origin	Left posterior aortic sinus of the ascending aorta
Course	Short left main stem between pulmonary trunk and left auricle, dividing into two (occasionally three) roughly equal terminal branches
Branches read on the film	Anterior interventricular artery (descends in the anterior interventricular groove, giving diagonal and septal branches); circumflex artery (curves around the obtuse border in the left atrioventricular groove, giving the left marginal artery); a ramus intermedius is a recognised normal variant arising between the two, taking the course of a first diagonal branch
Termination	Circumflex continues towards the crux; in most hearts ends by anastomosing with the RCA

4. Anatomical names vs the angiographic (clinical) names used to report the film

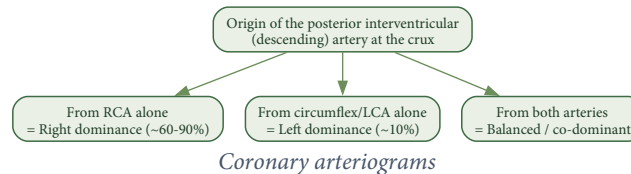
Anatomical name	Angiographic / clinical name
Anterior interventricular branch of the LCA	Left Anterior Descending (LAD)
Posterior interventricular branch of the RCA (or circumflex, if left-dominant)	Posterior Descending Artery (PDA)
Right marginal branch of the RCA	Acute marginal branch
Left marginal branch(es) of the circumflex	Obtuse Marginal branch(es) (OM)
Conal artery, when it arises as a separate ostium from the aortic sinus rather than from the RCA	Third coronary artery

This dual nomenclature must be known, since RGUHS-style clinical vignettes and angiogram reports use the right-hand column exclusively.

5. Coronary dominance as read off the arteriogram

- **Dominance is decided purely by which artery is seen to give the posterior interventricular (descending) artery at the crux** — not by which vessel supplies more myocardium (the LCA almost always supplies the larger territory regardless of dominance).
- **Right dominance** — PDA arises from the RCA; the majority pattern (~60% of hearts per Gray's Anatomy 41e; simplified Indian texts such as BD Chaurasia and Vishram Singh quote ~90%, not separating out a balanced category).
- **Left dominance** (~10% of hearts) — the RCA is too small to reach the crux; the circumflex continues as the PDA and also supplies the AV node. This is the pattern illustrated in the IB Singh coronary-angiogram figure, where the left film shows the posterior interventricular branch arising from the circumflex.

- **Balanced/co-dominant pattern** — parallel posterior interventricular branches arise from both arteries, both reaching the diaphragmatic interventricular groove.



6. Collateral pathways visible on the arteriogram

- **Annulus of Vieussens** — the anastomotic ring formed by the right and left conal arteries around the pulmonary conus.
- **SA nodal arterial ring** around the superior vena cava/right atrium.
- Fine subendocardial and arteriolar anastomoses between RCA and LCA branches.
- These channels are of no functional value in **sudden** occlusion (the coronary arteries behave as functional end arteries), but in **slowly progressive** stenosis they dilate and become angiographically visible as **collateral filling** of the diseased vessel from its neighbour — a sign, on the film, of chronic rather than acute coronary artery disease.

7. Non-invasive coronary arteriography — CT and MR (recent advances)

- **ECG-gated multidetector-row CT (MDCT)** coronary angiography now reconstructs the same branching pattern non-invasively: oblique **volume-rendered** 3-D images demonstrate the RCA arising from the right sinus of Valsalva and coursing in the right atrioventricular groove to the posterior interventricular artery, and the LCA arising from the left sinus and trifurcating into the LAD, circumflex and ramus intermedius, with their diagonal and obtuse marginal branches — essentially the same anatomy read off a conventional catheter arteriogram, but acquired without arterial puncture.
- Such CT reconstructions are also the modality of choice for demonstrating **congenital coronary anomalies** (e.g., anomalous origin of a coronary artery from the pulmonary trunk, or from the opposite/wrong aortic sinus) before they are confirmed by catheter angiography.
- This CT correlate is why the same branch-labelling conventions (conal, marginal, diagonal, PDA) apply equally to catheter arteriograms and to CT coronary angiograms.

Applied / Clinical anatomy

- **Localising stenosis:** the arteriogram is the principal tool for locating atherosclerotic narrowing. Approximate frequency of critical stenosis by vessel — anterior interventricular (LAD) artery 40–50%, right coronary artery 30–40%, circumflex branch of the LCA 15–20%.
- **“Widow-maker” artery** — proximal LAD stenosis/occlusion is so named because the LAD supplies the largest myocardial territory (most of the left ventricle); its sudden blockage carries the highest mortality.
- **Angina pectoris vs myocardial infarction:** angina reflects reversible ischaemia on a critically narrowed but patent vessel (pain on exertion, relieved by rest/nitrates); myocardial infarction follows sudden thrombotic occlusion with irreversible necrosis of the corresponding arteriographic territory.

- ▶ **Congenital coronary anomalies**, e.g. anomalous origin of the left coronary artery from the pulmonary trunk (Bland–White–Garland syndrome), are diagnosed and pre- and post-operatively assessed by coronary arteriography/CT angiography.
- ▶ **Percutaneous transluminal coronary angioplasty (PTCA)/stenting** — performed through the same catheter access used for diagnostic arteriography; a balloon dilates the stenotic segment shown on the film and a stent is deployed to maintain patency.
- ▶ **Coronary artery bypass grafting (CABG)** — for multivessel or long-segment disease seen on the arteriogram; the great saphenous vein, left internal thoracic (mammary) artery (LIMA) or radial artery is grafted from the aorta (or the proximal coronary artery) to the vessel distal to the block, and post-operative graft patency is itself confirmed by follow-up arteriography.

High-yield exam pointers

- ▶ Coronary arteriogram = selective catheter injection of contrast into the RCA/LCA ostium via the femoral or radial artery, filmed by cine-fluoroscopy.
- ▶ Standard oblique projections: **RCA — LAO view**; **LCA — RAO view** (both films are needed to read the complete coronary pattern).
- ▶ RCA arises from the **anterior aortic sinus**; branches identifiable on the film — conal, SA nodal (~60%), (acute) marginal, posterior interventricular/PDA.
- ▶ LCA arises from the **left posterior aortic sinus**; short left main divides into **LAD** and **circumflex** ($\pm$ ramus intermedius); circumflex gives the obtuse marginal branch(es).
- ▶ **Dominance** = the artery seen giving the posterior interventricular (PDA) branch at the crux — right-dominant in the majority, left-dominant in ~10%, balanced in the remainder.
- ▶ Angiographic $\neq$ anatomical names: LAD, PDA, acute marginal, obtuse marginal (OM), and "third coronary artery" (isolated conal ostium) must be recognised.
- ▶ Collateral filling on an arteriogram signals chronic, not acute, occlusion (functional end-artery physiology otherwise).
- ▶ LAD ("widow-maker") is the commonest site of critical stenosis; ECG-gated CT coronary angiography now reproduces the same branch anatomy non-invasively.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the ascending aorta cut across to show its three sinuses, and the origin/course of both coronary arteries in the atrioventricular grooves, labelling:

- ▶ Ascending aorta with **anterior (right coronary) sinus**, **left posterior (left coronary) sinus**, and the non-coronary (right posterior) sinus.
- ▶ **Right coronary artery** in the right atrioventricular groove → **conal artery**, **SA nodal artery**, **right (acute) marginal artery**, **posterior interventricular (descending) artery** at the **crux of the heart** → **AV nodal artery**.
- ▶ **Left coronary artery** (short left main) → **anterior interventricular (LAD) artery** with diagonal and septal branches, and **circumflex artery** in the left atrioventricular groove → **left (obtuse) marginal artery**.
- ▶ **Annulus of Vieussens** (ring formed by right + left conal arteries around the pulmonary conus).
- ▶ Mark the **crux** clearly, since dominance is read at this single point.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh Textbook of Anatomy Vol 2 6e; BD Chaurasia Human Anatomy Vol 1 8e; Vishram Singh Textbook of Anatomy Vol 1 4e; Moore's Clinically Oriented Anatomy 9e. Coverage note: exact fluoroscopic angulation values (degrees of LAO/RAO/cranial-caudal tilt) are catheterisation-laboratory technique rather than core anatomy and are not detailed in the corpus beyond the LAO/RCA-RAO/LCA convention captured in the Vishram Singh figure; this level of radiographic-projection detail is sufficient for the PG anatomy syllabus.



Cross section of the abdomen at the level of L1

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction The vertebral level of L1 corresponds to the **transpyloric plane** (Addison's plane) — a horizontal reference plane lying midway between the suprasternal notch and the pubic symphysis (roughly a hand's breadth below the xiphisternal joint). Posteriorly it intersects the lower half of the body of L1, the L1/L2 disc, or the upper half of L2 (higher in males, lower in females); anteriorly it strikes the costal margin at the tip of the 9th costal cartilage, where the linea semilunaris crosses. This level is the single most "crowded" horizontal section in the abdomen — the hila/roots of the stomach, kidneys, pancreas, coeliac axis, superior mesenteric artery, portal vein and cisterna chyli, and the termination of the spinal cord all converge here — which is why it is a classic cross-sectional/radiological anatomy exam question.

Surface anatomy defining the L1 (transpyloric) plane

Landmark	Detail
Anterior	Tip of the 9th costal cartilage on each side; crossed by the linea semilunaris; a palpable "step" in the costal margin
Posterior	Lower part of the body of L1 (range lower T12–lower L2)
Relative position	Midway between suprasternal notch and pubic symphysis; midway between xiphisternal joint and umbilicus, or slightly below
One level above (T12)	Coeliac trunk origin; xiphisternal joint plane; lowest level of pleura
One level below (L1–L2/L2)	Subcostal plane ($\approx$ L2–L3); pancreatic head and duodenojejunal flexure

Posterior wall & skeletal framework at L1

- **Vertebral body of L1** forms the posterior midline structure; its **vertebral canal**, at this level, contains the **tapering conus medullaris** — in adults the spinal cord terminates, on average, at the middle third of the body of L1 (range T11–L3); below this the canal contains only the **cauda equina** and filum terminale in CSF.
- **Crura of the diaphragm** flank the aorta anteriorly to the vertebral body — the **right crus** (arising from L1–L3 bodies) is larger and longer than the **left crus** (arising from L1–L2 bodies); at L1 the two crura are still separate (they fuse higher, at the lower border of T12, to form the median arcuate ligament).
- **Psoas major** bulges on each side of the vertebral body; **quadratus lumborum** lies lateral to psoas; **erector spinae** forms the posterior paravertebral mass. The tip of the **12th rib** lies close behind, related to the renal angle.

Major vascular & lymphatic structures at L1

Structure	Position / relation at L1
Abdominal aorta	Lies just to the left of the midline, anterior to the vertebral body, between the crura
Origin of the superior mesenteric artery	Arises from the aorta most commonly at L1, close to the transpyloric plane
Origin of the renal arteries	Arise from the aorta most commonly between the lower border of L1 and upper L2
Inferior vena cava	Lies to the right of the aorta, anterior and slightly lateral to the vertebral body
Left renal vein	Crosses anterior to the aorta, posterior to the SMA, to join the IVC (the "nutcracker" angle)
Origin of the portal vein	Behind the neck of the pancreas, formed by the confluence of the splenic vein and the superior mesenteric vein
Cisterna chyli	Lies in front of the L1–L2 vertebral bodies, behind the right crus, to the right of the aorta — origin of the thoracic duct

Visceral structures seen in the section

Region	Structure(s)
Right side	Liver (a much smaller area than at the T12 section, since the inferior border is being approached); gallbladder fundus if the cut is slightly high; right kidney and its hilum
Left/midline	Pylorus of stomach (an inconstant finding — present in only some sections); neck and uncinate process of pancreas anterior to the SMV/portal confluence; spleen (superior part/hilum, if the cut is slightly high)
Midline, retroperitoneal	Origin of the SMA and SMV; duodenojejunal flexure (commonly at L1, range lower T11–upper L3)
Both sides	Hila of both kidneys with their renal vessels — the most constant and prominent feature of this section
Anterior cavity	Coils of jejunum and part of the transverse colon occupy the greater part of the peritoneal cavity, since most of the liver has already been "left behind" at the level above
Peritoneal detail	The neck of pancreas lies in the floor of the lesser sac; the epiploic foramen (of Winslow) lies just above this level, at the right free margin of the lesser omentum

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 5.104 — Transverse magnetic resonance images (MRIs) of abdomen. A. Level of T10 vertebra and esophageal hiatus. B. Level of L1–L2 vertebra and renal vessels and hilum. C. Level of L5 vertebra and bifurcation of aorta. (Moore — Clinically Oriented Anatomy — 9e, p.926)

(Panel B of the figure above is the exact level asked — reproduce it for the answer.)

For the free-hand exam diagram, draw an oval outline (anterior convexity, flat-to-concave back over the vertebral body) and label, from anterior to posterior/medial to lateral:

- ▶ Anterior abdominal wall (linea alba, recti, oblique muscles)
- ▶ Ao — abdominal aorta (left of midline)
- ▶ IVC — inferior vena cava (right of midline)
- ▶ RLL — right lobe of liver (right upper quadrant)
- ▶ GB — gallbladder (if section is slightly high)
- ▶ D — duodenum (around the pancreatic head, right side)
- ▶ P — pancreas (neck, crossing the midline anterior to the great vessels)
- ▶ PC — portal confluence (SMV + splenic vein, behind the pancreatic neck)
- ▶ RK / LK — right and left kidney, with **hilum**, **renal vessels** medially
- ▶ LRV / LRA — left renal vein (anterior to aorta) and left renal artery
- ▶ PF — perirenal fat around each kidney
- ▶ I — coils of jejunum/ileum; TC — transverse colon
- ▶ PS — psoas major; DBM — deep back (erector spinae) muscles
- ▶ VB / VC — vertebral body of L1 and vertebral canal (conus medullaris/cauda equina)

Applied / Clinical anatomy

- ▶ **Systematic CT/MRI reading at this level:** identify the vertebral body (L1) → aorta anteriorly to its left, IVC to its right → look for the SMA taking off anteriorly from the aorta and the left renal vein crossing anterior to the aorta just below it → trace the pancreatic neck crossing the midline anterior to the portal confluence → locate both renal hila medially on the kidneys → note psoas major flanking the vertebral body.
- ▶ **Renal vein (nutcracker) entrapment syndrome:** because the left renal vein crosses the acute angle between the SMA (anteriorly) and the aorta (posteriorly) at this level, downward traction or a narrow aortomesenteric angle can compress it (and occasionally the third part of the duodenum), producing left flank pain and haematuria.
- ▶ **Pancreatic neck as the surgical line of transection** in pancreaticoduodenectomy (Whipple's procedure) — it is deliberately divided anterior to the portal vein/SMV confluence that lies directly behind it at this level.
- ▶ **Coeliac axis compression (median arcuate ligament syndrome)** occurs just above this level, where the crura fuse; understanding that the crura are still separate at L1 clarifies why the compression is a T12-level, not an L1-level, phenomenon.
- ▶ **Renal angle** (between the 12th rib and lateral border of erector spinae) overlies the kidney near this level and is the site of tenderness elicited in acute pyelonephritis/renal colic.

- ▶ **Nodal spread of testicular/ovarian malignancy:** because the gonadal vessels arise from the aorta close to the renal vessels (embryological descent of the gonads), lymphatic spread from testicular or ovarian tumours targets the para-aortic (lumbar) nodes at this renal-hilar level rather than the inguinal nodes.
- ▶ **Conus medullaris termination:** since the spinal cord ends, on average, at L1, lumbar puncture is deliberately performed lower — at the L3/L4 or L4/L5 interspace — to avoid cord injury.
- ▶ Ultrasound/CT of the abdomen routinely use this level to identify the **renal hila, SMA origin and pancreatic neck** as landmarks for staging pancreatic and renal tumours and for guided biopsy.

High-yield exam pointers

- ▶ L1 = transpyloric (Addison's) plane; anterior landmark = 9th costal cartilage tip; posterior landmark = lower body of L1.
- ▶ The **hila of both kidneys with renal vessels** are the most constant feature of the L1 cross-section.
- ▶ **SMA and renal arteries both arise from the aorta at/near L1** (lower border of L1 for renal arteries).
- ▶ **Portal vein origin** (SMV + splenic vein confluence) lies behind the **neck of the pancreas** at this level.
- ▶ **Pylorus** is an inconstant finding at this exact section — present in some individuals, absent in others.
- ▶ **Duodenojejunal flexure** commonly lies at L1.
- ▶ **Cisterna chyli** lies anterior to L1–L2, behind the right crus, right of the aorta.
- ▶ **Spinal cord terminates (conus medullaris)**, on average, at the middle third of L1.
- ▶ Liver occupies a **smaller** area of the section than at the T12 level; coils of jejunum/transverse colon fill most of the remaining cavity.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 2 8e; IB Singh Textbook of Anatomy Vol 2 6e; Moore's Clinically Oriented Anatomy 9e.



Cross section of the midbrain at the level of superior colliculus

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction — The midbrain (mesencephalon), the shortest segment of the brainstem (about 2.5 cm long and 2.5 cm wide), is studied internally by transverse sections at two standard levels because its grey/white-matter pattern changes along its length — a **lower level through the inferior colliculi** and an **upper level through the superior colliculi**. A coronal plane through the **cerebral aqueduct** (connecting the 3rd and 4th ventricles) divides each section into a small dorsal **tectum** and a large ventral **cerebral peduncle**; the peduncle is further split by the **substantia nigra** into a dorsal **tegmentum** and a ventral **crus cerebri**. The section at the superior-collicular level is a classic RGUHS spotter/essay because it is the only level at which the **oculomotor nuclear complex**, **Edinger–Westphal nucleus** and **red nucleus** are cut, forming the anatomical basis of Weber's, Benedikt's and Parinaud's syndromes.

1. Plane of section and gross zonal division

- ▶ The section is taken through the **upper (rostral) part of the midbrain**, at the level of the two superior colliculi on the dorsal surface and the emerging **oculomotor nerve** roots in the interpeduncular fossa ventrally.
- ▶ A coronal plane through the **cerebral aqueduct** (surrounded by **central/periaqueductal grey matter**) separates the section into the **tectum** (posterior, containing the paired superior colliculi) and the **cerebral peduncle** (anterior, much the larger part).
- ▶ Each cerebral peduncle is subdivided, dorsal to ventral, into the **tegmentum**, the **substantia nigra**, and the **crus cerebri (basis pedunculi)**; the substantia nigra and crus cerebri are essentially constant at every midbrain level, whereas the tegmentum and tectum contents vary with the level.
- ▶ **Crus cerebri** — a semilunar band of purely descending fibres, arranged medial to lateral: **frontopontine fibres** (medial one-sixth), **corticospinal and corticonuclear fibres** (middle two-thirds), and **temporo-, parieto- and occipitopontine fibres** (lateral one-sixth).
- ▶ **Substantia nigra** — a curved, pigmented band of grey matter (thicker medially) between tegmentum and crus cerebri, with a dorsal **pars compacta** (melanin/dopamine-containing cells) and a ventral **pars reticularis** (fewer cells, intermingled with crus fibres); nigrostriatal fibres carry dopamine to the corpus striatum, and its degeneration underlies Parkinsonism.

2. Grey matter at the level of the superior colliculi

Structure	Position / features
Central (periaqueductal) grey matter	Surrounds the cerebral aqueduct; houses the oculomotor and mesencephalic-trigeminal nuclei
Oculomotor (III) nucleus	Ventromedial part of the central grey; the two sides fuse into a single triangular complex bounded laterally by the medial longitudinal fasciculus (MLF)

Structure	Position / features
Edinger–Westphal (accessory oculomotor) nucleus	Dorsal to the rostral two-thirds of the main oculomotor nucleus; parasympathetic supply to sphincter pupillae and ciliaris (relayed in the ciliary ganglion)
Mesencephalic nucleus of the trigeminal nerve	Lateral part of the central grey, same position as at the inferior-collicular level; carries proprioception from muscles of mastication and ocular/ facial muscles
Superior colliculus	Tectum; a flattened mass of seven concentric alternating grey/white laminae (zonal, superficial grey, optic, intermediate grey, deep grey, deep white and periventricular strata)
Pretectal nucleus	Small group of neurones deep to the superolateral part of the superior colliculus; receives the lateral root of the optic tract and projects bilaterally to the Edinger–Westphal nuclei — the relay for the pupillary light reflex
Red nucleus	Ovoid, cigar-shaped mass, about 0.5 cm in diameter, dorsomedial to the substantia nigra; pink/red in fresh specimens from its rich vascularity and iron-containing pigment — appears for the first time at this level
Substantia nigra	Present at all midbrain levels (see above)

- **Superior colliculus connections** — afferents from the retinae (mainly contralateral, via the lateral geniculate body and superior brachium), the spinal cord (pain/tactile fibres via the spinotectal tract), the frontal and occipital visual cortex (conjugate eye movements), and the inferior colliculus; efferents form the **tectospinal and tectobulbar tracts**, mediating reflex movements of the eyes, head and neck to visual stimuli.
- **Red nucleus connections** — afferents: cerebellorubral fibres from the contralateral dentate nucleus (via the superior cerebellar peduncle), corticorubral fibres from the ipsilateral motor cortex (areas 4, 6), pallidorubral fibres, plus fibres from the subthalamic nucleus, hypothalamus, substantia nigra and tectum; efferents: rubrospinal, rubrobulbar (to motor nuclei of V, VII, and also III, IV, VI) and rubroreticular tracts, plus rubro-olivary, rubrothalamic, rubrocerebellar and rubronigral fibres.
- The emerging **oculomotor nerve** fibres pass ventrally through the tegmentum, intersecting the red nucleus and the medial part of the substantia nigra, and leave through the sulcus on the medial side of the crus cerebri into the interpeduncular fossa.

3. White matter (fibre tracts) at this level

- **Dorsal tegmental decussation (of Meynert)** — crossing of tectospinal/tectobulbar fibres arising from the superior colliculi.
- **Ventral tegmental decussation (of Forel)** — crossing of rubrospinal fibres arising from the red nuclei.

- ▶ **Medial longitudinal fasciculus (MLF)** — lies ventrolateral to the oculomotor nuclear complex, linking it with vestibular and other ocular-motor mechanisms.
- ▶ **Lemnisci** — the medial, trigeminal and spinal lemnisci continue as a curved band lateral to the red nucleus (more lateral than at the inferior-collicular level, because of the intervening red nucleus); the **lateral lemniscus is no longer present**, having already terminated in the nucleus of the inferior colliculus below.
- ▶ **Reticular formation** — present, as at every level of the brainstem.
- ▶ **Cerebral aqueduct**, surrounded by the periaqueductal grey, separates tectum from tegmentum.
- ▶ Distinguishing this level from the inferior-collicular section: the **red nucleus and the oculomotor/Edinger–Westphal complex appear only here**; the **ventral tegmental decussation (rubrospinal)** replaces the decussation of the superior cerebellar peduncles seen lower down; and the **lateral lemniscus is absent**.

4. Blood supply

- ▶ **Arterial** — basilar artery; posterior cerebral arteries; superior cerebellar arteries; posterior choroidal arteries; branches of the anterior choroidal arteries.
- ▶ **Venous** — drains into the great cerebral vein (of Galen) and the basal veins.

□ Fig 5.15 — TS of midbrain at the level of superior colliculus (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.524)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse section through the upper (rostral) part of the midbrain and label, dorsal to ventral:

- ▶ **Tectum:** paired **superior colliculi** (shown with alternating laminae), **superior brachium** and **lateral geniculate body** at the margin, **pretectal nucleus** deep to the superolateral part of each colliculus
- ▶ **Cerebral aqueduct**, surrounded by **central (periaqueductal) grey matter**
- ▶ **Tegmentum:** **oculomotor nucleus** (fused, triangular, ventromedial) with the **Edinger–Westphal nucleus** dorsal to it; **mesencephalic nucleus of V** in the lateral central grey; **medial longitudinal fasciculus** ventrolateral to the oculomotor complex; **dorsal tegmental decussation (Meynert)**; paired **red nuclei** (central); **ventral tegmental decussation (Forel)** within/around them; combined **medial, trigeminal and spinal lemnisci** lateral to the red nucleus; emerging **oculomotor nerve (III)** fibres coursing through the red nucleus and substantia nigra
- ▶ **Substantia nigra**, ventral to each red nucleus
- ▶ **Crus cerebri** (basis pedunculi) on each side — labelled medial to lateral: frontopontine, corticospinal/corticonuclear, temporo-parieto-occipitopontine fibres
- ▶ **Interpeduncular fossa** between the two crura, with the emerging oculomotor nerve

Applied / Clinical anatomy

Syndrome	Structures damaged	Clinical picture
Weber's syndrome	Oculomotor nerve fibres + crus cerebri (PCA branch occlusion)	Ipsilateral lateral squint, ptosis, dilated pupil fixed to light and accommodation (III palsy); contralateral hemiplegia (corticospinal) and contralateral lower-face/tongue weakness (corticobulbar)
Benedikt's syndrome	Oculomotor fibres + red nucleus + medial/spinal lemnisci + superior cerebellar peduncle (tegmental ischaemia)	Same ipsilateral III palsy, plus contralateral loss of pain/temperature and of tactile/joint/vibration sense, and contralateral tremor/involuntary movements
Parinaud's syndrome	Superior colliculi / posterior commissure (classically pineal-region tumour compression)	Selective paralysis of upward gaze; other eye movements normal
Argyll Robertson pupil	Pretectal nucleus (or its connections)	Light reflex lost, accommodation reflex preserved

- ▶ **Obstructive hydrocephalus** — a tumour or inflammatory narrowing at this level compresses the cerebral aqueduct, producing dilatation of the third and lateral ventricles.

- ▶ **Radiological/cross-sectional correlate** — on axial CT/MRI at this level the paired red nuclei and substantia nigra flank the aqueduct, with the crura cerebri diverging anteriorly around the interpeduncular fossa; this is the standard slice used to assess aqueductal patency, to localise pineal-region masses compressing the superior colliculi/posterior commissure (Parinaud's syndrome), and, on susceptibility-weighted/iron-sensitive MRI sequences, to evaluate the substantia nigra for the nigral iron and dopaminergic changes of Parkinsonism.
- ▶ **Parkinsonism** — degeneration of the dopaminergic pars compacta of the substantia nigra (present at this level, as at all midbrain levels) depletes striatal dopamine.
- ▶ **Localizing principle** — a brainstem lesion classically produces an *ipsilateral* cranial-nerve deficit with a *contralateral* hemiplegia/hemianaesthesia; at this level the oculomotor nerve is the localizing cranial nerve.

Recent advances

- ▶ High-density electrophysiology in awake mice (>5000 neurones) shows the superior colliculus performs **audiovisual temporal (multisensory) integration** through non-linear summation of auditory and visual inputs, with posterior-medial populations (representing peripheral space) showing the sharpest temporal discrimination — refining the classical "sensory-map overlay" model of collicular function (Bianchini et al., *Nature Communications*, 2025;16:9615) [PMID: 41168155].
- ▶ Recordings in primates during free viewing of dynamic scenes show the **saliency response in the superior colliculus at the future saccade goal predicts fixation duration**, indicating the colliculus actively computes where and for how long gaze will next rest, rather than merely relaying a static visual-saliency map (Heeman et al., *Journal of Neuroscience*, 2025;45(3):e0428242024) [PMID: 39572235].
- ▶ (*According to PubMed.*)

High-yield exam pointers

- ▶ This is the **upper of the two standard TS levels** of the midbrain (the other being the inferior-collicular level); aqueduct divides tectum (dorsal) from cerebral peduncle (ventral), the peduncle further split by substantia nigra into tegmentum and crus cerebri.
- ▶ Structures appearing **only at this level**: **oculomotor nucleus + Edinger–Westphal nucleus, red nucleus, pretectal nucleus, ventral tegmental decussation (Forel)**; the **lateral lemniscus is absent** (already ended in the inferior colliculus).
- ▶ **Superior colliculus** = 7 alternating laminae; visual reflex centre; afferents from retina, spinotectal tract, visual cortex, inferior colliculus; efferents = tectospinal/tectobulbar tracts crossing as the **dorsal tegmental decussation (Meynert)**.
- ▶ **Red nucleus** ~0.5 cm, dorsomedial to substantia nigra; rubrospinal tract crosses as the ventral tegmental decussation (of Forel).
- ▶ Crus cerebri lamination (medial → lateral): **frontopontine (1/6) — corticospinal/corticonuclear (2/3) — temporo/parieto/occipitopontine (1/6)**; substantia nigra (pars compacta/pars reticularis) constant at every level.

- ▶ **Weber** = III nerve + crus cerebri; **Benedikt** = Weber + medial lemniscus + red nucleus; **Parinaud** = superior colliculi/posterior commissure (upward-gaze palsy, pineal tumour); pretectal lesion → **Argyll Robertson pupil**.
- ▶ Blood supply: basilar, posterior cerebral, superior cerebellar, posterior choroidal and anterior choroidal arteries; venous drainage to the great cerebral and basal veins.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Clinical Neuroanatomy 4e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e (figure).



Cross section of thorax at T4 level

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction The fourth thoracic (T4) vertebra marks one of the two "landmark" transverse levels of cross-sectional thoracic anatomy (the other being T5). A transverse (axial) section through the **upper part of the body of T4** passes entirely through the **superior mediastinum**, and its single most important structure is the **arch of aorta**, cut obliquely because the arch is vertically/obliquely disposed while the section is horizontal. The **lower border of T4 / the T4–T5 intervertebral disc** corresponds anteriorly to the **sternal angle (manubriosternal joint)** and constitutes the **transverse thoracic plane** — the surgical/radiological boundary between the superior and inferior mediastinum, and the level at which the trachea bifurcates (in the cadaver/supine position). Both sub-levels must be described together because RGUHS cross-sectional questions are conventionally taught as a T4–T5 pair.

Vertebral level, surface marking & the transverse thoracic plane

- ▶ **Transverse thoracic plane** = horizontal plane through the manubriosternal joint (sternal angle) anteriorly and the **T4–T5 intervertebral disc** (or lower border of the body of T4) posteriorly; it separates the superior from the inferior mediastinum.
- ▶ **Superior mediastinum**: bounded above by the superior thoracic aperture, below by this oblique plane running from the sternal angle to the lower part of the body of T4; limited laterally by the mediastinal pleura.
- ▶ **Surface correlate**: the sternal angle is palpated by running a finger down the manubrium from the suprasternal notch to the first bony ridge — clinically used to count ribs (2nd costal cartilage articulates here) and to locate deep structures.
- ▶ **Structures classically intersected by the transverse thoracic plane** (Moore's landmark table): sternal angle, **aortic arch** (its beginning/end), **bifurcation of the trachea**, **arch of the azygos vein** (draining into the SVC).
- ▶ One vertebral level higher (T3, mid-manubrium level) is where the **superior vena cava is formed** by union of the two brachiocephalic veins, and where the three great-vessel branches (brachiocephalic trunk, left common carotid, left subclavian) arise from the **summit of the arch**.

Structures in the transverse section at the upper part of T4

□ Fig 11.1 — Transverse section of thorax at the level of the upper part of T4 vert (IB Singh — Textbook of Anatomy Vol 2 — 6e, p.142)

(Real cadaveric cross-section, inferior view — labelled: manubrium, superior vena cava, arch of aorta with the openings of its branches, oesophagus, left lung, pleural cavity, parietal pleura.)

Region-wise breakdown of this section (inferior view, as conventionally drawn/photographed):

Region	Structure(s) seen
Anterior (centre)	Manubrium sterni; remnants of thymus
Central	Arch of aorta , cut as a half-cut oblique tube (because a vertical/oblique structure is cut transversely); the origins/openings of the brachiocephalic trunk, left common carotid and left subclavian arteries are seen within its lumen
Right of the arch	Superior vena cava , lying on the right side of the anterior end of the arch
Behind the arch, in front of the vertebral body	Trachea (still undivided at this level), with the oesophagus immediately behind it and in front of the T4 vertebral body
Posterolateral, left side	Thoracic duct , lying posterior and to the left of the oesophagus
On either side	Right and left lungs , each invested by visceral and parietal pleura , occupying the bulk of the section
Posterior	Body of T4 vertebra

- Because the arch of aorta is the dominant structure, this level is sometimes simply remembered as "**the arch-of-aorta section**."
- The trachea is still a single tube here — its bifurcation is seen only in the next lower (T4–T5/"T5 upper part") section.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw an inferior-view transverse (axial) outline of the thorax at the upper part of T4 and label:

- ▶ Body of T4 vertebra (posterior midline)
- ▶ Manubrium sterni (anterior midline)
- ▶ Arch of aorta (centre, cut obliquely) with openings of brachiocephalic trunk, left common carotid and left subclavian arteries within it
- ▶ Superior vena cava (right of the anterior end of the arch)
- ▶ Trachea (anterior to oesophagus, single lumen)
- ▶ Oesophagus (anterior to vertebral body)
- ▶ Thoracic duct (posterior and to the left of the oesophagus)
- ▶ Right lung + visceral/parietal pleura
- ▶ Left lung + visceral/parietal pleura
- ▶ Remnants of thymus (anterior, between the great vessels and manubrium)

Relations of the arch of aorta at this level

The arch of aorta begins and ends at the level of T4 vertebra / sternal angle (continuing the ascending aorta anteriorly and becoming the descending thoracic aorta posteriorly, adjacent to the T4 vertebra). Its relations, conventionally taught as "five structures on each aspect":

Aspect	Structures
Posterior and to the right	Trachea; oesophagus; left recurrent laryngeal nerve; thoracic duct; vertebral column
Anterior and to the left	Left lung and pleura; left phrenic nerve; left vagus nerve; left cardiac nerves; left superior intercostal vein
Superior (concavity gives off)	Brachiocephalic trunk; left common carotid artery; left subclavian artery; left brachiocephalic vein; thymus
Inferior (concavity related to)	Left principal bronchus; bifurcation of the pulmonary trunk; ligamentum arteriosum; left recurrent laryngeal nerve; superficial cardiac plexus

Level-to-level correlation: T3 → T4 (upper part) → T4–T5 disc

Presenting T4 in continuity with the level immediately above and below is standard exam practice, since the mediastinal picture changes sharply over this short span:

Level	Key feature
T3 (mid-manubrium)	Summit of the arch of aorta; origin of brachiocephalic trunk, left common carotid and left subclavian arteries; formation of the SVC (union of the two brachiocephalic veins)

Level	Key feature
T4, upper part	Body of the arch of aorta cut obliquely with its three branch-openings; SVC to its right; trachea (undivided) anterior to oesophagus; thoracic duct posterolateral to oesophagus on the left
T4–T5 disc (= sternal angle / transverse thoracic plane)	Ascending aorta anterior to the pulmonary trunk; descending aorta posterior to the pulmonary trunk; bifurcation of the trachea into right and left principal bronchi, lying behind the bifurcating pulmonary trunk and in front of the oesophagus; terminal parts of SVC and azygos vein; mediastinal lymph nodes between the bronchi; junction of superior and inferior mediastinum

CT correlation & recent advances in cross-sectional imaging

- ▶ On axial CT/MRI of the thorax, the T4 cut corresponds to the "**three-vessel/arch level**" familiar to radiology and cardiothoracic surgery trainees — used as a fixed reference slice while scrolling through mediastinal windows to identify the aortic arch, its branches, and the SVC before descending to the "bifurcation/carina level" one slice below.
- ▶ **Multidetector CT (MDCT) angiography** with thin (≤ 1 mm) collimation and multiplanar/3D volume-rendered reconstruction now allows the arch and its branch origins to be displayed exactly as in the cadaveric cross-section, and is the modality of choice for planning **TEVAR (thoracic endovascular aortic repair)** and evaluating arch anomalies, aneurysms and dissections.
- ▶ **ECG-gated cardiac CT** reduces pulsation artefact at this level (the arch is a highly mobile structure), improving delineation of the aorto-pulmonary window.
- ▶ Cross-sectional teaching increasingly correlates the classical cadaveric plate with the **CT "lung window"** vs "**mediastinal window**" pair — the lung window shows the air-filled bronchial tree and vessels as branching shadows, while the mediastinal window shows the soft-tissue detail of the arch, SVC, oesophagus and nodes described above.
- ▶ Virtual/CT bronchoscopy and 3D airway reconstruction are now used to teach the T4–T5 tracheal bifurcation (carina) level immediately inferior to this section.

Applied / Clinical anatomy

- ▶ **Sternal angle (T4–T5 level) as a clinical reference:** used to count ribs/intercostal spaces, to locate the second costal cartilage, and to mark the boundary between superior and inferior mediastinum during mediastinoscopy/mediastinotomy.
- ▶ **Aortic arch aneurysm or dissection** at this level may compress the trachea (stridor/dyspnoea), oesophagus (dysphagia) or the left recurrent laryngeal nerve as it hooks under the arch — producing hoarseness (the cardiovocal or "Ortner's" phenomenon).
- ▶ **Central venous catheter tip placement:** the SVC begins at this level (T3, formed by the union of the two brachiocephalic veins) and descends several vertebral levels further to end at the cavoatrial junction — a central line whose tip lies "too high" (malpositioned) corresponds anatomically to this upper, T3–T4 part of the SVC rather than its intended lower end.

- ▶ **Thoracic duct** at this level (posterolateral to the oesophagus, on the left) is at risk during oesophagectomy/mediastinal lymph-node dissection — injury causes chylothorax.
- ▶ **Bronchoscopy/mediastinoscopy landmark:** the carina, one level below (T4–T5 disc), is the key endoscopic landmark for staging lung malignancy and for correct double-lumen endotracheal tube placement.
- ▶ **Barium swallow:** an enlarged left atrium or a vascular ring/aberrant subclavian artery at this level indents the oesophageal shadow, exploited radiologically.

High-yield exam pointers

- ▶ T4 level (upper part) = **arch-of-aorta section**, entirely within the superior mediastinum.
- ▶ Arch of aorta begins and ends at the level of T4 vertebra/sternal angle; its **summit is at the T3–T4 disc** (mid-manubrium level).
- ▶ Arch cut obliquely in cross section ("half-cut oblique tube") because it is a vertically/obliquely running structure.
- ▶ Order of structures anteroposteriorly at T4: SVC (right of arch) → arch of aorta (with 3 branch-openings) → trachea → oesophagus → thoracic duct (posterolateral, left) → vertebral body.
- ▶ Trachea is **undivided** at T4 (upper part); it bifurcates at the **T4–T5 disc / sternal angle plane** (transverse thoracic plane).
- ▶ Transverse thoracic plane intersects: sternal angle, aortic arch, tracheal bifurcation, arch of azygos vein — the classic boundary between superior and inferior mediastinum.
- ▶ Arch of aorta relations = "5 structures on each of 4 aspects" (anterior-left, posterior-right, superior, inferior) — high-yield mnemonic table.
- ▶ Clinically: CVP line tip, thoracic duct injury, recurrent laryngeal nerve palsy from arch pathology, and mediastinoscopy all reference this level.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Anatomy, Vol. 2, 6e (Chapter: Cross-Sectional, Radiological and Surface Anatomy of Thorax; and Blood Vessels of Thorax); BD Chaurasia — Human Anatomy, Vol. 1, 8e; Vishram Singh — Textbook of Anatomy, Vol. 1, 4e; Moore's Clinically Oriented Anatomy 9e.



Cross sectional anatomy at the level of C2 vertebra (labeled diagram only)

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

A transverse (axial) section taken through the body of the second cervical vertebra — the **axis (C2)** — cuts the neck at the level of the naso-oropharyngeal junction, just above the hyoid bone. Because the axis is the pivot on which the atlas and skull rotate, this level is anatomically distinctive: it shows the strongest and most specialised cervical vertebra, the point of sharpest angulation of the vertebral artery

in its cervical course, the superior cervical sympathetic ganglion, and a carotid sheath in which the common carotid artery has already bifurcated. No thyroid gland, trachea or oesophagus is seen here — unlike the more familiar C7 or thyroid-cartilage sections. The level is routinely correlated with axial CT/MRI of the craniovertebral junction and is tested purely as a labelled-diagram spotter.

Vertebral-level correlation and surface anatomy

Anterior midline structure	Vertebral level
Angle of mandible / tip of transverse process of atlas (midway between mastoid process and angle of mandible)	C1 (atlas)
Naso-oropharyngeal junction (soft palate/uvula) — the level of this section	C2 (axis)
Hyoid bone	C3
Upper border/notch of thyroid cartilage	C3/C4
Body of thyroid cartilage	C4–C5
Cricoid cartilage	C6

- ▶ The tip of the transverse process of the atlas is a standard surface-marking landmark, midway between the mastoid process and the angle of the mandible; the axis lies just below this line, so a C2-level section falls a little below the angle of the mandible and a little above the hyoid (C3).
- ▶ Because it lies above the hyoid, this section shows **no infrahyoid strap muscles, thyroid gland, larynx, trachea or oesophagus** — the visceral compartment here is purely the **pharynx** (oropharynx merging into nasopharynx), not the airway/foregut tube seen lower down.

Osteology — the axis (C2) vertebra in section

- ▶ The **axis** is the strongest of the cervical vertebrae. Its **body** is thick and, unlike other cervical vertebrae, projects a vertical bony peg — the **dens (odontoid process)** — from its upper surface; a section taken through the upper part of the body therefore cuts the dens in cross-section, while a section lower down through the vertebral arch shows only the body, pedicles and laminae.
- ▶ **Dens (odontoid process)**: held against the posterior surface of the anterior arch of the atlas by the **transverse ligament of the atlas** (the horizontal band of the cruciate ligament), which embraces the neck of the dens and prevents its posterior displacement into the vertebral canal; its apex is anchored to the anterior margin of the foramen magnum by the **apical ligament**, and its sides by the **alar ("check") ligaments** to the occipital condyles.
- ▶ **Pedicles and laminae** continue back from the body to a single, thick, bifid **spinous process** in the midline (the largest of the cervical spines — the palpable prominence just below that of the atlas).
- ▶ **Transverse processes**, each pierced by a **foramen transversarium** for the vertebral artery and its venous plexus; the foramen transversarium of the axis lies more medially placed than in the other cervical vertebrae, which is why the vertebral artery must angle sharply laterally as it leaves it (see below).
- ▶ **Superior articular facets**: two large, flat, nearly horizontal surfaces on the body, on which the atlas (and the skull) rotates — the essential feature of the atlantoaxial pivot joint.

- **Inferior articular facets:** oriented like those of typical cervical vertebrae, forming the zygapophyseal joint with C3.

Vertebral (spinal) canal — spinal cord segment C2 and meninges

- From without inwards, the canal contains: **epidural fat and the internal vertebral venous plexus**, the **dura mater**, the **arachnoid mater** with CSF in the subarachnoid space, and the **spinal cord** (the C2 segment) suspended within it by the **denticulate ligaments** running out to the dura on each side.
- The cord at this level, above the cervical enlargement (C5–T1), is oval and shows the standard **cervical cross-section**: **large grey matter**; a **slender posterior (dorsal) horn** reaching almost to the surface; a **massive anterior (ventral) horn**; **no lateral horn** (first appears at T1); a **well-developed reticular formation**; and proportionately **massive white matter**, with **both fasciculus gracilis (medial) and cuneatus (lateral)** in the posterior columns — cuneatus is absent below mid-thoracic levels, so its presence is a cervical marker.
- The **C2 spinal nerve** is unusual — it emerges not through a typical intervertebral foramen but between the **posterior arch of the atlas and the lamina of the axis**. Its **dorsal ramus**, the largest of all cervical dorsal rami, passes between the lamina of the axis and obliquus capitis inferior and divides into the **greater occipital nerve** (medial branch) and a smaller lateral branch; its ventral ramus joins C1 and C3 in the cervical plexus.

Vascular compartment — vertebral artery, carotid sheath and sympathetic trunk

- **Vertebral artery (second part):** ascends vertically through the foramina transversaria of the upper six cervical vertebrae; still vertical at the axis, but immediately above this level it runs **upwards and laterally** to the more laterally placed foramen transversarium of the atlas — its sharpest angulation, and a point of surgical importance in C1–C2 instrumentation. Accompanied by a venous plexus and a sympathetic branch; ventral rami of the cervical nerves lie posterior to it.
- **Carotid sheath:** the **common carotid** has already **bifurcated (at C3–C4)**, so the sheath contains separate **internal carotid** (posteromedial, deep to posterior belly of digastric) and **external carotid** (anteromedial) arteries, with the **internal jugular vein** lateral to both and the **vagus nerve** in the groove between artery and vein.
- **Related cranial nerves:** **hypoglossal nerve** descends between IJV and ICA, medial to posterior belly of digastric; **glossopharyngeal nerve** passes forward between ICA and ECA towards stylopharyngeus/pharyngeal wall; **accessory nerve** descends towards the posterior triangle.
- **Sympathetic trunk:** posterior to the carotid sheath, on the prevertebral fascia. The **superior cervical ganglion** (largest of the three cervical ganglia) lies precisely at the C1–C2 level — a landmark for the chain at this section.

Muscular compartments

- **Prevertebral group** (anterior to the body, deep to prevertebral fascia): **longus capitis** (towards basiocciput) and the superior oblique fibres of **longus colli** (towards the anterior tubercle of atlas).

- ▶ **Paravertebral/posterior group:** **semispinalis capitis**, **splenius capitis**, **longissimus capitis**, with **trapezius** more superficially; **obliquus capitis inferior** is cut near its origin from the axis spinous process.
- ▶ **Sternocleidomastoid** — the dominant anterolateral landmark, superficial and lateral to the carotid sheath, dividing the section into anterior and posterior triangular compartments as usual.
- ▶ **Suprahyoid group:** **posterior belly of digastric** and **stylohyoid** cross superficial to the ICA/IJV; the **styloid muscles** (stylopharyngeus, styloglossus, stylohyoid) descend between the internal and external carotid arteries towards the pharynx, tongue and hyoid.

Visceral compartment and fascial spaces

- ▶ **Pharynx:** posterior wall (superior constrictor + buccopharyngeal fascia) lies anterior to the prevertebral muscles; this level is the **oropharynx merging into the nasopharynx**, with the palatine tonsil bed laterally between the tonsillar folds.
- ▶ **Parapharyngeal space**, lateral to the pharyngeal wall, contains the carotid sheath structures and styloid-muscle group; the deep lobe/tail of parotid may approach it anterolaterally.
- ▶ **Retropharyngeal space** (largest interfascial space of the neck) lies between buccopharyngeal and alar fasciae, extending skull base to mediastinum; the "**danger space**", between alar and prevertebral fasciae, extends further down to the diaphragm — the more feared route of infection spread.
- ▶ **Fascial planes:** **investing layer** encircling the neck (enclosing sternocleidomastoid/trapezius); **prevertebral fascia** enclosing the prevertebral/paravertebral muscles and forming the posterior-triangle floor; **buccopharyngeal fascia** over the pharyngeal wall. **No pretracheal fascia** here — it begins only from the hyoid downward.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw one transverse (inferior-view) outline of the neck at the C2 (axis) level and label exactly:

- ▶ **Body of the axis** with the **dens (odontoid process)** projecting from it (or, if the cut is through the arch, the **pedicles, laminae and bifid spinous process**)
- ▶ **Transverse processes** with **foramen transversarium** on each side, transmitting the **vertebral artery** and its venous plexus
- ▶ **Superior articular facets** (for the atlas) and **inferior articular facets** (for C3) of the axis
- ▶ **Vertebral (spinal) canal**: epidural fat/venous plexus, dura mater, subarachnoid CSF, **spinal cord (C2 segment)** with its H-shaped grey matter, and the **denticulate ligaments**
- ▶ **Dorsal and ventral rami of the C2 spinal nerve**, emerging between the posterior arch of atlas and lamina of axis
- ▶ **Internal carotid artery** (posteromedial) and **external carotid artery** (anteromedial) within the **carotid sheath**, with the **internal jugular vein** lateral to both and the **vagus nerve** in the groove between artery and vein
- ▶ **Hypoglossal nerve** and **glossopharyngeal nerve**, medial to the posterior belly of digastric
- ▶ **Sympathetic trunk** with the **superior cervical ganglion**, posterior to the carotid sheath
- ▶ **Posterior belly of digastric** and the **styloid muscles** (stylopharyngeus, styloglossus, stylohyoid), between the two carotid arteries
- ▶ **Longus capitis** and **longus colli** (prevertebral group), anterior to the vertebral body
- ▶ **Semispinalis capitis, splenius capitis, longissimus capitis** (paravertebral group), **obliquus capitis inferior** (near its origin) and **trapezius**, posterior to the vertebral arch
- ▶ **Sternocleidomastoid**, anterolaterally
- ▶ **Oropharynx** (posterior wall) with the **palatine tonsil bed**, flanked by the **parapharyngeal space** and, posteriorly, the **retropharyngeal space**
- ▶ **Investing, prevertebral and buccopharyngeal layers of deep cervical fascia**

Applied / Clinical anatomy

- ▶ **Odontoid fractures**: Type I (tip avulsion at the alar-ligament attachment — rare, stable), **Type II** (through the narrow base/neck of the dens — **commonest, high non-union rate** from its poor, watershed blood supply), Type III (extends into the cancellous body of the axis — heals better from greater bone contact).
- ▶ **Hangman's fracture**: bilateral fracture through the pars interarticularis of the axis from severe hyperextension; the widened canal often spares the cord despite the dramatic injury.
- ▶ **Transverse-ligament rupture**: frees the dens, producing **atlantoaxial subluxation** — the atlas/skull then move independently of the dens, risking cord/medullary compression; this dislocation, not the fracture, is the lethal event in judicial hanging.
- ▶ **Vertebral artery vulnerability**: its sharp lateral angulation just above the axis makes this segment a recognised hazard during posterior C1–C2 instrumentation (e.g., pars/pedicle screws) and in extreme rotational injury.

- ▶ **Greater occipital neuralgia:** entrapment of the C2 dorsal ramus as it pierces semispinalis capitis/trapezius causes pain over the back of the scalp to the vertex.
- ▶ **Retropharyngeal/danger-space infection:** an abscess here can track down through the danger space into the posterior mediastinum — a surgical emergency.
- ▶ **Imaging correlation:** axial CT/MRI at C2 assesses craniovertebral-junction trauma, adenoidal/tonsillar and parapharyngeal masses (carotid-space paragangliomas, deep-lobe parotid tumours), and the upper deep cervical (level II, jugulodigastric) nodes.

High-yield exam pointers

- ▶ Axis = **strongest cervical vertebra**; only one bearing a **dens**, held by the **transverse ligament of the atlas**.
- ▶ **Vertebral artery** vertical at this level, then angles **sharply laterally** just above it to reach the atlas — the most surgically vulnerable point of its cervical course.
- ▶ **Superior cervical ganglion** lies at the **C1–C2 level**, posterior to the carotid sheath.
- ▶ Common carotid has **already bifurcated** below this level — sheath contains **separate internal and external carotid arteries**.
- ▶ **Dorsal ramus of C2** (largest cervical dorsal ramus) → **greater occipital nerve**.
- ▶ Cervical cord: massive grey matter, slender far-reaching posterior horn, massive anterior horn, no lateral horn, **both gracilis and cuneatus** present.
- ▶ **Retropharyngeal and danger spaces** are potential infection routes into the mediastinum.
- ▶ **No thyroid, trachea, oesophagus or pretracheal fascia** here — distinguishes it from the C7/thyroid-cartilage sections.
- ▶ **Type II odontoid fracture** (base of dens) — notoriously high non-union rate (poor watershed supply).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; IB Singh — Textbook of Anatomy Vol 3 6e; BD Chaurasia — Human Anatomy Vol 3-4 8e; Vishram Singh — Textbook of Anatomy Vol 3 4e.

Coverage note: the library's dedicated cross-sectional-anatomy chapter (IB Singh, Vol 3, "Cross-Sectional, Radiological and Surface Anatomy of Head and Neck") illustrates only the C7-vertebra and thyroid-cartilage neck levels — no captioned C2-level neck cross-section exists in the corpus. This description is therefore built by combining the corpus's verified axis-vertebra osteology, vertebral-artery course, carotid-sheath, sympathetic-trunk, cervical-cord and fascial-space anatomy with standard vertebral-level correlations, rather than reproducing a single source figure.



Cross sectional anatomy at the level of L1 vertebra (labeled diagram)

Asked in: Paper IV Oct 2006 — RGUHS MD/MS Anatomy

Definition / Introduction A transverse (axial) section through the body of the first lumbar (L1) vertebra corresponds almost exactly to the **transpyloric plane of Addison** — a horizontal reference plane lying midway between the suprasternal notch and the pubic symphysis. Posteriorly this plane usually cuts the lower half of the L1 body, the L1/L2 intervertebral disc, or the upper half of L2 (overall range lower T12 to lower L2, higher in men than women); anteriorly it strikes the ninth costal cartilage. Because the origin of the superior mesenteric artery, the renal vessels, the neck of the pancreas and formation of the portal vein, the pylorus, the gallbladder fundus, the duodenojejunal flexure and the termination of the spinal cord all cluster around this single level, an axial CT/MRI slice at L1 is one of the most information-dense "orientation slices" in abdominal cross-sectional imaging and a classic anatomy exam section.

1. Vertebral column and contents of the spinal (vertebral) canal

- ▶ **Body of L1:** kidney-shaped on cross-section, wider transversely than antero-posteriorly; its concave posterior surface, together with the pedicles and laminae, encloses the triangular vertebral (neural) canal, closed posteriorly by the single midline spinous process.
- ▶ **Spinal cord:** in the adult the cord terminates as the **conus medullaris**, on average at the level of the middle third of the body of L1 (range as high as mid-T11 to as low as mid-L3) — a level that corresponds closely to the transpyloric plane itself.
- ▶ Below the conus, the canal contains the **cauda equina** (lumbar and sacral nerve roots) floating in CSF within the dural sac, the **filum terminale**, epidural (extradural) fat, and the internal vertebral venous plexus against the vertebral body.
- ▶ **Applied point:** because the cord may still occupy the canal at this level, lumbar puncture and spinal anaesthesia are performed lower, at the L3/L4 or L4/L5 interspace, never at L1.

2. Posterior abdominal wall musculature

Muscle/layer	Position at this level	Key relation
Psoas major	Paired, immediately lateral to the vertebral body	Kidney and ureter lie on its anterior surface; enclosed in psoas fascia
Quadratus lumborum	Lateral to psoas major	Lies between the 12th rib above and the iliac crest/lumbar transverse processes below
Erector spinae + transversospinalis	Posterior to the vertebral (neural) arch, in the paravertebral groove	Enclosed by the posterior and middle layers of thoracolumbar fascia
Diaphragmatic crura	Anterior to the vertebral body, flanking the aorta	Right crus arises from the bodies/discs of the upper three lumbar vertebrae; left crus from the upper two

- The **thoracolumbar fascia** contributes three laminae identifiable in cross-section: an anterior layer in front of quadratus lumborum, a middle layer between quadratus lumborum and erector spinae, and a posterior layer behind erector spinae — together enclosing these muscle masses.
- The paravertebral prominence of the vertebral body creates a **paravertebral gutter** on each side, occupied by the kidney and its perinephric fat.

3. Great vessels and other retroperitoneal structures

Structure	Finding at the L1 level
Abdominal aorta	Lies anterior and slightly left of the vertebral body; the coeliac trunk has already been given off just above, at T12; the superior mesenteric artery arises here, close to the transpyloric plane; the renal arteries arise a little lower (lower L1 to upper L2)
Inferior vena cava	To the right of the aorta, against right psoas/right crus; already fully formed (its own formation by union of the common iliac veins occurs much lower, at L5) and ascending toward the caval opening of the diaphragm
Left renal vein	Crosses anterior to the aorta, just below the origin of the SMA, to drain into the IVC — the classic "nutcracker" relation
Portal vein	Formed behind the neck of the pancreas at the level of the L1/L2 disc by union of the superior mesenteric and splenic veins
Kidneys	Renal hilum centred at about L1/L2–L2 (left slightly higher than right); upper poles reach as high as T12/L1, deep to ribs 11–12; each is surrounded by perirenal fat within renal (Gerota's) fascia, with pararenal fat lying external to it
Suprarenal glands	Cap the upper poles of the kidneys — right gland tucked behind the IVC and bare area of the liver; left gland applied to the stomach bed/lesser sac
Ureters	Begin their descent at approximately this level, applied to the tips of the lumbar transverse processes
Sympathetic trunk, coeliac and aorticorenal ganglia	Lie on the antero-lateral aspect of the vertebral body, medial to psoas and medial to the suprarenal glands

4. Peritoneal cavity and alimentary viscera

- **Stomach:** the pyloric part lies at, or just to the right of, the L1 body, in the transpyloric plane.
- **Pancreas:** the **neck** (continuous with the body) crosses the aorta and vertebral column exactly at the L1/L2 disc level — this is precisely where the portal vein is formed behind it; the head lies within the duodenal C-loop to the right (projected over L2), and the tail runs up and to the left toward the splenic hilum, a little above this plane.

- ▶ **Duodenum:** the second (descending) part lies to the right, alongside L1–L3; the **duodenojejunal flexure** commonly sits at L1, where the root of the small-bowel mesentery begins its oblique course down to the right iliac fossa.
- ▶ **Liver:** the left lobe crosses the midline anteriorly at this level; the fundus of the **gallbladder**, at the tip of the 9th costal cartilage, lies close to the transpyloric plane on the right.
- ▶ **Spleen:** posterolateral on the left, deep to ribs 9–12, related to the tail of pancreas; its hilum lies a little above this plane.
- ▶ **Transverse colon:** crosses the upper abdomen anteriorly; the left colic (splenic) flexure lies close to the tail of the pancreas and spleen.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 5.96 — *Fascia and aponeuroses of abdominal wall at level of renal hila. A. Re (Moore — Clinically Oriented Anatomy — 9e, p.906)*

(Real labelled plate above — Moore's transverse section at the level of the renal hila, essentially the L1 vertebral/transpyloric level. Reproduce a similar labelled diagram by hand with the following, arranged concentrically from the vertebral body outward.)

- ▶ **Centre (posterior midline):** body of L1 vertebra with vertebral canal — conus medullaris/cauda equina, dura mater.
- ▶ **Immediately anterolateral to body:** psoas major (both sides); crura of diaphragm anterior to the aorta.
- ▶ **In the midline anterior to the vertebra:** abdominal aorta (with SMA origin), IVC to its right, left renal vein crossing between them.
- ▶ **Paravertebral gutters:** right and left kidneys with renal fascia, perirenal fat, suprarenal glands capping the upper poles.
- ▶ **Anterior to the great vessels:** neck/body of pancreas with the portal vein forming behind it; second part of duodenum on the right; duodenojejunal flexure on the left.
- ▶ **Further anterior/lateral:** stomach (pyloric part) and left lobe of liver anteriorly, spleen posterolaterally on the left, descending/transverse colon.
- ▶ **Posterior wall:** quadratus lumborum, erector spinae/transversospinalis, thoracolumbar fascia (anterior, middle, posterior layers), 12th rib tips.
- ▶ **Outer margin:** anterolateral abdominal wall muscles — external oblique, internal oblique, transversus abdominis, rectus abdominis in its sheath.

Applied / Clinical anatomy

- ▶ **Surface marking use of the transpyloric plane:** locates the pylorus, the neck of pancreas, the fundus of gallbladder (tip of 9th costal cartilage), the hila of both kidneys, the origin of the SMA, and the duodenojejunal flexure — used routinely when describing "structures at L1" in viva and imaging reports.
- ▶ **Cross-sectional imaging landmark:** an axial CT/MRI slice at this level is used to identify the pancreatic neck, confirm the origin of the SMA and renal arteries, and stage pancreatic

head/neck and renal masses; it is also the reference slice for planning a coeliac plexus block (needle passed alongside the L1 body, anterior to it, to reach the coeliac ganglia).

- ▶ **"Nutcracker" phenomenon:** compression of the left renal vein between the aorta and the origin of the SMA at this level can cause left-sided haematuria and pelvic congestion.
- ▶ **Thoracolumbar (T12–L1) junction:** the commonest site of vertebral burst/Chance fractures in trauma because of the transition from the relatively fixed thoracic spine to the mobile lumbar spine; because the conus medullaris may still lie at this level, such fractures risk a mixed conus medullaris/cauda equina injury.
- ▶ **Renal access procedures:** percutaneous nephrostomy or renal biopsy performed at this level risks the pleural recess and ribs 11–12 posteriorly, given the close relation of the kidney's upper pole to the costodiaphragmatic recess.
- ▶ **Duodenojejunal flexure/SMA relation:** the flexure and root of the mesentery beginning here are relevant to the anatomy of **SMA syndrome** (compression of the third part of duodenum between the SMA and aorta) and to midgut malrotation assessment.
- ▶ **Aortic pathology:** the SMA/renal-artery origins at this level are key landmarks in planning endovascular aneurysm repair and are commonly involved in juxtarenal abdominal aortic aneurysms.

High-yield exam pointers

- ▶ L1 level = **transpyloric plane** (plane of Addison): posteriorly at lower L1 body/L1-L2 disc/upper L2; anteriorly at the 9th costal cartilage.
- ▶ Spinal cord terminates (conus medullaris) on average at the **middle third of L1 body** in adults — hence lumbar puncture is done at L3/L4 or lower.
- ▶ **SMA** arises at L1 (close to the transpyloric plane); **coeliac trunk** at T12 (just above); **renal arteries** at lower L1–upper L2.
- ▶ **Portal vein** forms behind the neck of pancreas at the L1/L2 disc, from union of the superior mesenteric and splenic veins.
- ▶ **Pancreatic neck** crosses the aorta/vertebral column precisely at this level; head lies in the duodenal C-loop (right), tail toward the splenic hilum (left, slightly above the plane).
- ▶ Renal hila lie at about L1/L2–L2; suprarenal glands cap the upper poles of the kidneys.
- ▶ Duodenojejunal flexure commonly at L1; root of small-bowel mesentery begins here running to the right iliac fossa.
- ▶ Posterior abdominal wall, medial to lateral: vertebral body/psoas → quadratus lumborum → erector spinae/transversospinalis, all invested by the three layers of thoracolumbar fascia.
- ▶ IVC lies to the right of the aorta throughout this level; left renal vein crosses anterior to the aorta below the SMA origin.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; BD Chaurasia Human Anatomy Vol 2 8e. Coverage note: the corpus does not contain a dedicated radiology cross-sectional atlas; vertebral-level relations above are drawn from Gray's surface-anatomy data (Mirjalili et al 2012a, 2012b) and Moore's labelled transverse-section figure at the level of the renal hila, cross-checked against standard descriptions of the transpyloric plane.



Cross sectional anatomy at the level of the sternal angle

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

The sternal angle (angle of Louis) is the palpable transverse ridge at the manubriosternal joint, about 5 cm below the suprasternal (jugular) notch, where the manubrium and body of the sternum meet at a slight posterior angulation. A horizontal plane drawn through this joint anteriorly and through the lower border of the T4 vertebral body / the T4–T5 intervertebral disc posteriorly is the **transverse thoracic plane**, commonly called the "sternal angle plane." It is the single most important reference level in cross-sectional and radiological thoracic anatomy because it marks the junction of the superior and inferior mediastinum — a transverse section taken exactly through it (the "angle of Louis section") captures the mediastinum in structural transition, with the great vessels changing from a side-by-side to an antero-posterior arrangement.

1. The sternal angle as a surface landmark

Feature	Level / significance
Manubriosternal joint	Fixed anterior point of the plane; palpable ridge ~5 cm below the suprasternal notch; site of manubriosternal synchondrosis, which may ossify with age
2nd costal cartilage	Articulates with the sternum precisely at the angle; the standard starting point for counting ribs and intercostal spaces clinically
Posterior vertebral level	Lower border of the T4 body / the T4–T5 intervertebral disc; corresponds to the interval between the 3rd and 4th thoracic spinous processes posteriorly
Named plane	Transverse thoracic plane (plane of Ludwig) — used interchangeably with "sternal angle plane"

2. What the plane divides — subdivision of the mediastinum

Division	Boundaries
Superior mediastinum (above the plane)	Manubrium anteriorly; upper four thoracic vertebrae posteriorly; superior thoracic aperture above; transverse thoracic plane below
Inferior mediastinum (below the plane)	Body of sternum anteriorly; T5–T12 vertebrae posteriorly; diaphragm below; further subdivided by the pericardium into anterior, middle and posterior parts

A section through the sternal angle plane therefore cuts through the last part of the superior mediastinum's great-vessel pattern just as the pericardium (middle mediastinum) and posterior mediastinal structures are beginning.

3. Structures transected in the section (anterior → posterior)

Structure	Description at this level
Manubriosternal joint + 2nd costal cartilage	Most anterior structures cut
Ascending aorta	Lies anterior to the pulmonary trunk — the arch has already terminated by this level, so only the ascending part is seen anteriorly
Pulmonary trunk	Its bifurcation into right and left pulmonary arteries is seen sandwiched between the ascending aorta (in front) and descending aorta (behind)
Descending thoracic aorta	Lies posterior to the pulmonary trunk — the arch has already begun its descent by this level
Trachea → right & left principal bronchi	The trachea has just bifurcated above this level; the two principal bronchi are seen behind the bifurcation of the pulmonary trunk and in front of the oesophagus
Oesophagus	Immediately posterior to the bronchi, anterior to the vertebral body
Superior vena cava & azygos vein	Their terminal parts are seen on the right side, just before the azygos vein arches over the root of the right lung to join the SVC
Thoracic duct	On the left side , posterior to the descending aorta
Mediastinal (tracheobronchial) lymph nodes	Found between the two principal bronchi, at the carina
Right and left lungs	Occupy the bulk of the section, with pleura and the earliest hilar structures now appearing

4. Detailed relations — why the pattern changes at this level

- **Aorta:** the arch of aorta begins posterior to the 2nd right sternocostal joint (at the sternal angle) and ends posterior to the 2nd left sternocostal joint beside the T4 vertebra; consequently, at the

plane of the sternal angle itself the ascending aorta (anterior) and descending aorta (posterior) are both cut, with the **pulmonary trunk bifurcation** wedged between them — quite unlike the T4-level section (just above), where the arch alone is seen as a single half-cut oblique tube.

- ▶ **Pericardium:** the fibrous pericardium is carried up by the ascending aorta to the level of the sternal angle, so the anterior part of this section already lies within the pericardial sac.
- ▶ **Ligamentum arteriosum:** passes from the root of the left pulmonary artery to the under-surface of the aortic arch just above this plane; it is the most common site of aortic coarctation and lies close to the left recurrent laryngeal nerve.
- ▶ **Nerves:** the right phrenic nerve lies between the SVC and the mediastinal pleura; the vagi lie close to the trachea/oesophagus; the left recurrent laryngeal nerve hooks around the aortic arch just superior to this level.
- ▶ **Carina:** the ridge separating the two principal bronchial openings lies at or just above this plane and is a key bronchoscopic landmark whose shape alters in subcarinal lymph-node enlargement or carcinoma.

5. Postural variation at the sternal angle plane

Because the plane itself is fixed by bone, but the soft mediastinal contents shift under gravity, the structures actually transected differ with body position:

Structure	Supine position	Erect (sitting/standing) position
Arch of aorta	Lies superior to the plane	Transected by the plane
Bifurcation of trachea	Transected by the plane	Lies inferior to the plane
Central tendon of diaphragm / inferior border of heart	At the xiphisternal joint / T9 level	At the middle of the xiphoid process / T9–T10 disc level

This is a classic examiner point: cadaveric dissection (supine) and an erect chest radiograph do not show identical relations at the "same" sternal angle level.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

embed: ![Fig 11.2 — Transverse section of thorax at the level of upper part of T5 vertebra (IB Singh — Textbook of Anatomy Vol 2 — 6e, p.143)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/e5ae9ef349dd3c0e.jpg)

Reproduce a transverse (inferior-view) section at the sternal angle/T4–T5 disc level with these labels:

- ▶ Thoracic wall / manubriosternal joint (anterior)
- ▶ Pleural cavity (each side)
- ▶ Ascending aorta (anterior)
- ▶ Bifurcation of pulmonary trunk into right and left pulmonary arteries (centre)
- ▶ Left (and right) principal bronchus (behind pulmonary trunk bifurcation)
- ▶ Descending (thoracic) aorta (posterior)
- ▶ Oesophagus (posterior, behind the bronchi)
- ▶ Azygos vein (right posterolateral, arching toward SVC)
- ▶ Right and left lungs (bulk of the section)

Applied / Clinical anatomy

- ▶ **Rib and intercostal-space counting** always starts from the 2nd costal cartilage at the sternal angle — used to localise the apex beat (5th left intercostal space), sites for pleural aspiration/intercostal drain insertion, and cardiac auscultation areas.
- ▶ **Mediastinoscopy** for biopsy of paratracheal and subcarinal lymph nodes (in lung cancer/lymphoma staging) is performed through a suprasternal incision, with the scope advanced along the trachea toward this plane.
- ▶ **Central venous catheter tip placement:** the catheter tip must lie well below this plane, at the SVC–right atrial junction, to avoid perforation or arrhythmia — the sternal angle plane is the proximal limit to keep clear.
- ▶ **Double-lumen endotracheal tube / bronchoscopy:** confirming the tube or scope tip relative to the carina depends on the postural variation described above — the bifurcation is at the sternal angle plane supine but drops below it when the patient sits up, which matters in intraoperative positioning.
- ▶ **Aortic coarctation and patent ductus arteriosus/ligamentum arteriosum** pathology cluster just above this plane; recurrent laryngeal nerve palsy (hoarseness) can result from an aortopulmonary-window mass or a large aortic arch aneurysm compressing the nerve here.
- ▶ **Chylothorax** from thoracic-duct injury during oesophageal or mediastinal surgery reflects the duct's left-posterior relation to the descending aorta at this level.
- ▶ **Cross-sectional/radiological correlation:** on axial CT at this level the heart shadow (mainly atria) appears centrally with the right and left principal bronchi, pulmonary vessels and oesophagus behind it and the descending aorta postero-laterally — directly matching the cadaveric section; on a plain PA chest radiograph, the arch of aorta produces the "aortic knuckle"

just above this level and the carina's angle (widened by subcarinal nodal disease) is assessed on CT/bronchoscopy at this plane.

embed: ![Fig 11.3 — Cross-section (axial section) of thorax obtained by CT scan (IB Singh — Textbook of Anatomy Vol 2 — 6e, p.143)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/53516df8b1d19ca0.jpg)

High-yield exam pointers

- ▶ Sternal angle = manubriosternal joint = surface marker for the **transverse thoracic plane**, corresponding posteriorly to the **T4–T5 intervertebral disc**.
- ▶ This plane divides the mediastinum into **superior** (above) and **inferior** (below, further split by the pericardium into anterior/middle/posterior).
- ▶ At this level: **ascending aorta anterior, pulmonary trunk bifurcation in the middle, descending aorta posterior** — the arch of aorta has already begun and ended.
- ▶ **Right and left principal bronchi** lie behind the pulmonary trunk bifurcation and in front of the **oesophagus**; **thoracic duct** lies on the left, posterior to the descending aorta.
- ▶ **2nd costal cartilage** attaches at the sternal angle — the starting point for clinical rib counting.
- ▶ **Postural variation** is a favourite viva point: arch of aorta and tracheal bifurcation lie superior/at the plane (supine) versus at/inferior to the plane (erect).
- ▶ **Carina** and mediastinal (tracheobronchial) lymph nodes lie at this level — key in bronchoscopy and oncological staging.
- ▶ Ligamentum arteriosum (site of coarctation) and the left recurrent laryngeal nerve lie just superior to this plane.

SOURCE & COVERAGE

IB Singh — Textbook of Anatomy Vol 2, 6e (Chapter: Cross-Sectional, Radiological and Surface Anatomy of Thorax); Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e.



Cross sectional anatomy of Pons at the level of Facial colliculus

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction — The internal structure of the pons is conventionally studied at two transverse levels — a **caudal (lower) level**, which passes through the **facial colliculus**, and a **rostral (upper) level**, which passes through the trigeminal nuclei. At every level the pons is divided by the transversely running fibres of the **trapezoid body** into an anterior **basilar (ventral) part**, containing pontine nuclei and cortico-pontine/pontocerebellar fibres, and a posterior **tegmentum**, which is continuous with the medullary tegmentum and carries the cranial-nerve nuclei and ascending sensory tracts. The section at the facial colliculus level is a classic RGUHS spot/essay figure because a single small area contains the abducens and facial nuclei, four vestibular and two cochlear nuclei, and the medial longitudinal fasciculus — the basis of Foville, Millard–Gubler, Raymond and locked-in syndromes.

1. Level of the section and floor landmarks

- ▶ The section is taken through the **caudal one-third of the pons**, just rostral to the pontomedullary junction.
- ▶ The **fourth ventricle** cavity lies dorsal to the tegmentum; its floor here shows, on each side of the **median sulcus**, an oval elevation — the **facial colliculus** — at the level of the **superior fovea**, with the **sulcus limitans** and **vestibular area** lateral to it.
- ▶ The **inferior cerebellar peduncle (restiform body)**, still prominent at this caudal level, forms the dorsolateral margin of the section (the middle cerebellar peduncle becomes dominant only more rostrally); its medial part, the **juxtarestiform body**, carries vestibulo-cerebellar fibres.

2. Basilar (ventral) part — constant at every level of the pons

Component	Detail
Grey matter	Pontine nuclei — scattered masses of neurones embedded among the fibre bundles
Longitudinal white fibres	Corticospinal, corticonuclear (corticobulbar) and corticopontine fibres descending from the cerebral cortex; the corticopontine fibres end on pontine-nucleus neurones and break the pyramidal bundles into smaller fascicles
Transverse white fibres	Pontocerebellar fibres , arising from the pontine nuclei, decussate and enter the contralateral middle cerebellar peduncle to reach the cerebellar cortex — the principal cortico-ponto-cerebellar relay

3. Tegmentum — grey matter (cranial-nerve nuclei) at this level

Nucleus	Position	Connections
Abducens (VI) nucleus	Paramedian, immediately beneath the facial colliculus, in the floor of the fourth ventricle; ~6,500 neurones, in line with the III/IV/XII somatic motor column	Motor neurones → lateral rectus; internuclear neurones cross the midline and ascend in the contralateral MLF to the medial-rectus subnucleus of III (horizontal conjugate gaze)
Facial (VII) motor nucleus	Ventrolateral to the abducens nucleus, deep in the reticular formation, dorsal to the lateral part of the medial lemniscus	Axons loop over the abducens nucleus (internal genu) then descend ventrolaterally between the facial nucleus and the spinal trigeminal nucleus to emerge at the cerebellopontine angle
Superior salivatory & lacrimal nucleus	Medial to the facial motor nucleus	Preganglionic parasympathetic (nervus intermedius) fibres → chorda tympani (submandibular/sublingual glands) and greater petrosal nerve (lacrimal gland)
Nucleus solitarius (rostral, gustatory part)	Lateral to the superior salivatory nucleus	Taste from the anterior two-thirds of tongue via chorda tympani
Vestibular nuclear complex	Medial vestibular nucleus (complete at this level, lateral to the abducens nucleus, related to the inferior cerebellar peduncle) + superior part of the lateral vestibular nucleus + inferior part of the superior vestibular nucleus	Afferents from vestibular nerve; efferents to MLF, cerebellum and (lateral nucleus) the vestibulospinal tract
Cochlear nuclei (dorsal/posterior and ventral/anterior)	Dorsal and ventral to the inferior cerebellar peduncle respectively	Cochlear-nerve afferents → trapezoid body, superior olivary and lateral-lemniscal nuclei
Spinal nucleus and tract of the trigeminal nerve	Anteromedial aspect of the inferior cerebellar peduncle	Pain/temperature from the face; second-order fibres cross and ascend as the trigeminal lemniscus
Superior olivary complex & trapezoid nuclei	Ventral tegmentum, alongside the trapezoid body	Auditory relay; some fibres enter the MLF, mediating tensor tympani/stapedius reflexes

4. Formation of the facial colliculus

- The **facial colliculus** is produced entirely by the peculiar looping course of facial nerve fibres — a textbook example of **neurobiotaxis**.
- Efferent axons leave the facial motor nucleus and first run **dorsomedially**, arching over and around the abducens nucleus (its **internal genu**); this loop of fibres raises the floor of the fourth ventricle as the facial colliculus.

- The fibres then curve back **ventrolaterally**, passing between the facial nucleus (medially) and the spinal nucleus of the trigeminal nerve (laterally), and finally emerge on the surface at the **cerebellopontine angle**, in the groove between the olive and the restiform body, close to the pontomedullary junction.
- Functionally, this detour keeps the facial fibres close to the **medial longitudinal fasciculus** (coordinating lip/tongue movements during articulation) and lets the facial nucleus communicate with the trigeminal nucleus to complete reflex arcs (e.g., corneal reflex, proprioception from facial muscles).

5. Tegmentum — white matter (tracts) at this level

Tract / bundle	Position	Function
Medial lemniscus	Most ventral part of the tegmentum, a flattened transverse band near the median raphe	Discriminative touch, vibration, conscious proprioception (contralateral dorsal-column–medial-lemniscus pathway)
Spinal lemniscus (anterior + lateral spinothalamic)	Lateral to the medial lemniscus	Pain, temperature, crude touch (contralateral)
Trigeminal lemniscus	Lateral part of the same transverse band, between spinal and medial lemnisci	Pain, temperature and touch from the contralateral half of the face
Lateral lemniscus	Dorsolateral tegmentum	Ascending auditory pathway to the inferior colliculus
Trapezoid body	Transverse decussating fibres just dorsal to the basilar part	Auditory pathway (crossed cochlear fibres)
Medial longitudinal fasciculus (MLF)	Paramedian, immediately beneath the floor of the fourth ventricle	Links vestibular nuclei with III, IV and VI nuclei — conjugate eye movements
Central tegmental tract, tectospinal and rubrospinal tracts	Central/ventral tegmentum, ventral to the MLF	Reticulo-olivary/rubral connections; reflex head-turning; facilitation of flexor tone
Reticular formation	Diffuse throughout the tegmentum	Consciousness, cardiorespiratory centres — present at every level of the brainstem

6. Blood supply

- The pons is supplied by **pontine branches of the basilar artery**, conventionally grouped as **paramedian**, **short circumferential** and **long circumferential** branches (the last including the anterior inferior cerebellar artery, which passes close to the facial and abducens nerve roots).
- Paramedian/short-circumferential occlusion damages the basilar (ventral) part first — the basis of the ventral pontine (Millard-Gubler/Raymond) syndromes and, if bilateral, of locked-in syndrome.

□ Fig 21.11 — A transverse section through the pons at the level of the facial colliculus (Gray's Anatomy — Standring — 41e, p.445)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse section through the caudal pons; divide it with a transverse line (trapezoid body) into a ventral basilar part and a dorsal tegmentum, then label, dorsal (floor) to ventral (base):

- ▶ **Fourth ventricle** cavity, with the **facial colliculus** marked in its floor beside the **median sulcus**; **sulcus limitans**/vestibular area lateral to it
- ▶ **Medial longitudinal fasciculus** (paramedian, just beneath the floor); **abducens nucleus** beneath the colliculus
- ▶ **Genu of the facial nerve** looping over the abducens nucleus, and the **facial nerve** fibres curving ventrolaterally to the **facial (motor) nucleus**
- ▶ **Medial, lateral and superior vestibular nuclei**; dorsal and ventral **cochlear nuclei**; **restiform body** (**inferior cerebellar peduncle**) and **juxtarestiform body** at the lateral margin
- ▶ **Spinal nucleus and tract of the trigeminal nerve**, medial to the restiform body
- ▶ **Central tegmental tract** and **reticular formation** filling the central tegmentum
- ▶ **Lateral lemniscus**, **trapezoid nucleus** and **trapezoid body** (transverse fibres) in the ventral tegmentum
- ▶ **Medial lemniscus**, **spinal (spinothalamic) lemniscus** and **trigeminal lemniscus**, arranged medial to lateral, just dorsal to the basilar part
- ▶ **Pontine nuclei**, **descending corticospinal/corticonuclear fibres** and **transverse pontocerebellar fibres** entering the **middle cerebellar peduncle**, in the basilar part

Applied / Clinical anatomy

- ▶ **Foville syndrome** (dorsal/tegmental pontine lesion): damages the facial nucleus/fibres, the abducens nucleus and the adjacent **paramedian pontine reticular formation** (horizontal-gaze centre) → ipsilateral LMN facial palsy with ipsilateral conjugate gaze palsy (loss of ipsilateral lateral rectus and contralateral medial rectus movement together); convergence remains normal.
- ▶ **Millard–Gubler syndrome** (ventral/basal pontine lesion, paramedian basilar branches): damages the corticospinal tract and the facial-nerve fascicle as it traverses the basal pons → ipsilateral LMN facial palsy + contralateral hemiplegia; if the lesion is extensive it also involves the abducens fibres, adding ipsilateral medial squint.
- ▶ **Raymond syndrome**: a purely ventral basal lesion of the corticospinal tract and abducens nerve fibres (facial nerve spared) → ipsilateral medial squint + contralateral hemiplegia.
- ▶ **Locked-in syndrome**: bilateral ventral (basal) pontine infarction, typically from basilar artery thrombosis/short circumferential branch occlusion, destroys the corticospinal and corticonuclear tracts on both sides → quadriplegia and anarthria, but the dorsal tegmentum (reticular formation) and ascending sensory pathways are spared, so the patient is **fully conscious with no sensory loss** and communicates only by vertical eye movements and blinking.

- ▶ **Pontine haemorrhage** ("PPP"): deep coma (reticular formation damage), **pin-point pupils** (interrupted descending sympathetic fibres), **hyperpyrexia** (severed descending hypothalamic thermoregulatory fibres) and bilateral facial + four-limb paralysis; usually fatal.
- ▶ **Internuclear ophthalmoplegia (INO)**: a lesion of the MLF between the abducens nucleus and the contralateral oculomotor (medial rectus) subnucleus causes failure of adduction of the ipsilateral eye on attempted contralateral gaze, with nystagmus of the abducting eye; convergence is preserved — classically seen in demyelinating disease.
- ▶ **Bell's palsy vs supranuclear facial palsy**: neurones for the upper face receive bilateral corticonuclear input while those for the lower face receive predominantly contralateral input, so a nuclear/infranuclear (LMN) lesion at this level causes complete ipsilateral facial paralysis, whereas a supranuclear (UMN) lesion spares the forehead.
- ▶ **Cerebellopontine angle tumours** (e.g., vestibular schwannoma): the facial (with nervus intermedius) and vestibulocochlear nerves emerge/enter together at the angle between the olive, restiform body and lower border of the pons, close to this level, explaining combined VII + VIII deficits.

High-yield exam pointers

- ▶ Pons is divided by the **trapezoid body** into a ventral **basilar part** (pontine nuclei + descending/pontocerebellar fibres) and a dorsal **tegmentum** (cranial-nerve nuclei + ascending tracts) — true at every level.
- ▶ **Facial colliculus** = internal genu of the facial nerve looping over the abducens nucleus — a **neurobiotaxis** example, unique to this level.
- ▶ Two motor grey masses define the level: **abducens nucleus** (beneath the colliculus) and **facial motor nucleus** (ventrolateral to it).
- ▶ All four **vestibular nuclei** and both **cochlear nuclei** are represented here, related to the inferior cerebellar peduncle.
- ▶ The MLF lies paramedian beneath the floor — key to both Foville syndrome and internuclear ophthalmoplegia.
- ▶ **Millard–Gubler** = ventral lesion (VII fascicle + corticospinal ± VI); **Foville** = dorsal lesion (VII + VI nuclei + PPRF) — a classic exam discriminator.
- ▶ **Locked-in syndrome** spares the dorsal tegmentum, so consciousness, vertical gaze and sensation remain intact.
- ▶ Blood supply: **paramedian, short circumferential and long circumferential** (AICA) branches of the basilar artery.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Human Neuroanatomy; IB Singh Textbook of Anatomy Vol 3 6e; BD Chaurasia Human Anatomy Vol 3 –4 8e.



Cross sectional anatomy of thorax at the level of T4

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction

A transverse (axial) section of the thorax at the level of the body of the 4th thoracic vertebra (T4) is one of the two classical "must-know" cross-sectional levels of the mediastinum taught for cross-sectional and radiological anatomy — the other being the T5 level. The T4 section passes through the **superior mediastinum** and characteristically cuts the **arch of the aorta**, which runs almost sagittally, so that the transverse section slices through it obliquely and shows it as a curved, "half-cut" tube with the origins of its three branches opening into it. This level lies just above the **transverse thoracic plane** (plane of Ludwig), the surgical/radiological reference plane at the manubriosternal joint and the T4–T5 intervertebral disc that divides the mediastinum into superior and inferior parts — which is why the T4 section is used to teach the disposition of the great vessels and viscera immediately before that plane.

1. Skeletal framework and plane of section

Boundary	Structure at this level
Anterior	Manubrium sterni (lower part, approaching the manubriosternal joint)
Posterior	Body of T4 vertebra, vertebral (spinal) canal and its contents
Lateral/posterolateral	Ribs — posterior parts seen as curved bony arcs; costovertebral and costotransverse joints
Reference plane	Lies just above the transverse thoracic plane (plane of Ludwig), which passes through the T4–T5 disc and the sternal angle and separates the superior from the inferior mediastinum (Gray's Anatomy 41e)

2. General disposition of the section

- ▶ The bulk of the section is occupied by the **right and left lungs** (upper-lobe parenchyma). Since the section lies above the pulmonary hila, no bronchi, pulmonary vessels or lymph nodes of the lung root are cut here — only lung substance and its investing visceral pleura are seen.
- ▶ Between the two lungs lies the **superior mediastinum**, which is "shrink-wrapped" laterally by the tightly applied costomediastinal (mediastinal) parietal pleura.
- ▶ Posteriorly are the vertebral body and canal, the paravertebral **sympathetic trunks**, and the muscles of the back.
- ▶ Anteriorly, deep to the manubrium, the **thymus** (or its fatty remnant in the adult) occupies the triangular retrosternal space bounded by the reflections of the costomediastinal pleura on each side.

3. Contents of the superior mediastinum cut at this level

Structure	Position / description at the T4 level
Thymus / thymic remnant	Most anterior structure, in the retrosternal triangular space behind the manubrium
Superior vena cava (SVC)	To the right, anterior to the right end of the aortic arch
Arch of aorta	Central; because the arch is disposed almost vertically/sagittally, the transverse section cuts across it obliquely and it appears as a half-cut, curved tube; the origins of its three branches — brachiocephalic trunk, left common carotid artery, left subclavian artery — are seen opening from within the arch
Trachea	In the midline, immediately anterior to the oesophagus; the T4 level closely corresponds to the tracheal bifurcation (carina) in many subjects — Gray's Anatomy 41e correlates axial CT images running from T4 (carina) down to T6
Oesophagus	Immediately behind the trachea, anterior to the body of T4
Thoracic duct	Posterior and to the left of the oesophagus, ascending along its left margin toward the root of the neck
Left recurrent laryngeal nerve	Related to the left side of the arch/trachea, lying in or approaching the tracheo-oesophageal groove
Vagus nerves	Close to the trachea and oesophagus on either side
Phrenic nerves	Lie laterally, between the mediastinal pleura and the great vessels
Sympathetic cardiac nerves, para-tracheal/brachiocephalic lymph nodes	Scattered in the loose areolar tissue of the superior mediastinum

4. Pleura and lungs at this level

- ▶ Only the **costal and mediastinal parts of the parietal pleura** are cut at this height (the diaphragmatic reflection and costodiaphragmatic recess lie well below this level).
- ▶ The **pleural cavity** is seen as a thin potential space (containing a capillary film of serous fluid) between the parietal and visceral layers — depicted as a fine line in a cadaveric or CT section.
- ▶ The lung parenchyma seen belongs to the upper lobes only; the fissures and hilar structures are not yet encountered at this superior level.

5. Radiological correlation

- ▶ On an **axial CT image** at this level: the air-filled trachea appears as a round, midline lucency; the arch of aorta is a curved soft-tissue-density structure with 2–3 vascular openings corresponding to its branches; the SVC is an oval opacity to the right of the arch; both lungs appear as large areas of low attenuation (air) traversed by vascular markings.

- ▶ On a **plain PA chest radiograph**, the segment of the aortic arch cut at this level corresponds to the "**aortic knuckle**" — the convex shadow on the left border of the mediastinal silhouette, just below the clavicle — and, in the left anterior oblique projection, the "**aortic window**" (a radiolucent area between the aortic arch above and the bifurcation of the pulmonary trunk below) is seen just caudal to this level (AK Datta).
- ▶ Multidetector CT with multiplanar/3-D reconstruction and MR angiography are now the standard modalities for delineating the arch and its branches at this level in life, correlating directly with the cadaveric cross-section described here.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

embed: ![Fig 11.1 — Transverse section of thorax at the level of the upper part of T4 vert (IB Singh — Textbook of Anatomy Vol 2 — 6e, p.142)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/868cd3bad2f8140b.jpg)

Reproduce a transverse (inferior-view) section with the following labels:

- ▶ Manubrium sterni (anterior)
- ▶ Body of T4 vertebra (posterior)
- ▶ Superior vena cava (right side)
- ▶ Arch of aorta with the openings of its three branches (brachiocephalic trunk, left common carotid, left subclavian)
- ▶ Trachea / bifurcation of trachea (carina)
- ▶ Oesophagus (immediately behind trachea)
- ▶ Thoracic duct (posterolateral to oesophagus, left side)
- ▶ Right lung and left lung (bulk of the section)
- ▶ Pleural cavity and parietal pleura (lining each hemithorax)

Applied / Clinical anatomy

- ▶ An **aortic arch aneurysm** at this level can compress the trachea (stridor, dyspnoea) and the oesophagus (dysphagia — "dysphagia aortica"), and can stretch or compress the left recurrent laryngeal nerve, producing hoarseness of voice.
- ▶ **Superior mediastinal masses** encountered at this level — a retrosternal ("plunging") goitre descending from the neck, thymoma, lymphoma, and germ-cell tumours arising in the thymic remnant — present as a widened mediastinal shadow on chest radiograph and are precisely localised by axial CT/MRI at this level.
- ▶ **Left recurrent laryngeal nerve palsy** from a bronchogenic carcinoma of the left lung apex, an enlarging aortic arch aneurysm, or iatrogenic injury during ligation of a patent ductus arteriosus is explained by the nerve's intimate relation to the arch at this level.
- ▶ **Chylothorax**, from injury to the thoracic duct during thoracic surgery (e.g., oesophagectomy) at or near this level, follows from the duct's posterolateral (left-sided) relation to the oesophagus here.

- ▶ The T4 level is a key reference plane for **nodal staging** of bronchogenic and oesophageal carcinoma on CT (paratracheal and aortopulmonary-window nodal stations) and for confirming safe **central venous catheter** tip position, which should lie well below this level, at the SVC–right atrial junction.
- ▶ Understanding this level is essential for interpreting axial CT/MRI thorax images and for identifying the correct plane in cross-sectional practical/OSCE stations, which frequently use a photograph or CT slice at exactly this level.

High-yield exam pointers

- ▶ T4 level cuts the **superior mediastinum**; the adjacent T5 level (sternal angle/transverse thoracic plane) marks the junction of superior and inferior mediastina.
- ▶ **Arch of aorta** is the single most important structure at this level — seen as a half-cut oblique tube giving off brachiocephalic trunk, left common carotid, and left subclavian arteries.
- ▶ **Trachea lies anterior to oesophagus; oesophagus lies anterior to the vertebral body.**
- ▶ SVC lies to the right of, and anterior to, the aortic arch.
- ▶ **Thoracic duct** lies posterior and to the left of the oesophagus.
- ▶ The **carina** (tracheal bifurcation) commonly correlates with the T4 level on axial CT (Gray's Anatomy 41e).
- ▶ **Thymus/its remnant** is the most anterior mediastinal structure, in the retrosternal triangular space.
- ▶ Only **upper-lobe** lung parenchyma is seen — the section lies above the pulmonary hila.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Anatomy Vol 2, 6e (Chapter: Cross-Sectional, Radiological and Surface Anatomy of Thorax); Moore's Clinically Oriented Anatomy 9e; AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen).



Cross sectional anatomy of Upper pons

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction — The pons, the middle segment of the brainstem, is conventionally studied in transverse section at **two standard levels** because its internal grey/white-matter pattern changes along its length — a **lower (caudal) level through the facial colliculus** (VI/VII nerve nuclei) and an **upper (rostral, cranial) level through the motor and principal sensory nuclei of the trigeminal nerve**. At every level the pons is divided by a plane along the floor of the fourth ventricle into a large ventral **basilar (ventral) part**, whose structure is uniform throughout its length, and a dorsal **tegmentum**, whose contents differ between the two levels. The upper-pons section is a classic RGUHS spotter/essay because it is the only pontine level at which the **trigeminal motor and main sensory nuclei** are cut and the **superior cerebellar peduncle** (not the inferior) bounds the fourth ventricle, forming the anatomical basis of the jaw-jerk and corneal reflexes and of trigeminal-neuralgia localisation.

1. Plane of section and gross zonal division

- ▶ The section is taken through the **upper (cranial) part of the pons**, at the level where the **motor and principal (main) sensory nuclei of the trigeminal (V) nerve** lie in the tegmentum.
- ▶ The pons is divisible into a **basilar part** (ventral, continuous below with the pyramids of the medulla and laterally with the middle cerebellar peduncle) and a **tegmental part** (dorsal, the direct upward continuation of the medullary tegmentum, i.e. the medulla minus the pyramids).
- ▶ At this level the small, narrowing cavity of the **fourth ventricle** is bounded dorsolaterally on each side by the **superior cerebellar peduncle** and roofed by the **superior medullary velum** — replacing the inferior cerebellar peduncle and wide rhomboid floor seen at the lower (facial-colliculus) level.
- ▶ Nuclear components of the **abducent (VI), facial (VII) and vestibulocochlear (VIII) nerves**, together with the **trapezoid body**, are *not* seen at this level — they belong to the lower pontine section.

2. Grey matter at the upper pontine level

Structure	Position / features
Motor nucleus of trigeminal nerve	Dorsolateral tegmentum, beneath the lateral part of the fourth ventricle; its efferent fibres pass anteriorly through the pons and emerge on its anterior (basilar) surface as the motor root of V
Principal (main) sensory nucleus of trigeminal nerve	Lies lateral to the motor nucleus; continuous caudally with the spinal nucleus of V and rostrally with the mesencephalic nucleus of V in the midbrain
Mesencephalic nucleus of V (lower end)	Begins to appear at this level, lateral part of the central grey; contains unipolar proprioceptive neurones (the only primary sensory cell bodies inside the CNS), conveying stretch impulses from the muscles of mastication

Structure	Position / features
Nucleus of the lateral lemniscus	Small relay nucleus lying medial to the (now well-formed) lateral lemniscus; relay in the auditory pathway
Locus coeruleus (nucleus pigmentosus pontis)	Lateral pontine tegmentum near the floor of the fourth ventricle, related to the superior cerebellar peduncle; extends from the lower midbrain down to this pontine level; noradrenergic (cell group A6)
Parabrachial nuclei / Kölliker–Fuse nucleus	Lateral tegmental grey related to the superior cerebellar peduncle; part of the pneumotaxic centre regulating respiratory rhythm
Reticular formation	Present throughout, as at every brainstem level

3. White matter (fibre tracts) at this level

- ▶ Immediately dorsal to the basilar part, four lemnisci lie side by side, **medial to lateral: medial lemniscus** (most anterior, somatotopically arranged neck–arm–trunk–leg, medial to lateral), **trigeminal lemniscus** (crossed trigeminothalamic fibres from the spinal and principal sensory nuclei of V), **spinal lemniscus** (anterior + lateral spinothalamic tracts), and the **lateral lemniscus** (auditory pathway, now well formed, unlike the lower level).
- ▶ **Superior cerebellar peduncles** occupy the dorsolateral tegmentum on each side, bounding the narrowed fourth ventricle (efferent cerebellar outflow to the red nucleus/thalamus; their decussation occurs slightly more rostrally, at the inferior-collicular level of the midbrain).
- ▶ **Medial longitudinal fasciculus (MLF)** — paramedian, in the most posterior part of the tegmentum, interconnecting nuclei of III, IV, VI, vestibular nuclei and the spinal accessory nucleus for conjugate eye/head movements.
- ▶ **Tectospinal tract** — lies ventral to the MLF.
- ▶ **Central tegmental tract** and scattered extrapyramidal/autonomic fibres are also present.
- ▶ **Rubrospinal tract** lies in the lateral tegmentum, close to the superior cerebellar peduncle.

4. Basilar (ventral) part — constant at every pontine level

- ▶ **Grey matter** — the **pontine nuclei**, scattered among longitudinal and transverse fibres; they form the relay of the **corticopontocerebellar pathway**, projecting to the *opposite* half of the cerebellum.
- ▶ **White matter, longitudinal fibres** — **corticospinal and corticonuclear (pyramidal) tracts**, and **corticopontine fibres** ending on the pontine nuclei.
- ▶ **White matter, transverse fibres** — **pontocerebellar fibres**, arising from the pontine nuclei, decussating, and entering the contralateral cerebellar hemisphere via the **middle cerebellar peduncle**.

5. Upper vs lower pons — key differentiating points

Feature	Lower (facial colliculus) level	Upper (trigeminal) level
Peduncle bounding 4th ventricle	Inferior cerebellar peduncle	Superior cerebellar peduncle
Roof of 4th ventricle	Wide rhomboid floor	Narrowing cavity, roofed by superior medullary velum
Cranial nerve nuclei	VI, VII (facial colliculus), vestibular & cochlear (VIII), spinal nucleus of V, superior salivatory/lacrimal	Motor + principal sensory nuclei of V ; (VI, VII, VIII nuclei absent)
Trapezoid body	Present (decussating cochlear fibres)	Absent
Lemnisci (ventral tegmentum)	Medial + spinal lemniscus only (lateral lemniscus not yet formed)	Four lemnisci : medial, trigeminal, spinal, lateral (all well formed)
Locus coeruleus	Just beginning	Well developed, continuous with midbrain
Classic lesion	Millard–Gubler syndrome	Trigeminal sensory/motor deficits, loss of corneal & jaw-jerk reflexes

6. Blood supply

- ▶ **Paramedian branches** of the basilar artery supply the medial basilar (ventral) part.
- ▶ **Short circumferential branches** supply the anterolateral pons.
- ▶ **Long circumferential branches**, together with contributions from the **superior cerebellar artery (SCA)** and **anterior inferior cerebellar artery (AICA)**, supply the posterolateral tegmentum, including the superior cerebellar peduncle and trigeminal nuclei at this level.
- ▶ Venous drainage is via pontine veins to the petrosal and basal veins.

□ Fig 5.10 — TS of upper pons (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.521)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse section through the upper (cranial) part of the pons and label, dorsal to ventral / medial to lateral:

- ▶ **Fourth ventricle** (small, narrowed cavity), roofed by the **superior medullary velum**, bounded dorsolaterally on each side by the **superior cerebellar peduncle**
- ▶ **Motor nucleus of trigeminal nerve** (dorsolateral, medial to the sensory nucleus) with its **emerging motor root** passing anteriorly through the pons
- ▶ **Principal (main) sensory nucleus of trigeminal nerve**, lateral to the motor nucleus
- ▶ **Locus coeruleus** near the floor of the ventricle, medial to the superior cerebellar peduncle
- ▶ **Medial longitudinal fasciculus (MLF)**, paramedian, posterior tegmentum; **tectospinal tract** ventral to it
- ▶ Four lemnisci, medial to lateral, immediately behind the basilar part: **medial lemniscus** — **trigeminal lemniscus** — **spinal lemniscus** — **lateral lemniscus** (label as "MTSL")
- ▶ **Reticular formation**, occupying the central tegmentum
- ▶ **Basilar (ventral) part**: scattered **pontine nuclei** among **longitudinal fibres** (corticospinal, corticonuclear, corticopontine) and **transverse pontocerebellar fibres** passing into the **middle cerebellar peduncle** on each side

Applied / Clinical anatomy

- ▶ **Jaw-jerk reflex** — the only significant supraspinal monosynaptic stretch reflex: stretch of the jaw-closing muscles (masseter, temporalis, medial pterygoid) is sensed by muscle-spindle afferents whose unipolar cell bodies lie in the **mesencephalic nucleus of V**; these project monosynaptically onto the **motor nucleus of V** at this pontine level, which drives the jaw-closing muscles. An exaggerated jaw jerk indicates a bilateral upper motor neurone lesion *above* the pons (pseudobulbar palsy); an absent jaw jerk suggests a lesion of the trigeminal nuclei/nerve itself.
- ▶ **Corneal reflex** — afferent limb via the ophthalmic division of the trigeminal nerve to the principal sensory/spinal nucleus of V; efferent limb bilaterally via the facial nerve nucleus (orbicularis oculi). Loss of the corneal reflex is an early sign of a lesion involving the trigeminal nuclei or nerve at this level, e.g. in cerebellopontine-angle tumours.
- ▶ **Trigeminal neuralgia** — classically due to neurovascular compression of the trigeminal nerve root at its entry into the upper pons, most often by an aberrant loop of the **superior cerebellar artery**; microvascular decompression at this root entry zone relieves the pain in most cases.
- ▶ **Cerebellopontine-angle syndrome (acoustic neuroma)** — an enlarging Schwann-cell tumour of the vestibulocochlear nerve can extend to compress the adjacent trigeminal nerve/nuclei, adding loss of the corneal reflex and facial numbness to its tinnitus, deafness, vertigo and ipsilateral facial (VII)/cerebellar (flocculus) signs.
- ▶ **Locked-in syndrome** — thrombosis of the short circumferential branches of the basilar artery infarcts the **basilar (ventral) part of the pons** (present at every pontine level, including this one), destroying corticospinal/corticonuclear fibres bilaterally. The patient is quadriplegic and aphonic

but **conscious** (reticular formation spared) with **normal sensation** (ascending tracts spared); preserved vertical eye movements/blinking allow limited communication.

- ▶ **Upper (dorsal) pontine tegmental infarction** — occlusion of long circumferential or superior cerebellar artery branches here gives ipsilateral cerebellar ataxia (superior cerebellar peduncle), contralateral loss of pain/temperature and touch (spinal/medial lemnisci), and, if the trigeminal nuclei are involved, ipsilateral facial sensory loss with absent corneal reflex — illustrating the brainstem localising rule of an *ipsilateral* cranial-nerve deficit with a *contralateral* long-tract deficit.
- ▶ **Radiological correlate** — on axial CT/MRI at this level the paired superior cerebellar peduncles flank the narrow fourth ventricle dorsally, the trigeminal nuclei lie in the dorsolateral tegmentum, and the basilar pons lies ventrally; this is the standard slice used to localise trigeminal root/nucleus pathology and pontine tegmental infarcts.

Recent advances

- ▶ Ultra-high-field 7-T MRI of the human brainstem (susceptibility and quantitative-frequency mapping, validated against ex vivo histology) can now directly resolve the transverse pontocerebellar fibres, the superior cerebellar peduncles, the lateral lemniscus, and the parabrachial and locus coeruleus nuclei at the rostral (upper) pontine level in living subjects — structures previously identifiable only on light microscopy — improving in vivo localisation of upper-pons pathology (Donatelli et al., *European Radiology Experimental*, 2023;7:99) [PMID: 37968363].
- ▶ A 2025 case report demonstrates how targeted MRI sequences at the **trigeminal root entry zone** can detect subtle neurovascular contact with signal change even in previously operated, refractory trigeminal neuralgia, reinforcing MRI's role in confirming true neurovascular conflict at the upper-pons trigeminal root before repeat microvascular decompression (Borges et al., *Revista de Neurología*, 2025;80(9):e42818) [PMID: 41201151].
- ▶ (According to PubMed.)

High-yield exam pointers

- ▶ Upper pons cross-section is taken at the level of the **motor and principal sensory nuclei of the trigeminal nerve**; distinguish from the lower (facial-colliculus) level.
- ▶ Fourth ventricle bounded here by the **superior cerebellar peduncle** (not inferior) and roofed by the **superior medullary velum**.
- ▶ Nuclei of VI, VII, VIII and the **trapezoid body** are absent at this level.
- ▶ Four lemnisci lie ventral tegmentum, medial to lateral: **medial — trigeminal — spinal — lateral** ("MTSL").
- ▶ **Locus coeruleus** and the **pneumotaxic centre** (parabrachial/Kölliker–Fuse nuclei) lie in the lateral tegmentum here.
- ▶ Basilar part is constant at every level: **pontine nuclei** + corticospinal/corticonuclear/corticopontine fibres + pontocerebellar fibres to the middle cerebellar peduncle.

- ▶ **Jaw jerk** = mesencephalic nucleus of V (afferent) → motor nucleus of V (efferent), the only supraspinal monosynaptic reflex; **corneal reflex** = sensory nucleus of V (afferent) → facial nucleus (efferent).
- ▶ Clinical correlates: trigeminal neuralgia (SCA compression at root entry zone), cerebellopontine-angle syndrome, locked-in syndrome (bilateral basal-pons infarct).
- ▶ Blood supply: paramedian, short- and long-circumferential branches of the basilar artery, plus AICA and SCA contributions.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3-4 8e (figure); Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; IB Singh's Textbook of Anatomy Vol 3 6e.



CT scan

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction

Computed tomography (CT), also called computerised axial tomography (CAT) scanning, is a cross-sectional radiological imaging technique in which a rotating X-ray tube and an opposing array of detectors measure the differential attenuation of X-rays as they pass through the body, and a computer reconstructs this attenuation data into a "slice" or tomogram (Greek *tomo* = cut/slice) of the part being examined. Each picture element (pixel)/volume element (voxel) of the reconstructed image is assigned a radiodensity value on the **Hounsfield scale**. CT was invented and introduced into clinical use by **Godfrey N. Hounsfield in 1970**; because CT images correspond almost exactly to true anatomical cross-sections, CT is the single most important modality linking radiological anatomy to gross anatomy, and forms the backbone of modern cross-sectional anatomy teaching.

Principle and technique of image formation

- ▶ Plain radiographic techniques give only a **two-dimensional projection of a three-dimensional structure**, so structures in the path of the beam overlap one another. CT overcomes this by producing true cross-sectional images.
- ▶ Within the **gantry** of the scanner, the **X-ray tube and the detector array rotate together around the long axis of the body**; a fan-shaped beam is sent through the body from many angular positions during a single 360° rotation.
- ▶ Detectors opposite the tube measure the transmitted (unabsorbed) radiation from each projection; these overlapping radial absorption measurements are processed by a computer, which calculates the **mean attenuation coefficient of each voxel** in the chosen plane.
- ▶ Voxel attenuation depends on the amount of air, water, fat or bone present; the computer displays this as a regular **matrix of pixels**, with high-attenuation tissue (bone) appearing white (radiopaque) and low-attenuation tissue (air) appearing black (radiolucent) — the same convention as a plain film.

- ▶ Because data are gathered for the whole volume scanned, the computed matrix holds information about the entire part; the scanner can generate slices at any level and, via **multiplanar reconstruction (MPR)**, reformat the same dataset into sagittal, coronal, oblique or even three-dimensional images.
- ▶ **Viewing convention:** axial (transverse) CT/MRI images are viewed as though standing at the foot of a supine patient looking towards the head; coronal images as if the patient faces the observer; sagittal images as if standing at the patient's left side.
- ▶ Modern scanners allow up to **25° of gantry angulation** (useful in spinal imaging); direct coronal imaging of the head/face is now largely superseded by MPR from a helical dataset.

□ Fig 16.9 — CT scan of the abdomen with contrast in an axial plane. (Source: Fig. 4.88A, Page 289, *Gray's Anatomy for Students*, Drake, Vogl, Mitchell.) (Vishram Singh — *General Anatomy* — 4e, p.667)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled block diagram of the CT imaging chain:

- ▶ **Gantry** enclosing the **X-ray tube** and the opposing **detector array**, both rotating around the **axis of rotation** (the patient's long axis)
- ▶ **Fan-shaped X-ray beam** traversing the body part
- ▶ **Patient couch/table**, which advances the patient longitudinally through the gantry (continuously, in spiral/helical CT)
- ▶ **Computer/console**, receiving the detector signals and reconstructing the attenuation matrix into an image
- ▶ The reconstructed **axial "slice"**, drawn as a cross-sectional grey-scale image oriented as if viewed from the patient's feet

Hounsfield scale, attenuation and windowing

- ▶ Each pixel's mean attenuation value is compared with that of water and displayed on the **Hounsfield scale**, where water is defined as **0 HU**.

Tissue	Attenuation (Hounsfield units)
Air	about –1000
Fat	about –100
Water (reference)	0
Soft tissue (muscle, viscera)	+20 to +70
Bone	greater than +400

- ▶ The HU range (roughly –1000 to +1000 or more) far exceeds the number of grey shades the eye can discriminate, so the operator selects a display "**window**" — a chosen **window width and window level (centre)** — that spreads only the HU range of interest across the visible grey scale. A narrow window is used for soft tissue (brain, abdominal viscera), and wider **lung window** and **bone window** settings display aerated lung and cortical bone without losing detail at the extremes.

- ▶ Windowing lets the same raw dataset be re-displayed as a lung-window, bone-window or soft-tissue-window image without re-scanning the patient — this is routinely exploited when the same acquisition is used to assess both the lung parenchyma and the mediastinum/skeleton on a single chest CT.
- ▶ In CT terminology, a high-attenuation area is described as showing **increased density**, and a low-attenuation area as showing **decreased density**, on the printed image.

Evolution of CT technology

- ▶ **Conventional (axial/step-and-shoot) CT (CCT)**: an early movable X-ray tube with detector(s) rotates in an arc to acquire one slice; the table then increments before the next slice — the original Hounsfield design.
- ▶ **Spiral/helical CT (SCT)**: the table moves continuously while the tube rotates continuously, so the beam traces a **spiral (helical) path**. Continuous volumetric acquisition lets images be viewed from any angle, overlying structures removed by computer manipulation, and display enhanced by colour coding.
- ▶ **Multidetector/multislice helical CT (MDCT)**: multiple detector rows acquire several slices per rotation in sub-second times, so a whole-body scan (skull base to thighs) is completed within one breath-hold. This permits **dynamic imaging** of vessels at successive contrast phases (CT angiography) and routine **multiplanar reconstruction (MPR)** in sagittal/coronal planes.
- ▶ **3-D reconstruction**: since the scanned volume is a continuous data set, the computer can also generate surface/volume-rendered 3-D images from the same acquisition.

Contrast media used with CT

- ▶ **Radiopaque (positive) contrast**: aqueous iodinated compounds given intravenously to opacify vessels and enhance solid organs/lesions (basis of contrast-enhanced CT and CT angiography), or given orally/rectally to opacify the gastrointestinal lumen.
- ▶ **Radiolucent (negative) contrast**: gas/air, occasionally used to distend a hollow viscus.
- ▶ **Functions**: (1) delineation of tubular/luminal and vascular structures that would otherwise blend with surrounding soft tissue; (2) **lesion enhancement** — an abnormal mass differentiated from normal parenchyma by its distinct pattern/timing of enhancement.
- ▶ No specific preparation is generally needed for CT of the brain, spine or musculoskeletal system; chest/abdomen/pelvis studies usually need IV iodinated contrast, which defines vascular relationships and differentiates normal from pathological soft tissue.

Advantages, limitations and comparison with allied imaging modalities

Feature	CT	Plain radiograph	Ultrasonography	MRI
Uses ionising radiation	Yes	Yes	No	No
Type of image	True cross-sectional (tomographic)	2D projection, with superimposition	Real-time cross-sectional	Cross-sectional, any plane

Feature	CT	Plain radiograph	Ultrasonography	MRI
Soft-tissue contrast	Moderate	Poor	Moderate, operator-dependent	Excellent
Best demonstrates	Bone, lung, acute haemorrhage, calcification, trauma	Skeletal/chest survey	Foetus, gallbladder/biliary tree, cystic vs solid masses, Doppler flow	Brain and spinal cord, joints, soft-tissue tumours
Typical scan time	Seconds	Instantaneous	Real time	Several minutes
Safe with pacemaker/ferromagnetic implant	Yes	Yes	Yes	No (may be an absolute contraindication)

- **Advantages:** rapid acquisition (valuable in trauma/critically ill patients); excellent depiction of deep-seated lesions, bone and lung parenchyma; permits MPR, 3-D reconstruction and CT angiography; safe with pacemakers/metallic implants (unlike MRI); more widely available and cheaper than MRI.
- **Limitations:** uses **ionising radiation** (cumulative dose a concern, especially in children/pregnancy); inferior soft-tissue contrast versus MRI; needs **iodinated contrast** for many studies, with risk of contrast reactions/nephrotoxicity; prone to artefact from metal implants and motion.

Recent advances in CT imaging

- **Photon-counting detector CT (PCD-CT):** converts each X-ray photon directly into an electrical signal (single-step), unlike conventional scintillation detectors — improving spatial resolution, reducing electronic noise, and giving inherent spectral (energy-resolved) information without a dual-source design, enabling further reduction of radiation and iodinated-contrast dose. Benefit across cardiac, thoracic, neurovascular, abdominal, musculoskeletal and paediatric imaging is now supported by a large, growing high-impact literature base (De Bondt et al, *J Belgian Soc Radiol* 2026) [DOI: 10.5334/jbsr.4190]; ("Toward Broader Clinical Adoption of Photon-Counting CT," *Radiology* 2026) [DOI: 10.1148/radiol.251496]; (Rajendran et al, *Radiology* 2022) [PMID: 34904876].
- **Deep-learning image reconstruction (DLR):** AI-trained algorithms are progressively replacing filtered back-projection/iterative reconstruction, giving diagnostic-quality images from lower-dose acquisitions. **TrueFidelity** (GE, 2019) was the first FDA-cleared DLR technique, followed by **Precise Image** (Philips, 2022); both now routinely lower dose in coronary CT angiography and abdominal/low-dose lung/urolithiasis protocols (Koetzier et al, *Radiology* 2023) [PMID: 36719287].
- **CT coronary angiography (CTCA)** is now endorsed as a first-line investigation for stable chest pain, given its high negative predictive value for excluding obstructive coronary disease (Ihdayhid et al, *Heart Lung Circ* 2023) [PMID: 36610819].

(According to PubMed/journal sources cited above; DOIs: 10.5334/jbsr.4190, 10.1148/radiol.251496, 10.1148/radiol.221257, 10.1016/j.hlc.2022.12.003.)

Applied / Clinical anatomy

- ▶ **Cross-sectional anatomy teaching:** axial CT slices of the thorax, abdomen and pelvis are correlated with cadaveric transverse sections at defined vertebral levels to teach the disposition of great vessels, viscera and mediastinal/retroperitoneal structures — the most direct link between CT and gross/radiological anatomy in the MD/MS curriculum.
- ▶ **Trauma imaging:** whole-body ("pan-scan") CT is the investigation of choice in the haemodynamically stable polytrauma patient, rapidly detecting intracranial/intra-abdominal haemorrhage, solid-organ injury and complex fractures.
- ▶ **CT angiography (CTA):** contrast-enhanced volumetric CT of cerebral, pulmonary, coronary or peripheral vessels has replaced conventional catheter angiography for most diagnostic indications.
- ▶ **Oncology:** central to tumour detection, staging, response monitoring, and radiotherapy planning ("simulation CT").
- ▶ **Image-guided intervention:** CT guides percutaneous biopsy, abscess drainage and tumour ablation with precise anatomical localisation.
- ▶ **Specialised CT:** HRCT of lung parenchyma, temporal bone and paranasal sinuses; CT urography; CT colonography ("virtual colonoscopy").
- ▶ **Radiosensitive groups:** ultrasonography/MRI are preferred over CT in pregnancy and children whenever diagnostically adequate, because of ionising radiation.

High-yield exam pointers

- ▶ CT (CAT scan) invented and introduced clinically by **Godfrey N. Hounsfield in 1970**.
- ▶ Principle: X-ray tube and detector array rotate together around the body; the computer calculates the **attenuation of each voxel** and reconstructs a true cross-sectional slice — overcoming the 2D-superimposition limitation of plain radiography.
- ▶ **Hounsfield unit (HU)** scale, water = 0: air $\approx$ -1000, fat $\approx$ -100, soft tissue +20 to +70, bone > +400.
- ▶ **Windowing** (width + level) allows the same raw dataset to be displayed as lung, bone or soft-tissue window images.
- ▶ Evolution: **conventional (step-and-shoot) CT** → **spiral/helical CT (continuous gantry + table motion)** → **multidetector/multislice CT (MDCT)** — sub-second, single-breath-hold whole-body scans with routine **multiplanar reconstruction (MPR)**.
- ▶ Viewing convention: axial images viewed as if standing at the patient's feet; coronal as if the patient is facing you; sagittal as if standing at the patient's left side.
- ▶ CT vs MRI: CT is faster, cheaper and safe with pacemakers/metal implants, and is superior for bone/lung/acute haemorrhage; MRI has superior soft-tissue contrast and no ionising radiation.
- ▶ Iodinated contrast media (IV) opacify vessels and enhance lesions for CT angiography; oral/rectal contrast opacifies the GI lumen.

- Name a recent advance: **photon-counting detector CT** combined with **deep-learning image reconstruction**, giving higher spatial resolution at lower radiation dose.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — General Anatomy 4e; Moore's Clinically Oriented Anatomy 9e; IB Singh — Textbook of Anatomy Vol 1 6e. Recent-advances citations are from PubMed/indexed journals (2022–2026) per the answer-bank's recency-enrichment method.



Describe in detail about the Radiological techniques used in Abdomen and pelvis

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction

Radiological (imaging) anatomy of the abdomen and pelvis is the study of the disposition, size and contour of abdominal and pelvic viscera by techniques that visualise internal structures without surgical intervention. Plain radiography rests on differential absorption of X-rays — dense tissues such as bone absorb more and appear white (radiopaque), while air-filled structures absorb least and appear black (radiolucent), soft tissue and fluid being intermediate grey. Since most abdominal viscera are soft-tissue organs of similar density, several complementary methods — plain radiography, contrast radiography, ultrasonography (USG), computed tomography (CT) and magnetic resonance imaging (MRI) — have been developed to outline them individually and demonstrate pathological lesions.

1. Classification of imaging techniques used in the abdomen and pelvis

Category	Sub-type	Principal abdominopelvic application
Methods using ionizing radiation	Conventional imaging — (i) plain radiography (ii) contrast radiography	KUB film; barium studies, pyelography, cholecystography, hysterosalpingography
	Computed tomography (CT/CAT) scanning — conventional (CCT), spiral/helical (SCT)	Cross-sectional imaging of solid organs, retroperitoneum, trauma, staging
	Radioisotope scanning (nuclear medicine) — SPECT, PET	Functional/metabolic imaging, tumour staging
Methods not using ionizing radiation	Ultrasonography (USG)	Gallbladder, kidney, pancreas, uterus, ovaries, prostate
	Magnetic resonance imaging (MRI)	Pelvic soft tissues, rectal/prostatic/cervical staging, MRCP

2. Plain radiography (plain skiagram/KUB) of the abdomen

- ▶ **Nomenclature:** the anteroposterior plain film of the abdomen is variously called the *straight film* (taken in acute abdomen), *survey/scout film* (taken before a contrast study) or **KUB film** (Kidney–Ureter–Bladder), the acronym reflecting its principal use.
- ▶ **Preparation:** the gastrointestinal tract is emptied of food, gas and faeces — antitflatulents/laxatives for about 3 days, oral fasting for about 12 hours, and an enema if constipated; an unprepared film is used only in surgical emergencies, where gas/faecal shadows may mask significant findings.
- ▶ **Systematic reading:**
 - **Bony shadows** — lower ribs, lumbar vertebrae, upper hip bones, sacrum and sacroiliac joints; used as landmarks and screened for fractures/scoliosis.
 - **Soft-tissue shadows** — domes of the diaphragm, psoas major margins, kidney outlines (made visible by lucent perirenal fat), liver below the right dome, spleen.
 - **Gas shadows** — the gastric fundal air bubble under the left dome of the diaphragm; scattered intestinal gas, often intermixed with faecal shadows.
 - **Abnormal shadows** — calcified renal/biliary calculi, pancreatic calcification, free sub-diaphragmatic gas (perforation), and abnormal air-fluid levels or distended loops (intestinal obstruction).

□ Fig 36.1 — Plain X-ray abdomen (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.535)

Substance	Radiographic shadow
Gas/air	Black (radiolucent)
Fat	Dark grey
Soft tissue	Light grey
Fluid	Hazy
Bone/calcification	White (radiopaque)
Metal/contrast media	Brilliant white

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Sketch an outline of the bony pelvis and lower ribs on either side of the vertebral column and label: lower ribs, lumbar vertebrae (bodies + transverse processes), upper part of hip bones, sacrum with sacroiliac joints, psoas major shadow (both sides), renal outline (perirenal fat), gastric fundal air bubble under left dome of diaphragm, liver shadow below right dome, scattered bowel-gas shadows.

3. Contrast radiography of the gastrointestinal tract — barium studies

A radiopaque suspension of barium sulphate (inert, insoluble, not absorbed from the gut) is used to outline the mucosal pattern of the alimentary canal under fluoroscopy or on serial films; air may be added for a **double-contrast** study that better shows haustral/mucosal detail. A good contrast medium

must be non-toxic, adequately radiopaque or radiolucent, easily administrable and easily available; organic iodides are used for the biliary and urinary tracts and iodized oil for the genital passage.

Study	Technique	Key radiological findings
Barium swallow	50% barium suspension swallowed 2–3 times, patient erect behind the fluoroscope	Oesophagus outlined posterior to the aortic arch, left bronchus and left atrium; left-atrial enlargement narrows the oesophageal shadow
Barium meal	300–400 mL of 5% suspension drunk, serial films under fluoroscopy	Stomach shows a triangular mass below the fundal air bubble; duodenal cap (poorly-developed circular folds); jejunum/ileum show a feathery/floccular pattern; medium reaches the ileocaecal region in 3–4 h, hepatic flexure ~6 h, splenic flexure ~9 h, descending colon ~11 h, sigmoid colon ~16 h; evacuated in 16–24 h
Barium enema	~2 L suspension via rectum from a can 2–4 ft high; stopped when barium reaches the terminal ileum	Rectum and sigmoid colon dilated; characteristic haustrations, most prominent proximally; double-contrast method (air after evacuation) accentuates the mucosal outline

4. Contrast radiography of the urinary tract — pyelography and cystography

Pyelography (urography) visualises the pelvicalyceal system, ureter and bladder by an iodine-based radiopaque dye, named according to the route of administration.

Feature	Excretory / descending / intravenous pyelography (IVP)	Retrograde / ascending pyelography
Route of dye	20–40 cc of a warm iodine compound (urograffin 60–76% or Conray 420/280) injected intravenously	5–10 mL of 6–8% sodium iodide (Conray 280) injected via a ureteric catheter passed through a cystoscope
Timing	Serial films at 5, 15 and 30 minutes; peak concentration at 15–20 min, bladder filled by 30 min	Injection stopped when the patient complains of pain; >10 mL suggests hydronephrosis; general anaesthesia is contraindicated (risk of pelvic overdistension)

Feature	Excretory / descending / intravenous pyelography (IVP)	Retrograde / ascending pyelography
Normal findings	Minor calyces cup-shaped (renal papillae project into them); renal pelvis funnel-shaped; ureter traced along tips of lumbar transverse processes, sacroiliac joint and ischial spine to the bladder; bladder oval/triangular	Only one renal pelvis outlined at a time; the ureteric catheter is itself visible on the film
Value	Both an anatomical and a physiological (functional) test	Technically difficult, done only by urologists

Cystography visualises the lower urinary tract by injecting dye directly into the bladder through a cystoscope.

5. Contrast studies of the biliary tract and female genital tract

- ▶ **Cholecystography** (now largely superseded) — contrast excreted by the liver and concentrated in the gallbladder is given orally overnight or intravenously; films taken 14–16 hours later outline the gallbladder, cystic duct and bile duct; non-visualisation suggests hepatic impairment, cystic-duct block or obstructive liver disease.
- ▶ **Endoscopic retrograde cholangiopancreatography (ERCP)** — contrast is injected into the common bile duct via a catheter passed through an endoscope, outlining the intrahepatic radicles, bile duct, pancreatic duct and gallbladder; also used therapeutically (stone extraction, stenting).
- ▶ **Hysterosalpingography (HSG)** — performed within the first 5–10 days of the menstrual cycle; a cannula placed in the internal os delivers 5–10 mL of iodized oil (lipiodol), outlining the uterine cavity and uterine tubes; spill of dye into the peritoneal cavity through the tubal ostia confirms tubal patency — the principal indication being the work-up of female infertility.

6. Cross-sectional and non-ionizing imaging — ultrasonography, CT and MRI

- ▶ **Ultrasonography** — a beam of high-frequency sound (3.5–20 MHz) is reflected as echoes at tissue interfaces and reconstructed into a real-time image; it is non-invasive, uses no ionizing radiation, and is the **investigation of choice for the gallbladder** (seen as a cystic, oval, narrow-necked shadow in the right upper quadrant along with the bile duct and portal vein) as well as for the kidneys, pancreas, uterus, ovaries and prostate; gas and bone are poorly penetrated, limiting bowel and osseous imaging; Doppler USG additionally assesses blood flow in major abdominal vessels.
- ▶ **Computed tomography (CT)** — a rotating X-ray source/detector acquires multiple angular projections reconstructed by computer into axial slices, each voxel's mean attenuation displayed on the **Hounsfield scale**; spiral CT permits multiplanar reconstruction, and oral/intravenous contrast is routinely used to opacify bowel and vasculature.

Tissue	Approximate Hounsfield value
Air	≈ −1000 HU
Fat	≈ −100 HU
Water	0 HU (reference)
Soft tissue	+20 to +70 HU
Bone	> +400 HU

Cross-sectional (CT/MRI) study of the abdomen is conventionally described at four transverse levels:

Vertebral level	Key structures seen
T10	Oesophagogastric junction; crura of diaphragm; aorta and IVC; costodiaphragmatic recesses; liver (right), stomach/spleen (left)
T12	Pyloric antrum/canal; gallbladder first appears; coeliac trunk division; superior poles of kidneys with suprarenal glands; portal triad
L1–L2 (just below transpyloric plane)	Renal hila with renal vessels; uncinat process of pancreas; origin of superior mesenteric artery/vein
L3–L4	Bowel loops suspended by mesentery; branches of the aorta in the mesentery; IVC to the right of the aorta; abdominal wall muscle layers

- **Magnetic resonance imaging (MRI)** — exploits resonance of hydrogen protons (abundant in body water/fat) placed in a strong magnetic field and excited by radiofrequency pulses; **T1-weighted** images give the best "anatomy weighting" (fluid dark, fat bright) while **T2-weighted** images render fluid bright; it is entirely non-ionizing, gives superior soft-tissue contrast to CT, and images in any plane — making it the modality of choice for staging pelvic malignancy (rectal, cervical, prostatic) and for MR cholangiopancreatography (MRCP).

Applied / Clinical anatomy

- A KUB film is the first investigation in renal/ureteric colic (radiopaque calculi), acute abdomen (free sub-diaphragmatic gas of perforation) and intestinal obstruction (air-fluid levels, distended loops).
- Barium studies remain valuable for peptic ulcer, gastric carcinoma, diverticular disease and intussusception; barium is contraindicated if perforation is suspected — water-soluble Gastrografin is substituted.
- IVP demonstrates hydroureter/hydronephrosis proximal to an obstruction; the ureter's skeletal relations (lumbar transverse-process tips → sacroiliac joint → ischial spine → pubic tubercle) are key to interpreting urograms.
- USG is first-line in acute cholecystitis/cholelithiasis, renal-mass characterisation (solid vs cystic), ovarian cysts and obstetric assessment.
- Hysterosalpingography is central to female infertility work-up (tubal patency) and detecting uterine anomalies.

- ▶ CT is primary in abdominal trauma (solid-organ injury) and intra-abdominal/pelvic malignancy staging; MRI is preferred for rectal, cervical and prostatic cancer staging, and is contraindicated with pacemakers or ferromagnetic implants.

High-yield exam pointers

- ▶ KUB = Kidney–Ureter–Bladder view; a *scout* film precedes any contrast study.
- ▶ Barium sulphate is inert, insoluble and radiopaque; never given if gut perforation is suspected.
- ▶ Descending (IV) pyelography is both anatomical and functional; retrograde (ascending) pyelography visualises one side at a time and shows the catheter — general anaesthesia is contraindicated in it.
- ▶ Hounsfield scale: air $\approx$ -1000 HU, fat $\approx$ -100 HU, water = 0 HU, soft tissue $+20$ to $+70$ HU, bone $> +400$ HU.
- ▶ Ultrasonography is the investigation of choice for the gallbladder and most pelvic soft-tissue organs — no ionizing radiation.
- ▶ Hysterosalpingography is timed to days 5–10 of the cycle; peritoneal spill of dye confirms tubal patency.
- ▶ On cross-sectional imaging, the gallbladder first appears at the T12 level and the renal hila at the L1–L2 level (just below the transpyloric plane).
- ▶ MRI: T1-weighted = "anatomy weighting" (fat bright, fluid dark); T2-weighted = fluid bright; no ionizing radiation.
- ▶ ERCP and cholecystography both use contrast excreted by the liver, but ERCP delivers it directly into the bile duct via an endoscope, while cholecystography relies on oral/intravenous absorption.

SOURCE & COVERAGE

BD Chaurasia's Human Anatomy, Vol 2, 8e (Radiological and Imaging Procedures); IB Singh's Textbook of Anatomy, Vol 2, 6e (Cross-Sectional, Radiological and Surface Anatomy of Abdomen and Pelvis); Vishram Singh's General Anatomy, 4e (Radiological/Imaging Anatomy); Gray's Anatomy (Standring) 41e (Hounsfield scale/CT attenuation values); Weir & Abrahams' Imaging Atlas of Human Anatomy, 6e (CT voxel/Hounsfield methodology, MRI weighting terminology, USG frequency range).

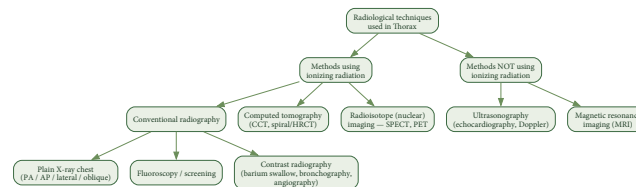


Describe in detail about the Radiological techniques used in Thorax

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction Radiological (imaging) anatomy of the thorax is the study of the bones, lungs, mediastinum, heart, great vessels and airway as depicted by medical imaging, used to diagnose structural and functional disease without invasive intervention. Wilhelm Conrad Röntgen discovered X-rays in November 1895, and the plain chest radiograph remains, even today, the single most requested investigation in clinical medicine. Imaging is based on the principle of **differential absorption** — tissues of different density (air < fat < water/soft tissue < bone < contrast media/metal) attenuate the X-ray beam to different degrees, producing radiolucent (dark) and radiopaque (white) shadows on the film. Techniques used to study the thorax are conventionally grouped into those using **ionizing radiation** (plain and contrast radiography, CT, radioisotope imaging) and those that do **not** (ultrasonography, MRI).

1. Classification of radiological techniques used in the thorax



Describe in detail about the Radiological techniques used in Thorax

2. Plain radiography (X-ray chest)

- ▶ A plain skiagram of the chest is the commonest thoracic investigation; it is conventionally taken as a **postero-anterior (PA) view**, with the patient erect, in full inspiration and both hands placed on the waist/hips so that the scapulae are pulled clear of the lung fields.
- ▶ In PA view, X-rays travel posterior→anterior and strike a film placed anteriorly; structures closer to the film are sharper, so PA is preferred for lung/heart detail, while an **AP (supine/portable) view** is used in bed-bound patients and better shows the thoracic spine.
- ▶ **Lateral and oblique views** supplement the PA film by removing overlapping shadows; an apical lordotic view better profiles the lung apices.
- ▶ Structures to be systematically studied on a PA chest film:

Structure	Radiographic appearance
Soft tissues	Nipples (both sexes) and breast shadow over lower lung fields
Bones	Posterior rib ends denser (more calcium) than anterior; costal cartilages unseen unless calcified; vertebrae and scapular margins may overlap lung fields
Trachea	Air-filled radiolucent shadow in the midline neck, opposite lower cervical/upper thoracic vertebrae

Structure	Radiographic appearance
Diaphragm	Two dome-shaped shadows, right slightly higher than left; costophrenic angles at the pleural reflection; gastric air bubble under the left dome, liver shadow under the right
Lungs	Translucent on full inspiration; divided into upper (to 2nd costal cartilage), middle (2nd–4th, includes hilum) and lower zones; hilar shadows are dense (bronchi, pulmonary/bronchial vessels, nodes)
Mediastinal (cardiovascular) shadow	Right border (above down): right brachiocephalic vein, superior vena cava, right atrium, inferior vena cava. Left border (above down): aortic knuckle/arch, pulmonary trunk, left auricle, left ventricle

- **Cardiothoracic assessment:** the transverse cardiac diameter is normally about half the transverse thoracic-cage diameter; the heart becomes tubular and descends on deep inspiration. Three habitus-related patterns of the cardiovascular shadow occur — **transverse** (obese, pregnant, infants), **oblique** (majority) and **vertical** (narrow-chested). A film exceeding the normal ratio suggests cardiomegaly; loss of the sharp costophrenic angle suggests pleural effusion.

□ Fig 21.9 — X-ray chest PA view. (A) Actual radiograph and (B) tracing of the cardiac shadow (Vishram Singh — *Textbook of Anatomy Vol 1 — 4e, p.825*)

3. Fluoroscopy (screening)

- Instead of recording the image on film, the X-ray beam is projected on a fluorescent screen and viewed directly (or via an image intensifier); this permits a **dynamic, real-time study** — e.g., movements of the diaphragmatic domes during inspiration/expiration can be observed.
- Detail is inferior to a static film, and the radiation dose to patient/operator is a limitation, but fluoroscopy is still used to guide catheter placement, bronchography and contrast swallow studies.

4. Contrast (special) radiological procedures of the thorax

- **Barium swallow (oesophagogram):** a 50% suspension of barium sulphate is swallowed 2–3 times while the patient stands behind the fluoroscopic screen; the normal oesophagus lies posterior to the aortic arch, the left principal bronchus and the left atrium. An enlarged left atrium (e.g., mitral stenosis) indents/narrows the oesophageal shadow — a classic sign taught with this technique.
- **Bronchography:** a radio-opaque (iodized-oil) contrast medium is instilled into the tracheobronchial tree via a catheter and X-rays outline the bronchial tree; largely superseded by CT but retained as the teaching example of airway contrast study.
- **Coronary angiography:** contrast dye is injected into the coronary vessels under fluoroscopic guidance; the resulting angiogram localises sites of coronary narrowing.
- Contrast media are either **radiopaque** (barium sulphate, organic iodine compounds) or **radiolucent** (air/gas, used for double-contrast technique); a good contrast medium must be non-toxic, adequately radiopaque/radiolucent, and easy to administer.

□ Fig 11.3 — Cross-section (axial section) of thorax obtained by CT scan; section viewed from the foot end of the patient, passing through the upper part of the heart (mainly atria), just below the tracheal bifurcation. Air-filled areas (lungs, bronchial lumen) appear dark (IB Singh — Textbook of Anatomy Vol 2 — 6e, p.143)

5. Cross-sectional imaging — Computed Tomography (CT) of the thorax

- ▶ **Principle:** a movable X-ray tube and a computerised detector (scanner) rotate around the body part; radiodensity at every point of a thin "slice" is computed and displayed as a cross-sectional (axial) tomogram — hence "computerised (axial) tomography." Invented for clinical use by Godfrey Hounsfield (1970).
- ▶ **Spiral (helical) CT:** the patient table moves longitudinally while the tube rotates continuously, so the beam traces a spiral path; this large volumetric dataset can be reformatted by computer into images in any plane, and unwanted structures can be digitally removed.
- ▶ Transverse CT/MR images of the thorax are conventionally viewed **as if from the patient's feet** — the top of the image is anterior and the image's left edge is the patient's right side.
- ▶ Two classic transverse levels are taught for cross-sectional/CT anatomy of the thorax:
 - **Upper part of T4 vertebra** (superior mediastinum): arch of aorta cut obliquely, giving off the brachiocephalic trunk, left common carotid and left subclavian arteries; oesophagus anterior to the vertebral body, trachea anterior to the oesophagus, SVC to the right of the arch, thymus anteriorly, thoracic duct posterolateral (left) to the oesophagus.
 - **Upper part of T5 vertebra** ("angle of Louis" section, manubriosternal joint/2nd costal cartilage level): ascending aorta anterior and descending aorta posterior to the pulmonary trunk, which bifurcates here into right and left pulmonary arteries; the trachea has just bifurcated, so right and left principal bronchi lie behind the pulmonary-trunk bifurcation and in front of the oesophagus; terminal SVC, azygos vein, mediastinal lymph nodes and (posterior to the descending aorta, on the left) the thoracic duct are also seen.
- ▶ **High-resolution CT (HRCT)** of the lung parenchyma and CT pulmonary angiography are modern extensions of this same principle (see Coverage note).

6. Magnetic resonance imaging (MRI) of the thorax

- ▶ **Principle:** MRI images the physiological distribution of hydrogen protons (abundant in body water/fat) using a strong external magnetic field plus radiofrequency pulses (nuclear magnetic resonance, NMR); the emitted signal is computer-reconstructed into an image. It uses **no ionizing radiation**.
- ▶ **Weighting:** T1-weighted images show fluid dark and fat bright; T2-weighted images show fluid bright — used to characterise mediastinal masses and fluid collections.
- ▶ MRI is particularly useful for **soft-tissue contrast** in the mediastinum — delineating the mediastinal viscera, lymph nodes and lung roots, and for examining the breast — and can be reconstructed as axial, sagittal or coronal sections, or as a **reconstructed MR angiogram** of the heart and great vessels to display all cardiac chambers and vessels non-invasively.

7. Ultrasonography and echocardiography

- ▶ **Echocardiography** (ultrasonic cardiography) records the position and movement of the heart from echoes of a high-frequency ultrasound beam reflected at tissue interfaces; it can detect even small pericardial effusions and small structural lesions.

- ▶ **Doppler echocardiography** additionally records the direction, volume and velocity of blood flow through the cardiac chambers and great vessels — used to assess valve function and shunts.
- ▶ General USG principles apply: gas/bone poorly transmit sound, so the air-filled lung itself is not well imaged by ultrasound, restricting its thoracic use mainly to the heart, pleura (effusion) and chest wall.

8. Radioisotope (nuclear medicine) imaging

- ▶ A gamma-emitting radioisotope (commonly **technetium-99m** or an iodine isotope) is introduced into the body and taken up selectively by target tissue; a gamma camera detects the emission. Increased uptake creates a "hot" area, reduced uptake a "cold" area.
- ▶ **SPECT** and **PET** are the tomographic (3-D, sectional) forms of nuclear imaging; PET in particular reveals metabolic/functional change at the cellular level (useful in staging thoracic malignancy) earlier than the structural change detectable on CT or MRI.

9. Bronchoscopy

- ▶ A rigid (older) or fibre-optic flexible (modern) bronchoscope is passed down the trachea to directly visualise the tracheobronchial tree; at the tracheal bifurcation the **carina**, a keel-like ridge separating the two principal bronchi, is identified.
- ▶ Uses: direct visualisation, obtaining bronchial secretions/tissue for examination, and removal of foreign bodies. The carina's appearance is distorted, widened and immobile when infiltrated by metastatic tracheobronchial lymph nodes, as in bronchogenic carcinoma — an important diagnostic sign.

Applied / Clinical anatomy

- ▶ **Pleural effusion**: fluid in the costodiaphragmatic recess blunts/obliterates the costophrenic angle on a PA film.
- ▶ **Cardiomegaly**: transverse cardiac shadow exceeds half the thoracic-cage width.
- ▶ **Mitral stenosis**: barium swallow shows posterior indentation of the oesophagus by an enlarged left atrium.
- ▶ **Bronchogenic carcinoma**: widened, immobile carina on bronchoscopy/CT; altered hilar shadow on plain film.
- ▶ **Foreign-body aspiration**: more often lodges in the right main bronchus (wider, shorter, more vertical than the left) — retrieved by bronchoscopy.
- ▶ **Position-dependent variation**: gravity makes the arch of aorta, tracheal bifurcation and diaphragm shift relative to the sternal-angle plane between supine and erect posture — relevant when comparing a portable/ICU film with a standing film.
- ▶ **Aortic-arch aneurysm** may stretch the left recurrent laryngeal nerve (hoarseness), and is detectable as mediastinal widening on chest radiograph/CT.

High-yield exam pointers

- ▶ PA view is standard for chest films; AP is used when the patient cannot stand (portable/ICU).

- ▶ Right heart border (top→bottom): brachiocephalic vein, SVC, right atrium, IVC. Left heart border: aortic knuckle, pulmonary trunk, left auricle, left ventricle.
- ▶ Barium swallow — oesophagus lies posterior to the aortic arch, left bronchus, and left atrium; enlarged left atrium narrows/indents the oesophageal shadow.
- ▶ Carina — keel-shaped ridge at tracheal bifurcation; widened and fixed carina = tracheobronchial lymph-node metastasis (bronchogenic carcinoma).
- ▶ CT/MRI thoracic slices are read from the patient's feet — image's anterior surface is "up," image's left is the patient's right.
- ▶ T4 CT level = arch of aorta with its three branches; T5 CT level = bifurcation of the pulmonary trunk and of the trachea ("angle of Louis" level).
- ▶ Echocardiography = ultrasonic cardiography; Doppler echo adds blood-flow/velocity data.
- ▶ MRI uses hydrogen-proton NMR, no ionizing radiation; T1 = fluid dark, T2 = fluid bright.
- ▶ Nuclear imaging (SPECT/PET) uses technetium-99m/iodine isotopes; PET detects metabolic change earliest, useful in lung cancer staging.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Anatomy Vol 2, 6e ("Cross-Sectional, Radiological and Surface Anatomy of Thorax"); BD Chaurasia — Human Anatomy Vol 1, 8e ("Surface Marking and Radiological Anatomy of Thorax"); Vishram Singh — General Anatomy 4e ("Radiological/Imaging Anatomy") and Vishram Singh — Textbook of Anatomy Vol 1, 4e; Moore's Clinically Oriented Anatomy 9e (Radiography, CT and MRI of the Mediastinum).

Coverage note: the corpus grounds plain radiography, fluoroscopy, barium studies, bronchography, coronary angiography, T4–T5 cross-sectional/CT anatomy, MRI weighting, echocardiography/Doppler and basic nuclear-imaging principles in detail. HRCT protocols and V/Q scintigraphy specifics are only lightly covered and are given here at standard textbook level.



Describe the section of the midbrain at the level of the superior colliculi

Asked in: Paper IV Oct 2006 — RGUHS MD/MS Anatomy

Definition / Introduction — The midbrain (mesencephalon) is the short (~2 cm), narrow segment of the brainstem connecting the pons/cerebellum below to the diencephalon above; its cavity, the cerebral aqueduct (of Sylvius), links the third and fourth ventricles. It is conventionally studied by cutting transverse sections at two levels — through the inferior colliculi and through the superior colliculi. The section through the superior colliculi is taken through the rostral (upper) half of the midbrain and is a favourite viva/theory cut because it uniquely shows the oculomotor nuclear complex, the red nucleus in full cross-section, and the laminated superior colliculus.

Orientation and Subdivisions of the Section

- ▶ The cerebral aqueduct lies centrally, surrounded by the **periaqueductal (central) grey matter**; the section is divided by the aqueduct into a posterior **tectum** and an anterior **cerebral peduncle**.
- ▶ The **tectum** (roof), lying posterior to the aqueduct, is formed at this level by the two **superior colliculi**, joined across the midline by the **posterior (tectal) commissure**.
- ▶ Each **cerebral peduncle** (anterior to the aqueduct) is subdivided, from front to back, into three parts: the **crus cerebri** anteriorly, the **substantia nigra** in the middle, and the **tegmentum** posteriorly.
- ▶ On surface view, the two superior colliculi are larger than the inferior pair and together with them form the corpora quadrigemina; the **oculomotor (III) nerve** emerges ventrally through the interpeduncular fossa at this level (the trochlear nerve, by contrast, emerges at the lower, inferior-collicular level).

Grey Matter at This Level

Structure	Position	Chief connections / function
Oculomotor nucleus	Ventromedial part of central grey, close to midline; the two sides fuse into a single triangular complex	Motor supply to extra-ocular muscles (except lateral rectus and superior oblique)
Edinger–Westphal nucleus	Dorsal to the rostral two-thirds of the oculomotor nucleus (part of the III nerve complex)	Parasympathetic supply to sphincter pupillae and ciliaris via ciliary ganglion
Mesencephalic nucleus of trigeminal nerve	Lateral edge of central grey, same position as at the inferior-collicular level	Unipolar first-order proprioceptive neurons from muscles of mastication, TMJ, ocular and facial muscles

Structure	Position	Chief connections / function
Superior colliculus	Tectum; a flattened, laminated mass of seven alternating grey/white layers	Afferents: retina (mainly contralateral, via lateral geniculate body/superior brachium), spinal cord (spinotectal), frontal & occipital visual cortex, inferior colliculus. Efferents: tectospinal and tectobulbar tracts — reflex turning of eyes, head and neck to visual stimuli
Pretectal nucleus	Deep to the superolateral part of the superior colliculus	Afferents from lateral root of optic tract; efferents to Edinger–Westphal nuclei of both sides — relay for the pupillary light and consensual reflexes
Red nucleus	Ovoid, ~0.5 cm diameter, dorsomedial to substantia nigra; pink in fresh tissue (rich vascularity + iron pigment)	Afferents: contralateral dentate nucleus via decussating superior cerebellar peduncle, corticorubral fibres, pallidorubral fibres, subthalamic nucleus, substantia nigra. Efferents: rubrospinal, rubro-olivary, rubroreticular, rubrothalamic tracts
Substantia nigra	Crescentic band between tegmentum and crus cerebri, continuing from the lower level	Pars compacta (dopaminergic, melanin-pigmented) projects nigrostriatal fibres to corpus striatum; pars reticulata is GABAergic
Reticular formation	Ventrolateral part of tegmentum, smaller than at pontine levels	Diffuse ascending/descending integrative connections

White Matter at This Level

- **Crus cerebri** contains the same three tract groups as at the inferior-collicular level: **corticospinal and corticonuclear fibres** in the middle two-thirds, **frontopontine fibres** in the medial one-sixth, and **parieto-, occipito- and temporopontine fibres** in the lateral one-sixth.
- **Lemnisci** — the medial, trigeminal and spinal lemnisci continue upward as a curved band dorsomedial to the substantia nigra; the **lateral lemniscus is no longer present at this level**, since it has already terminated in the nucleus of the inferior colliculus below.
- **Medial longitudinal fasciculus (MLF)** lies ventrolateral to the oculomotor nucleus, carrying vestibular and interconnecting fibres to the III, IV, VI nerve nuclei.
- **Dorsal tegmental decussation (of Meynert)** — formed by the crossing tectospinal and tectobulbar fibres arising from the superior colliculus.
- **Ventral tegmental decussation (of Forel)** — formed by the crossing rubrospinal fibres arising from the red nucleus.

- ▶ **Central tegmental tract** traverses the tegmentum, linking red nucleus/reticular formation to the inferior olivary complex.
- ▶ **Emerging fibres of the oculomotor nerve** pass ventrally through the tegmentum, piercing the red nucleus and the medial part of the substantia nigra, to emerge in the interpeduncular fossa through a sulcus on the medial surface of the crus cerebri.

□ Fig 21.16 — A transverse section of the midbrain at the level of the superior colliculi. (Gray's Anatomy — Standring — 41e, p.451)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw an oval outline (crus cerebri anteriorly, tegmentum posteriorly) with the small central aqueduct, and label: Cerebral aqueduct, Superior colliculus, Periaqueductal (central) grey matter, Reticular formation, Medial geniculate nucleus, Oculomotor nucleus (with Edinger–Westphal nucleus), Medial longitudinal fasciculus, Red nucleus, Substantia nigra, Interpeduncular fossa, Central tegmental tract, Parieto-, occipito- and temporopontine fibres, Medial lemniscus, Corticospinal and corticonuclear fibres, Frontopontine fibres, Emerging oculomotor nerve fibres, Crus cerebri, Posterior perforated substance.

Key Point-of-Difference from the Inferior Collicular Level

Feature	Superior colliculus level	Inferior colliculus level
Cranial nerve emerging	Oculomotor (III), ventrally	Trochlear (IV), dorsally, after decussating in superior medullary velum
Somatic efferent nucleus	Oculomotor nucleus (+ Edinger–Westphal)	Trochlear nucleus
Tectal grey mass	Superior colliculus (visual reflex centre)	Inferior colliculus (auditory relay)
Lateral lemniscus	Absent (already terminated)	Present, in the lemniscal band
Prominent decussation	Dorsal & ventral tegmental decussations	Decussation of superior cerebellar peduncles
Named grey nucleus in tegmentum	Red nucleus (full cross-section)	Nucleus of the inferior colliculus

Blood Supply

- ▶ Chiefly by the **basilar artery** and its terminal branches; also by the **posterior cerebral artery**, **superior cerebellar artery**, **posterior choroidal artery**, and branches of the **anterior choroidal artery**.
- ▶ Venous drainage is into the **great cerebral vein** and the **basal vein**.

Applied / Clinical Anatomy

- ▶ **Weber's syndrome (superior alternating hemiplegia)** — occlusion of a paramedian/circumflex branch of the posterior cerebral artery damages the crus cerebri and the emerging oculomotor nerve, producing ipsilateral third-nerve palsy (ptosis, dilated fixed pupil, "down-and-out" eye)

with contralateral hemiplegia (corticospinal involvement) and contralateral weakness of the lower face and tongue (corticobulbar involvement).

- ▶ **Benedikt's syndrome** — a tegmental lesion involving the red nucleus, medial and spinal lemnisci, superior cerebellar peduncle fibres and the emerging oculomotor fibres, giving ipsilateral III nerve palsy with contralateral loss of proprioception/vibration and pain/temperature sensation, plus contralateral tremor and involuntary movements (red nucleus/cerebellar peduncle involvement).
- ▶ **Parinaud's syndrome** — compression of the superior colliculi, classically by a pineal region tumour, causes selective loss of upward conjugate gaze.
- ▶ **Argyll Robertson pupil** — a lesion of the pretectal nucleus/pathway abolishes the pupillary light reflex while the accommodation reflex is preserved.
- ▶ **Parkinsonism** — degeneration of the substantia nigra pars compacta (dopaminergic neurons visible at this level too) causes striatal dopamine deficiency, producing rigidity, bradykinesia and resting tremor.
- ▶ Surgical/radiological relevance: the level of the superior colliculi is the key landmark for pineal region and quadrigeminal cistern imaging, and for stereotactic localisation of the red nucleus and substantia nigra.

High-yield exam pointers

- ▶ Section is cut through the tectum (paired superior colliculi + posterior commissure) and cerebral peduncle (crus cerebri, substantia nigra, tegmentum).
- ▶ Only the **oculomotor nucleus** (with Edinger–Westphal) is seen at this level; the trochlear nucleus belongs to the inferior-collicular section.
- ▶ The **lateral lemniscus disappears** at this level — a key differentiator from the lower section.
- ▶ Red nucleus, substantia nigra and mesencephalic nucleus of V are seen at both levels, but the red nucleus is best/most completely seen here.
- ▶ Two decussations characterise the tegmentum: **dorsal tegmental (of Meynert)** — tectospinal/tectobulbar; **ventral tegmental (of Forel)** — rubrospinal.
- ▶ Superior colliculus = visual reflex centre (7 laminae); connects with retina, spinotectal tract, visual cortex, inferior colliculus.
- ▶ Clinical eponyms to recall: Weber's, Benedikt's, Parinaud's syndromes and the Argyll Robertson pupil.
- ▶ Crus cerebri fibre order (medial→lateral): frontopontine, corticonuclear/corticospinal, parieto-occipito-temporopontine.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 3-4 8e (Brainstem); Vishram Singh — Clinical Neuroanatomy 4e (Brainstem chapter).



Describe the structure of mid brain at the level of superior colliculus

Asked in: Paper IV Nov 2017 — RGUHS MD/MS Anatomy

Definition / Introduction — The midbrain (mesencephalon) is the shortest and narrowest part of the brainstem, about 2 cm long, connecting the pons below to the diencephalon above. Its cavity, the **cerebral aqueduct (of Sylvius)**, connects the third and fourth ventricles. Because the grey- and white-matter pattern changes along its length, the midbrain is conventionally studied in transverse section at two standard planes — a lower plane through the **inferior colliculi** and an upper plane through the **superior colliculi**. The superior-collicular section is a favourite RGUHS spotter/essay because it is the only level at which the **oculomotor nuclear complex (III nucleus + Edinger–Westphal nucleus)**, the **red nucleus** and the **pretectal nucleus** are cut — the anatomical basis of Weber's, Benedikt's and Parinaud's syndromes.

1. Plane of section and gross zonal division

- ▶ The section passes through the two **superior colliculi** on the dorsal (tectal) surface and through the emerging **oculomotor (III) nerve** rootlets in the interpeduncular fossa ventrally.
- ▶ The **cerebral aqueduct**, surrounded by **central (periaqueductal) grey matter**, divides the section into a small dorsal **tectum** (the paired superior colliculi and the posterior commissure) and a much larger ventral **cerebral peduncle**.
- ▶ Each cerebral peduncle is further subdivided, posterior to anterior, into the **tegmentum**, the **substantia nigra**, and the **crus cerebri (basis pedunculi)**.
- ▶ **Crus cerebri** — purely descending fibres arranged medial to lateral: **frontopontine fibres** (medial one-sixth), **corticospinal and corticonuclear fibres** (middle two-thirds), and **temporo-, parieto- and occipitopontine fibres** (lateral one-sixth).
- ▶ **Substantia nigra** — a pigmented lamina of grey matter between tegmentum and crus cerebri, present at every midbrain level; concerned with control of muscle tone.

2. Grey matter at the level of the superior colliculi

Structure	Position	Salient features
Central (periaqueductal) grey matter	Surrounds the cerebral aqueduct	Houses the oculomotor and mesencephalic-trigeminal nuclei
Nucleus of the oculomotor nerve (III)	Ventromedial part of the central grey matter	The nuclei of the two sides lie very close together, almost as a single complex; related ventrally to the medial longitudinal fasciculus; fibres pass forward through the red nucleus and medial substantia nigra to emerge in the interpeduncular fossa; supplies 4½ extraocular muscles (all except lateral rectus and superior oblique)

Structure	Position	Salient features
Edinger–Westphal nucleus	Forms part of the oculomotor complex, dorsal to the main nucleus	Parasympathetic preganglionic neurones; fibres relay in the ciliary ganglion to supply sphincter pupillae and ciliaris — mediates the light reflex and accommodation
Mesencephalic nucleus of the trigeminal nerve	Lateral part of the central grey matter (same position as at the inferior-collicular level)	Unipolar first-order sensory cells; carries proprioception from the muscles of mastication, facial/ocular muscles, teeth and temporomandibular joint
Superior colliculus	Tectum	Laminated grey matter forming the visual reflex centre (see section 4)
Pretectal nucleus	Deep to the superolateral part of the superior colliculus	Receives the lateral root of the optic tract; projects bilaterally to the Edinger–Westphal nuclei — the relay for the pupillary light reflex; its lesion produces the Argyll Robertson pupil
Red nucleus	Rounded/ovoid mass, about 0.5 cm in diameter, dorsomedial to the substantia nigra	Appears for the first time at this level ; pink/red in the fresh state owing to vascularity and an iron-containing pigment in its neurons
Substantia nigra	Between tegmentum and crus cerebri	Present at all midbrain levels (see section 1)

3. White matter at the level of the superior colliculi

- **Ascending lemnisci** — the **medial, trigeminal and spinal lemnisci** continue as a curved bundle, lying **more laterally** than at the inferior-collicular level because of the intervening red nucleus. The **lateral lemniscus is no longer present**, having already terminated in the inferior colliculus below.
- **Crus cerebri** — same fibre arrangement as described above (frontopontine / corticospinal-corticonuclear / temporo-parieto-occipitopontine).
- **Dorsal tegmental decussation** — crossing of the **tectospinal and tectobulbar fibres** arising in the superior colliculus, sweeping ventral to the central grey matter.
- **Ventral tegmental decussation** — crossing of the **rubrospinal fibres** arising in the red nucleus.
- **Medial longitudinal fasciculus** — lies close to the midline, ventral/ventrolateral to the oculomotor nuclear complex; links the nuclei of cranial nerves III, IV, VI and the vestibular nuclei with each other and with the cervical spinal cord, coordinating conjugate eye and head movements.
- **Reticular formation** — present at this level as at every level of the brainstem, situated lateral to the decussating fibres.

- ▶ **Emerging oculomotor nerve fibres** — pass ventrally through the red nucleus and the medial part of the substantia nigra to leave on the medial side of the crus cerebri, in the interpeduncular fossa; the human oculomotor nerve carries about 15,000 axons.
- ▶ **Posterior commissure** — in the tectum, connecting the two superior colliculi/pretectal regions.

4. The superior colliculus — detailed structure and connections

- ▶ **Lamination** — the superior colliculus is an obviously laminated structure with **seven alternating grey/white layers** from surface to depth: zonal, superficial grey (stratum cinereum), optic, intermediate grey, deep grey, deep white, and periventricular strata.
- ▶ **Afferents** — the retina (chiefly the contralateral field, via the optic tract and lateral geniculate region, giving a retinotopic map with the fovea represented anterolaterally), the spinal cord (spinotectal fibres carrying pain/touch), the occipital and temporal visual cortex (corticotectal fibres, concerned with ocular-following movements), and the inferior colliculus.
- ▶ **Efferents** — form the **tectospinal and tectobulbar tracts**, which decussate as the dorsal tegmental decussation and descend to the cervical cord and to the motor nuclei of the ocular cranial nerves; other efferents pass to the pretectal nucleus, lateral geniculate body and pulvinar.
- ▶ **Function** — the principal visual reflex centre of the brainstem: mediates reflex conjugate movements of the eyes, head and neck in response to visual (and some auditory/somatic) stimuli; connected to the lateral geniculate body by the **superior brachium**.

□ Fig 5.15 — TS of midbrain at the level of superior colliculus (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.524)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a transverse section through the upper (rostral) part of the midbrain and label, dorsal to ventral:

- ▶ **Tectum:** paired **superior colliculi** (with alternating laminae), **posterior commissure** joining them, **superior brachium** at the margin, **pretectal nucleus** deep to the superolateral part of each colliculus
- ▶ **Cerebral aqueduct**, surrounded by **central (periaqueductal) grey matter**
- ▶ **Tegmentum:** fused **oculomotor (III) nuclear complex** in the ventromedial central grey with the **Edinger–Westphal nucleus**; **mesencephalic nucleus of V** in the lateral central grey; **medial longitudinal fasciculus**; **dorsal tegmental decussation** (tectospinal/tectobulbar); paired **red nuclei**; **ventral tegmental decussation** (rubrospinal) around them; combined **medial, trigeminal and spinal lemnisci** lateral to the red nucleus; emerging **oculomotor nerve (III)** rootlets coursing through the red nucleus and substantia nigra
- ▶ **Substantia nigra**, ventral to each red nucleus
- ▶ **Crus cerebri**, labelled medial to lateral: frontopontine, corticospinal/corticonuclear, temporo-parieto-occipitopontine fibres
- ▶ **Interpeduncular fossa** between the two crura, with the emerging oculomotor nerve

5. Distinguishing the superior-collicular level from the inferior-collicular level

Feature	Inferior-collicular level	Superior-collicular level
Collicular nucleus	Inferior colliculus — auditory relay; receives lateral lemniscus; efferents via inferior brachium to medial geniculate body	Superior colliculus — visual reflex centre; efferents via superior brachium to lateral geniculate body
Cranial nerve nucleus	Trochlear (IV) nucleus , ventromedial central grey; its fibres pass dorsally and decussate in the superior medullary velum	Oculomotor (III) nucleus with Edinger–Westphal nucleus
Grey matter unique to the level	—	Red nucleus and pretectal nucleus appear for the first time
Lemnisci present	Four — medial, trigeminal, spinal and lateral	Three — medial, trigeminal and spinal (lateral lemniscus already terminated)
Tegmental decussation	Decussation of the superior cerebellar peduncles	Dorsal tegmental decussation (tectospinal/tectobulbar) + ventral tegmental decussation (rubrospinal)

6. Blood supply

- **Arterial** — branches of the basilar artery, together with the **posterior cerebral**, **superior cerebellar**, **posterior communicating** and **anterior choroidal** arteries.
- **Venous** — drains into the great cerebral vein (of Galen) and the basal veins.

Applied / Clinical anatomy

Syndrome / condition	Structures damaged	Clinical picture
Weber's syndrome	Emerging oculomotor (III) fibres + crus cerebri (occlusion of a branch of the posterior cerebral artery)	Ipsilateral III nerve palsy — ptosis, dilated pupil fixed to light and accommodation, eye deviated down and out; contralateral hemiplegia (corticospinal fibres)
Benedikt's syndrome	III nerve fibres + red nucleus + medial lemniscus ($\pm$ superior cerebellar peduncle)	Same ipsilateral III palsy, plus contralateral loss of proprioceptive/tactile sensation and contralateral tremor/involuntary movements from red-nucleus damage
Parinaud's syndrome	Superior colliculi / posterior commissure (classically compression by a pineal-region tumour)	Paralysis of conjugate upward gaze, with vertical nystagmus
Argyll Robertson pupil	Pretectal nucleus or its connections (classically neurosyphilis)	Light reflex lost; accommodation reflex retained
Aqueductal obstruction	Tumour or gliotic narrowing of the cerebral aqueduct at this level	Non-communicating (obstructive) hydrocephalus with dilatation of the third and lateral ventricles

- **Localising principle** — a lesion at this level classically produces an *ipsilateral* cranial-nerve deficit (III nerve) with a *contralateral* hemiplegia/hemianaesthesia, since the corticospinal and lemniscal fibres have not yet crossed at this rostral level.
- **Parkinsonism** — although covered fully at the substantia-nigra level common to the whole midbrain, its dopaminergic pars compacta is also transected in this section.

High-yield exam pointers

- The superior-collicular section is the **upper of the two standard transverse-section levels** of the midbrain; the aqueduct separates the tectum (dorsal) from the cerebral peduncle (ventral), and the substantia nigra further splits the peduncle into tegmentum and crus cerebri.
- Structures appearing **only at this level**: **oculomotor nucleus + Edinger–Westphal nucleus, red nucleus, pretectal nucleus**, and the **ventral tegmental decussation** (rubrospinal).
- **Superior colliculus** = seven alternating laminae; visual reflex centre; afferents from retina, spinotectal tract and visual cortex; efferents = tectospinal/tectobulbar tracts crossing in the dorsal tegmental decussation.

- ▶ **Lemnisci**: only three remain (medial, trigeminal, spinal) — the lateral lemniscus has already ended in the inferior colliculus; the bundle lies more lateral than below because the red nucleus intervenes.
- ▶ **Red nucleus** $\approx$ 0.5 cm, dorsomedial to substantia nigra, gives rise to the rubrospinal tract (crosses as the ventral tegmental decussation).
- ▶ Crus cerebri lamination (medial $\rightarrow$ lateral): **frontopontine** (1/6) — **corticospinal/corticonuclear** (2/3) — **temporo/parieto/occipitopontine** (1/6).
- ▶ **Weber** = III nerve + crus cerebri; **Benedikt** = Weber + red nucleus + medial lemniscus; **Parinaud** = superior colliculi/posterior commissure (upward-gaze palsy); pretectal lesion $\rightarrow$ **Argyll Robertson pupil**.
- ▶ Blood supply: basilar artery and its branches, posterior cerebral, superior cerebellar, posterior communicating and anterior choroidal arteries.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; BD Chaurasia's Human Anatomy Vol 3-4 8e (text and figure); IB Singh's Textbook of Human Neuroanatomy.



Cross-Sectional Anatomy of the Upper Limb at the Middle of the Arm

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction A transverse section through the **middle of the arm** (roughly midway between the acromion and the lateral epicondyle, i.e. just below the insertions of deltoid and coracobrachialis) cuts across a single bone, the **humerus**, enclosed in a tubular sleeve of **deep (brachial) fascia**. Medial and lateral **intermuscular septa** pass from this sleeve to the medial and lateral supracondylar ridges of the humerus, dividing the arm into an **anterior (flexor) compartment** and a **posterior (extensor) compartment**, each with its own muscles, one principal nerve and one principal artery. This precise level is a favourite "spot" question because several structures change compartment, side, or plane exactly here, and it is the classic site of radial-nerve injury in shaft-of-humerus fractures.

1. Level of the section and superficial layer

- ▶ **Plane**: transverse cut through the middle third of the arm — below the insertions of deltoid and coracobrachialis, above the point where arm structures fan out into the cubital fossa.
- ▶ **Skin** — circumferential.
- ▶ **Superficial fascia** contains, from lateral to medial:
 - **Cephalic vein** — subcutaneous, along the lateral border of biceps.
 - **Posterior cutaneous nerve of the forearm** (branch of radial nerve) — posterolaterally.
 - **Medial cutaneous nerve of the forearm**, running with the **basilic vein** on the medial side; the basilic vein **pierces the deep fascia** at about this level to become sub-fascial.

- The upper-arm-only cutaneous nerves (intercostobrachial nerve, upper lateral cutaneous nerve of arm) have already ended proximal to this plane and are **not** seen here.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

embed: ![Fig 20.2 — Transverse section of arm at the middle of its length (mid arm section) (IB Singh — Textbook of Anatomy Vol 1 — 6e, p.253)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/195e22d92281bfec.jpg)

Labels to reproduce (draw an oval "skin" outline; a triangular humeral shaft centrally; the anterior compartment muscle mass above/in front of the bone and the posterior compartment mass behind it, separated by medial and lateral intermuscular septa):

- Skin and superficial fascia (outline)
- **Biceps brachii** (anterior, most superficial)
- **Brachialis** (deep to biceps)
- **Triceps brachii** (posterior, all three heads fused into one mass at this level)
- **Humerus** — shaft, triangular in cross-section
- **Musculocutaneous nerve** — between biceps and brachialis
- **Cephalic vein** — subcutaneous, lateral
- **Median nerve** — just medial to the brachial artery
- **Brachial artery** (with venae comitantes)
- **Radial nerve** — anterolateral, between brachialis and the origin of brachioradialis
- **Brachioradialis** — thin muscle origin, lateral
- **Radial collateral arteries** — with the radial nerve
- **Extensor carpi radialis longus** — lateral, next to brachioradialis
- **Middle collateral branch of profunda brachii artery** — posterolateral, close to bone
- **Medial cutaneous nerve of forearm** — subcutaneous, medial
- **Basilic vein** — subcutaneous, medial
- **Superior ulnar collateral artery and Inferior ulnar collateral artery** — medial, close to septum
- **Ulnar nerve** — medial, on the triceps (posterior compartment)

3. Deep fascia, intermuscular septa and the two compartments

Compartment	Boundary	Nerve	Artery
Anterior (flexor)	Deep fascia in front + medial & lateral intermuscular septa	Musculocutaneous nerve (median and ulnar nerves are only in transit, giving no motor branches to arm muscles here)	Brachial artery
Posterior (extensor)	Deep fascia behind + same two septa	Radial nerve	Profunda brachii artery

- ▶ The septa are **thin and ill-defined in the upper third** of the arm but become well-defined from the level of insertion of coracobrachialis downwards — i.e. exactly the level of this section.
- ▶ Some structures deliberately **pierce these septa** to change compartment as they descend — this is the crux of the "middle of the arm" question (see Section 5).

4. Anterior compartment — contents at this level

Structure	Position / relations
Biceps brachii	Both heads already fused into one muscle belly; most superficial anteriorly
Brachialis	Deep to biceps; its upper fibres of origin begin at this level
~~Coracobrachialis~~	Absent — it has already been inserted into the medial surface of the humerus proximal to this level (at the junction of the upper and middle thirds)
Musculocutaneous nerve	Between biceps and brachialis, supplying both; continues below as the lateral cutaneous nerve of the forearm
Median nerve	Has just crossed the brachial artery from lateral to medial side — lies medial to the artery at and below this level
Brachial artery (+ venae comitantes)	On the front of the humerus, having just shifted from the medial side of the arm to its anterior aspect
Radial nerve (+ radial collateral vessels)	Antero-laterally, having pierced the lateral intermuscular septum, running between brachialis (medially) and the origin of brachioradialis (laterally)

5. Posterior compartment — contents at this level

Structure	Position / relations
Triceps brachii	Long, lateral and medial heads form one continuous muscle mass filling the compartment; medial head lies deepest
Ulnar nerve (+ superior & inferior ulnar collateral vessels)	Has just pierced the medial intermuscular septum (together with the superior ulnar collateral artery) and lies on the medial head of triceps, close to the septum
Profunda brachii artery — middle collateral branch	Continues down in the groove close to the bone, posterolaterally, to anastomose behind the lateral epicondyle

6. "Crossing-point" changes that define the middle of the arm

This exact level is chosen for questions because five independent structures change their plane, side or compartment here (level of insertion of coracobrachialis ≈ middle of the arm):

System	Change occurring at this level
Bone	The circular upper shaft of the humerus becomes triangular (3 borders — anterior, medial, lateral; 3 surfaces — anterolateral, anteromedial, posterior)
Nutrient foramen	Directed distally (away from the fast-growing proximal end), opening near the medial border close to this level
Fascia	Medial and lateral intermuscular septa become well-defined from here downward
Muscle	Coracobrachialis and deltoid are inserted at this level; upper end of origin of brachialis and of the medial head of triceps
Artery	Brachial artery passes from the medial side of the arm to its anterior aspect; profunda brachii artery divides into radial collateral (anterior descending) and middle collateral (posterior descending) branches; superior ulnar collateral artery arises and pierces the medial septum with the ulnar nerve; the nutrient artery enters the bone
Vein	Basilic vein pierces the deep fascia to become sub-fascial; the two venae comitantes of the brachial artery may unite into a single brachial vein
Nerve	Median nerve crosses the brachial artery from lateral to medial side; ulnar nerve pierces the medial intermuscular septum into the posterior compartment; radial nerve pierces the lateral intermuscular septum into the anterior compartment

Applied / Clinical anatomy

- **Radial nerve palsy:** the radial nerve and profunda brachii artery run in the spiral (radial) groove on the posterior surface of the humerus, in direct contact with bone — a **mid-shaft fracture of the humerus** commonly injures the radial nerve here, producing **wrist drop** (loss of extension at the wrist and fingers) with sensory loss over a narrow strip on the back of the forearm and the lateral dorsum of the hand.
- Triceps usually **escapes paralysis** in an arm-level radial nerve injury because the branches to its long and lateral heads arise high up, in the axilla/upper arm, proximal to the usual injury site — only elbow extension against the medial head is weak.
- Other causes of radial nerve compression at this level: "**Saturday night palsy**" (arm hanging over a chair edge) and **crutch palsy**.
- **Compartment syndrome of the arm** is uncommon compared with the forearm and leg (the septa here are less rigid), but is recognised after severe trauma or extensive reconstructive/vascular surgery.

- ▶ The **brachial artery** can be compressed most effectively against bone in the middle of the arm (over the flattened area near the coracobrachialis insertion) — relevant to arterial compression for haemorrhage control and to blood-pressure cuff placement over the mid-arm.
- ▶ Because the **median nerve** has already crossed to the medial side of the brachial artery by this level, it (rather than the radial nerve) is the nerve at risk in **supracondylar fractures** of the humerus more distally, together with the brachial artery itself (Volkmann's ischaemic contracture).
- ▶ Brachial artery puncture for **blood gas analysis** and BP auscultation both exploit its superficial, palpable course along the medial border of biceps through the arm.

High-yield exam pointers

- ▶ Single bone (**humerus**) enclosed by deep fascia forming **anterior (flexor)** and **posterior (extensor)** osteofascial compartments via **medial and lateral intermuscular septa**.
- ▶ Anterior compartment nerve = **musculocutaneous**; artery = **brachial**. Posterior compartment nerve = **radial**; artery = **profunda brachii**.
- ▶ **Coracobrachialis** is **absent** at true mid-arm level — it has already inserted proximally.
- ▶ Three nerves show a defining "**crossing**" event at this level: median (lateral→medial across brachial artery), ulnar (anterior→posterior compartment through medial septum), radial (posterior→anterior compartment through lateral septum).
- ▶ Humeral shaft is **triangular** (not circular) from this level downward — 3 borders, 3 surfaces.
- ▶ **Basilic vein** pierces deep fascia here; cephalic vein stays subcutaneous throughout the arm.
- ▶ Radial nerve + profunda brachii artery lie in the **spiral (radial) groove** on the posterior humeral surface just proximal to this plane — the anatomical basis of **wrist drop** in mid-shaft humeral fractures.
- ▶ Mnemonic for anterior compartment muscles proximal to coracobrachialis insertion: "**BBC**" — Biceps, Brachialis, Coracobrachialis.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 1 8e; AK Datta — Human Anatomy Vol 3 (Upper & Lower Limb); Vishram Singh — Textbook of Anatomy Vol 1 4e; IB Singh — Textbook of Anatomy Vol 1 6e (source of the embedded cross-sectional plate, Fig 20.2); Moore's Clinically Oriented Anatomy 9e.



Draw and label the cross sectional anatomy at the level of L1 vertebra

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction A transverse (axial) section through the body of the **first lumbar (L1) vertebra** corresponds almost exactly to the **transpyloric plane of Addison** — a horizontal surface plane lying midway between the suprasternal notch and the pubic symphysis. It is the single most information-dense horizontal section of the trunk: the pylorus, the neck and uncinate process of the pancreas, the origin of the superior mesenteric vessels, the hila of both kidneys, the origin of the portal vein, the cisterna chyli, and the termination of the spinal cord all cluster at this one level. For this reason it is a favourite cross-sectional/radiological anatomy question, and the diagram must be built up systematically — vertebra and canal first, then the posterior-wall muscles and great vessels, and finally the visceral contents — so that every structure is placed correctly relative to the others.

Surface landmark: the transpyloric plane at L1

Feature	Detail
Position	Midway between the suprasternal notch and the pubic symphysis (a hand's-breadth below the xiphisternal joint)
Anterior point	Tip of the 9th costal cartilage of each side, crossed by the linea semilunaris
Posterior point	Body of L1 (may fall from the lower T12 body to the upper L2 body depending on build/sex)
One level above (T12)	Origin of the coeliac trunk; lowest extent of the pleura
At this level	Pylorus (inconstant), neck of pancreas, origin of the SMA, hila of the kidneys, termination of the spinal cord
Just below (upper L2)	Duodenojejunal flexure — 1 cm below the transpyloric plane, 3 cm left of the median plane

Vertebra and vertebral (spinal) canal at L1

- ▶ The **body of L1** is kidney-shaped in transverse section (wider transversely than antero-posteriorly), continuing posteriorly into a pair of short **pedicles**, then the **laminae**, a single midline **spinous process**, and paired **transverse processes** that give origin to slips of psoas major and, more laterally, to the posterior lamina of the thoracolumbar fascia.
- ▶ The **vertebral canal** lies immediately behind the body and contains, from outside in: epidural fat and the internal vertebral venous plexus, the dura mater enclosing the thecal sac, and, within the CSF, the tapering **conus medullaris** or the beginning of the **cauda equina** — in the adult the spinal cord terminates, on average, at the middle third of the body of L1, so a section taken exactly at L1 very often captures the conus–cauda transition.
- ▶ **Anterior and posterior longitudinal ligaments** lie on the front and back of the vertebral body respectively.

Posterior abdominal wall muscles and diaphragmatic crura

- **Psoas major** bulges from each side of the vertebral body and disc; the lumbar **sympathetic trunk** runs along its medial border.
- **Quadratus lumborum** lies posterolateral to psoas major, and the **erector spinae** mass lies further back, flanking the spinous process.
- The **right crus of the diaphragm** (arising from the first three or four lumbar vertebral bodies) and the **left crus** (arising from the first two or three lumbar bodies) are both still present at L1, applied as paired muscular pillars to the front and sides of the vertebral body, flanking the aorta.

Great vessels and lymphatics seen in the section

Structure	Position / relation at L1
Abdominal aorta	Just to the left of the midline, anterior to the vertebral body, between the two crura
Origin of the superior mesenteric artery	Arises from the front of the aorta at this level, just below the coeliac trunk
Origin of the renal arteries	Arise a little lower, at the L1/L2 intervertebral disc level
Inferior vena cava	To the right of the aorta, anterior to the right side of the vertebral body
Left renal vein	Crosses anterior to the aorta, just below the SMA origin, to join the IVC — the classic "nutcracker" angle
Portal vein origin	Behind the neck of the pancreas, formed by confluence of the splenic vein and the superior mesenteric vein
Cisterna chyli	Anterior to the L1–L2 vertebral bodies, to the right of the aorta, deep to the right crus

Visceral (organ) structures seen in the section

Region	Structure(s)
Right side	Liver — a much smaller area than at the T12 section, since most of the gland has already been "left behind" above; gallbladder fundus if the cut is slightly high; right kidney
Left/midline	Pylorus of stomach (an inconstant finding, present in only some sections); neck and uncinate process of pancreas lying anterior to the SMV/splenic-vein confluence
Midline, retroperitoneal	Origin of the superior mesenteric artery and vein; the duodenojejunal flexure lies just below this level (upper L2), held up by the suspensory muscle of the duodenum

Region	Structure(s)
Both sides	Hila of both kidneys with their renal vessels — the single most constant and prominent feature of this section
Anterior peritoneal cavity	Coils of jejunum and part of the transverse colon (root of transverse mesocolon) occupy most of the remaining space
Note	The spleen is not a regular finding at true L1 level — it lies mainly at the T10–T11 level and is only occasionally caught if the cut is high

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 5.104 — Transverse magnetic resonance images (MRIs) of abdomen. A. Level of T10 vertebra and esophageal hiatus. B. Level of L1–L2 vertebra and renal vessels and hilum. C. Level of L5 vertebra and bifurcation of aorta. (Moore — Clinically Oriented Anatomy — 9e, p.926)

(Panel B of this Moore plate — captioned "Level of L1–L2 vertebra and renal vessels and hilum" — is the exact real cross-section for this question; reproduce it freehand for the exam.)

For the hand-drawn exam diagram, draw an oval outline (convex anteriorly, flattened posteriorly over the vertebral body, seen from below) and label, working from the centre outward:

- ▶ **VB / VC** — body of L1 vertebra and vertebral canal (conus medullaris/cauda equina within the thecal sac)
- ▶ **Ao** — abdominal aorta (left of midline) and **SMA** taking off anteriorly from it
- ▶ **IVC** — inferior vena cava (right of midline)
- ▶ **LRV** — left renal vein crossing anterior to the aorta; **LRA** — left renal artery
- ▶ **P** — neck/uncinate process of pancreas crossing the midline anteriorly
- ▶ **PC** — portal confluence (splenic vein + SMV) behind the pancreatic neck
- ▶ **RK / LK** — right and left kidney, each with its **hilum and renal vessels**, surrounded by **PF** (perirenal fat)
- ▶ **D** — duodenum related to the pancreatic head
- ▶ **RLL** — right lobe of liver (reduced in extent); **GB** — gallbladder fundus if the cut is slightly high
- ▶ **I** — coils of jejunum/ileum; **TC** — transverse colon
- ▶ **PS** — psoas major (with sympathetic trunk on its medial border); **DBM** — deep back (erector spinae) muscles
- ▶ Right and left **crura of the diaphragm** flanking the vertebral body
- ▶ Anterior abdominal wall layers: external oblique, internal oblique, transversus abdominis, recti

Applied / Clinical anatomy

- ▶ **Systematic reading of an axial CT/MRI at L1:** identify the vertebral body → the aorta anterior to it and slightly left, the IVC to its right → look for the SMA taking off anteriorly and the left renal vein crossing just below it → trace the pancreatic neck anterior to the portal confluence → locate the renal hila medially on each kidney → note psoas major flanking the vertebral body on each side.
- ▶ **Nutcracker (renal vein entrapment) syndrome:** the left renal vein crosses the acute angle between the SMA anteriorly and the aorta posteriorly at this level; a narrow aortomesenteric angle compresses the vein, producing left flank pain and haematuria.
- ▶ **Pancreaticoduodenectomy (Whipple's procedure):** the neck of the pancreas — lying directly anterior to the portal vein/SMV confluence at this level — is the deliberate line of surgical transection.

- ▶ **Median arcuate ligament (coeliac axis compression) syndrome** occurs just above this level, at the point where the two crura fuse in front of the aorta; because the crura are still separate at true L1, this remains a T12-level rather than an L1-level phenomenon.
- ▶ **Conus medullaris termination:** since the spinal cord ends, on average, at L1, lumbar puncture and spinal anaesthesia are deliberately performed lower, at the L3/L4 or L4/L5 interspace, to avoid cord injury.
- ▶ **Suprarenal versus infrarenal abdominal aortic aneurysm:** because the renal arteries arise just below the SMA near the L1/L2 disc, this junction is the key landmark distinguishing the two types, which in turn determines the feasibility of standard endovascular aneurysm repair.
- ▶ **Pott's spine (vertebral tuberculosis) and psoas abscess:** caries of the L1 vertebral body can track down within the psoas sheath (seen flanking the vertebral body at this level) to present as a swelling below the inguinal ligament.
- ▶ **Cisterna chyli and chyle leak:** its position anterior to the L1–L2 vertebral bodies, to the right of the aorta, is relevant to iatrogenic chylous ascites during para-aortic lymph-node dissection or aortic surgery at this level.

High-yield exam pointers

- ▶ L1 vertebral level ≈ **transpyloric plane (plane of Addison)** — midway between the suprasternal notch and the pubic symphysis; anterior landmark = 9th costal cartilage tip.
- ▶ The **hila of both kidneys with their renal vessels** are the most constant feature of the true L1 cross-section.
- ▶ Cranio-caudal order of aortic branches near this level: **coeliac trunk (T12/L1) → superior mesenteric artery (L1) → renal arteries (L1/L2 disc)**.
- ▶ **Left renal vein** crosses anterior to the aorta just below the SMA origin ("nutcracker" angle) to reach the IVC.
- ▶ **Portal vein origin** (SMV + splenic vein confluence) lies immediately behind the **neck of the pancreas** at this level.
- ▶ **Pylorus** is an inconstant finding at exactly this section; the **duodenojejunal flexure** lies just below it, 1 cm below the transpyloric plane at the upper part of L2.
- ▶ **Both crura of the diaphragm** are still separate and present at L1, flanking the aorta.
- ▶ **Spinal cord (conus medullaris) terminates**, on average, at the middle third of the body of L1.
- ▶ Liver occupies a much **smaller** area at this level than at T12; jejunal coils and transverse colon fill most of the remaining peritoneal cavity.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; IB Singh — Textbook of Anatomy Vol 2 6e; BD Chaurasia — Human Anatomy Vol 2 8e.



Draw the diagram of transverse section at the level of T4 vertebra

Asked in: Paper IV May 2011 — RGUHS MD/MS Anatomy

Definition / Introduction A transverse (axial) section of the thorax at the **upper part of the body of the 4th thoracic (T4) vertebra** is one of the two classical "must-draw" cross-sectional levels of the mediastinum in undergraduate and postgraduate anatomy — the other being the T5 level immediately below it. This section lies entirely within the **superior mediastinum**, and its single most important feature is the **arch of the aorta**, which — being an obliquely/vertically disposed structure cut by a horizontal plane — appears as a curved, "half-cut" tube giving off the origins of its three branches. The level correlates anteriorly with the **manubrium sterni** (T3–T4 level) and lies just above the **transverse thoracic plane** (sternal angle / T4–T5 disc), the surgical-radiological boundary that separates the superior from the inferior mediastinum. This exercise is examined both as a labelled diagram and as the basis for correlating cadaveric cross-sectional anatomy with axial CT/MRI of the thorax.

1. Vertebral level, surface marking & mediastinal boundaries

- ▶ The **manubrium sterni** (≈ 4 cm long) lies at the level of the bodies of T3 and T4 vertebrae; the section in question is taken through the upper part of T4, i.e., just above the manubriosternal joint.
- ▶ The **sternal angle (angle of Louis)** is palpated as a transverse ridge about 5 cm below the suprasternal notch; it lies at the level of the **T4–T5 intervertebral disc**, one level below the section being described here.
- ▶ **Superior mediastinum — boundaries:**

Boundary	Structure
Anterior	Manubrium sterni
Posterior	Bodies of the upper four thoracic vertebrae
Superior	Plane of the superior thoracic aperture (thoracic inlet)
Inferior	Transverse thoracic plane — sternal angle in front, lower border of body of T4 behind
On each side	Mediastinal (costomediastinal) pleura

- ▶ Because the section is taken through the **upper part** of T4 (above its lower border), it lies wholly within the superior mediastinum, above the transverse thoracic plane — the trachea is therefore still **undivided** at this level (its bifurcation occurs only at the lower border of T4/T4–T5 disc, one section lower).

2. Structures seen in the transverse section at the upper part of T4

□ Fig 11.1 — Transverse section of thorax at the level of the upper part of T4 vertebra-inferior view (IB Singh — Textbook of Anatomy Vol 2 — 6e, p.142)

(Real cadaveric cross-section, inferior view, as printed in the textbook: labelled manubrium, superior vena cava, arch of aorta with the openings of its branches, oesophagus, left lung, pleural cavity and parietal pleura.)

Region-wise disposition of the section (viewed from below, as conventionally drawn):

Region	Structure(s) seen
Anterior, midline	Manubrium sterni; thymus (or its fatty remnant in the adult), in the retrosternal space
Right of centre	Superior vena cava , lying anterior to the right end of the aortic arch
Centre	Arch of aorta — cut obliquely as a "half-cut" curved tube because the arch runs almost vertically while the section is transverse; the origins/openings of the brachiocephalic trunk, left common carotid artery and left subclavian artery are seen within its lumen
Behind the arch, in the midline	Trachea — still a single, undivided tube at this level
Immediately behind the trachea	Oesophagus , lying anterior to the body of T4
Posterolateral, left side	Thoracic duct , posterior and to the left of the oesophagus
On either side, bulk of the section	Right and left lungs (upper-lobe parenchyma), each invested by visceral and parietal pleura, with the pleural cavity as a thin potential space between them
Posterior, midline	Body of T4 vertebra and vertebral canal

- The **anteroposterior order** of the principal superior-mediastinal structures at this level — thymus → great veins (SVC) → great arteries (arch of aorta) → airway (trachea) → alimentary tract (oesophagus) → lymphatic duct (thoracic duct) → vertebral body — is the standard systemic sequence taught for every level of the superior mediastinum.
- Since the section lies above the pulmonary hila, **no bronchi, pulmonary vessels, or hilar lymph nodes** are cut — only lung substance and its pleural coverings are seen laterally.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw an inferior-view transverse (axial) outline of the thorax at the upper part of T4 and label:

- ▶ Manubrium sterni (anterior midline)
- ▶ Body of T4 vertebra and vertebral canal (posterior midline)
- ▶ Superior vena cava (right of the anterior end of the arch)
- ▶ Arch of aorta, cut obliquely, with the openings of the brachiocephalic trunk, left common carotid artery and left subclavian artery within it
- ▶ Trachea (single lumen, anterior to the oesophagus)
- ▶ Oesophagus (immediately behind the trachea, anterior to the vertebral body)
- ▶ Thoracic duct (posterior and to the left of the oesophagus)
- ▶ Thymus / thymic remnant (anterior, between the great vessels and the manubrium)
- ▶ Right lung and left lung, each with visceral and parietal pleura
- ▶ Pleural cavity (thin space between the two pleural layers)

4. Relations of the arch of aorta at this level

The arch begins behind the upper border of the right 2nd sternocostal joint and ends at the lower border of the body of T4 by becoming continuous with the descending thoracic aorta — i.e., its beginning and end lie at the same vertebral level, even though it begins anteriorly and ends posteriorly:

Aspect	Structures related
Anterior and to the left	Left phrenic nerve, lower cervical cardiac branch of left vagus, superior cervical cardiac branch of left sympathetic chain, left vagus nerve (4 nerves, in that order, front to back); left superior intercostal vein; left pleura and lung; remains of thymus
Posterior and to the right	Trachea (with deep cardiac plexus and tracheobronchial lymph nodes); oesophagus; left recurrent laryngeal nerve; thoracic duct; vertebral column
Superior (convexity)	Three branches — brachiocephalic trunk, left common carotid artery, left subclavian artery — all crossed near their origin by the left brachiocephalic vein
Inferior (concavity)	Bifurcation of the pulmonary trunk; left principal bronchus; ligamentum arteriosum with the superficial cardiac plexus on it; left recurrent laryngeal nerve

5. Level-to-level correlation

Presenting T4 in continuity with the levels immediately above and below is standard practice, since the mediastinal picture changes sharply over a short span:

Level	Key feature
T3 / mid-manubrium	Union of the two brachiocephalic veins forms the superior vena cava; the three great-vessel branches arise from the summit of the arch
T4, upper part (this section)	Arch of aorta cut obliquely, with its three branch-openings; SVC to its right; undivided trachea anterior to the oesophagus; thoracic duct posterolateral to the oesophagus on the left; wholly within the superior mediastinum
T4–T5 disc / sternal angle (transverse thoracic plane)	Ascending aorta anterior to the pulmonary trunk, descending aorta posterior to it; bifurcation of the trachea in the cadaver, into right and left principal bronchi (in the living, erect subject the bifurcation lies at the lower border of T6, descending further on inspiration); terminal parts of the SVC and azygos vein; junction of the superior and inferior mediastinum

6. Recent advances in cross-sectional & radiological imaging of this level

- ▶ **Multidetector CT (MDCT)**, thin-collimation (≤ 1 mm) with multiplanar/3-D volume rendering, now displays the arch and its branch origins in a plane matching this cadaveric section, and is the modality of choice for planning TEVAR and evaluating arch anomalies, aneurysms and dissection.
- ▶ **ECG-gated cardiac CT** minimises pulsation artefact from the mobile arch, sharpening delineation of the aorto-pulmonary window and great-vessel origins here.
- ▶ Teaching now routinely pairs the cadaveric plate with CT "**lung window**" vs "**mediastinal window**" images at the same axial level — the former shows the air-filled airway and vascular shadows, the latter resolves arch/SVC/oesophagus/node detail.
- ▶ **Virtual/CT bronchoscopy** and 3-D airway reconstruction teach the transition from this undivided-trachea level to the bifurcation one level below.
- ▶ **MR angiography** gives a radiation-free alternative for follow-up imaging of the arch, particularly in younger patients with congenital anomalies.

Applied / Clinical anatomy

- ▶ An **aortic arch aneurysm or dissection** at this level may compress the trachea (stridor, dyspnoea) or the oesophagus (dysphagia — "dysphagia aortica"), and can stretch the **left recurrent laryngeal nerve** as it hooks under the arch, producing hoarseness of voice.
- ▶ **Superior mediastinal masses** at this level — retrosternal ("plunging") goitre descending from the neck, thymoma, lymphoma, or germ-cell tumours of the thymic remnant — present as a widened mediastinal shadow on chest radiograph and are localised precisely by axial CT/MRI here.
- ▶ **Central venous catheter tip position:** the SVC is formed one level above (T3) and descends further to end at the cavoatrial junction; a line whose tip lies at this T4 level is too high (malpositioned) and should be advanced further.

- ▶ **Thoracic duct**, posterolateral to the oesophagus on the left at this level, is at risk during oesophagectomy or mediastinal lymph-node dissection — injury produces **chylothorax**.
- ▶ **Sternal angle / transverse thoracic plane**, one level below, is the surface and radiological landmark used to count ribs (2nd costal cartilage), to bound mediastinoscopy/mediastinotomy, and to localise the tracheal bifurcation (carina) for bronchoscopy and correct double-lumen endotracheal tube placement.
- ▶ On a **barium swallow**, a dilated left atrium or a vascular ring/aberrant right subclavian artery at this level indents the oesophageal shadow — a classical radiological correlate of the anatomy at this section.

High-yield exam pointers

- ▶ T4 (upper part) section lies entirely within the **superior mediastinum**; the single dominant structure is the **arch of aorta**, seen as a half-cut oblique tube.
- ▶ Arch of aorta gives off, within its lumen at this level, the **brachiocephalic trunk, left common carotid and left subclavian arteries**.
- ▶ Anteroposterior order at this level: thymus → SVC (right of arch) → arch of aorta → trachea (undivided) → oesophagus → thoracic duct (posterolateral, left) → vertebral body.
- ▶ SVC lies to the right of, and anterior to, the arch; **thoracic duct** lies posterior and to the left of the oesophagus.
- ▶ **Trachea is undivided** at T4 upper part; bifurcation occurs at the **lower border of T4 / T4–T5 disc** in the cadaver (T6 in the living, erect subject).
- ▶ Section lies above the pulmonary hila, so no bronchi/pulmonary vessels/hilar nodes are seen — only lung substance and pleura.
- ▶ Arch of aorta relations: 4 structures anterior-and-left, 5 posterior-and-right, 3 branches superiorly, and pulmonary trunk/left bronchus/ligamentum arteriosum inferiorly — a compact, high-yield table.
- ▶ Clinically linked to aortic arch pathology (RLN palsy, tracheo-oesophageal compression), thymic/mediastinal masses, CVP line positioning, and thoracic duct injury.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Anatomy, Vol. 2, 6e (Chapter: Cross-Sectional, Radiological and Surface Anatomy of Thorax); BD Chaurasia — Human Anatomy, Vol. 1, 8e; Vishram Singh — Textbook of Anatomy, Vol. 1, 4e; Moore's Clinically Oriented Anatomy 9e.



Horizontal section at the level of L-1 vertebra

Asked in: Paper IV Sep 2007 — RGUHS MD/MS Anatomy

Definition / Introduction — A horizontal (axial/transverse) section at the level of the first lumbar (L1) vertebra corresponds, in surface anatomy, to the **transpyloric plane of Addison**, one of the four standard levels (T10, T12, L1–L2, L3–L4) used to teach the cross-sectional and radiological anatomy of the abdomen. This level is of exceptional anatomical importance because it is the transitional zone at which the coeliac axis territory hands over to the superior-mesenteric territory, the portal vein is formed, both renal pedicles are encountered, and — in the vertebral canal lying posteriorly — the spinal cord itself terminates as the conus medullaris. A CT/MR axial slice at this level is one of the most information-dense cuts of the entire abdomen and is therefore a favourite for both anatomy viva and radiology correlation.

1. The transpyloric plane — definition and vertebral relations

Feature	Description
Eponym	Transpyloric plane of Addison
Anterior reference	Lies midway between the suprasternal (jugular) notch of the manubrium and the upper border of the pubic symphysis — approximately midway between the xiphisternal joint and the umbilicus, or slightly below it
Costal-margin crossing	Crosses the costal margin at the tip of the 9th costal cartilage on each side, where the linea semilunaris meets the costal margin (a palpable "step" in the rib margin)
Classical (Indian-curriculum) vertebral level	Body of L1, near its lower border (BD Chaurasia, Vishram Singh)
Refined vertebral range (Gray's 41e, Mirjalili et al)	Posteriorly intersects the lower half of the L1 body, the L1/2 intervertebral disc, or the upper half of L2 in most individuals; overall range lower T12 to lower L2. The plane sits slightly higher in males (lower L1–L1/2) than in females (lower L2)
Distinction from neighbouring planes	Subcostal plane (joining the lowest points of the costal margin, usually the 10th costal cartilage) lies lower, at L2; transtubercular plane (iliac tubercles) lies at L5

2. Structures classically transected by the plane

- ▶ Pylorus of the stomach — present in the plane in many, but not all, individuals (inconstant)
- ▶ First (superior) part of the duodenum, beginning just distal to the pylorus
- ▶ Neck of the pancreas, overlying the union of the superior mesenteric and splenic veins
- ▶ Origin of the hepatic portal vein, formed behind the neck of the pancreas at the L1/2 disc level
- ▶ Origin of the superior mesenteric artery from the abdominal aorta
- ▶ Origins of the right and left renal arteries

- ▶ **Hila of both kidneys** — the **left hilum** lies **slightly higher** than the right (the right kidney is pushed down by the liver)
- ▶ **Fundus of the gallbladder**, at the point where the plane meets the **right linea semilunaris/9th costal cartilage** (present in the plane in only about a third of supine individuals; lies below the plane in most others)
- ▶ **Duodenojejunal flexure** (at the lower part of this range, close to L1–L2)
- ▶ **Termination of the spinal cord** (conus medullaris) in the vertebral canal behind

3. Region-wise structures seen in the cross-section itself

Region	Structures in the section
Anterior abdominal wall	Rectus abdominis in the midline; external oblique, internal oblique and transversus abdominis in the flanks
Right side	Reduced bulk of the right lobe of liver ; inferior vena cava anterolateral to the vertebra; first/second parts of the duodenum ; head and neck of pancreas with the common bile duct; hilum and upper pole of the right kidney ; right suprarenal gland
Midline (anterior to the vertebral body)	Pyloric antrum/pylorus (if present at this level); neck of pancreas overlying the splenic vein–SMV confluence forming the portal vein ; origin of the superior mesenteric artery ; the abdominal aorta ; the left renal vein , which crosses anterior to the aorta and posterior/inferior to the SMA on its way to the IVC
Left side	Body/fundus region of the stomach ; tail of pancreas and splenic vessels at the splenic hilum, with the inferior pole of the spleen often included; hilum and upper pole of the left kidney ; left suprarenal gland ; region of the splenic (left colic) flexure
Posterior (vertebra and posterior wall)	Body, pedicles and spinous process of L1 vertebra ; the vertebral (spinal) canal containing the conus medullaris /upper cauda equina roots, dural sac and epidural fat; crura of the diaphragm flanking the aorta (right crus from the upper three lumbar vertebrae, left crus from the upper two); medial and lateral arcuate ligaments (attached to the L1 body and L1 transverse process respectively); psoas major , quadratus lumborum , erector spinae , and the tips of the 12th ribs posterolaterally

4. Comparison with the neighbouring standard cross-sectional levels

Level	Key distinguishing content
T10 (through xiphoid process)	Oesophagogastric junction; crura around the oesophageal orifice; superior part of spleen; tail of pancreas; coeliac trunk division

Level	Key distinguishing content
T12 (below the xiphoid)	Pyloric antrum and canal; gallbladder first appears ; superior poles of kidneys with suprarenal glands; portal triad (CBD, hepatic artery, portal vein); splenic hilum
L1–L2 (present topic)	Pylorus inconstant; hila of both kidneys prominent ; uncinate process of pancreas ; origin of SMA and SMV ; liver bulk much reduced; coils of intestine occupy most of the cavity; if the cut passes just below the SMA origin, the left renal vein is seen crossing between aorta and SMA
L3–L4	Coils of intestine suspended by mesentery predominate; three flat abdominal wall muscles well seen; branches of aorta in the mesentery; IVC to the right of the aorta

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a **kidney-shaped outline** representing the transverse section at L1, viewed **from below** (as in CT convention — patient's right on the observer's left). Label:

- ▶ Vertebral body of L1 with pedicles and spinous process (posterior midline)
- ▶ Vertebral canal — conus medullaris/cauda equina roots
- ▶ Crura of diaphragm (right and left) flanking the aorta
- ▶ Abdominal aorta
- ▶ Origin of superior mesenteric artery
- ▶ Left renal vein crossing between aorta and SMA
- ▶ Inferior vena cava (right anterolateral to vertebra)
- ▶ Neck of pancreas overlying splenic vein/SMV confluence → portal vein
- ▶ Duodenum (1st/2nd parts), right side
- ▶ Head/uncinate process of pancreas, right side
- ▶ Right lobe of liver (reduced)
- ▶ Hilum of right kidney + right suprarenal gland
- ▶ Stomach (pyloric antrum/body region), left side
- ▶ Tail of pancreas + splenic vessels/spleen, left side
- ▶ Hilum of left kidney + left suprarenal gland
- ▶ Psoas major and quadratus lumborum bilaterally
- ▶ Rectus abdominis, oblique/transversus muscle layers of the anterior wall
- ▶ 12th ribs posterolaterally

Applied / Clinical anatomy

- ▶ **Surface-marking utility:** the transpyloric plane is the single most useful abdominal reference line for locating the pylorus, the fundus of the gallbladder (junction with the right linea

semilunaris/9th costal cartilage — relevant to Murphy's sign localisation), the hila of the kidneys, the neck of the pancreas, and the root of the transverse mesocolon during clinical examination and surgical planning.

- ▶ **"Nutcracker" phenomenon:** at this exact level the **left renal vein is compressed between the aorta (posteriorly) and the origin of the SMA (anteriorly)**. Pathological narrowing here produces **nutcracker syndrome** — left flank pain, haematuria, and pelvic congestion — and is diagnosed on precisely this axial CT/MR slice.
- ▶ **Pancreatic neck as a surgical landmark:** the neck of the pancreas, lying anterior to the SMV–portal vein confluence at this level, is the conventional line of transection in a **pancreaticoduodenectomy (Whipple's operation)**; tumours of the head/neck can invade the SMV/portal vein early because of this intimate relation.
- ▶ **Portal vein imaging:** since the portal vein forms just behind the pancreatic neck at the L1/L2 disc level, this slice is the standard level for assessing **portal vein patency/thrombosis** and for planning porto-systemic shunt or liver transplant surgery.
- ▶ **Renal vascular imaging:** the renal artery origins at this level are the reference slice for **renal artery stenosis**, **live-donor nephrectomy** planning, and localisation of **adrenal incidentalomas** on CT.
- ▶ **Thoracolumbar (T12–L1) junction fractures:** this is the **commonest site of vertebral compression/burst fracture**, because it is the transition point between the rigid, kyphotic thoracic spine (splinted by the rib cage) and the mobile lumbar spine. Because the spinal cord terminates as the conus medullaris at approximately this level, a burst fracture here can produce a **mixed conus medullaris/cauda equina syndrome** (combined upper- and lower-motor-neurone bladder, bowel and lower-limb signs).
- ▶ **Lumbar puncture safety:** knowledge that the cord ends around the L1 (occasionally as low as L2/L3) level is precisely why a diagnostic or spinal-anaesthesia lumbar puncture is always performed at the **L3/L4 or L4/L5 interspace**, well below the conus.

High-yield exam pointers

- ▶ Horizontal section at L1 corresponds to the **transpyloric plane of Addison**: midway between the suprasternal notch and pubic symphysis; crosses the costal margin at the 9th costal cartilage; posteriorly at the lower L1 body/L1–2 disc (range lower T12–lower L2; higher in males).
- ▶ Mnemonic organs on the plane: **P**ylorus, **D**uodenum (1st part), **N**eck of pancreas, origin of **S**MA, origin of **p**ortal vein, **h**ila of both kidneys, fundus of **g**allbladder, **D**J flexure, termination of the **s**pinal cord.
- ▶ Left kidney hilum lies slightly higher than the right (right kidney depressed by the liver).
- ▶ Left renal vein crosses between the aorta and the SMA at this level — the classic site of the **nutcracker phenomenon**.
- ▶ Conus medullaris terminates near this level — hence lumbar puncture is done below L2/L3.
- ▶ One of the four "landmark" cross-sectional teaching levels of the abdomen: **T10 → T12 → L1–L2 → L3–L4**.
- ▶ T12–L1 is the commonest site of vertebral (burst/compression) fracture — the thoracolumbar junction.

- Both crura of the diaphragm (right from upper 3 lumbar vertebrae, left from upper 2) and the medial/lateral arcuate ligaments relate to the L1 body/transverse process, so both are cut in this section.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; BD Chaurasia Human Anatomy Vol 2 8e; IB Singh Textbook of Anatomy Vol 2 6e; Vishram Singh Textbook of Anatomy Vol 2 4e.

Coverage note: No genuinely matching labelled real-figure plate of a transverse section at the L1 level was found in the indexed figure library for embedding; the "Diagram to draw" box above should be used for hand reproduction.



Horizontal section of cerebrum

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction A horizontal (axial/transverse) section of the cerebrum is a cut made in a plane roughly parallel to the base of the skull. The classic teaching plane — used in gross-anatomy, neuroanatomy and radiology — passes through the **interventricular foramen (of Monro)**, and in a single view demonstrates the corpus callosum, the lateral ventricles, the **corpus striatum** (caudate nucleus + lentiform nucleus), the **thalamus**, the **internal capsule**, and the insular grey/white matter of one hemisphere mirrored in the other. It is the single most important descriptive section in neuroanatomy because it displays the relations of the basal nuclei to the internal capsule — the substrate of the commonest disabling capsular stroke — and it corresponds closely to a standard axial CT/MRI slice used in stroke imaging.

1. Plane and level of the section

- Cut in a plane parallel to the base of the skull, at the level of the **interventricular foramen**, so that both cerebral hemispheres are seen symmetrically about the midline.
- In the midline, from front to back: genu of the **corpus callosum** → **septum pellucidum** → **third ventricle** → crura of the **fornix/splenium** region.
- On each side of the midline lies the **corpus striatum** (caudate nucleus + lentiform nucleus), separated from the **thalamus** by the **internal capsule**.
- Deep to the insular cortex, from lateral to medial: **insula** → **extreme capsule** → **claustrum** → **external capsule** → **putamen** (lateral part of lentiform nucleus) → **globus pallidus** (medial part) → **internal capsule** → **thalamus/caudate nucleus**.

2. Grey matter nuclei seen in the section

Nucleus	Shape/position in this plane	Key relations
Caudate nucleus (head)	Rounded, bulges into the anterior horn of the lateral ventricle	Medial to anterior limb of internal capsule; joined to putamen by grey bands across the anterior limb (giving the "striated" look)
Lentiform nucleus	Wedge-shaped with broad convex base directed laterally	Divided by the external (lateral) medullary lamina into putamen (lateral, darker) and globus pallidus (medial, paler); globus pallidus further split by the internal (medial) medullary lamina into outer and inner segments
Thalamus	Large ovoid mass medial to the internal capsule	Forms the lateral wall of the third ventricle; separated from caudate body by the stria terminalis and thalamostriate vein
Clastrum	Thin sheet of grey matter	Lies between the putamen (external capsule) and the insula (extreme capsule); regarded as a detached part of the insular cortex
Insula (Island of Reil)	Cortex buried in the depth of the lateral sulcus	Overlies the extreme capsule/clastrum/external capsule complex

3. White matter structures seen in the section

- ▶ **Corpus callosum** — its genu is cut anteriorly in the midline; the trunk roofs the central part (body) of each lateral ventricle.
- ▶ **Septum pellucidum** — thin vertical sheet between the two anterior horns/bodies of the lateral ventricles, stretched between the corpus callosum and the fornix.
- ▶ **Corona radiata** — fan of projection fibres converging on the internal capsule from the cerebral cortex above; fibres are cut across (transversely) in this plane.
- ▶ **Internal capsule** — V-shaped band of white fibres, concavity directed laterally (detailed below).
- ▶ **External capsule** — thin lamina of white matter between the putamen and the claustrum.
- ▶ **Extreme capsule** — thin lamina of white matter between the claustrum and the cortex of the insula.

□ Fig 8.20 — Horizontal section through corpus striatum, thalamus and internal caps (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.568)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a horizontal section through one cerebral hemisphere at the level of the interventricular foramen and label:

- ▶ Head of caudate nucleus
- ▶ Thalamus
- ▶ Internal capsule — anterior limb, genu, posterior limb
- ▶ Putamen
- ▶ Globus pallidus (outer and inner segments)
- ▶ External capsule
- ▶ Claustrum
- ▶ Extreme capsule
- ▶ Insula
- ▶ (Bilateral figure, if time permits) genu of corpus callosum, septum pellucidum, third ventricle, anterior horn of lateral ventricle

4. Internal capsule — boundaries, parts and fibre composition

In this plane the internal capsule appears as a V-shaped compact bundle of white fibres with its **concavity directed laterally**; it is bounded medially by the caudate nucleus and thalamus, and laterally by the lentiform nucleus.

Part	Boundaries	Chief fibres carried
Anterior limb	Between head of caudate nucleus (medially) and anterior part of lentiform nucleus (laterally)	Frontopontine fibres; anterior/superior thalamic radiation (frontal-lobe connections)
Genu	Bend between anterior and posterior limbs, concavity facing laterally	Corticonuclear (corticobulbar) fibres to contralateral cranial-nerve motor nuclei
Posterior limb	Between thalamus (medially) and posterior part of lentiform nucleus (laterally)	Corticospinal fibres (anterior two-thirds, arranged upper-limb → trunk → lower-limb from front to back); frontopontine/parietopontine fibres; extrapyramidal fibres
Retrolentiform part	Behind the lentiform nucleus	Parieto-occipitopontine fibres; posterior thalamic (optic) radiation to occipital cortex
Sublentiform part	Below the lentiform nucleus	Temporopontine fibres; inferior thalamic (auditory) radiation from medial geniculate body to temporal cortex

- ▶ Corticopontine fibres (fronto-, parieto-, occipito-, temporo-pontine) form the largest single group (~2/3 of all fibres) and relay in the pontine nuclei before crossing to the opposite cerebellar cortex (cortico-ponto-cerebellar pathway).
- ▶ Extrapyramidal fibres (corticorubral, corticostriate, corticonigral) run close to the corticospinal fibres and are therefore also damaged in posterior-limb lesions.

5. Ventricular system seen in this plane

- ▶ **Anterior horn of the lateral ventricle** — lies in front of the interventricular foramen, floored and walled laterally by the head of the caudate nucleus, roofed by the corpus callosum, and separated from its fellow by the septum pellucidum.
- ▶ **Body (central part)** of the lateral ventricle continues behind the foramen — its floor, medial to lateral, is formed by the fornix, thalamus (upper surface), stria terminalis/thalamostriate vein, and the body of the caudate nucleus.
- ▶ **Interventricular foramen (of Monro)** — connects each lateral ventricle to the midline **third ventricle**, whose lateral wall is formed by the thalamus.
- ▶ Choroid plexus of the lateral ventricle covers the medial part of the thalamus at the floor of the body of the ventricle.

6. Arterial supply of the internal capsule and basal nuclei

Artery	Part supplied	Clinical note
Lateral striate branches of middle cerebral artery	Posterior limb (largest branch = artery of cerebral haemorrhage/Charcot's artery)	Commonest site of hypertensive intracerebral haemorrhage
Medial striate/ recurrent artery of Huebner (from anterior cerebral artery)	Genu and anterior limb	Occlusion → contralateral face and upper-limb weakness
Anterior choroidal artery (from internal carotid artery)	Retrolentiform and sublenticular parts (posterior third of posterior limb)	Thrombosis → contralateral visual field defect (hemianopia) and hearing loss
Direct branches of internal carotid artery	Genu	—
Central branches of posterior communicating and posterolateral central branches of posterior cerebral artery	Retrolentiform/sublenticular parts	Contribute to posterior capsular territory

Applied / Clinical anatomy

- ▶ Because motor and sensory fibres from the entire cerebral hemisphere are compacted into this small area, even a small vascular lesion of the internal capsule produces widespread deficits — **contralateral spastic hemiplegia with sensory loss** ("capsular stroke"), the commonest cause being rupture of the lateral striate (Charcot's) branch of the middle cerebral artery.

- ▶ Small deep infarcts here (often in hypertensive small-vessel disease) are the classic **lacunar strokes** — pure motor or pure sensory lacunar syndromes localise precisely to the posterior limb/genu.
- ▶ This is essentially the plane of a standard **axial CT/MRI section through the basal ganglia**, used routinely to localise capsular/ganglionic bleeds and infarcts and to assess mass effect on the ventricles.
- ▶ The corpus striatum seen in this section is part of the extrapyramidal system; its degeneration or dysfunction underlies **Parkinsonism** (nigrostriatal dopamine loss), **chorea** (caudate/putamen), **athetosis**, and **hemiballismus** (subthalamic nucleus, adjoining the posterior limb region).
- ▶ Stereotactic functional neurosurgery (pallidotomy, thalamotomy, deep brain stimulation electrode placement) uses coordinates referenced to structures visualised in exactly this horizontal plane.

High-yield exam pointers

- ▶ Internal capsule in horizontal section = **V-shaped, concavity lateral**; bounded medially by caudate/thalamus, laterally by lentiform nucleus.
- ▶ Five parts: anterior limb, genu, posterior limb, retrolentiform part, sublenticular part.
- ▶ Lateral-to-medial order deep to insula: **insula** → **extreme capsule** → **claustrum** → **external capsule** → **putamen** → **globus pallidus** → **internal capsule** → **thalamus/caudate**.
- ▶ Genu carries **corticonuclear** fibres; anterior two-thirds of posterior limb carries **corticospinal** fibres (upper limb–trunk–lower limb, front to back).
- ▶ **Charcot's artery** (lateral striate branch of MCA) = commonest source of hypertensive capsular haemorrhage.
- ▶ **Recurrent artery of Huebner** supplies the genu/anterior limb; **anterior choroidal artery** supplies the retro-/sublenticular parts.
- ▶ Lentiform nucleus = putamen (lateral) + globus pallidus (medial), separated by the external medullary lamina.
- ▶ This plane corresponds to the routine axial CT/MRI slice through the basal ganglia used in stroke imaging.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Clinical Neuroanatomy 4e; BD Chaurasia — Human Anatomy Vol 3-4 8e; IB Singh — Textbook of Human Neuroanatomy; Snell — Clinical Neuroanatomy 7e.



Horizontal section through abdomen at the level of L4

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction A horizontal (transverse/axial) section through the abdomen at the vertebral level of L4 cuts the posterior abdominal wall just below the umbilicus, through the body of the L4 vertebra. This level is of special cross-sectional and radiological importance because three independently useful landmarks coincide here — the **supracristal plane (Tuffier's line)**, the **bifurcation of the abdominal aorta**, and the safe zone for **lumbar puncture** below the termination of the spinal cord. It is a standard axial level studied in CT/MRI cross-sectional anatomy of the retroperitoneum.

Surface planes and vertebral landmarks at this level

Plane	Vertebral level	Landmark it joins
Transumbilical plane	L3/L4 intervertebral disc	Umbilicus
Supracristal plane (Tuffier's line)	Body of L4 (or L4/5 disc) and its spinous process	Highest points of the two iliac crests
Transtubercular (intertubercular) plane	Body of L5	Tubercles of the iliac crest (≈ 5 cm posterior to each ASIS)

- ▶ The supracristal plane is the key surface marker for this question — it "usually lies at the level of the L4 body or L4/5 disc and its spinous process," and the **bifurcation of the abdominal aorta lies approximately in this plane** (Gray's Anatomy 41e).
- ▶ Tuffier's line is also the line "on which the spine of L4 usually lies in adults" — used clinically to count vertebral spines from below upward.

Vertebral and musculoskeletal framework seen in the section

- ▶ **Body of L4 vertebra** — pedicles, laminae and spinous process posteriorly, flanked by the intervertebral discs (L3/4 above, L4/5 below).
- ▶ **Vertebral (spinal) canal** — contains only the **cauda equina** and **filum terminale** at this level, since the spinal cord (conus medullaris) normally terminates around the L1 vertebral body (range: middle T11 to middle L3); this is precisely why a needle introduced at/around the supracristal plane is safe.
- ▶ **Psoas major** (right and left) — bulges anterolaterally against the vertebral body, the principal muscular landmark of the posterior wall at this level.
- ▶ **Quadratus lumborum** (right and left) — lies posterolateral to psoas major.
- ▶ **Erector spinae (sacrospinalis) and multifidus** with the **three layers of thoracolumbar fascia** — posteriorly, flanking the spinous process.
- ▶ **Anterolateral abdominal wall** — the three flat muscles (external oblique, internal oblique, transversus abdominis) laterally; **rectus abdominis** within its sheath anteriorly, separated in the midline by the linea alba.
- ▶ **Parietal peritoneum** clearly demarcates the true peritoneal cavity from the subperitoneal (extraperitoneal) fatty/areolar layer that clothes psoas, quadratus lumborum, the great vessels, the ureters and the vertebral column.

Major vessels at L4

Vessel	Position / behaviour at L4
Abdominal aorta	In/near the midline, anterior and slightly to the left of the L4 body; bifurcates into the right and left common iliac arteries at the upper border of L4 — i.e., within or just below this very section
Inferior vena cava	Lies to the right of the aorta; already a single trunk at this level, since it is formed lower down — by the union of the two common iliac veins anterior to the L5 vertebral body
Median sacral artery	A small midline branch arising just above the aortic bifurcation, descending anterior to L4/L5 and the sacrum
Gonadal and lumbar vessels	Seen coursing laterally in the retroperitoneal fat, over psoas major
Inferior mesenteric artery/vein	IMA (already given off higher, at L3) sends left-colic/sigmoid branches into the mesocolon/mesentery near this level; the IMV ascends along the left psoas surface

Gastrointestinal and peritoneal contents

- ▶ The most striking feature of a section at this level is the mass of **coils of jejunum and ileum suspended by the mesentery**, occupying the central and anterior part of the cavity — various mesenteric folds and the primary/secondary branches of the aorta running within the mesentery are seen in cross-section.
- ▶ **Ascending colon** (right) and **descending colon** (left) lie posterior to the peritoneum in the right and left paracolic gutters — they are secondarily retroperitoneal.
- ▶ **Root of the mesentery** — about 15 cm long, running obliquely from the left side of the L2 vertebra (duodenojejunal flexure) down to the right sacroiliac joint (ileocaecal junction); at the L4 level its oblique line is angling toward the right side, and classically it crosses (left to right) the third part of the duodenum, the aorta, the inferior vena cava, the right ureter, the right gonadal vessels, the right genitofemoral nerve and the right psoas major.
- ▶ **Kidneys are usually not seen at L4** — the normal adult kidney is only ~11 cm long with its hilum at L1/L2 (right slightly lower than left), so its lower pole is normally exhausted by about L3. This "absence of renal shadow" is itself a useful teaching point distinguishing the L4 section from the L1–L3 sections.
- ▶ **Ureters** — seen as small rounded structures on the anterior surface of psoas major bilaterally, continuing their descent toward the pelvic brim.

Nerves and lymphatics

- ▶ **Genitofemoral nerve** — lies on the anterior surface of psoas major on each side.
- ▶ **Lumbar sympathetic trunk** — runs along the anterolateral aspect of the vertebral body, on the **medial margin of psoas major**, on each side.

- ▶ The **lumbar plexus (L1–L4 ventral rami)** is being formed within the substance of psoas major through this vertical range.
- ▶ **Para-aortic (lateral aortic), preaortic and paracaval lumbar lymph nodes** surround the great vessels, draining the posterior abdominal wall, kidneys, gonads and (via the mesenteric nodes) the small and large gut.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label a schematic transverse (axial) section through the abdomen at the L4 level, from posterior to anterior:

- ▶ Body of L4 vertebra with spinous process; pedicles/laminae; vertebral canal containing cauda equina + filum terminale
- ▶ Erector spinae (sacrospinalis) with 3 layers of thoracolumbar fascia (both sides)
- ▶ Quadratus lumborum (both sides)
- ▶ Psoas major (both sides), with genitofemoral nerve on its anterior surface and lumbar sympathetic trunk on its medial margin
- ▶ Ureter (both sides), lying on psoas major
- ▶ Abdominal aorta (midline/left, at or just above its bifurcation into common iliac arteries)
- ▶ Inferior vena cava (right of aorta, already a single trunk)
- ▶ Ascending colon (right paracolic gutter) and descending colon (left paracolic gutter)
- ▶ Coils of jejunum/ileum with mesentery (oblique root crossing toward the right sacroiliac joint)
- ▶ Parietal peritoneum separating peritoneal cavity from extraperitoneal fat
- ▶ External oblique, internal oblique, transversus abdominis (three flat muscles, both flanks)
- ▶ Rectus abdominis in rectus sheath, with linea alba anteriorly
- ▶ Skin and subcutaneous fat

Real cross-sectional plate (for orientation)

□ Fig 5.104 — Transverse magnetic resonance images (MRIs) of abdomen. A. Level of T1 (Moore — Clinically Oriented Anatomy — 9e, p.926)

In this serial MRI set, panel (C) — at the lowest level shown, where "BAo" (bifurcation of the aorta) is labelled — corresponds to the L4/upper-L5 plane discussed above; panels (A) and (B) are the more cephalad T-spine/upper-lumbar levels included for orientation and comparison.

How the L4 section differs from higher levels (for comparison/recall)

Level	Key distinguishing content
T12	Pylorus/tail of pancreas, coeliac trunk division, superior poles of kidney + suprarenal, portal triad, splenic hilum
L1–L2	Renal hila with renal vessels (both kidneys prominent), uncinate process of pancreas, origin of SMA/SMV

Level	Key distinguishing content
L3–L4	Coils of small intestine with mesentery dominate; 3 flat abdominal muscles well seen; aortic branches within the mesentery; IVC to the right of aorta; peritoneum vs subperitoneal fat clearly distinguished; 3 layers of thoracolumbar fascia and pre-/paravertebral muscles seen; kidneys no longer present ; aorta at/near its bifurcation

Applied / Clinical anatomy

- ▶ **Lumbar puncture / spinal anaesthesia** — the supracristal (Tuffier's) line, crossing the L4 spine/body, is the standard bedside landmark used to identify the L3/4 or L4/5 interspace, both safely below the adult conus medullaris ($\approx$ L1/L2).
- ▶ **Abdominal aortic aneurysm** — most infrarenal aneurysms involve the segment approaching the bifurcation; a pulsatile expansile mass is classically palpated just below/at the umbilical level, and rupture at this site is a surgical emergency.
- ▶ **Aortic bifurcation as a radiological marker** — CT/MR angiography uses the L4 level to define the origin of the common iliac vessels for endovascular graft planning and to assess retroperitoneal lymphadenopathy (para-aortic nodes, e.g. in testicular tumour staging/retroperitoneal lymph node dissection).
- ▶ **Psoas abscess** — a cold (tuberculous) abscess of the vertebral column tracks within the psoas sheath from this level down to present as a swelling below the inguinal ligament or in the lumbar (Petit's) triangle.
- ▶ **Ureteric calculus** — a stone impacted where the ureter crosses the pelvic brim (near the common iliac bifurcation, just caudal to this section) causes referred pain along the L1 dermatome; the ureter's psoas-related course through this section is a key imaging correlate on IVU/CT-KUB.
- ▶ **Root-of-mesentery injuries** — in blunt abdominal trauma, avulsion/tear at the root of the mesentery (which passes obliquely through this territory) produces mesenteric vascular injury and shock.
- ▶ **Absent kidney shadow** at L4 on cross-section helps a candidate/radiologist localise the level correctly and distinguish it from a section through the renal hila.

High-yield exam pointers

- ▶ Supracristal plane (Tuffier's line) = highest points of iliac crests = crosses **L4 body/spinous process**; classic **lumbar-puncture landmark**.
- ▶ Abdominal aorta **bifurcates at the upper border of L4** into right and left common iliac arteries — coincides with the supracristal plane.
- ▶ IVC is formed lower, **anterior to L5**, by union of the common iliac veins — so at L4 it is already a **single vessel to the right of the aorta**.
- ▶ **Kidneys are not usually seen** at L4 — normal renal span is roughly T12 to L3.
- ▶ Root of the mesentery (~15 cm) runs from the **L2 vertebra** (duodenojejunal flexure) to the **right sacroiliac joint** (ileocaecal junction), obliquely crossing this territory and overlying the

duodenum (3rd part), aorta, IVC, right ureter, right gonadal vessels, right genitofemoral nerve and right psoas major.

- ▶ Ascending and descending colon occupy the right and left **paracolic gutters**; small-bowel coils with mesentery dominate the centre of the field.
- ▶ Lumbar sympathetic trunk lies on the **medial border of psoas major**; genitofemoral nerve lies on its **anterior surface**.
- ▶ Vertebral canal at this level carries only the **cauda equina + filum terminale**, the cord itself having ended around L1.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Anatomy Vol 2, 6e (Cross-Sectional, Radiological and Surface Anatomy of Abdomen and Pelvis); AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen); Moore's Clinically Oriented Anatomy 9e; Vishram Singh — Textbook of Anatomy Vol 2, 4e; BD Chaurasia — Human Anatomy Vol 2, 8e.

Coverage note: no textbook plate in the library is captioned specifically "section at L4" (the closest labelled cross-sectional plate, IB Singh Fig. 26.3, covers the combined L3–L4 level, used above); the embedded Moore MRI panel showing the aortic bifurcation is used as the nearest genuine labelled radiological correlate for this exact vertebral level.



Hysterosalpingography

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — Hysterosalpingography (HSG) is a radiological method in which a radio-opaque contrast medium is instilled through the cervical canal into the uterine cavity, so that the **uterus and both uterine (fallopian) tubes are visualised and the patency of the tubes confirmed**. The radiograph so obtained is called a **hysterosalpingogram**. It is done preferably within the **first 5 to 10 days of the menstrual cycle**, and remains the classical contrast study for the anatomy of the uterine cavity and tube, used chiefly in the work-up of female infertility and of congenital anomalies of the genital tract.

1. Anatomical basis — the uterus as demonstrated on HSG

Feature	Anatomy	HSG correlate
Shape/size	Pear-shaped organ, length ~7.5 cm, breadth at fundus ~5 cm, thickness ~2.5 cm	Triangular contrast shadow, apex directed down toward the cervical canal
Fundus	Dome-shaped part above the level of the tubal openings, entirely covered by peritoneum, has no cavity	Forms the smooth upper border of the triangular cavity shadow

Feature	Anatomy	HSG correlate
Body	Extends from fundus to isthmus; contains the uterine cavity (site of implantation)	The triangular radiolucent-outlined cavity itself; its two superior (cornual) angles are continuous with the interstitial part of each tube
Isthmus	Circular constriction between body and cervix; forms the obstetric "lower uterine segment"	Seen as a narrowing at the lower end of the cavity shadow, above the internal os
Cervix	Lower cylindrical part; upper supravaginal + lower vaginal portions; the internal os is where the cannula seats	Cannula tip and initial pooling of contrast are seen here before the cavity fills
Normal position	Anteversion (cervix bent forward ~90° on the vaginal axis) and anteflexion (body bent forward on the cervix)	Determines the projection in which the triangular cavity is best profiled

2. Anatomical basis — the uterine tube as demonstrated on HSG

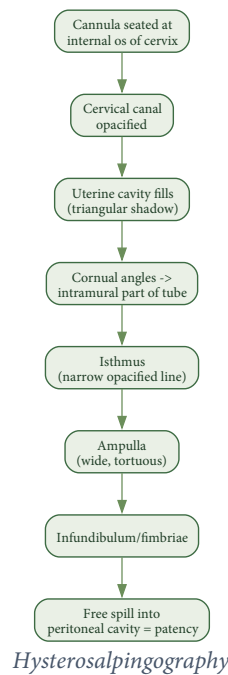
The uterine tube is about 10 cm long and is described, from medial to lateral, in four parts — each has a distinct HSG appearance because of its differing calibre and wall structure.

Part	Length/calibre	Structural feature	HSG appearance
Intramural (interstitial) part	~1 cm; lies within the uterine wall	Opens into the uterine cavity at its superior angle by a narrow uterine ostium (~1 mm)	The narrowest point of tubal filling, continuous with the cornual angle of the cavity
Isthmus	Medial 1/3, 2–3 cm	Narrow, rounded, cord-like; thick circular muscle acts as a sphincter delaying passage of the zygote	A thin, straight opacified line — the segment most often mistaken for "block" if it goes into spasm
Ampulla	Lateral 2/3, 6–7 cm, ~4 mm diameter	Thin-walled, dilated, tortuous; arches over the ovary; the site of fertilisation	A wider, tortuous, wavy opacified segment
Infundibulum	Funnel-shaped lateral end with fimbriae (one, the ovarian fimbria, attached to the ovary)	Free, fimbriated opening into the peritoneal cavity	The point from which contrast spills as free droplets into the peritoneal cavity if the tube is patent

3. Procedure / technique

- **Timing:** performed in the first 5–10 days of the cycle (the proliferative phase, before ovulation) — the endometrium is thin, giving a smoothly outlined cavity, and any early pregnancy is not disturbed.

- ▶ A **tight-fitting cannula** is introduced through the vagina into the **internal os of the cervix** and fixed (with a vulsellum/tenaculum on the cervix) so that contrast cannot reflux out.
- ▶ The cannula is connected to a syringe, and **5–10 ml of an iodised oil (lipiodol)** — or, in current practice, a water-soluble iodinated contrast — is injected under fluoroscopic control.
- ▶ Serial **skiagrams (radiographs)** are exposed as the medium progressively fills the cervical canal, the uterine cavity, and then each uterine tube in sequence.
- ▶ **Spill of the dye into the peritoneal cavity**, seen pooling around bowel loops in the pelvis, is looked for and taken as proof of tubal patency.



4. Normal vs abnormal HSG findings

Finding	Normal	Abnormal (clinical correlate)
Cavity outline	Smooth triangular shadow	Filling defect (polyp/fibroid), or a midline septum splitting the cavity
Cavity contour	Single triangular cavity, two cornua	Two separate horns/cavities — bicornuate uterus or uterus didelphys
Tube calibre	Uniform, tapering isthmus, dilated ampulla	Segmental block, or a grossly dilated, sacculated tube (hydrosalpinx)
Peritoneal spill	Free, diffuse spill bilaterally	No spill = tubal block/occlusion (commonest cause worked-up in infertility)

□ Fig 31.8 — Hysterosalpingogram showing the triangular uterine cavity, the fallopian tube, and contrast in the vaginal canal (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.479)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled coronal diagram of a normal hysterosalpingogram, showing:

- ▶ Vaginal canal and cervical canal, with the **cannula tip at the internal os**
- ▶ The **triangular uterine cavity** — fundus above, isthmus narrowing below, both **cornual** (superior) angles
- ▶ Each uterine tube arising from a cornual angle, its four parts labelled in sequence: **intramural (interstitial) part** → **isthmus (narrow)** → **ampulla (wide, tortuous)** → **infundibulum with fimbriae**
- ▶ Small **droplets of spilled contrast** free in the peritoneal cavity beyond each fimbriated end, to indicate patency

Applied / Clinical anatomy

- ▶ **Chief indication:** assessment of **tubal patency in female infertility/sterility** — free bilateral peritoneal spill excludes tubal block, the commonest tubal-factor cause of infertility that HSG is ordered to exclude.
- ▶ **Other indication:** detection of **anomalies of the female genital tract**, since the shape of the contrast-filled cavity directly reflects the shape of the uterine cavity.
- ▶ **Embryological basis of uterine anomalies seen on HSG:** the uterus and uterine tubes develop from the paired **paramesonephric (Müllerian) ducts**; their lower parts normally fuse in the midline (with resorption of the intervening septum) to form a single uterine body, while the unfused cranial parts remain as the separate uterine tubes. Disorders of this fusion produce anomalies that HSG classically demonstrates:
 - **Failure of fusion** → **uterus didelphys** (two separate uterine bodies/cavities, often two cervices).
 - **Fusion occurs but the septum fails to resorb** → **septate uterus** (single external contour, cavity divided by a midline septum).
 - **Partial fusion** → **bicornuate uterus** (two horns opening into a single cervix).
 - **Failure of development/canalisation of one duct** → **unicornuate uterus**, sometimes with a rudimentary contralateral horn.
- ▶ **Comparison with the insufflation (Rubin's) test:** tubal patency can also be tested by pushing air into the uterine cavity — if the tube is patent, air escapes into the peritoneal cavity producing an audible hiss/bubbling heard with a stethoscope over the iliac fossa. HSG is preferred because it additionally gives a **visual, structural record** of the cavity and tube, not just a patency signal.
- ▶ **Anatomical reason for the isthmal sphincter mattering clinically:** the thick circular muscle of the tubal isthmus can go into transient spasm during the procedure, producing a false appearance of tubal block — a recognised pitfall when interpreting a hysterosalpingogram.
- ▶ **Relations exploited by the technique:** the cervix is fixed and the internal os is directly accessible per vaginam, allowing a cannula to be seated without surgery; the tube's free fimbriated opening into the peritoneal cavity is what allows spilled contrast to outline the pouch of Douglas and paracolic gutters.

- ▶ **Complications:** uterine cramping pain, vasovagal reactions, pelvic infection (hence contraindicated in active pelvic inflammatory disease and in pregnancy), and rarely intravasation of contrast into the myometrial venous/lymphatic channels.
- ▶ **Current practice:** laparoscopic chromopertubation (dye test under direct vision) and pelvic ultrasound/sonosalpingography are now often used alongside or instead of HSG, but HSG remains the standard, minimally invasive first-line test of tubal patency because of the anatomical detail of the cavity and tube it provides on a single film.

High-yield exam pointers

- ▶ HSG = radio-opaque contrast (iodised oil/lipiodol, or water-soluble contrast) injected via a cannula at the internal os → visualises uterine cavity + tubes → confirms tubal patency by peritoneal spill.
- ▶ Done in the first 5–10 days of the cycle (proliferative phase, before ovulation).
- ▶ Normal uterine cavity shadow is **triangular**; the two superior (cornual) angles continue into the intramural part of each tube.
- ▶ Tube shown in four parts, medial to lateral: **intramural (1 cm) → isthmus (2–3 cm, narrow, sphincteric) → ampulla (6–7 cm, wide, site of fertilisation) → infundibulum with fimbriae** (free peritoneal opening).
- ▶ **Free bilateral spill of contrast into the peritoneal cavity = patent tubes**; absent spill = tubal block, the key finding sought in infertility work-up.
- ▶ HSG also demonstrates **congenital uterine anomalies** (bicornuate, septate, didelphys, unicornuate) arising from abnormal fusion/resorption of the paramesonephric ducts.
- ▶ **Rubin's insufflation test** (air + auscultation) is the older, non-visual alternative test of tubal patency.
- ▶ Isthmal muscular spasm during the procedure can mimic a tubal block — a known false-positive pitfall.
- ▶ Contraindicated in pregnancy and active pelvic infection.

SOURCE & COVERAGE

BD Chaurasia — Human Anatomy Vol 2 8e; Vishram Singh — Textbook of Anatomy Vol 2 4e; IB Singh — Textbook of Anatomy Vol 2 6e; Larsen — Human Embryology 6e; Langman's Medical Embryology (Sadler) 14e; Sontakke — Textbook of Human Embryology; Moore — The Developing Human 9e; IB Singh — Human Embryology (CBME 2021).



Intravenous pyelography

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction — Intravenous pyelography (IVP), also called intravenous urography (IVU) or **descending pyelography**, is a contrast radiographic technique in which a water-soluble, iodine-containing contrast medium is injected into a peripheral vein, filtered and concentrated by the kidneys, and excreted into the urine, thereby rendering the **calyces, renal pelvis, ureter and urinary bladder** radiopaque on serial X-ray films. It exploits the normal anatomy and physiology of the urinary tract — glomerular filtration and tubular concentration of the contrast — to outline the pelvicalyceal system and the entire urinary passage in a single study. IVP was for decades the standard investigation for haematuria, renal colic and suspected urinary-tract calculus/anomaly, and remains the classical teaching model for the radiological anatomy of the kidney, ureter and bladder, even though it has now been largely superseded by computed tomographic urography (CTU) in clinical practice.

1. Anatomical basis of the technique

- ▶ **Position and level:** each kidney extends from the upper border of the **T12 vertebra to the L3 vertebra** (the right kidney lying slightly lower than the left); the **hilum lies at the L1 level**, and the **transpyloric plane** passes through the upper part of the hilum of the right kidney and the lower part of the hilum of the left kidney — the reference level at which the renal pelvis and calyces are sought on a film.
- ▶ **Renal sinus and collecting system:** the renal sinus, opening at the hilum, contains the renal pelvis, the branches of the renal artery and the tributaries of the renal vein. The **funnel-shaped renal pelvis** divides into **2–3 major calyces**, each of which subdivides into **7–13 minor calyces**; each minor calyx is indented by one to three conical **renal papillae** (apices of the renal pyramids), giving the calyx its normal concave, "cupped" outline on a pyelogram.
- ▶ **Physiological basis:** the iodinated contrast is handled exactly like a small, freely-filtered solute — it is filtered at the glomerulus, concentrated as water is reabsorbed along the nephron, and delivered via the collecting ducts (of Bellini) into the minor calyces, major calyces, pelvis, ureter and bladder in that anatomical sequence, which is why serial, correctly-timed films reproduce the passage of urine down the tract.
- ▶ **Renal rotation:** during development the kidney rotates so that the **hilum faces medially**; as a result the **posterior calyces come to lie relatively medially and the anterior calyces relatively laterally** — an important point when interpreting oblique views of the collecting system on a pyelogram.

2. Procedure / technique

- ▶ A **plain (control/scout) radiograph of the abdomen — the "KUB" film (Kidney–Ureter–Bladder)** — is taken first, to detect radio-opaque calculi and to check bowel preparation before contrast is given.
- ▶ A **water-soluble, iodine-containing contrast medium** is injected into a superficial vein of the arm (e.g. the **median cubital vein**).
- ▶ Serial films are then exposed at timed intervals:

- An **immediate/nephrogram-phase film** (contrast within the renal parenchyma, opacifying the cortex and pyramids).
 - **Pyelogram-phase films at about 5 and 15 minutes**, when contrast fills the minor and major calyces, the renal pelvis and the ureters.
 - A **delayed film** to show the contrast-filled **urinary bladder**, sometimes followed by a **post-micturition film**.
- **Descending vs ascending pyelography:** when contrast is introduced intravenously and excreted by the kidney, the study is a **descending (intravenous) pyelogram**; when contrast is instead introduced retrogradely into the ureter — via a catheter passed through a **cystoscope** placed in the bladder — the study is an **ascending (retrograde) pyelogram**. In a retrograde study the obstructed segment distal to a lesion can still be outlined (because contrast is introduced below it), whereas in a descending study the tract **distal to an obstruction may fail to opacify** because excretion of dye is impeded proximal to the block.

3. Structures visualised and the three classical constrictions of the ureter

Structure seen on IVP	Radiological appearance
Minor calyces	Small cup-shaped opacities with a concave ("cupped") margin produced by the projecting renal papilla
Major calyces	2–3 larger channels formed by confluence of minor calyces
Renal pelvis	Funnel-shaped opacity at the renal hilum, continuous with the ureter
Ureter	A narrow, continuous radiopaque line from renal pelvis to bladder, showing three sites of physiological narrowing
Urinary bladder	Opacified on the delayed film; outline may show trigone/indentations

- The ureter shows **three principal sites of relative narrowing**, clinically important because a ureteric calculus characteristically lodges there: (1) the **pelviureteric junction (PUJ)**; (2) where the ureter crosses the **pelvic brim** (at the bifurcation of the common iliac artery/external iliac vessels); and (3) as it obliquely traverses the **bladder wall** (vesicoureteric/intramural segment). Some texts describe up to **five constrictions** by additionally listing the point where the ureter is crossed by the **ductus deferens (or broad ligament of the uterus)** and its **opening at the trigone**, but the PUJ–pelvic brim–vesical triad is the classical, universally-taught set.
- **Course used to read the film:** the abdominal ureter runs downward in line with the **tips of the transverse processes of the lumbar vertebrae**; on entering the pelvis it crosses the **sacroiliac joint** and the anterior border of the **greater sciatic notch** to reach the **ischial spine**, where it turns medially to end at the base of the bladder at a level corresponding to the **pubic tubercle**.

□ Fig 5.81 — Intravenous urogram (pyelogram). The contrast medium was injected intravenously and was concentrated and excreted by the kidneys. This anterior projection shows the calices, renal pelvis, and ureter outlined by the contrast medium filling their lumina. (Moore — Clinically Oriented Anatomy — 9e, p.875)

□ Fig 24.23 — Constrictions in the course of ureter (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.404)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled schematic of a normal intravenous pyelogram (anterior projection), showing:

- ▶ Outline of both **kidneys** at the level of T12–L3, with the **renal pelvis** at the hilum (L1/transpyloric plane)
- ▶ 2–3 **major calyces** branching into 7–13 **minor calyces**, each drawn with a concave ("cupped") margin indented by a renal papilla
- ▶ Both **ureters** descending along the tips of the lumbar transverse processes, crossing the **pelvic brim**, then curving around the **ischial spine** to the bladder base
- ▶ The **three constriction sites** labelled on the ureter: **pelviureteric junction**, **pelvic brim** (crossing the **iliac vessels**), and **vesicoureteric/intramural junction**
- ▶ The **urinary bladder** outline at the base, with the **psoas** major shadow and lumbar vertebral bodies/transverse processes sketched in for orientation

Applied / Clinical anatomy

- ▶ **Indications:** haematuria, dysuria and loin pain/renal colic are the classical indications for IVP; it is also used to demonstrate urinary calculi, tumours, and congenital anomalies of the urinary tract.
- ▶ **Renal/ureteric colic — referred pain:** pain from a stone obstructing the **upper ureter** is referred to the loin and inguinal region (afferents accompany sympathetic fibres to the **T12 segment**), while a stone in the **middle/lower ureter** refers pain to the groin, thigh and scrotum/labium majus (afferents to the **L1–L2 segments**) — the clinical correlate of the "loin-to-groin" pain that prompts an IVP.
- ▶ **Hydronephrosis and hydroureter:** obstruction anywhere along the tract produces dilatation proximal to the block — dilatation of the calyces and pelvis (**hydronephrosis**) and/or of the ureter (**hydroureter**); the raised intrapelvic pressure of chronic obstruction **obliterates the normal cupping of the minor calyces**, so loss of calyceal cupping (blunting/clubbing) on a pyelogram is a key radiological sign of obstruction.
- ▶ **Stone impaction:** because the lumen is physiologically narrowest at the pelviureteric junction, the pelvic brim and the vesicoureteric junction, a ureteric calculus is most often arrested and impacted at one of these three sites — the same sites that appear as normal narrowings on a healthy IVP.
- ▶ **Congenital anomalies demonstrable on IVP:** duplex renal pelvis/ureter (two ureters draining one kidney), ectopic ureteric opening, pelviureteric junction obstruction (the commonest cause of congenital hydronephrosis), and rotational anomalies — since the kidney's normal rotation places posterior calyces medially and anterior calyces laterally, an abnormally rotated or horseshoe kidney characteristically shows calyces oriented differently from normal on the pyelogram.
- ▶ **Retrograde (ascending) pyelography** is the complementary procedure used when a lesion obstructs excretion (poor renal function, or when the segment distal to a block must still be

outlined): contrast is instilled through a ureteric catheter passed via a cystoscope, and the cystoscope/catheter themselves are visible in the image.

- ▶ **Modern context:** descending (intravenous) pyelography, based on the same anatomical principle of glomerular filtration and tubular excretion of contrast, has been carried forward into and largely replaced in current practice by **computed tomographic urography (CTU)** and MR urography, which give cross-sectional detail of the same pelvicalyceal system, ureter and bladder while also assessing the renal parenchyma and surrounding structures.

High-yield exam pointers

- ▶ IVP = descending/excretion pyelography — IV iodinated contrast filtered by glomeruli, concentrated by tubules, excreted into the collecting system.
- ▶ Sequence of films: plain KUB scout film → nephrogram phase → pyelogram phase (5–15 min, calyces/pelvis/ureter) → delayed bladder film.
- ▶ Structures shown, in order: minor calyces (2–3 major dividing from pelvis, 7–13 minor per kidney) → renal pelvis → ureter → bladder.
- ▶ Normal minor calyces appear "cupped" (concave) due to the projecting renal papilla; loss of cupping = hydronephrosis.
- ▶ Three classical sites of ureteric narrowing (where stones lodge): pelviureteric junction, pelvic brim (crossing iliac vessels), vesicoureteric junction.
- ▶ Ureter overlies the tips of the lumbar transverse processes in the abdomen; crosses the sacroiliac joint and curves round the ischial spine in the pelvis.
- ▶ Descending pyelography may fail to opacify the tract distal to an obstruction; retrograde (ascending) pyelography via cystoscope + ureteric catheter outlines it instead.
- ▶ Indications: haematuria, dysuria, loin pain/renal colic, suspected calculus/tumour/congenital anomaly.
- ▶ IVP has been largely replaced in current practice by CT urography (CTU)/MR urography, which use the same excretory principle with cross-sectional imaging.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2 8e; Vishram Singh — Textbook of Anatomy Vol 2 4e; Vishram Singh — General Anatomy 4e; IB Singh — Textbook of Anatomy Vol 2 6e; Moore's Clinically Oriented Anatomy 9e.



Labeled diagram of the cross sectional cord at the mid thoracic junction

Asked in: Paper IV Apr 2008 — RGUHS MD/MS Anatomy

Definition / Introduction — A transverse (cross) section through a mid-thoracic spinal segment shows the central H-shaped **grey matter** (anterior, posterior and — uniquely at this level — **lateral horns**) surrounded by **white matter** organised into anterior, lateral and posterior **funiculi** carrying ascending sensory and descending motor tracts. The thoracic level is a favourite "spotter"/diagram question because it is the only level that simultaneously shows (i) a lateral horn, (ii) a prominent nucleus dorsalis (Clarke's column), and (iii) the point ($\approx$ T6) where the **fasciculus cuneatus** first appears in the posterior column — findings absent at cervical, lumbar or sacral levels.

1. General architecture — why the thoracic level looks different

Feature	Thoracic segment	Cervical/lumbosacral enlargement
Overall size/shape	Small, oval to round; no enlargement	Larger, more oval (limb myotomes)
Grey:white ratio	Grey matter small , white matter relatively large (few myotomes to supply, but tracts have already accumulated fibres from below)	Grey matter bulky (large anterior horn for limb muscles)
Lateral (intermediolateral) horn	Present — sympathetic preganglionic column	Absent (except upper 2 lumbar segments)
Posterior column septum	Present from $\approx$T6 upward (splits gracilis/cuneatus)	Present throughout at cervical levels; absent below $\approx$ T6
Nucleus dorsalis (Clarke's column)	Large and prominent	Present but less prominent

2. Real labelled plate — grey matter of a thoracic segment

□ Fig 6.12 — Transverse section of the spinal cord at the level of thoracic segment (Vishram Singh — Clinical Neuroanatomy — 4e, p.167)

This genuine thoracic-level plate shows the H-shaped grey matter with **anterior horn, posterior horn and lateral horn**, the surrounding **substantia gelatinosa**, the **posterior median sulcus** and **anterior longitudinal (median) fissure/groove**. The lateral horn confirms the thoracic level (it disappears above T1 and below L2).

3. Grey matter — Rexed's laminae and named nuclear groups at this level

- ▶ Grey matter is organised cytoarchitecturally into **10 Rexed laminae (I–X)**, numbered dorsal to ventral.
- ▶ **Lamina I** (lamina marginalis) — thin cap at the tip of the posterior horn; relay for pain/temperature.
- ▶ **Lamina II** — substantia gelatinosa; densely packed small neurones; modulates nociception (gate-control).

- ▶ **Laminae III–IV** — nucleus proprius; main bulk of the posterior horn; relay for touch, two-point discrimination and vibration.
- ▶ **Laminae V–VI** — base of posterior horn; receive descending corticospinal collaterals and convergent cutaneous/muscle/visceral afferents.
- ▶ **Lamina VII** (intermediate zone) — at thoracic level contains **three** important nuclei:
 - **Posterior thoracic nucleus / nucleus dorsalis (Clarke's column)** — base of posterior horn; extends from C8 down to L3/L4; origin of the posterior spinocerebellar tract.
 - **Intermediolateral nucleus** — the lateral horn proper, present T1–L2; cell bodies of preganglionic sympathetic neurones.
 - **Intermediomedial nucleus** — runs the full length of the cord; visceral/autonomic reflex connections.
- ▶ **Lamina VIII** — spans the base of the anterior horn at thoracic level (propriospinal interneurons; commissural fibres).
- ▶ **Lamina IX** — clusters of large **alpha and gamma motor neurones** in the anterior horn (medial, central and lateral cell groups; at thoracic level there is no separate group for limb muscles).
- ▶ **Lamina X** — peri-central-canal grey, dorsal and ventral grey commissures.
- ▶ **Tract of Lissauer** (posterolateral fasciculus) — thin strip at the tip of the posterior horn where primary afferents ascend/descend 1–2 segments before synapsing.
- ▶ **Fasciculus proprius (propriospinal fibres)** — a thin rim of intersegmental fibres hugging the margin of the grey matter throughout its circumference, mediating intra/intersegmental spinal reflexes.

4. White matter — funiculi and the major tracts to label

Funiculus	Tract (ascending, <i>italics</i> = sensory)	Position	Function
Posterior	<i>Fasciculus gracilis</i>	Most medial	Touch, vibration, proprioception — lower trunk & lower limb
Posterior	<i>Fasciculus cuneatus</i>	Lateral to gracilis; appears only from ≈T6 upward	Touch, vibration, proprioception — upper trunk & upper limb
Lateral	<i>Posterior spinocerebellar tract</i>	Periphery, posterior part of lateral funiculus	Unconscious proprioception → cerebellum (ipsilateral)
Lateral	<i>Anterior spinocerebellar tract</i>	Periphery, anterior to the above	Unconscious proprioception → cerebellum
Lateral	<i>Lateral spinothalamic tract</i>	Anterior to spinocerebellar tracts	Pain and temperature (crossed)
Lateral	<i>Spinotectal / spinoreticular / spino-olivary tracts</i>	Intermingled with lateral spinothalamic	Spino-visual & spino-reticular reflexes; relay to inferior olive

Funiculus	Tract (ascending, italics = sensory)	Position	Function
Anterior	<i>Anterior spinothalamic tract</i>	Anterior funiculus	Crude touch and pressure (crossed)
Lateral	Lateral corticospinal tract	Bulk of posterior part of lateral funiculus	Voluntary motor (crossed at pyramidal decussation)
Lateral	Rubrospinal tract	Just anterior to lateral corticospinal	Facilitates flexor tone
Lateral	Olivospinal tract	Periphery, anterior part of lateral funiculus	Motor (influence on flexor muscle tone)
Lateral	Lateral vestibulospinal / reticulospinal (medullary)	Periphery, anterior part of lateral funiculus	Extensor tone, posture
Anterior	Anterior corticospinal tract	Close to anterior median fissure	Voluntary motor (uncrossed, crosses at segmental level)
Anterior	Tectospinal tract	Close to anterior median fissure	Reflex postural movements to visual/auditory stimuli
Anterior	Medial vestibulospinal / medial (pontine) reticulospinal	Anterior funiculus	Postural tone, autonomic/respiratory modulation
Circumferential	Fasciculus proprius	Rim around grey matter	Propriospinal intersegmental reflexes

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a circle (the cord outline, slightly compressed antero-posteriorly) with a shallow **posterior median sulcus** above and a deep **anterior median fissure** below; mark the **posterolateral** and **anterolateral sulci** where dorsal and ventral rootlets attach. In the centre draw the H/butterfly-shaped grey matter with the **central canal**. By convention, label **ascending tracts on the right half** and **descending tracts on the left half**. Exact labels to place:

- ▶ Grey matter: anterior horn (with alpha/gamma motor neurone groups), posterior horn (lamina I marginal zone, lamina II substantia gelatinosa, laminae III–IV nucleus proprius), **lateral horn (intermediolateral nucleus)**, **nucleus dorsalis (Clarke's column)** at the base of the posterior horn, intermediomedial nucleus, grey/ventral white commissure, central canal.
- ▶ Posterior funiculus: fasciculus gracilis (medial), **posterior intermediate sulcus/septum**, fasciculus cuneatus (lateral — note if present).
- ▶ Lateral funiculus: tract of Lissauer, lateral spinothalamic tract, anterior & posterior spinocerebellar tracts, spinotectal/spino-olivary tracts, lateral corticospinal tract, rubrospinal tract, olivospinal tract, lateral vestibulospinal tract, reticulospinal fibres.
- ▶ Anterior funiculus: anterior spinothalamic tract, anterior corticospinal tract, tectospinal tract, medial vestibulospinal/reticulospinal fibres.
- ▶ Fasciculus proprius encircling the grey matter.
- ▶ Anterior median fissure and its contained **anterior spinal artery**; posterior median sulcus.

Applied / Clinical anatomy

- ▶ **Vertebral level vs cord segment:** because the vertebral column outgrows the cord, a "mid-thoracic" spinal cord *segment* lies opposite a *higher* thoracic vertebral spinous process — a key point when correlating a vertebral fracture level with the cord segment likely damaged.
- ▶ **Segmental dermatome correlation:** the T4 dermatome corresponds to the **nipple line** and T10 to the **umbilicus**; these are used clinically to localise the upper level of a sensory deficit from a thoracic cord lesion.
- ▶ **Lateral horn/intermediolateral nucleus:** preganglionic sympathetic fibres from T1–L2 leave via white rami communicantes; a **T1 lateral horn/root lesion** (e.g., apical lung (Pancoast) tumour, cervical rib) can produce **Horner's syndrome** (miosis, ptosis, anhidrosis) by interrupting this outflow.
- ▶ **Nucleus dorsalis (Clarke's column) and posterior columns:** degeneration here (with the spinocerebellar and corticospinal tracts) is characteristic of **Friedreich's ataxia**, producing sensory ataxia plus cerebellar and pyramidal signs.
- ▶ **Fasciculus cuneatus boundary:** because the fasciculus cuneatus begins only around T6, a posterior-column lesion **below** mid-thoracic level affects only the fasciculus gracilis (lower-limb proprioception/vibration loss), while a lesion **above** this level also involves the fasciculus cuneatus (upper-limb loss too) — a classic localising point for "mid-thoracic" questions.

- ▶ **Vascular "watershed" vulnerability:** the vertebral arteries (via the anterior/posterior spinal arteries) supply only as far down as the cervical cord; the mid-to-lower cord depends on segmental **radicular arteries**, the largest being the **arteria radicularis magna (artery of Adamkiewicz)**, usually entering around the lower thoracic/upper lumbar region. The intervening upper-to-mid-thoracic segments (roughly T1–T4) receive comparatively sparse radicular contributions and are a recognised **watershed zone**, vulnerable to ischaemic infarction (e.g., after aortic surgery/hypotension).
- ▶ **Anterior spinal artery syndrome:** the anterior spinal artery supplies the anterior two-thirds of the cross-section (anterior and lateral grey columns, anterior and lateral white funiculi) via sulcal branches; thrombosis causes bilateral UMN paralysis below the lesion and loss of pain/temperature, with **touch, vibration and proprioception spared** (posterior columns supplied by the posterior spinal arteries).
- ▶ **Thoracic cord lesion (compressive, e.g., Pott's spine, extradural tumour, disc):** produces a **spastic paraparesis** with hyperreflexia and extensor plantar responses (bilateral corticospinal involvement), a sensory level, "sensory" ataxia and sphincter/bladder-bowel incontinence.
- ▶ **Hemisection (Brown-Séquard-type) at thoracic level:** ipsilateral UMN weakness and loss of proprioception/vibration below the lesion, with contralateral loss of pain and temperature beginning a segment or two below (due to the short ascent of fibres before decussation in the anterior white commissure).

High-yield exam pointers

- ▶ Thoracic segment = small, round/oval, **no enlargement**; grey matter small, white matter proportionally large.
- ▶ Only level with a true **lateral horn (intermediolateral nucleus, T1–L2)** — sympathetic preganglionic cell bodies.
- ▶ **Nucleus dorsalis (Clarke's column):** C8 to L3/L4; gives rise to the posterior spinocerebellar tract.
- ▶ **Fasciculus cuneatus appears only from ≈T6 upward**; below that, posterior column = fasciculus gracilis alone.
- ▶ Grey matter cytoarchitecture = **Rexed's 10 laminae**; laminae I–IV dorsal horn, V–VI base of dorsal horn, VII intermediate zone (Clarke's, IML, IM nuclei), VIII–IX ventral horn, X pericanalicular.
- ▶ Anterior spinal artery supplies anterior 2/3 of the cord (motor + pain/temperature); posterior spinal arteries supply posterior 1/3 (proprioception/vibration/touch) → basis of anterior spinal artery syndrome.
- ▶ T1–T4 segments are a relative **vascular watershed** between the cervical (vertebral artery) supply and the artery of Adamkiewicz.
- ▶ T4 dermatome = nipple line; T10 = umbilicus — used to localise the sensory level of a thoracic cord lesion.
- ▶ Draw ascending tracts on the right half, descending on the left half of the transverse section — standard exam diagram convention.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell — Clinical Neuroanatomy 7e; Vishram Singh — Clinical Neuroanatomy 4e; IB Singh — Textbook of Human Neuroanatomy; Moore's Clinically Oriented Anatomy 9e (dermatome correlation).



Magnetic resonance imaging (MRI) and its usefulness in learning anatomy

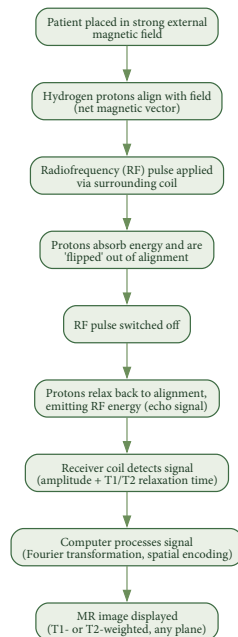
Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction

Magnetic resonance imaging (MRI) is a non-invasive imaging modality that visualises the physiological distribution of mobile hydrogen protons within body tissues, using the phenomenon of **nuclear magnetic resonance (NMR)** — the interaction of atomic nuclei (chiefly hydrogen) with a radiofrequency field in the presence of a strong external magnetic field. Because roughly 70–80% of the human body is water, and every tissue contains hydrogen in differing concentrations, MRI is able to generate high-resolution, multiplanar cross-sectional images that differentiate soft tissues far better than any other imaging technique. It does not use ionising radiation and is completely painless, which — together with its unmatched soft-tissue contrast and its ability to be reformatted in any anatomical plane — has made MRI one of the most important tools for teaching **radiological (imaging) anatomy** alongside conventional cadaveric dissection.

Principle of image formation

- ▶ The patient is placed at the centre of a scanner containing a powerful magnet, so that mobile hydrogen protons (which behave like tiny bar magnets) align themselves with the strong external magnetic field, producing a small net magnetic vector.
- ▶ A pulse of **radiofrequency (RF) energy**, transmitted through a coil placed around the body part, is applied at the resonance frequency of the hydrogen nucleus; the protons absorb this energy and are deflected ("flipped") away from their aligned position.
- ▶ When the RF pulse is switched off, the protons relax back towards their original, pre-excited alignment and, in doing so, emit the absorbed energy as small radiofrequency pulses ("echoes").
- ▶ The strength and frequency of these emitted pulses, together with the time taken by the protons to return to equilibrium, constitute the **signal**; a powerful computer analyses this signal (using Fourier transformation and spatial encoding) to reconstruct an anatomical image.
- ▶ Because information is gathered as a volume rather than a single projection, the same acquisition can be reconstructed as an axial, sagittal, coronal or oblique image — **multiplanar imaging** — without moving or repositioning the patient.



Magnetic resonance imaging (MRI) and its usefulness in learning anatomy

Weighting of images — T1 vs T2

The relative signal contrast between tissues can be manipulated by altering the pulse sequence and scanning parameters — this is called **weighting**, and it is the single most important practical concept for reading an MR image.

Feature	T1-weighted image	T2-weighted image
Fluid (e.g. cerebrospinal fluid)	Dark / low signal	Bright / high signal
Fat	Bright	Intermediate signal
Common nickname	"Anatomy weighting" — best demonstrates normal anatomical detail	Highlights fluid, oedema and most pathology
Typical use	Delineating normal structural (anatomical) detail	Detecting disease — tumour, inflammation, demyelination

- Special sequences build on this basic contrast: **fat-suppression sequences** (T2 fat saturation/STIR) are highly sensitive for soft-tissue or bone-marrow oedema that accompanies inflammation or tumour, while **gadolinium-enhanced, fat-saturated T1 images** highlight hypervascular lesions such as tumours and areas of blood–brain-barrier breakdown.
- The NMR signal can also be altered by introducing **paramagnetic contrast agents** (e.g. gadolinium), enabling enhanced demonstration of very small lesions, particularly within the brain.

Advantages and limitations

- MRI is completely **non-invasive**; no X-rays or ionising radiation are used, and it has no recognised biological hazard from the magnetic field itself.

- ▶ It provides **two- and three-dimensional images of any organ**, and — unlike a plain film or CT, which is essentially axial — produces sagittal, coronal and oblique images directly, in addition to axial sections.
- ▶ It is **superior to CT in soft-tissue contrast** and is the **first investigation of choice for detecting a tumour in the brain or spinal cord**.
- ▶ It can assess **blood flow within vessels and produce angiograms (MRA)**, in many cases without any injected contrast agent.
- ▶ Its principal limitations are practical rather than biological: an MRI scan **takes longer and costs roughly two-thirds more than a CT scan**, it is noisy and can provoke claustrophobia, and it cannot be performed at all in patients with certain implanted metallic/electronic devices (see below).

Apparatus and safety

- ▶ Routine high-field scanners use a **superconducting electromagnet immersed in liquid helium**, producing field strengths in the range of 3–8 Tesla (T); open magnets (for claustrophobic patients) and dedicated limb scanners use permanent magnets of 0.2–0.75 T.
- ▶ MRI does not use ionising radiation and has no recognised biological hazard from the magnetic field itself, but the strong field makes certain patients **absolutely unsafe** to scan: those with cardiac pacemakers or other implanted electro-inductive devices, ferromagnetic intracranial aneurysm clips, certain cardiac valve replacements, and intra-ocular metallic foreign bodies, due to the risk of device malfunction, clip displacement or injury.
- ▶ Patients with dental fillings or most modern (non-ferromagnetic) orthopaedic implants can usually be scanned, though these may still produce local image artefact; all loose metal objects and "MR-unfriendly" equipment must be excluded from the scan room.

Usefulness of MRI in learning anatomy

This is the crux of the question and deserves emphasis beyond MRI's purely diagnostic role.

- ▶ **Bridges cadaveric and living anatomy.** Since the 1960s, imaging has become an increasingly important component of medical anatomy instruction; MRI allows the student to see the same structures studied on the cadaver in a **living, physiological state** — in their natural position, with normal blood flow, tone and relations — reinforcing what is learnt on the dissection table.
- ▶ **True multiplanar sectional anatomy from a single acquisition.** A single MRI scan can be reformatted into sagittal, coronal, axial or oblique images without re-scanning, letting the student build a three-dimensional mental model of a region far more efficiently than serial cadaveric sections through the same part.
- ▶ **Unmatched soft-tissue differentiation.** Because MRI signal depends on tissue water/fat content, it clearly distinguishes individual muscles, ligaments, tendons, nerves, blood vessels and, in the brain, grey matter from white matter — detail that plain radiographs cannot show and that even CT shows poorly.
- ▶ **Ideal for neuroanatomy teaching.** T1- and T2-weighted brain MRI clearly demarcate the cerebral cortex, corpus callosum, basal ganglia (lentiform and caudate nuclei), thalamus, ventricular system, brainstem and cerebellum, and can be correlated directly with cross-sectional

neuroanatomy atlases — the reason MRI is now a routine companion to cadaveric brain dissection in postgraduate neuroanatomy teaching.

- ▶ **Ideal for musculoskeletal/joint anatomy teaching.** Structures around a joint that are easily damaged or distorted on dissection — the cruciate ligaments, menisci, collateral ligaments and articular cartilage of the knee, for example — are seen intact and in their normal relations on MRI, making it an excellent teaching adjunct for joint anatomy.
- ▶ **Advanced sequences extend anatomical understanding further.** Diffusion tensor imaging (DTI) and MR tractography visually reconstruct white-matter fibre tracts (e.g. the corticospinal tract, arcuate fasciculus, corpus callosum) that cannot be directly seen on gross dissection, CT or conventional MRI, giving students and researchers a three-dimensional appreciation of neural connections that was previously understood only from histology and post-mortem tracing studies.
- ▶ **Flexible, repeatable, self-directed learning.** Because MRI images can be archived and distributed electronically, self-guided imaging tutorials and radiology correlation sessions have become an increasingly valuable learning resource throughout medical school and postgraduate training, particularly as overall time allocated to formal anatomy dissection has fallen.
- ▶ **Textbook integration.** Modern anatomy texts (Chaurasia, Vishram Singh, Snell) now routinely place labelled MRI plates alongside gross-anatomy line diagrams specifically so that students correlate classical anatomical description with its living, radiological appearance — the basis of the "radiological anatomy" component of the MD/MS curriculum.

□ Fig 1.26 — MRI showing the structure of the brain. A: Sagittal. B: Coronal. Compa (Snell — *Clinical Neuroanatomy* — 7e, p.46)

□ Fig 82.9 — Left knee joint, T1-weighted coronal magnetic resonance image (MRI). K (Gray's Anatomy — Standring — 41e, p.1906)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simplified sagittal and coronal brain MRI schematic, labelled exactly as follows:

- ▶ **Sagittal section:** frontal lobe, longitudinal fissure, genu of corpus callosum, body of corpus callosum, septum pellucidum, anterior horn of lateral ventricle, fornix, third ventricle, thalamus, midbrain, pons, medulla oblongata, fourth ventricle, cerebellum.
- ▶ **Coronal section:** longitudinal fissure, genu of corpus callosum, septum pellucidum, anterior horn of lateral ventricle, head of caudate nucleus, lentiform nucleus, lateral sulcus, optic tract, temporal lobe, sphenoid bone, infundibular recess of third ventricle.
- ▶ Beside each labelled diagram, note briefly: grey matter (more water, less fat) versus white matter (more fat/myelin, less water) — the physiological basis of their differing MRI signal and the key point for "reading" the image correctly.

Applied / Clinical anatomy

- ▶ **Neuroanatomy:** MRI is the first investigation of choice for detecting brain and spinal cord tumours, and is highly sensitive for small, low-contrast lesions such as demyelinating (multiple sclerosis) plaques; it clearly visualises the brainstem, cerebellum and pituitary fossa, regions obscured on CT by dense skull-base bone.

- ▶ **Vascular anatomy:** magnetic resonance angiography (MRA) demonstrates the arterial and venous tree, in many cases without any contrast agent, allowing non-invasive assessment of blood flow and vascular anomalies.
- ▶ **Musculoskeletal system:** MRI is the investigation of choice for meniscal and cruciate/collateral ligament tears, joint effusions, avascular necrosis, osteomyelitis and soft-tissue tumours, since it depicts cartilage, ligaments and marrow that plain films and CT cannot.
- ▶ **Functional and connectivity imaging:** functional MRI (fMRI) localises "eloquent" cortex (e.g. motor, speech areas) before neurosurgery, and MR tractography maps white-matter tracts for pre-operative planning around brain tumours.
- ▶ **Contraindication awareness:** knowledge of absolute contraindications (pacemakers, ferromagnetic aneurysm clips, certain cardiac valves, intra-ocular metallic foreign bodies) is essential before requesting or performing MRI in any clinical setting.

High-yield exam pointers

- ▶ MRI is based on **nuclear magnetic resonance (NMR)** of mobile **hydrogen protons**; no ionising radiation is used.
- ▶ **T1-weighted:** fluid dark, fat bright ("anatomy weighting"); **T2-weighted:** fluid bright, fat intermediate (pathology weighting).
- ▶ High-field magnets: 3–8 T (superconducting, liquid-helium cooled); open/limb scanners: 0.2–0.75 T (permanent magnets).
- ▶ **Absolute contraindications:** cardiac pacemakers/electro-inductive implants, ferromagnetic aneurysm clips, certain prosthetic heart valves, intra-ocular metallic foreign bodies.
- ▶ MRI is the **first investigation of choice** for brain and spinal cord tumours; superior to CT for soft-tissue contrast in every region.
- ▶ True **multiplanar imaging** (sagittal, coronal, axial, oblique) from a single acquisition, without repositioning the patient.
- ▶ Advanced sequences: MR spectroscopy (MRS, biochemical assessment), functional MRI (fMRI, cortical activation), diffusion tensor imaging/MR tractography (white-matter fibre tract mapping).
- ▶ **Usefulness in learning anatomy:** correlates living, in-situ anatomy with cadaveric dissection; gives true multiplanar sectional views for building 3-D spatial understanding; excellent soft-tissue/grey-white differentiation for neuroanatomy and joint anatomy; basis of self-directed radiological-anatomy teaching in the modern curriculum.

SOURCE & COVERAGE

Vishram Singh — General Anatomy 4e; IB Singh — Textbook of Anatomy Vol 1 6e; Snell — Clinical Neuroanatomy 7e; Gray's Anatomy (Standring) 41e; Weir & Abrahams — Imaging Atlas of Human Anatomy 6e.



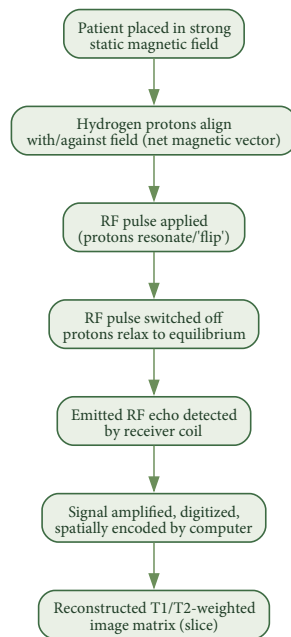
Magnetic Resonance Imaging (MRI)

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction Magnetic resonance imaging (MRI) is a cross-sectional imaging technique that generates high-resolution anatomical images by exploiting the behaviour of mobile hydrogen protons — abundant in the water and fat of soft tissues — when the patient is placed in a strong static magnetic field and pulsed with radiofrequency (RF) energy. It works on the principle of **nuclear magnetic resonance** (NMR), and unlike plain radiography, computed tomography (CT) or fluoroscopy, it uses no ionizing radiation at all. Since the human body is 70–80% water and hydrogen is present in nearly all tissues, MRI can differentiate soft tissues from one another far better than any other imaging modality, making it the investigation of choice for the central nervous system, spinal cord and musculoskeletal soft tissues.

1. Principle: nuclear magnetic resonance

- ▶ The spinning proton of the **hydrogen nucleus** behaves like a tiny bar magnet; when the patient is placed in the bore of a powerful magnet, these protons align either with or against the static magnetic field, producing a small net magnetic vector.
- ▶ A radiofrequency (RF) pulse (e.g., ≈ 46.3 MHz) broadcast from a coil generates a second magnetic field perpendicular to the static field, which "flips" the protons away from their aligned position — this is the state of **resonance**.
- ▶ When the RF pulse is switched off, the protons "relax" back to equilibrium, releasing the RF energy they had acquired as an echo, which is picked up by the receiver coil/antenna around the patient.
- ▶ This information is amplified, digitized and spatially encoded by a computer/array processor, which correlates the density and location of the returning signals into an image matrix.
- ▶ Grey matter (more water) differs in signal from white matter (more fat), and bone (minimal water) gives no signal — so the brain is seen clearly without impediment from the surrounding cranium. MRI thus differentiates tissues on **hydrogen (proton) density/mobility**, not radiodensity as in X-rays/CT.



Magnetic Resonance Imaging (MRI)

2. Instrumentation and magnet-strength grading

- ▶ MRI systems are graded by the **strength of the static magnetic field**, measured in Tesla (T); for comparison, the Earth's own magnetic field is only about 30–60 microtesla (μT).
- ▶ **Routine high-field systems** produce 3–7 T using a **superconducting electromagnet** immersed in liquid helium.
- ▶ **Open magnets** (for claustrophobic patients) and dedicated **limb scanners** use permanent magnets of 0.2–0.75 T (low field).
- ▶ Key components: the main magnet, gradient coils (for spatial localisation), an RF transmit/receive coil (built into the scanner bore or applied over the body part), the patient couch, and a computer/array-processor console that reconstructs and displays the image.
- ▶ MRI has **no recognised biological hazard** from the magnetic field or RF energy itself — its principal risks are mechanical/thermal, related to ferromagnetic objects (see Section 5).

3. Image weighting, contrast agents and radiological terminology

Different pulse sequences and scanning parameters alter the "weighting" of the image, producing different tissue-contrast patterns from the same patient:

Sequence	Fluid (e.g., CSF)	Fat	Common nickname/use
T1-weighted	Dark (low signal)	Bright (high signal)	"Anatomy weighting" — best for depicting anatomical detail
T2-weighted	Bright (high signal)	Intermediate signal	Best for depicting oedema, fluid, most pathology

Sequence	Fluid (e.g., CSF)	Fat	Common nickname/use
Fat-suppression (T2FS/STIR)	Bright	Suppressed (dark)	Highlights bone-marrow/soft-tissue oedema of inflammation or tumour
T1 fat-saturation + gadolinium	—	Suppressed	Exquisitely highlights hypervascularity (tumour, inflammation, blood-brain-barrier breakdown)

- ▶ **Contrast agents:** paramagnetic substances such as **gadolinium chelates** alter local proton relaxation and are used, especially with T1-fat-saturation sequences, to demonstrate enhancing lesions (e.g., small intracranial lesions, tumours).
- ▶ **Metallic artefact reduction sequences (MARS)** are specialised sequences that improve imaging around orthopaedic metalwork/joint prostheses.
- ▶ A shared radiological vocabulary describes brightness/darkness across all cross-sectional modalities:

Imaging modality	"Bright" shade	"Dark" shade
Plain radiograph	Radiopaque	Radiolucent
Ultrasonography	Hyperechoic	Hypoechoic
CT scan	High attenuation	Low attenuation
MRI	High signal	Low signal
Nuclear medicine (isotope) scan	"Hot" area	"Cold" area

4. Imaging planes and orientation

- ▶ MRI can directly acquire images in **any plane** — axial (transverse), sagittal, coronal or oblique — without repositioning the patient, unlike conventional CT, which historically required reformatting from axial data.
- ▶ **Axial** images are conventionally viewed as if standing at the patient's feet looking towards the head (patient's right on the viewer's left).
- ▶ **Sagittal** images show a slice through the long axis, anterior to posterior; **coronal** images show a slice through the long axis, right side to left side — multiplanar acquisition suits complex regions (posterior fossa, spinal cord, pelvis).

5. Advantages, limitations and biosafety

- ▶ **Advantages over CT/X-ray:** completely non-invasive; no ionizing radiation; superior soft-tissue contrast; direct multiplanar (2-D/3-D) imaging; can assess blood flow/vessels (MR angiography) without contrast in many protocols.

- ▶ **Limitations:** longer scan times (motion artefact); more expensive and less widely available than CT/USG; bone and calcification are poorly seen (minimal mobile protons); noisy, enclosed bore (claustrophobia).
- ▶ **Absolute/high-risk contraindications:** patients with a cardiac pacemaker or other implanted electro-inductive device, ferromagnetic intracranial aneurysm clips, certain cardiac valve replacements, or an intraocular metallic foreign body must never be scanned — there is a high risk of death or blindness from movement/heating of the ferromagnetic material.
- ▶ Many extracranial vascular clips and orthopaedic prostheses used today are "MRI-friendly" (non-ferromagnetic) though they may still cause local image artefact.
- ▶ Loose metal objects, "MR-unfriendly" anaesthetic equipment and credit cards/magnetic media must be excluded from the scan room — ferromagnetic objects can become dangerous projectiles ("missile effect") inside the bore.

□ Fig 12.3 — Magnetic resonance imaging (MRI): mid-sagittal MRI of the head (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.613)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple labelled block diagram of the MRI apparatus and workflow:

- ▶ **Superconducting main magnet** (cooled by liquid helium) — generates the static magnetic field
- ▶ **Gradient coils** (X, Y, Z) — superimpose small field gradients for spatial localisation/slice selection
- ▶ **RF transmit/receive coil** (body coil or dedicated surface coil, e.g., head coil, knee coil) — delivers the RF pulse and picks up the returning echo
- ▶ **Patient couch** — positions the patient at the isocentre of the magnet bore
- ▶ **Faraday-shielded scan room** — excludes external RF interference
- ▶ **Computer/array-processor console** — digitises, spatially encodes and reconstructs the image
- ▶ **Display monitor** — shows the reconstructed T1/T2-weighted slice (axial/sagittal/coronal)

Alongside it, sketch a labelled mid-sagittal T1-weighted MRI of the head (as in the figure above) — label the cerebrum, corpus callosum, brainstem, cerebellum and cranio-cervical junction, contrasting with the poorly-defined bony calvarium (minimal signal) that surrounds them.

Applied / Clinical anatomy

- ▶ **Central nervous system:** MRI is the **first investigation of choice** for detecting tumours of the brain and spinal cord, demyelinating disease (multiple sclerosis), stroke/infarction and posterior-fossa pathology, all of which are poorly seen on CT because of bone artefact in that region.
- ▶ **Musculoskeletal system:** the most efficient imaging technique for intervertebral disc prolapse, meniscal/ligamentous injuries of the knee and other joint soft-tissue pathology, and for periprosthetic soft tissue after joint replacement (using MARS).

- ▶ **Vascular system:** MR angiography (MRA) demonstrates the cerebral and peripheral arterial tree, often without the need for iodinated contrast, useful in stroke work-up and vascular anomaly assessment.
- ▶ **Body/oncological staging:** because of its excellent soft-tissue contrast, MRI (often with gadolinium) is the preferred modality for local staging of rectal, cervical, prostatic and breast malignancy, and for characterising mediastinal, thymic and thyroid masses.
- ▶ **Cardiac MRI** assesses myocardial and valvular anatomy/function without radiation, though patients with certain older prosthetic valves or pacemakers are excluded (contraindications as in Section 5).
- ▶ **Correlative teaching value:** because MRI directly reproduces the cardinal anatomical planes (axial, sagittal, coronal) used in gross anatomy dissection and cadaveric cross-sections, it has become central to the modern, formally examined "radiological/cross-sectional anatomy" component of the postgraduate curriculum.

Recent advances in magnetic resonance imaging

- ▶ **Functional MRI (fMRI):** exploits the fact that oxygenated haemoglobin is diamagnetic while deoxygenated haemoglobin is paramagnetic; this blood-oxygenation-dependent signal difference is used to map regional neuronal activity, and is now central to presurgical planning around eloquent cortex.
- ▶ **Diffusion tensor imaging (DTI) and MR tractography (MRT):** sequences that assess the anisotropy of water diffusion along white-matter fibre bundles (myelin/axons act as diffusion barriers); evolved from diffusion MRI (1985), it permits 3-D modelling of neural tracts not directly visible on conventional MRI/CT. **HARDI** (high angular resolution diffusion imaging) further refines tractography, validated against intraoperative electrical stimulation.
- ▶ **MR spectroscopy (MRS):** assesses brain biochemistry in vivo by exploiting the "chemical shift" of protons in different molecular environments; discernible spectral peaks for N-acetylaspartate (altered in multiple sclerosis, stroke, schizophrenia), choline and lactate (used to evaluate brain tumours) allow functional/metabolic assessment alongside structural imaging.
- ▶ **Molecular MRI (mMRI):** uses biomarkers that interact chemically with their surroundings to alter the image according to underlying molecular change, a direction that has expanded rapidly since the description of the human genome, with applications in early disease detection and pharmaceutical development.
- ▶ **Ultra-high-field research scanners** (up to 8 T and beyond) give markedly better spatial resolution and soft-tissue contrast, allowing MR depiction of the cerebral microvasculature approaching histological detail — relevant to research into reperfusion injury and tumour angiogenesis.
- ▶ **Metal artefact reduction sequences (MARS)** and improved fat-suppression techniques continue to extend MRI's use around orthopaedic implants and in inflammatory/oncological imaging.
- ▶ **Point-of-care low-field and portable MRI systems**, and AI/deep-learning-based image reconstruction, are increasingly used to shorten scan times and extend MRI access outside dedicated radiology suites — an evolving area still being incorporated into mainstream anatomy/radiology teaching.

High-yield exam pointers

- ▶ MRI works on the principle of **nuclear magnetic resonance (NMR)** — resonance of mobile hydrogen protons in a strong static magnetic field, excited by an RF pulse.
- ▶ **No ionizing radiation** is used — the safest cross-sectional modality with respect to radiation, but not free of hazard (ferromagnetic contraindications).
- ▶ High-field systems: 3–7 T, superconducting electromagnet + liquid helium; open/limb systems: 0.2–0.75 T, permanent magnets.
- ▶ **T1-weighted** = "anatomy weighting" (fat bright, fluid dark); **T2-weighted** = fluid bright, fat intermediate; **STIR/T2FS** = fat-suppressed, highlights oedema; gadolinium = paramagnetic contrast agent used with T1-fat-saturation.
- ▶ **Absolute contraindications**: cardiac pacemaker/electro-inductive implants, ferromagnetic aneurysm clips, certain cardiac valve replacements, intraocular metallic foreign body — risk of death/blindness.
- ▶ **First choice** for brain/spinal cord tumours and intervertebral disc prolapse; superior soft-tissue contrast to CT; images directly in any plane (axial/sagittal/coronal) without reformatting.
- ▶ Radiological convention: MRI signal is described as "**high/low signal**" (cf. radiopaque/radiolucent for X-ray, hyperechoic/hypoechoic for USG, high/low attenuation for CT).
- ▶ Recent advances arising from conventional MRI: **fMRI** (BOLD-type contrast), **DTI/tractography** (with HARDI), **MR spectroscopy**, and **molecular MRI**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e (Commentary 7.1, "Magnetic resonance imaging"); BD Chaurasia's Human Anatomy, Vol 3-4, 8e; Vishram Singh's General Anatomy, 4e; IB Singh's Textbook of Anatomy, Vol 1, 6e.



Medulla at motor and sensory decussation

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction The medulla oblongata is the caudal-most part of the brainstem, extending from the lower border of the pons to a plane just above the origin of the first cervical nerve, where it becomes continuous with the spinal cord. Its internal architecture is studied at four transverse levels — decussation of the pyramids, decussation of the lemnisci, the olives, and just inferior to the pons. The two most caudal levels — the **motor (pyramidal) decussation** and the **sensory (lemniscal/medial lemniscus) decussation** — mark the transition from a spinal-cord-like arrangement of grey and white matter to the brainstem pattern, and are where the corticospinal tract and the dorsal column–medial lemniscus system exchange sides.

1. Gross position and external landmarks (orientation)

- ▶ **Extent:** pons above to spinomedullary junction below (~C1 nerve root level); **closed part** below (central canal, corresponds to the two decussation levels) and **open part** above (fourth ventricle floor).
- ▶ **Anterior median fissure** and **posterior median fissure** divide the medulla into right and left halves; each half is further divided by the **anterolateral** and **posterolateral sulci** into anterior, lateral and posterior regions, exactly as in the spinal cord.
- ▶ **Pyramid** — longitudinal elevation on either side of the anterior median fissure, formed by corticospinal and corticobulbar fibres; rootlets of the **hypoglossal nerve (XII)** emerge through the anterolateral sulcus between pyramid and olive.
- ▶ **Olive** — oval elevation posterolateral to the pyramid, produced by the underlying inferior olivary nucleus; rootlets of **glossopharyngeal (IX)**, **vagus (X)** and the **cranial part of accessory (XI)** emerge through the posterolateral sulcus, behind the olive.
- ▶ **Posterior region** — three longitudinal elevations, medial to lateral: **fasciculus gracilis**, **fasciculus cuneatus** and **inferior cerebellar peduncle**; their upper ends expand into gracile and cuneate tubercles (nucleus gracilis/cuneatus beneath). The **tuberculum cinereum**, lateral to the cuneate tubercle, overlies the spinal nucleus of the trigeminal nerve.

2. Transverse section at the level of the motor (pyramidal) decussation

This is the lowest of the four levels and closely resembles a section through the spinal cord.

- ▶ **Grey matter:** the decussating pyramidal fibres separate the anterior (ventral) horn from the central grey matter; the detached anterior horn forms the **spinal nucleus of the accessory nerve** (laterally, extending down to about C5) and the **nucleus for the motor fibres of the first cervical nerve** (medially, continuous above with the hypoglossal nucleus). The central grey matter, with the central canal, is displaced dorsally. Nucleus gracilis and nucleus cuneatus are still continuous with the central grey matter. Laterally, the central grey matter is continuous with the **nucleus of the spinal tract of the trigeminal nerve**, capped by the spinal tract itself (an upward continuation of the substantia gelatinosa).
- ▶ **White matter:** the pyramids lie anteriorly. The great **motor (pyramidal) decussation** is the dominant feature — corticospinal fibres run backward and laterally across the midline to reach the contralateral lateral white column, where they continue as the **lateral corticospinal tract**.

Standard texts quote slightly different splits of this crossing, but concordantly describe the bulk (roughly 75–90%) of pyramidal fibres crossing here to form the lateral corticospinal tract, a smaller fraction descending uncrossed as the anterior corticospinal tract (crossing later at their segmental level), and a small residual fraction remaining permanently uncrossed. The **fasciculus gracilis** and **fasciculus cuneatus** occupy the broad posterior white column; a diffuse **reticular formation** appears in the lateral white column next to the spinal trigeminal nucleus.

Nuclei	Ascending tracts	Descending tracts
Nucleus gracilis (with its tract)	Anterior spinothalamic	Corticospinal (decussating here)
Nucleus cuneatus (with its tract)	Lateral spinothalamic	Medial longitudinal fasciculus
Spinal nucleus of trigeminal nerve (with its tract)	Anterior spinocerebellar	Tectospinal
Spinal nucleus of accessory nerve	Posterior spinocerebellar	Vestibulospinal
—	Spino-olivary, Spinotectal	Olivospinal, Rubrospinal

embed: ![Fig 5.5 — Transverse section (TS) of medulla oblongata at the level of pyramidal decussation (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.517)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/18a6a42ed900ebb4.jpg)

3. Transverse section at the level of the sensory (lemniscal) decussation

This section lies a little rostral to the pyramidal decussation, still within the closed part of the medulla.

- **Grey matter:** nucleus gracilis and nucleus cuneatus are now larger and are no longer continuous with the central grey matter. The **accessory cuneate nucleus** appears dorsolateral to the cuneate nucleus — functionally equivalent to Clarke's column, it relays unconscious proprioceptive impulses from the upper limb (via fasciculus cuneatus) and gives rise to **posterior (dorsal) external arcuate fibres**, which reach the cerebellum of the same side through the inferior cerebellar peduncle. Several cranial nerve nuclei make their first appearance in the central grey matter: the **hypoglossal nucleus** (ventromedial, close to the midline), the **dorsal nucleus of the vagus** (dorsolateral to it), and the **nucleus of the tractus solitarius** (dorsolateral to the dorsal vagal nucleus); the **nucleus ambiguus** lies within the reticular formation, medial to the spinal trigeminal nucleus. The lower part of the **inferior olivary nucleus** also comes into view.
- **White matter:** the nucleus gracilis and nucleus cuneatus give off **internal arcuate fibres**, which curve first ventrolaterally around the central grey matter and then ventromedially, decussating in the midline anterior to the central grey matter and posterior to the pyramids — this crossing is the **sensory (lemniscal) decussation**. After crossing, the fibres turn cranially to form the **medial lemniscus**, a flattened tract near the median raphe. In crossing, fibres from the two nuclei intercross so that gracile fibres come to lie ventral to cuneate fibres in the lemniscus; the resulting somatotopy places fibres from the leg most anteriorly, followed by trunk and upper limb, with the head/face represented most posteriorly. The pyramids lie anteriorly; the medial longitudinal fasciculus lies posterior to the medial lemniscus; the spinocerebellar and lateral/anterior spinothalamic tracts (together forming the "spinal lemniscus") occupy the anterolateral region.

Nuclei	Ascending tracts	Descending tracts
Nucleus gracilis + nucleus cuneatus (with tracts); accessory cuneate nucleus	Anterior spinothalamic	Corticospinal
Spinal nucleus of trigeminal nerve (with its tract)	Lateral spinothalamic	Medial longitudinal fasciculus
Hypoglossal, dorsal vagal, nucleus of tractus solitarius, nucleus ambiguus	Anterior spinocerebellar	Tectospinal
Inferior olivary nucleus (lower part), medial accessory olivary, arcuate nuclei	Posterior spinocerebellar	Vestibulospinal
—	Spino-olivary, Spinotectal	Olivospinal, Rubrospinal

embed: ![Fig 5.6 — TS of medulla oblongata at the level of sensory decussation (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.517)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/7fe23137a491bcdd.jpg)

4. Comparing the two decussation levels

Feature	Motor (pyramidal) decussation	Sensory (lemniscal) decussation
Position in medulla	Lowest level, at/near the spinomedullary junction	A little rostral, still in the closed part
Structure that crosses	Corticospinal (pyramidal) fibres	Internal arcuate fibres (2nd-order fibres from nucleus gracilis/cuneatus)
Site of crossing relative to central grey matter	Ventral to, separating ventral horn from central grey matter	Ventral to central grey matter, dorsal to the pyramids
Effect on grey matter	Ventral horn detached → forms spinal nucleus of accessory nerve + nucleus for C1	Nucleus gracilis/cuneatus enlarge and detach from central grey matter; accessory cuneate nucleus appears
Tract formed after crossing	Lateral corticospinal tract (contralateral)	Medial lemniscus (contralateral)
New cranial nerve nuclei seen	Spinal nucleus of accessory nerve (XI) forms from the detached ventral horn; spinal trigeminal nucleus/tract continue from below	Hypoglossal (XII), dorsal vagal (X), solitary tract nucleus, nucleus ambiguus first appear
Cavity	Central canal	Central canal (pushed further dorsally)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw two labelled transverse (Weigert-stain style) sections of the medulla, side by side:

- ▶ **TS at pyramidal decussation:** anterior/posterior median fissure; pyramid (both sides); decussating corticospinal fibres crossing the midline ventral to central grey matter; central canal with surrounding central grey matter (displaced dorsally); fasciculus gracilis and fasciculus cuneatus (posterior columns); nucleus gracilis, nucleus cuneatus; spinal nucleus and tract of trigeminal nerve; spinal nucleus of accessory nerve; reticular formation; lateral and anterior spinocerebellar tracts; lateral spinothalamic tract.
- ▶ **TS at sensory decussation:** pyramids (anterior); internal arcuate fibres curving around central grey matter and decussating in the midline; medial lemniscus (newly formed, dorsal to pyramids); nucleus gracilis, nucleus cuneatus, accessory cuneate nucleus; spinal nucleus and tract of trigeminal nerve; hypoglossal nucleus, dorsal nucleus of vagus, nucleus of tractus solitarius, nucleus ambiguus; medial longitudinal fasciculus (posterior to medial lemniscus); spinocerebellar and spinothalamic tracts (anterolateral); lower pole of inferior olivary nucleus.

Applied / Clinical anatomy

- ▶ **Medial medullary (Dejerine's anterior bulbar) syndrome** — the paramedian medulla, containing exactly the structures decussating at these two levels, is supplied by the **anterior spinal artery / medial medullary branches of the vertebral artery**. Occlusion produces a classic crossed (alternating) picture: (1) **contralateral hemiplegia** of the arm and leg, sparing the face, from destruction of the pyramid before its fibres have crossed; (2) **ipsilateral paralysis and wasting of half the tongue with deviation toward the lesion on protrusion**, from destruction of the hypoglossal nucleus/nerve (a lower motor neuron, uncrossed at this level); (3) **contralateral loss of position sense, vibration and tactile discrimination**, from destruction of the medial lemniscus, whose fibres have already crossed at the sensory decussation. Pain, temperature and facial sensation are characteristically spared, since the spinal (lateral) lemniscus and trigeminal pathways lie more laterally, outside the paramedian territory.
- ▶ **Lateral medullary (Wallenberg's) syndrome**, by contrast, follows occlusion of the **posterior inferior cerebellar artery** and damages the dorsolateral wedge of the medulla — sparing the pyramid and medial lemniscus (no hemiplegia, no contralateral proprioceptive loss), but producing crossed sensory loss (ipsilateral facial, contralateral body pain/temperature), ipsilateral palatal/pharyngeal/laryngeal paralysis, ataxia and Horner's syndrome. Contrasting the two syndromes at these exact levels tests whether the candidate understands the paramedian versus dorsolateral territories.
- ▶ **Bulbar palsy** — a lesion at or above the sensory decussation level, where the hypoglossal, dorsal vagal, solitary tract and nucleus ambiguus first appear, involves the IXth–XIIth cranial nerve nuclei together, producing dysphagia, dysarthria, nasal regurgitation and tongue wasting/fasciculation.
- ▶ **Surgical/traumatic relevance** — because the medulla descends to the foramen magnum, sudden hyperextension injuries (e.g. in judicial hanging) can drive the dens of the axis against the

medulla, damaging the vital respiratory and vasomotor centres and causing immediate death; the decussation levels lie just below these vital centres.

High-yield exam pointers

- ▶ Motor decussation = pyramidal decussation = crossing of **corticospinal** fibres → lateral corticospinal tract; lies at the lowest (most caudal) level of the medulla.
- ▶ Sensory decussation = lemniscal/medial lemniscus decussation = crossing of **internal arcuate fibres** (from nucleus gracilis and cuneatus) → medial lemniscus; lies a little higher than the motor decussation.
- ▶ At the pyramidal decussation, the crossing fibres lie ventral to the central grey matter (separating the ventral horn from it); at the sensory decussation, the crossing fibres (internal arcuate) lie ventral to the central grey matter but dorsal to the pyramids.
- ▶ Detached ventral horn at the pyramidal decussation level → spinal nucleus of accessory nerve + nucleus for first cervical nerve.
- ▶ Accessory cuneate nucleus (functional equivalent of Clarke's column) first appears at the sensory decussation level and relays upper-limb proprioception to the cerebellum via the inferior cerebellar peduncle.
- ▶ Cranial nerve nuclei of IX, X (dorsal nucleus, solitary tract) and XII first appear at/around the sensory decussation level; nucleus ambiguus lies deep in the reticular formation.
- ▶ Medial medullary syndrome (anterior spinal artery/vertebral artery) = contralateral hemiplegia + ipsilateral tongue palsy + contralateral loss of position/vibration/discriminative touch — the classic clinical correlate of these two decussations.
- ▶ Lateral medullary (Wallenberg's) syndrome (PICA) spares the pyramid and medial lemniscus because it damages the dorsolateral, not paramedian, medulla.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3–4, 8e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; Snell's Clinical Neuroanatomy 7e.



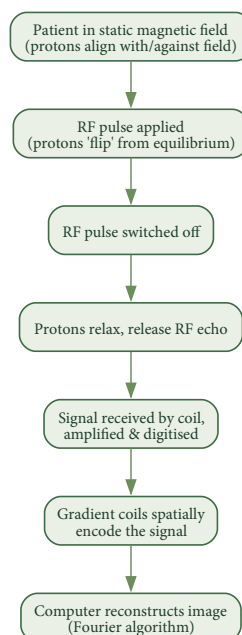
MRI (magnetic resonance imaging)

Asked in: Paper IV Oct 2006 — RGUHS MD/MS Anatomy

Definition / Introduction — Magnetic resonance imaging (MRI) is a non-ionising medical imaging technique that generates high-resolution anatomical images by exploiting **nuclear magnetic resonance (NMR)** — the interaction of mobile hydrogen protons (present abundantly in the water and fat of soft tissues) with a strong external magnetic field and pulsed radiofrequency (RF) energy. Since the human body is 70–80% water, the hydrogen proton is an ideal signal source. MRI is regarded as the most important advance in medical imaging since the discovery of X-rays (Röntgen, 1895) and is today the investigation of choice for the central nervous system, spinal cord and most soft-tissue lesions.

Principle of image formation

- ▶ The patient is placed in the bore of a powerful magnet. The spinning proton of the hydrogen nucleus behaves like a tiny bar magnet and aligns either **with** or **against** the static magnetic field, producing a small net magnetization vector.
- ▶ A pulse of **radiofrequency (RF) energy**, delivered by a coil built into the scanner or placed over the body part, generates a second magnetic field at right angles to the static field and "flips" the aligned protons away from equilibrium.
- ▶ When the RF pulse is switched off, the protons **relax** back to equilibrium, releasing the absorbed RF energy as an echo signal that is picked up by the receiver coil.
- ▶ This signal is amplified, digitised, and **spatially encoded** using gradient coils; complex mathematical algorithms (Fourier transformation) then correlate proton density and location into an image matrix.



MRI (magnetic resonance imaging)

Instrumentation

□ Fig 16.13 — MRI of the head. (MRI, magnetic resonance imaging.) (Vishram Singh — General Anatomy — 4e, p.676)

- **Main magnet** — routine high-field systems use a **superconducting electromagnet immersed in liquid helium**, producing field strengths of **3–7 Tesla (T)**; open magnets (for claustrophobic patients) and dedicated limb scanners use permanent magnets of **0.2–0.75 T**. (For comparison, the Earth's own magnetic field is only 30–60 μT .)
- **Gradient coils** — superimpose small, controlled variations on the main field to permit slice selection and spatial localisation.
- **RF transmit/receive coils** — built-in body coil or dedicated surface coils, deliver the excitation pulse and detect the returning echo.
- **Array processor/computer console** — digitises, spatially encodes and reconstructs the final image, which can be displayed in any plane.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple labelled schematic of the MRI unit for the exam answer sheet, with these exact labels: **Superconducting main magnet (bore) — Liquid helium reservoir — Gradient coils (X, Y, Z) — RF transmit–receive coil — Patient couch — Computer/array-processor console.**

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Weighting	Fluid (CSF) signal	Fat signal	Chief use
T1-weighted	Dark/low ("anatomy weighting")	Bright	Best anatomical detail
T2-weighted	Bright/high	Intermediate-to-bright	Detects oedema, inflammation, most pathology
Fat-suppressed (T2FS/STIR)	High signal fluid retained	Fat signal suppressed	Highly sensitive for bone-marrow/soft-tissue oedema
T1 fat-saturation + gadolinium contrast	—	Fat suppressed	Highlights hypervascularity/blood–brain-barrier breakdown (tumours, inflammation)

Contrast enhancement uses **gadolinium**, a paramagnetic agent, and is avoided in patients with severe renal impairment. Moving fluid (flowing blood) tends to appear **black on T1-weighted images** because excited protons move out of the imaging slice before re-emitting their signal.

Radiological terminology and comparison with other modalities

Imaging modality	Bright shade	Dark shade
Plain radiograph	Radiopaque	Radiolucent
Ultrasonography	Hyperechoic	Hypoechoic

Imaging modality	Bright shade	Dark shade
CT scan	High attenuation	Low attenuation
MRI	High signal	Low signal
Nuclear medicine (NMR/scintigraphy)	'Hot' areas	'Cold' areas

Unlike CT (which needs gantry angulation for non-axial planes) or plain radiography (fixed 2-D projection), an MRI computer can directly reconstruct **axial, sagittal, coronal and oblique** images from the same acquisition (multiplanar reconstruction), and images are conventionally viewed as though standing at the patient's feet for axial sections.

Advanced MRI techniques

- ▶ **MR spectroscopy (MRS)** — exploits the "chemical shift" of resonant protons in different biochemical environments to display a metabolite spectrum (e.g., N-acetylaspartate, choline, lactate) for a chosen brain volume; altered in multiple sclerosis, stroke, and brain tumours.
- ▶ **Functional MRI (fMRI)** — exploits the differing magnetic behaviour of oxygenated (diamagnetic) versus deoxygenated (paramagnetic) haemoglobin to map cortical activation.
- ▶ **Diffusion tensor imaging (DTI) / high angular resolution diffusion imaging (HARDI)** — model the asymmetric ("anisotropic") diffusion of water along white-matter fibre bundles, forming the basis of **MR tractography (MRT)**, used for pre-surgical mapping of eloquent brain regions and white-matter tracts.
- ▶ **MR angiography (MRA)** — visualises blood vessels without an injected contrast dye, though conventional catheter angiography is still preferred in many clinical situations.
- ▶ **Molecular MRI (mMRI)** — uses biomarkers that alter the image according to molecular/biochemical change in the region of interest.

Advantages of MRI

- ▶ Uses **no ionising radiation** and has no recognised biological hazard (subject to the safety exclusions below).
- ▶ Superior **soft-tissue contrast and resolution** compared with CT and plain radiography.
- ▶ Direct **multiplanar and three-dimensional** imaging without repositioning the patient.
- ▶ Combines **anatomical and functional** information (via fMRI, MRS, DTI/tractography).
- ▶ First investigation of choice for **brain and spinal cord tumours** and for **intervertebral disc prolapse**.
- ▶ Can assess blood flow and vasculature (MR angiography) without conventional contrast injection.

Contraindications, hazards and limitations

- ▶ **Absolute contraindications:** cardiac pacemakers or other implanted electro-inductive devices, ferromagnetic intracranial aneurysm clips, certain types of cardiac valve replacement, and intraocular metallic foreign bodies — examination carries a high risk of death or blindness and must never be undertaken.

- ▶ **Practical precautions:** loose metallic objects, "MR-unfriendly" anaesthetic equipment and credit cards must be excluded from the scanner room; many extracranial vascular clips and orthopaedic prostheses are now "MRI-friendly" but may still cause local artefact (reduced by metallic-artefact-reduction sequences, MARS).
- ▶ **Claustrophobia** in the narrow bore of high-field magnets — addressed by open, low-field permanent-magnet systems.
- ▶ **Cost and scan time** are greater than for CT or ultrasound; motion (respiratory, cardiac, peristaltic) can degrade images, though gated/fast sequences now reduce this.
- ▶ **Bone** contains minimal mobile protons and is poorly seen — MRI is not the modality of choice for acute fracture, where CT/plain radiography remain superior.
- ▶ Gadolinium contrast is best avoided in patients with significant renal impairment.

Applied / Clinical anatomy

- ▶ Because grey matter (more water) and white matter (more fat/myelin) differ in proton density, MRI clearly differentiates brain tissue, and, since bone contains minimal mobile protons, the brain is seen without the impediment of the surrounding cranium.
- ▶ MRI is the **investigation of choice** for suspected brain or spinal cord tumour and for lumbar/cervical **disc prolapse**.
- ▶ MR angiography of the carotid and cerebral vessels, and of major limb/visceral vessels, permits non-invasive vascular assessment.
- ▶ MR tractography assists **pre-surgical mapping** of eloquent cortical/white-matter pathways before brain-tumour resection.
- ▶ Standard viewing convention: axial CT/MRI images are viewed as if standing at the patient's feet (an inferior view); coronal images as if the patient faces the viewer; sagittal images as if standing at the patient's side.

High-yield exam pointers

- ▶ MRI is based on nuclear magnetic resonance (NMR) between mobile hydrogen protons and an external magnetic field plus RF pulses.
- ▶ Routine high-field magnets: 3–7 T (superconducting, liquid-helium cooled); open/limb magnets: 0.2–0.75 T.
- ▶ T1-weighted = "anatomy weighting" (fluid dark, fat bright); T2-weighted = fluid bright ("pathology weighting").
- ▶ Gadolinium is the standard paramagnetic contrast agent; avoid in severe renal impairment.
- ▶ Absolute contraindications: pacemakers, ferromagnetic aneurysm clips, certain heart-valve prostheses, intraocular metallic foreign bodies.
- ▶ No ionising radiation; superior soft-tissue contrast; direct multiplanar imaging — but poor for cortical bone/acute fracture and relatively slow/expensive.
- ▶ MRI is first choice for brain/spinal cord tumours and intervertebral disc prolapse.
- ▶ Advanced techniques: MRS (metabolite spectrum), fMRI (BOLD cortical mapping), DTI/HARDI → MR tractography, MRA (vessels), molecular MRI.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e ("Technical aspects and applications of diagnostic radiology" commentary — Magnetic resonance imaging); IB Singh — Textbook of Anatomy Vol 1, 6e (Introduction to Radiological Anatomy); Vishram Singh — General Anatomy, 4e; BD Chaurasia — Human Anatomy Vol 3-4, 8e; Moore's Clinically Oriented Anatomy, 9e.



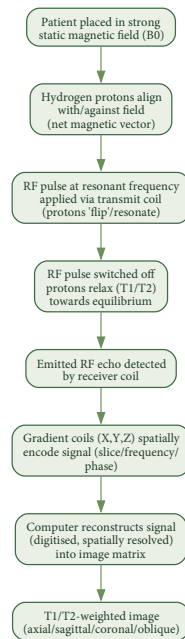
Principles of MRI

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction Magnetic resonance imaging (MRI) is a cross-sectional, multiplanar imaging technique whose entire physical basis is **nuclear magnetic resonance (NMR)** — the behaviour of mobile hydrogen protons when a patient is placed inside a strong static magnetic field and pulsed with radiofrequency (RF) energy. Because the human body is 70–80% water and hydrogen is present, in varying concentration, in almost every tissue, MRI generates the physiological distribution of these protons as a high-resolution anatomical image, without ionising radiation. Its principles are best grouped under three linked ideas: (i) generation of an NMR **signal** from excited protons, (ii) **spatial encoding** of that signal for computer localisation, and (iii) manipulation of pulse parameters to control tissue **contrast/weighting** — together with the instrumentation and safety that follow from them.

1. Principle of signal generation — nuclear magnetic resonance

- ▶ The **hydrogen proton** behaves like a tiny spinning bar magnet. When the patient is placed in the bore of a powerful magnet, these protons align themselves either with or against the static magnetic field, producing a small **net magnetic vector**.
- ▶ A **radiofrequency (RF) pulse** (broadcast at the resonant frequency of hydrogen, ≈ 46.3 MHz for the field strengths in clinical use) is transmitted through a coil placed around the body part; it generates a second magnetic field perpendicular to the static field that rotates or "flips" the net vector away from its aligned position — this is the state of **resonance**.
- ▶ When the RF pulse is switched off, the protons **relax** back towards equilibrium, giving up the RF energy they had acquired as a small emitted echo, which is picked up by the receiver coil/antenna around the patient.
- ▶ Two independent relaxation processes occur simultaneously, at different rates in different tissues, and both contribute to the raw signal: **T1 (spin-lattice) relaxation**, the realignment of the net vector back along the static field, and **T2 (spin-spin) relaxation**, the decay of the transverse signal as neighbouring protons dephase relative to one another. Together with **proton density**, T1 and T2 relaxation are the three tissue properties that determine MR signal strength.
- ▶ Tissues that are rich in mobile protons (fat, water) emit strong signals; tissues with few mobile protons (cortical bone, air) emit little or none — hence the brain is seen clearly, undegraded by the surrounding calvarium, which itself shows almost no signal.

*Principles of MRI*

2. Principle of spatial encoding — how the signal is localised

- ▶ A raw RF echo, by itself, carries no positional information. Superimposed **gradient coils** (X, Y, Z axes) vary the magnetic field strength linearly across the patient; since resonance frequency is directly proportional to local field strength, protons at different positions along the gradient precess at slightly different frequencies and phases.
- ▶ The scanner exploits this to achieve **slice selection**, **frequency encoding** and **phase encoding**, letting the computer work out exactly where in the body each part of the returning signal originated.
- ▶ Because localisation is electronic (gradient-based) rather than mechanical (unlike a rotating CT gantry), the same acquisition can be reconstructed directly as an **axial**, **sagittal**, **coronal**, or **oblique** image — true **multiplanar imaging** — and rendered as a three-dimensional volume.
- ▶ By convention, **axial** images are viewed as if standing at the patient's feet looking towards the head; **sagittal** images run anteroposteriorly through the long axis, and **coronal** images run from right side to left side.

3. Instrumentation and magnet-strength grading

- ▶ MRI systems are graded by the **strength of the static magnetic field**, measured in Tesla (T).
- ▶ **Routine high-field systems** produce 3–7 T using a **superconducting electromagnet** cooled by liquid helium.
- ▶ **Open magnets** (used for claustrophobic patients) and dedicated **limb scanners** use permanent magnets of 0.2–0.75 T (low field), trading some image quality for patient comfort/access.
- ▶ Key components: main magnet; gradient coils; an RF transmit/receive coil (whole-body coil in the bore, or a dedicated surface coil — head, knee, shoulder — for a specific region); patient couch positioning the region of interest at the magnet's isocentre; a Faraday-shielded scan room excluding external RF interference; and a computer/array-processor console that digitises, encodes and reconstructs the image.

- The static field and RF energy carry **no recognised biological hazard** in themselves — MRI's principal risks are mechanical/thermal, from ferromagnetic objects in or near the bore (see Applied/Clinical anatomy).

4. Image weighting — the principle of tissue contrast

Altering the **pulse sequence and scanning parameters** changes the relative contribution of T1 relaxation, T2 relaxation and proton density to the final signal — this manipulation is called **weighting**, and it is the key practical principle for "reading" an MR image, since the same anatomical slice can look very different depending on the sequence used.

Sequence	Fluid (e.g., CSF)	Fat	Common use/nickname
T1-weighted	Dark (low signal)	Bright (high signal)	"Anatomy weighting" — best depicts normal structural detail
T2-weighted	Bright (high signal)	Intermediate signal	Best depicts oedema, fluid and most pathology
Fat-suppression (T2FS/STIR)	Bright	Suppressed (dark)	Highlights bone-marrow/soft-tissue oedema of inflammation or tumour
T1 fat-saturation + gadolinium	—	Suppressed	Highlights hypervascular lesions and blood–brain-barrier breakdown

- **Contrast agents:** paramagnetic **gadolinium chelates** shorten the T1 relaxation time of nearby protons, producing a bright signal on T1-weighted (especially fat-saturated) images — used to demonstrate small enhancing lesions, e.g. intracranial tumours.
- **Flow-related signal void:** rapidly moving protons (flowing blood) leave the imaging slice before they can re-emit their signal and are replaced by unexcited protons — so flowing blood typically appears black ("flow void") on conventional images, a useful sign that helps distinguish vessels from other structures without contrast.
- **Metal artefact reduction sequences (MARS)** are specialised sequences that reduce image degradation around orthopaedic metalwork/joint prostheses.
- A shared radiological vocabulary is used to describe brightness/darkness across all cross-sectional modalities:

Imaging modality	"Bright"	"Dark"
Plain radiograph	Radiopaque	Radiolucent
Ultrasonography	Hyperechoic	Hypoechoic
CT scan	High attenuation	Low attenuation

Imaging modality	"Bright"	"Dark"
MRI	High signal	Low signal
Nuclear medicine scan	"Hot" area	"Cold" area

□ Fig 15.4 — Magnetic resonance imaging of sagittal section of brain showing interventricular foramen, choroid fissure and fourth ventricle (IB Singh — Textbook of Human Neuroanatomy, p.242)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple labelled block diagram of MRI apparatus + signal pathway, followed by a labelled sagittal brain MRI:

- ▶ **Superconducting main magnet** (liquid-helium cooled) — generates the static magnetic field (B₀)
- ▶ **Gradient coils** (X, Y, Z) — superimpose field gradients for slice-selection, frequency- and phase-encoding
- ▶ **RF transmit/receive coil** (body coil or surface coil, e.g., head coil) — delivers the RF pulse and detects the returning echo
- ▶ **Patient couch** — positions the region of interest at the magnet's isocentre
- ▶ **Faraday-shielded scan room** — excludes external RF interference
- ▶ **Computer/array-processor console** — digitises, spatially encodes and reconstructs the image; **Display monitor** — shows the reconstructed T1/T2-weighted slice.

Beside it, sketch a labelled mid-sagittal T1-weighted MRI of the brain (as in the figure above) — label the **choroid fissure**, **interventricular foramen** and **fourth ventricle**, together with the cerebrum, corpus callosum, brainstem and cerebellum, contrasting these clearly-defined soft-tissue structures with the poorly-defined, low-signal calvarium surrounding them.

5. Recent advances arising from the basic MRI principle

- ▶ **Functional MRI (fMRI)**: exploits the fact that oxygenated haemoglobin is diamagnetic while deoxygenated haemoglobin is paramagnetic; this **blood-oxygenation-level-dependent (BOLD)** signal difference localises regional neuronal activity (e.g., language and motor cortex) for pre-surgical planning.
- ▶ **Diffusion tensor imaging (DTI) and MR tractography (MRT)**: water molecules in living tissue move constantly due to thermal (Brownian) motion; within white matter this motion is preferentially directed along the long axis of myelinated fibres, because the axolemma restricts perpendicular diffusion. MR signals capture this anisotropic diffusion, and computer algorithms reconstruct it as three-dimensional fibre tracts. **HARDI** (high angular resolution diffusion imaging) further refines this technique.
- ▶ **MR spectroscopy (MRS)**: assesses brain biochemistry in vivo via the "chemical shift" of protons in different molecular environments; spectral peaks for N-acetylaspartate, choline and lactate allow metabolic assessment of tumours, stroke and multiple sclerosis alongside structural imaging.

- ▶ **Molecular MRI (mMRI):** uses biomarkers that interact chemically with their surroundings to alter the image according to underlying molecular change, aiding early disease detection and pharmaceutical development.
- ▶ **Ultra-high-field research scanners** (up to 8 T) give markedly better spatial resolution, approaching histological detail for the cerebral microvasculature — relevant to reperfusion-injury and tumour-angiogenesis research.
- ▶ **PET**, though a different modality, is often paired with MRI (PET-MRI) to add functional/metabolic information (blood flow, glucose uptake) that anatomical MRI alone cannot provide.

Applied / Clinical anatomy

- ▶ **Absolute/high-risk contraindications:** a patient with a cardiac pacemaker or other implanted electro-inductive device, a ferromagnetic intracranial aneurysm clip, certain cardiac valve replacements, or an intraocular metallic foreign body must **never** be scanned — there is a high risk of death or blindness from movement/heating of the ferromagnetic material inside the strong field.
- ▶ Many extracranial vascular clips and orthopaedic prostheses in current use are "MRI-friendly" (non-ferromagnetic), though they may still produce local artefact (reducible with MARS); loose metal objects, "MR-unfriendly" anaesthetic equipment and magnetic media must be excluded from the scan room, since ferromagnetic objects can become dangerous projectiles ("missile effect") when drawn into the bore.
- ▶ **Central nervous system:** MRI is the **first investigation of choice** for tumours of the brain and spinal cord, demyelinating disease and stroke — regions in which CT is degraded by dense skull-base/posterior-fossa bone artefact.
- ▶ **Musculoskeletal system:** the most efficient technique for intervertebral disc prolapse and for meniscal/ligamentous knee injury, since it directly depicts cartilage, ligaments and marrow.
- ▶ **Vascular system:** MR angiography (MRA) images the arterial/venous tree, in many protocols without any injected contrast, exploiting the natural flow-void/flow-related signal changes of moving blood.
- ▶ Because MRI directly reproduces the cardinal anatomical planes used in cadaveric dissection, it is central to the modern, formally examined "radiological/cross-sectional anatomy" component of the postgraduate curriculum.

High-yield exam pointers

- ▶ MRI is based on **nuclear magnetic resonance (NMR)** of mobile **hydrogen protons** — no ionising radiation is used.
- ▶ Signal generation: static field → RF pulse "flips" protons (resonance) → RF switched off → protons relax, emitting RF echo, governed by **T1 (spin-lattice)** and **T2 (spin-spin)** relaxation + proton density.
- ▶ Spatial encoding: **gradient coils** (X, Y, Z) make resonance frequency/phase position-dependent → true **multiplanar imaging** (axial/sagittal/coronal/oblique) from one acquisition, no gantry repositioning.

- ▶ High-field systems: 3–7 T, superconducting magnet + liquid helium; open/limb systems: 0.2–0.75 T, permanent magnets.
- ▶ **T1-weighted** = "anatomy weighting" (fat bright, fluid dark); **T2-weighted** = fluid bright, fat intermediate; **STIR/T2FS** = fat-suppressed, highlights oedema; **gadolinium** = paramagnetic T1 contrast agent.
- ▶ **Absolute contraindications**: cardiac pacemaker/electro-inductive implants, ferromagnetic aneurysm clips, certain prosthetic valves, intraocular metallic foreign body — risk of death/blindness.
- ▶ Radiological convention: MRI signal described as "**high/low signal**" (cf. radiopaque/radiolucent for X-ray, hyperechoic/hypoechoic for USG, high/low attenuation for CT).
- ▶ **First-choice** modality for brain/spinal cord tumours and disc prolapse; superior soft-tissue contrast to CT.
- ▶ Recent advances arising from the basic principle: **fMRI** (BOLD), **DTI/tractography** (with HARDI), **MR spectroscopy**, **molecular MRI**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e (Commentary 7.1, "Magnetic resonance imaging"); Vishram Singh's General Anatomy 4e; Moore's Clinically Oriented Anatomy 9e; IB Singh's Textbook of Human Neuroanatomy; Weir & Abrahams' Imaging Atlas of Human Anatomy 6e.



Section at the level of T4 vertebra

Asked in: Paper IV Apr 2006 — RGUHS MD/MS Anatomy

Definition / Introduction. A transverse (axial) section through the upper part of the body of the fourth thoracic (T4) vertebra passes entirely through the **superior mediastinum**, cutting the **arch of the aorta** itself in cross-section — described classically as a "half-cut oblique tube" — together with the trachea, oesophagus, superior vena cava (SVC), thymus and thoracic duct, flanked on each side by the right and left lungs and their pleurae. This level lies one vertebra *above* the more famous **sternal angle (T4–T5 disc) plane of Louis**, at which the arch terminates and the trachea/pulmonary trunk bifurcate; distinguishing the two planes is a common examiner's discriminator. Anteriorly the section is bounded by the body of the manubrium sterni (opposite T3–T4), posteriorly by the body of T4 vertebra, and on each side by mediastinal pleura and the medial surface of each lung.

Boundaries and skeletal framework of the section

- ▶ **Anteriorly**: body of the manubrium sterni — the manubrium is about 4 cm long and lies opposite the T3–T4 vertebrae; its **left half is anterior to the arch of the aorta**, while its **right half directly overlies the union of the two brachiocephalic veins forming the SVC**.
- ▶ **Posteriorly**: body of the T4 vertebra and the vertebral (spinal) canal containing the spinal cord and meninges.
- ▶ **On each side**: mediastinal (parietal) pleura, and the medial parts of the right and left lungs covered by visceral pleura; the ribs form the lateral bony wall.

- The plane lies above the roots of the lungs and above the pericardium — it is a pure **superior-mediastinal** section, unlike the T5/sternal-angle section which straddles the superior/inferior mediastinal junction.

Structures cut in the section

Structure	Position in the section	Key point
Arch of the aorta	Central, cut obliquely as it curves postero-superiorly and to the left	Its three branches — brachiocephalic trunk, left common carotid and left subclavian arteries — are seen arising within the concavity/summit of the arch
Superior vena cava	Anterior, to the right of the arch	Already fully formed; lies against the right side of the manubrium
Trachea	Midline, anterior to the oesophagus	Not yet bifurcated at this level (bifurcation occurs lower, near the sternal angle plane)
Oesophagus	Immediately posterior to the trachea, anterior to the T4 vertebral body	
Thoracic duct	Posterior and to the left of the oesophagus	Has already crossed from right to left lower down (crossing occurs about the level of T5, reaching the left margin of the oesophagus by the sternal-angle plane)
Thymus (or its fibrofatty adult remnant)	Anterior-most structure, in front of the great vessels	
Right and left lungs with pleura	Occupy the greater part of the section on each side	

Relations of the arch of the aorta as seen in this cross-section

The arch of the aorta is classically described as related to five structures on each of its four aspects — this composite is what the cross-section at T4 actually displays:

Aspect	Structures related
Superior	Brachiocephalic trunk, left common carotid artery, left subclavian artery, left brachiocephalic vein, thymus
Inferior	Left principal bronchus, bifurcation of the pulmonary trunk, ligamentum arteriosum, left recurrent laryngeal nerve, superficial cardiac plexus
Posterior and to the right	Trachea, oesophagus, left recurrent laryngeal nerve, thoracic duct, vertebral column

Aspect	Structures related
Anterior and to the left	Left lung and pleura, left phrenic nerve, left vagus nerve, left cardiac nerves, left superior intercostal vein

□ Fig 22.7 — Cross section of the superior mediastinum showing relations of the arch of the aorta (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.877)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw an inferior-view transverse (axial) outline of the thorax at the upper-T4 level and label:

- ▶ Body of manubrium sterni (anterior)
- ▶ Body of T4 vertebra (posterior) with vertebral canal
- ▶ Ribs (lateral bony wall)
- ▶ Arch of the aorta (cut obliquely, central) with its three branches — brachiocephalic trunk, left common carotid, left subclavian
- ▶ Superior vena cava (right, anterior to the arch)
- ▶ Trachea (midline, anterior to oesophagus)
- ▶ Oesophagus (posterior to trachea)
- ▶ Thoracic duct (posterior and left of oesophagus)
- ▶ Thymus/thymic remnant (anterior-most)
- ▶ Right and left lungs with visceral and parietal (mediastinal) pleura

T4-vertebra section vs the sternal angle (T4–T5 disc) section — a comparison

Feature	Section at T4 (upper part)	Section at sternal-angle plane (T4–T5 disc / upper T5)
Aorta	Arch seen in cross-section, mid-course	Arch terminates here — ascending aorta has ended, descending aorta begins
Trachea	Single, undivided tube	Bifurcates into right and left principal bronchi (classical teaching)
Pulmonary trunk	Still a single trunk, below the arch	Bifurcates into right and left pulmonary arteries just below this plane
Azygos vein	Ascending on the right, not yet arched forward	Arches over the root of the right lung to open into the SVC
Thoracic duct	Already on the left, posterior to the oesophagus	Reaches the left margin of the oesophagus by this plane
Mediastinal division	Section lies wholly within the superior mediastinum	This plane is itself the boundary separating superior from inferior mediastinum

Feature	Section at T4 (upper part)	Section at sternal-angle plane (T4–T5 disc / upper T5)
Clinical use	Landmark for arch/thymic/great-vessel pathology on CT	The single most important surface landmark of the thorax — rib counting, cardiac auscultation areas

Note (modern data): CT-based surface-anatomy studies (Mirjalili et al 2012, cited in Gray's Anatomy) show that in most adults the aortic-arch concavity, azygos-vein entry and tracheal bifurcation actually lie slightly *below* the classical sternal-angle description — most commonly opposite T5 (55% for the arch), T5 (49% for the azygos vein) and T6 (46% for the tracheal bifurcation) respectively, with a wide normal range. The T4/T4–T5-disc teaching level above remains the standard classical description used in the undergraduate/postgraduate curriculum and in most gross-anatomy texts.

Applied / Clinical anatomy

- ▶ The **sternal angle** (T4–T5 disc, one level below this section) is the most important palpable bony landmark of the thorax — the starting point for counting ribs, and the surface marker for the boundary between superior and inferior mediastinum.
- ▶ **Central venous catheters:** the tip of a right internal jugular/subclavian central line lies in the SVC just deep to the manubrium, close to this level.
- ▶ **Mediastinoscopy** is performed through a small incision just above the jugular notch of the manubrium to biopsy paratracheal and subcarinal lymph nodes at and below this level — used for staging bronchogenic carcinoma and diagnosing sarcoidosis/lymphoma.
- ▶ An **aortic-arch aneurysm** at this level can compress the trachea, oesophagus or the left recurrent laryngeal nerve (producing hoarseness), reproducing exactly the relations tabulated above.
- ▶ **Thymoma** or thymic hyperplasia (associated with myasthenia gravis) presents as an anterior mediastinal mass at precisely this level on CT.
- ▶ **Coarctation of the aorta** most commonly occurs near the ligamentum arteriosum, i.e. just inferior to the arch cut in this section.
- ▶ **Widening of the mediastinal shadow** on a chest radiograph after blunt chest trauma (e.g. a deceleration injury) suggests haemorrhage from a lacerated great vessel (aorta or SVC) at this level.
- ▶ **Postural note:** in the supine position the arch of the aorta lies slightly superior to the transverse thoracic plane, whereas in the erect/sitting position it is transected by that plane — relevant when comparing supine CT with erect chest radiography.
- ▶ This is one of the two "must-know" cross-sectional levels of the thorax in the RGUHS curriculum (the other being the T5/sternal-angle section through the lung roots) and is a favourite spotter/diagram question.

High-yield exam pointers

- ▶ Section at T4 = through the **arch of the aorta itself**; section at the sternal-angle (T4–T5 disc) = through its **termination** and the tracheal/pulmonary-trunk bifurcations.

- ▶ Three branches of the arch — brachiocephalic trunk, left common carotid, left subclavian — arise **within** the arch at this level.
- ▶ SVC lies anterior and to the **right** of the arch; oesophagus lies posterior to the trachea; thoracic duct is posterior and to the **left** of the oesophagus.
- ▶ Left half of manubrium is anterior to the arch; right half overlies the SVC/brachiocephalic-vein union.
- ▶ The trachea has **not yet bifurcated** at T4 — bifurcation is a sternal-angle-plane event.
- ▶ Thymus lies anterior-most in the section — key CT correlate for thymoma/myasthenia gravis.
- ▶ Modern CT data (Mirjalili 2012) show these classical levels are, on average, one vertebra lower than traditionally taught.
- ▶ Mediastinoscopy and central-line placement are the two commonest clinical procedures referable to this level.

SOURCE & COVERAGE

Vishram Singh — Textbook of Anatomy Vol 1, 4e; IB Singh — Textbook of Anatomy Vol 2, 6e; BD Chaurasia — Human Anatomy Vol 1, 8e; Moore's Clinically Oriented Anatomy, 9e; Gray's Anatomy (Standing), 41e.



Section at Transpyloric plane

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — The **transpyloric plane** (also called the **upper horizontal plane** or **Addison's superior clinical plane**) is an imaginary horizontal reference plane used to describe the level of abdominal viscera and to construct the nine regions of the abdomen. It lies midway between the suprasternal (jugular) notch and the symphysis pubis, roughly a hand's-breadth below the xiphisternal joint. Anteriorly it crosses the tips of the **9th costal cartilages**; posteriorly it corresponds to the **lower part of the body of the L1 vertebra**. A transverse (axial) section taken at this level is a classic cross-sectional/radiological-anatomy exercise because it slices through the pylorus, the biliary and pancreatic viscera, the origins of the great abdominal vessels, and the renal hila almost simultaneously.

1. Surface landmarks and vertebral level

Landmark	Description
Anterior extent	Tips of the 9th costal cartilages on each side (also the point where the linea semilunaris begins)
Posterior extent	Lower part of the body of L1 vertebra (T12–L1 disc space to mid-L1, per standard vertebral-level tables)
Vertical position	Midway between the suprasternal notch and pubic symphysis; a hand's-breadth below the xiphisternal joint

Landmark	Description
Eponym	Addison's plane (superior clinical plane); together with the transtubercular (Addison's inferior) plane it demarcates the 9 regions of the abdomen
Postural note	In the supine position it transects the pylorus (hence the name); on standing , the mobile viscera sag and the pylorus falls to a slightly lower level

2. Structures transected by the plane

System	Structures at/near the transpyloric level
Stomach/duodenum	Pylorus of the stomach (pyloric antrum/canal); beginning (superior part) of the duodenum ; the duodenojejunal flexure is classically listed with this plane by Moore's <i>Clinically Oriented Anatomy</i> , though its precise vertebral correlate is a little lower, at L2
Hepatobiliary	Fundus of the gallbladder (where the linea semilunaris meets the costal margin, tip of the 9th right costal cartilage)
Pancreas	Neck of the pancreas , lying across the vertebral column anterior to the great vessels
Kidneys	Hila of both kidneys — precisely, the plane crosses the upper part of the hilum of the right kidney and the lower part of the hilum of the left kidney (the right kidney lies about half a vertebra lower than the left because of the overlying liver)
Great vessels	Origin of the superior mesenteric artery from the aorta; origin/formation of the hepatic portal vein behind the neck of the pancreas (union of the splenic vein and superior mesenteric vein)
Peritoneum	Attachment of the root of the transverse mesocolon
Spinal cord	Termination of the spinal cord (conus medullaris) , which in the adult ends at the lower border of L1 — essentially at this plane
Coeliac trunk	Arises from the aorta just above the plane, at the T12–L1 disc

3. Cross-sectional (transverse) anatomy at this level

Read from **anterior to posterior**, a transverse section at the transpyloric plane shows:

- **Abdominal wall (anterior/lateral)**: skin and superficial fascia; in the midline the paired **rectus abdominis** muscles enclosed in the **rectus sheath**, separated by the **linea alba**; laterally the three flat muscles — **external oblique**, **internal oblique**, **transversus abdominis** — with the costal margin (9th costal cartilage tips) cut anterolaterally.

- ▶ **Peritoneal cavity, right side:** a large slice of **liver** (right lobe, part of quadrate/caudate lobe near the midline) with the **fundus of the gallbladder** peeping out at the tip of the 9th costal cartilage; the **first (superior) part of the duodenum** related to the neck of the pancreas and porta hepatis structures.
- ▶ **Peritoneal cavity, left side:** the **pyloric antrum/pylorus** of the stomach; the **lesser sac** lying immediately behind the stomach, in front of the pancreas; the **spleen** may appear posterolaterally with its hilum and splenic vessels if the section is taken at the upper part of the plane.
- ▶ **Midline, retroperitoneal:** the **neck of the pancreas** crossing anterior to the L1 vertebral body and the great vessels; behind it, the **splenic vein** joins the **superior mesenteric vein** to form the **hepatic portal vein**; the **abdominal aorta** (giving off the SMA at this level, with the coeliac trunk just above) lies anterior and slightly left of the vertebral body; the **inferior vena cava** lies to its right.
- ▶ **Posterolateral (retroperitoneal):** the **right and left kidneys**, sectioned through their hila with the renal vessels entering/leaving; **root of the transverse mesocolon** crossing the duodenum and the front of the kidneys.
- ▶ **Posterior wall:** the body of **L1 vertebra** with its vertebral (spinal) canal containing the **conus medullaris/upper cauda equina**; the **psoas major** muscles flanking the vertebral body on each side; the **quadratus lumborum** lateral to psoas; the **erector spinae** and **thoracolumbar fascia** posteriorly, with **latissimus dorsi** as the most superficial posterior muscle.

□ Fig 5.104 — Transverse magnetic resonance images (MRIs) of abdomen. A. Level of T1 (Moore — Clinically Oriented Anatomy — 9e, p.926)

(Panel B of this MRI series, cited by Moore's Clinically Oriented Anatomy as the "level of L1–L2 vertebra and renal vessels and hilum," corresponds to a true axial section at the transpyloric level.)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a **transverse (axial) section through the abdomen at the level of L1**, and label:

- ▶ Body of L1 vertebra + vertebral canal (conus medullaris/cauda equina)
- ▶ Psoas major (both sides)
- ▶ Quadratus lumborum
- ▶ Erector spinae + thoracolumbar fascia; latissimus dorsi (posterior-most)
- ▶ Abdominal aorta (with SMA origin)
- ▶ Inferior vena cava
- ▶ Right kidney — upper part of hilum + renal vessels
- ▶ Left kidney — lower part of hilum + renal vessels
- ▶ Neck of pancreas (crossing the midline)
- ▶ Splenic vein + superior mesenteric vein uniting to form the portal vein (behind pancreatic neck)
- ▶ Pylorus/pyloric antrum of stomach (left side)
- ▶ First part of duodenum (right side, related to pancreatic neck)
- ▶ Liver — right lobe and part of left/caudate lobe
- ▶ Fundus of gallbladder (tip of right 9th costal cartilage)
- ▶ Spleen with splenic hilum (posterolateral, left)
- ▶ Root of transverse mesocolon
- ▶ Rectus abdominis + rectus sheath, linea alba (anterior)
- ▶ External oblique, internal oblique, transversus abdominis (lateral wall)
- ▶ Tips of 9th costal cartilages (anterolateral, marking the plane)

4. Right-left asymmetry at this level

- ▶ The **liver** dominates the right side of the section (pushing the right kidney about half a vertebral body lower than the left), while the **stomach and spleen** dominate the left side.
- ▶ The plane crosses the **upper** part of the right renal hilum but the **lower** part of the left renal hilum — a frequently tested point (BD Chaurasia).
- ▶ The **inferior vena cava** lies to the right of the aorta and vertebral column throughout this level; the **aorta** lies just to the left of the midline, anterior to the vertebral body.
- ▶ The **coeliac trunk** (just above the plane) divides into left gastric, splenic and common hepatic arteries — the splenic artery running left toward the spleen, the hepatic artery right toward the liver — reinforcing the left/right visceral split seen in the section.

5. Uses of the transpyloric plane

- ▶ Together with the **transtuberular plane** (through the iliac tubercles/L5) and the two **midclavicular/lateral vertical planes**, it divides the abdomen into the classical **nine regions**: right/left hypochondrium and epigastrium (upper zone), right/left lumbar and umbilical region (middle zone), right/left iliac fossa and hypogastrium (lower zone).

- ▶ Used as a quick surface guide in **surgery and radiology** to localise the pylorus, gallbladder fundus, pancreatic neck, renal hila and the origin of the coeliac axis/SMA without imaging.
- ▶ Serves as one of the standard **CT/MRI axial reference levels** in cross-sectional abdominal imaging (alongside T10, T12 and L3–L4 sections).

Applied / Clinical anatomy

- ▶ **Lumbar puncture safety:** the spinal cord (conus medullaris) ends at the lower border of L1, essentially at the transpyloric level — this is why diagnostic/spinal-anaesthetic lumbar puncture is deliberately performed lower, at the L3–L4 or L4–L5 interspace, to avoid cord injury.
- ▶ **Pyloric surgery:** the plane is used to mark the pylorus for pyloromyotomy (infantile hypertrophic pyloric stenosis) and gastric surgery; in the erect position the pylorus sags below the plane, which is why supine imaging/positioning is preferred for this landmark.
- ▶ **Gallbladder disease:** the fundus of the gallbladder, at the intersection of the transpyloric plane and the linea semilunaris (tip of the right 9th costal cartilage), is the surface point for eliciting **Murphy's sign** and for percutaneous cholecystostomy.
- ▶ **Pancreatic pathology:** a mass at the "neck of pancreas" on cross-sectional imaging is localised to this level; tumours here can compress the portal vein formed just behind it (early portal hypertension/obstructive jaundice).
- ▶ **Renal surgery/biopsy:** the plane approximates the level of the renal hila and pedicle, useful in planning nephrectomy incisions and percutaneous renal access.
- ▶ **Splenic trauma:** the spleen's upper pole/hilum may be included in a high transpyloric-level section, relevant to blunt trauma and splenectomy planning.
- ▶ **Vascular access/aneurysm:** origins of the coeliac trunk and SMA at/just above this level are key landmarks in mesenteric and coeliac angiography.

High-yield exam pointers

- ▶ Transpyloric plane = midway between suprasternal notch and pubic symphysis; anterior — tip of 9th costal cartilage; posterior — lower border of L1 vertebral body.
- ▶ Right renal hilum: **upper** part on the plane; left renal hilum: **lower** part on the plane (right kidney is lower than left).
- ▶ Structures transected: pylorus, first part of duodenum ($\pm$ duodenojejunal flexure), fundus of gallbladder, neck of pancreas, hila of both kidneys, origin of SMA, formation of portal vein, root of transverse mesocolon.
- ▶ Coeliac trunk arises just **above** the plane (T12–L1 disc); SMA arises **at** the plane (L1).
- ▶ Spinal cord (conus medullaris) terminates at L1 — coincides with this plane; hence lumbar puncture is done below L2.
- ▶ Together with the transtubercular plane, it demarcates the **9 regions of the abdomen** (epigastric/hypochondriac, umbilical/lumbar, hypogastric/iliac).
- ▶ In supine posture the plane truly transects the pylorus; on standing, gravity carries the pylorus slightly below the plane.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 2 8e; IB Singh Textbook of Anatomy Vol 2 6e; Moore's Clinically Oriented Anatomy 9e.



Sectional study of midbrain

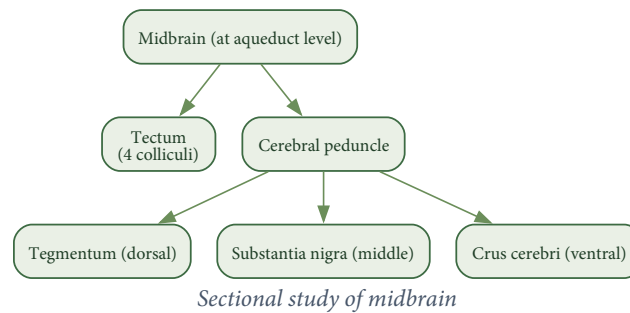
Asked in: Paper IV 14-Jul-2023 — RGUHS MD/MS Anatomy

Definition / Introduction — The midbrain (mesencephalon) is the shortest segment of the brainstem, not more than 2 cm long, connecting the pons and cerebellum below to the diencephalon above as it traverses the tentorial notch. A coronal plane through the **cerebral aqueduct** (which links the third and fourth ventricles) divides it into a small dorsal **tectum** (corpora quadrigemina) and a large ventral **cerebral peduncle**, the latter further split by the **substantia nigra** into a dorsal **tegmentum** and a ventral **crus cerebri**. Because the internal pattern of grey and white matter changes along its length, the midbrain is conventionally studied by transverse sections at two standard levels — through the **inferior colliculi** and through the **superior colliculi**.

External features

Ventral surface — Two **crura cerebri** emerge from the cerebral hemispheres and converge downward to enter the pons, forming the postero-lateral boundaries of the **interpeduncular fossa**. Each crus is superficially corrugated by underlying longitudinal fibres and is crossed transversely by the optic tract, the posterior cerebral artery, the superior cerebellar artery and the taenia pontis. The **oculomotor nerve** emerges through a groove (oculomotor sulcus) on the medial side of the crus cerebri, in the interpeduncular fossa. The floor of the fossa is pitted by fine vessels and is called the **posterior perforated substance**.

Dorsal surface — Four rounded elevations, the two **superior** and two **inferior colliculi** (corpora quadrigemina), lie below the pineal gland and are separated from each other by a cruciform sulcus; its upper limit forms a depression for the pineal body and its lower limit continues as the **frenulum veli**. The **trochlear nerve** — the only cranial nerve to arise from the dorsal aspect of the brainstem and the only one to decussate completely — emerges one on each side of the frenulum after crossing in the superior medullary velum, then winds around the lateral aspect of the cerebral peduncle to appear ventrally, lateral to the oculomotor nerve, running forward between the posterior cerebral and superior cerebellar arteries to reach the cavernous sinus. Thick ridges of white matter, the **brachia**, pass from each colliculus: the **superior brachium** carries optic-tract fibres to the superior colliculus (connecting it to the lateral geniculate body), and the **inferior brachium** carries auditory fibres from the inferior colliculus to the medial geniculate body.



Crus cerebri and substantia nigra (constant at both levels)

- **Crus cerebri** — semilunar, convex externally, concave internally; contains only descending fibres, arranged medial to lateral: **frontopontine fibres** (medial 1/6), **corticospinal and corticonuclear fibres** (middle 2/3), and **temporo-, parieto- and occipitopontine fibres** (lateral 1/6).
- **Substantia nigra** — a curved, pigmented band of grey matter lying between tegmentum and crus cerebri throughout the length of the midbrain; divided into a dorsal **pars compacta** (melanin-pigmented, dopaminergic cells) and a ventral **pars reticularis** (fewer cells, intermingled with crus fibres). Nigrostriatal fibres carry dopamine to the corpus striatum; degeneration produces **Parkinsonism**.

Transverse section at the level of the inferior colliculi

Grey matter

- Central (periaqueductal) grey matter contains the **trochlear nucleus** (close to the median plane, just posterior to the medial longitudinal fasciculus; its fibres curve dorsally and decussate in the superior medullary velum) and the **mesencephalic nucleus of the trigeminal nerve** (lateral edge of central grey; carries proprioception from muscles of mastication, teeth, and ocular/facial muscles).
- **Nucleus of the inferior colliculus** — a large ovoid mass beneath the surface elevation; receives the lateral lemniscus and superior olivary afferents and relays auditory impulses (via the inferior brachium) to the medial geniculate body — part of the auditory pathway and auditory reflexes.
- **Substantia nigra** (present at all levels).
- **Reticular formation** — smaller than in the pons, lying ventrolateral between the medial lemniscus and central grey matter.

White matter

- **Decussation of the superior cerebellar peduncles** — occupies the central tegmentum; the single most important feature at this level.
- The ascending **lemnisci** form a curved band dorsal to the substantia nigra, arranged medial to lateral: **medial lemniscus** → **trigeminal lemniscus** → **spinal lemniscus** → **lateral lemniscus** (the last ends here in the inferior colliculus and is not seen higher up).
- **Medial longitudinal fasciculus (MLF)** — beside the median plane, ventral to the trochlear nucleus.
- **Tectospinal tract** — ventral to the MLF; **rubrospinal tract** — ventral to the decussating superior cerebellar peduncle fibres.

Transverse section at the level of the superior colliculi

Grey matter

- ▶ Central grey matter contains the **oculomotor nucleus** (the two sides fuse into a single triangular complex, ventromedial, bounded laterally by the MLF) with the **Edinger–Westphal nucleus** (parasympathetic component supplying sphincter pupillae and ciliaris) forming its dorsal part; emerging fibres pass ventrally through the tegmentum, pierce the red nucleus and medial substantia nigra, and leave via the oculomotor sulcus into the interpeduncular fossa. The mesencephalic nucleus of V occupies the same position as at the lower level.
- ▶ **Superior colliculus** — a flattened mass of seven alternating grey/white laminae; afferents from the retina (via the lateral geniculate body/superior brachium), spinotectal tract (pain/tactile), frontal and occipital visual cortex, and the inferior colliculus; efferents form the tectospinal and tectobulbar tracts, mediating reflex eye, head and neck movements to visual stimuli.
- ▶ **Pretectal nucleus** — deep to the superolateral part of the superior colliculus; relays retinal fibres to the Edinger–Westphal nuclei of both sides — the afferent-to-efferent link for the pupillary light and consensual light reflexes.
- ▶ **Red nucleus** — a cigar-shaped, ~0.5 cm mass dorsomedial to the substantia nigra, pink in fresh specimens (vasculature + iron pigment). Afferents: cerebellorubral (from contralateral dentate nucleus, via superior cerebellar peduncle), corticorubral (ipsilateral areas 4, 6), pallidorubral, plus fibres from the subthalamic nucleus, hypothalamus, substantia nigra and tectum. Efferents: rubrospinal, rubrobulbar and rubroreticular tracts (crossing as the ventral tegmental decussation), plus rubro-olivary, rubrothalamic, rubrocerebellar and rubronigral fibres.

White matter

- ▶ **Dorsal tegmental decussation (of Meynert)** — tectospinal/tectobulbar fibres from the superior colliculi.
- ▶ **Ventral tegmental decussation (of Forel)** — rubrospinal fibres from the red nuclei.
- ▶ MLF lies ventrolateral to the oculomotor nucleus; the same lemnisci as below (medial, trigeminal, spinal) persist, but the **lateral lemniscus has already terminated** in the inferior colliculus and is absent here.
- ▶ Emerging fibres of the oculomotor nerve traverse the tegmentum.

Real plate (both levels, fully labelled): embed: ![Fig 5.25 — Transverse sections of the midbrain. A: At the level of the inferior colliculus. B: At the level of the superior colliculus (Snell — Clinical Neuroanatomy — 7e, p.233)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/74bb9b613ac8225d.jpg)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce two transverse sections of the midbrain side by side, labelling:

- ▶ **Inferior-colliculus level:** cerebral aqueduct with cerebrospinal fluid; central grey matter; nucleus of inferior colliculus; nucleus of trochlear nerve; mesencephalic nucleus of trigeminal nerve; lateral, trigeminal, spinal and medial lemnisci (medial→lateral); decussation of superior cerebellar peduncles; medial longitudinal fasciculus; region of reticular formation; corticospinal and corticonuclear fibres; frontopontine fibres; temporopontine fibres; substantia nigra; interpeduncular fossa; tectum / tegmentum / crus cerebri brackets.
- ▶ **Superior-colliculus level:** cerebral aqueduct; central grey matter; mesencephalic nucleus of trigeminal nerve; nucleus of oculomotor nerve; medial longitudinal fasciculus; reticular formation; red nucleus; substantia nigra; decussation of rubrospinal tracts; corticospinal and corticonuclear fibres; frontopontine fibres; temporopontine fibres; oculomotor nerve fibres emerging into interpeduncular fossa.

Comparison of the two levels

Feature	Level of inferior colliculi	Level of superior colliculi
Cavity	Cerebral aqueduct	Cerebral aqueduct
Tectal nucleus	Inferior colliculus (auditory)	Superior colliculus (visual, 7 laminae)
Cranial nerve nucleus	Trochlear nucleus	Oculomotor nucleus + Edinger–Westphal nucleus
Special grey matter	Mesencephalic nucleus of V	Mesencephalic nucleus of V; red nucleus (first appears here); pretectal nucleus
Motor decussation	Decussation of superior cerebellar peduncles	Dorsal tegmental (Meynert, tectospinal) + ventral tegmental (Forel, rubrospinal) decussations
Lemnisci present	Medial, trigeminal, spinal, lateral	Medial, trigeminal, spinal (lateral lemniscus absent — already ended)
Descending tracts in crus	Corticospinal/corticonuclear, fronto-/temporopontine	Same
Substantia nigra	Present	Present

Blood supply of the midbrain

- ▶ **Arterial** — basilar artery; posterior cerebral arteries; superior cerebellar arteries; posterior choroidal arteries; branches of the anterior choroidal arteries.
- ▶ **Venous** — drains into the great cerebral vein (of Galen) and the basal veins.

Applied / Clinical anatomy

- ▶ **Weber's syndrome** — occlusion of a branch of the posterior cerebral artery infarcts the oculomotor nerve fibres and the crus cerebri: ipsilateral lateral squint, ptosis, and a dilated pupil fixed to light and accommodation (III nerve palsy); contralateral hemiplegia (corticospinal tract) with contralateral lower-facial and tongue weakness (corticobulbar tract).
- ▶ **Benedikt's syndrome** — tegmental ischaemia additionally involves the medial and spinal lemnisci, the red nucleus and superior cerebellar peduncle fibres: same ipsilateral III nerve signs, plus contralateral loss of pain/temperature (spinal/trigeminal lemnisci), contralateral loss of tactile/joint/vibration sense (medial lemniscus), and contralateral tremor/involuntary movements (red nucleus involvement).
- ▶ **Parinaud's syndrome** — compression of the superior colliculi, classically by a pineal-region tumour, causing selective loss of upward conjugate gaze with other eye movements preserved.
- ▶ **Argyll Robertson pupil** — a lesion near the pretectal nucleus abolishes the light reflex while accommodation reflex is retained.
- ▶ **Obstructive hydrocephalus** — a midbrain tumour, or external compression, narrows the cerebral aqueduct, causing dilatation of the third and lateral ventricles.
- ▶ **Parkinsonism** — degeneration of the dopaminergic pars compacta of the substantia nigra depletes striatal dopamine.
- ▶ **Localizing principle** — any brainstem lesion classically produces an *ipsilateral* cranial-nerve deficit with a *contralateral* hemiplegia/hemianaesthesia ("crossed" or "alternating" syndrome); the cranial nerve involved localizes the level of the lesion — oculomotor at midbrain level, as above.

High-yield exam pointers

- ▶ Midbrain is the shortest brainstem segment (≤ 2 cm); cerebral aqueduct connects the 3rd and 4th ventricles.
- ▶ Two standard levels for internal study: inferior-colliculus level and superior-colliculus level; substantia nigra and crus cerebri are constant at both.
- ▶ Trochlear nerve: only cranial nerve to emerge dorsally and the only one to decussate completely (in the superior medullary velum).
- ▶ Red nucleus and oculomotor (+ Edinger–Westphal) nucleus appear ONLY at the superior-colliculus level — a favourite differentiating point.
- ▶ Crus cerebri fibre lamination (medial→lateral): frontopontine (1/6) — corticospinal/corticonuclear (2/3) — temporo/parieto/occipitopontine (1/6).
- ▶ Decussations: superior cerebellar peduncle (at IC level, in tegmentum) vs dorsal tegmental (Meynert, tectospinal) and ventral tegmental (Forel, rubrospinal) at SC level.
- ▶ Weber = III nerve + crus cerebri; Benedikt = Weber + medial lemniscus + red nucleus; Parinaud = superior colliculi (upward-gaze palsy, pineal tumour).
- ▶ Substantia nigra pars compacta degeneration → Parkinsonism; pretectal nucleus lesion → Argyll Robertson pupil.

SOURCE & COVERAGE

Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; Gray's Anatomy (Standing) 41e.



Sections of cerebrum at the level of interventricular formation

Asked in: Paper IV Sep 2007 — RGUHS MD/MS Anatomy

Definition / Introduction — A coronal (frontal) section of the cerebrum taken through the **interventricular foramen (foramen of Monro)** is a standard "cut-section" exercise in gross neuroanatomy. This plane passes through the junction of the anterior horn and the body of the lateral ventricle, at (or just behind) the level of the anterior commissure, and displays in one section the corpus callosum, septum pellucidum, fornix, thalamus, third ventricle and the entire basal-nuclear/internal-capsule complex. It is a favourite "identify the section and label the parts" question because it tests the candidate's three-dimensional grasp of the ventricular system and the corpus striatum simultaneously.

1. The interventricular foramen — the landmark that defines the plane

- ▶ The interventricular foramen (of Monro) is the **oval/crescentic aperture** through which each lateral ventricle communicates with the third ventricle.
- ▶ **Boundaries:** anteriorly by the **column (crus) of the fornix**; posteriorly by the **anterior tubercle (rostral pole) of the thalamus**. Gray's Anatomy states the foramen "is located immediately posterior to the column of the fornix and separates the fornix from the anterior nucleus of the thalamus."
- ▶ It lies at the same coronal level as the **anterior commissure**, where the diverging bodies of the fornix turn downward to become the columns.
- ▶ Through it, the **choroid plexus** of the lateral ventricle becomes continuous with that of the third ventricle, and the **thalamostriate, septal and choroidal veins** unite here to form the **internal cerebral vein** — an important radiological/surgical landmark.
- ▶ The **subfornical organ**, a circumventricular organ devoid of a blood–brain barrier, lies exactly at this level, in the roof of the third ventricle just below the foramen.

2. Plane and general topography of the section

Cutting the cerebrum coronally at this foramen produces a section that, from above downward and medial to lateral, shows (in sequence):

- ▶ Falx cerebri and the interhemispheric (longitudinal) fissure superiorly, with the two **cingulate gyri**.
- ▶ The **genu/body of the corpus callosum** roofing the section.
- ▶ The **septum pellucidum**, separating the two anterior horns/bodies of the lateral ventricles, carrying the columns of the fornix in its lower free edge.

- The **lateral ventricle** cut at the anterior-horn/body junction, with the **caudate nucleus** bulging into its floor and lateral wall.
- The **thalamus** medially, the **third ventricle** in the midline, and the entire **corpus striatum–internal capsule–insula** complex laterally on each side.
- The **cerebral cortex mantle** (frontal opercular cortex above, insula in the depth of the lateral sulcus, and orbital/temporal cortex below) forming the outer rim.

3. Structures seen in the coronal section (region-wise)

Region	Structures cut at this level
Dorsal/roof	Falx cerebri, superior sagittal sinus, cingulate gyrus, genu/body of corpus callosum
Midline	Septum pellucidum (with column of fornix in its lower border), third ventricle (upper/anterior part), anterior commissure (just anterior/at this plane), subfornical organ
Ventricular	Body/anterior horn of lateral ventricle, choroid plexus continuing through the foramen, internal cerebral vein formation
Basal nuclei (corpus striatum)	Head/body of caudate nucleus (medial, forms floor of anterior horn), lentiform nucleus — putamen (lateral) and globus pallidus (medial), separated by the external medullary lamina; fundus striati (fusion of caudate head and putamen) inferiorly
Internal capsule	Anterior limb (between caudate head and putamen) and its genu , lying medial and adjacent to the interventricular foramen
Capsular sheets	External capsule (between putamen and claustrum), claustrum , extreme capsule (between claustrum and insular cortex)
Cortex	Insula , buried in the floor of the lateral (Sylvian) sulcus, covered by fronto-parietal and temporal opercula; frontal-lobe cortex above; orbital/temporal cortex below
Diencephalon	Rostral/anterior pole (tubercle) of thalamus , hypothalamus below the hypothalamic sulcus
White matter	Corona radiata converging into the internal capsule; fibres of the anterior commissure crossing the midline just in front

4. The corpus striatum and internal capsule at this level

- The **caudate nucleus** (C-shaped) has its head bulging into the floor of the anterior horn; the head is fused inferiorly with the putamen at the **fundus striati**, continuous below with the anterior perforated substance.
- The **lentiform nucleus** is wedge/triangular in coronal section, lying lateral to the internal capsule; it is divided by the **external medullary lamina** into a lateral **putamen** and medial **globus pallidus**

(the pallidum itself further split by the internal medullary lamina into medial and lateral segments).

- ▶ Caudate + putamen = **striatum (neostriatum)**; globus pallidus = **pallidum (paleostriatum)**; caudate + lentiform together = **corpus striatum**.
- ▶ The **internal capsule** is V-shaped in horizontal section, its vertex (**genu**) lying medially between the caudate head and the thalamus; at the coronal level of the interventricular foramen the section passes through its **anterior limb** (between caudate head and putamen, carrying fronto-pontine fibres) and its **genu** (carrying corticonuclear/corticobulbar fibres) — the genu lies medial and adjacent to the foramen itself, a fact used radiologically to localise the anterior limb/genu junction on cross-sectional imaging.
- ▶ **Clastrum**, a thin sheet of grey matter lateral to the lentiform nucleus, is separated from it by the external capsule and from the insular cortex by the extreme capsule.

5. Ventricular system and CSF flow at this level

- ▶ The **lateral ventricle** here is at the transition between its anterior horn (triangular, floor and lateral wall formed by the caudate head) and its body (roofed by corpus callosum, floor by caudate body/stria terminalis, medial wall by septum pellucidum).
- ▶ CSF formed in the lateral ventricle's choroid plexus drains through the interventricular foramen into the **third ventricle**, and thence via the cerebral aqueduct to the fourth ventricle (**Monro → aqueduct → fourth ventricle → subarachnoid space**).
- ▶ The **third ventricle**, a narrow midline slit between the two thalami/hypothalami, is at its widest, most anterior part at this coronal level, roofed by the fornix/tela choroidea and bounded anteriorly by the diverging columns of the fornix and the anterior commissure.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 12.1 — Coronal section of cerebrum showing basal nuclei (IB Singh — Textbook of Human Neuroanatomy, p.206)

Label, from midline outward on one side, in a coronal section at the level of the interventricular foramen:

- ▶ Falx cerebri / superior sagittal sinus
- ▶ Cingulate gyrus
- ▶ Genu/body of corpus callosum
- ▶ Septum pellucidum (with column of fornix in its free edge)
- ▶ Lateral ventricle (body/anterior horn) with choroid plexus
- ▶ Caudate nucleus (head/body)
- ▶ Thalamus (anterior tubercle) and third ventricle in the midline
- ▶ Internal capsule — anterior limb and genu
- ▶ Lentiform nucleus — putamen (lateral) and globus pallidus (medial)
- ▶ External capsule → Claustrum → Extreme capsule
- ▶ Insula, buried under the frontal/parietal/temporal opercula
- ▶ Lateral (Sylvian) sulcus and overlying frontal-lobe cortex

Applied / Clinical anatomy

- ▶ **Hydrocephalus:** the interventricular foramen is one of the narrowest bottlenecks of the ventricular system; its obstruction (by a **colloid cyst of the third ventricle**, an intraventricular tumour, or a choroid plexus mass) causes progressive enlargement of one or both lateral ventricles — unilateral if only one foramen is blocked, bilateral if both are, or if a midline mass obstructs the third ventricle at this level.
- ▶ **Charcot's artery ("artery of cerebral haemorrhage"):** the largest of the lateral lenticulostriate (striate) branches of the middle cerebral artery supplies the corpus striatum and the anterior limb of the internal capsule seen in this very section; rupture of its micro-aneurysms (Charcot–Bouchard aneurysms) is the classic cause of hypertensive basal-ganglia/internal-capsule haemorrhage, which may burst medially into the lateral or third ventricle at this level, producing a dense, contralateral hemiplegia (capsular stroke).
- ▶ **Stereotactic/radiological localisation:** the interventricular foramen and the anterior commissure–posterior commissure (AC–PC) line are key landmarks on CT/MRI for localising deep targets (basal ganglia, thalamus) during stereotactic neurosurgery; the position of the foramen also marks where the internal capsule genu can be estimated on axial images.
- ▶ **Surgical corridor:** neuroendoscopic third-ventriculostomy and colloid-cyst excision are approached through this very foramen, making its size, boundaries and related veins (thalamostriate, septal, internal cerebral) of direct operative importance.
- ▶ **CSF cytology/vascular landmark:** the internal cerebral vein, formed at the foramen, is a reliable venous landmark for the roof of the third ventricle on cerebral angiography/venography.

High-yield exam pointers

- ▶ Interventricular foramen (of Monro): bounded anteriorly by column of fornix, posteriorly by anterior tubercle of thalamus.
- ▶ At this level: caudate head + putamen + globus pallidus = corpus striatum; internal capsule shows anterior limb + genu.
- ▶ Sequence lateral to medial: insula → extreme capsule → claustrum → external capsule → lentiform nucleus (putamen, globus pallidus) → internal capsule → thalamus/caudate.
- ▶ Septum pellucidum carries the column of the fornix in its lower free border; separates the two anterior horns.
- ▶ Choroid plexus and thalamostriate/septal/choroidal veins converge here to form the internal cerebral vein.
- ▶ Foramen obstruction (colloid cyst, tumour) → obstructive hydrocephalus.
- ▶ Charcot's artery (lateral lenticulostriate branch of MCA) supplies this region — classic site of hypertensive intracerebral haemorrhage.
- ▶ Subfornical organ (a circumventricular organ) lies at this exact level.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; IB Singh — Textbook of Human Neuroanatomy; Vishram Singh — Clinical Neuroanatomy 4e; BD Chaurasia — Human Anatomy Vol 3–4, 8e; Snell — Clinical Neuroanatomy 7e.



Sequential axial CT images

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction Computed tomography (CT) is a cross-sectional imaging technique in which a rotating X-ray tube and an opposing detector array measure the attenuation of X-rays passing through the body from many angles; a computer converts this data into the radiodensity of each volume element (**voxel**) of a thin transverse "slice." A **sequential axial CT series** is simply a set of such transverse (axial) slices acquired one after another at fixed intervals through a body region — for example the abdomen, thorax or head — so that, viewed together in order from superior to inferior (or vice versa), they build up a continuous, three-dimensional picture of the disposition of viscera, vessels and skeleton. This "stack-of-slices" concept is the anatomical basis of every modern cross-sectional imaging study and is why CT anatomy is taught level-by-level (e.g., T4, T10, L1, L3–L4) rather than as a single isolated section.

1. Physical principle of CT

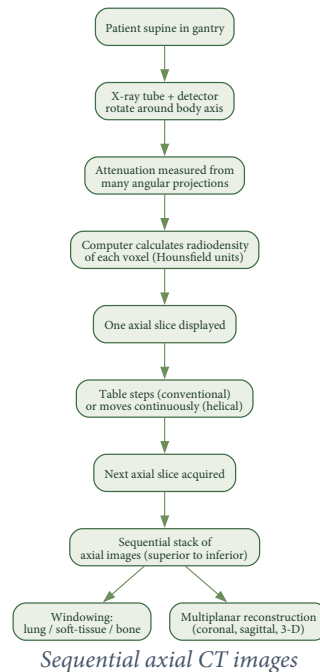
- ▶ CT was invented for clinical use by **Godfrey N. Hounsfield in 1970** (Nobel Prize, 1979, shared with Allan Cormack), and the technique is also called computerised axial tomographic (CAT) scanning — Greek *tomo* = "cut"/"slice."

- ▶ The X-ray tube rotates around the body part in an arc, sending a fan-shaped beam through the tissue; detectors on the opposite side measure the transmitted radiation from many angular projections.
- ▶ A computer compares the multiple overlapping absorption readings and calculates the **radiodensity of every voxel**, displaying it as a grey-scale value on a matrix of picture elements (pixels) — dense tissue (bone) appears white/bright, air appears black.
- ▶ This mean attenuation value is expressed on the **Hounsfield scale (Hounsfield units, HU)**, referenced to water = 0 HU:

Tissue	Approximate Hounsfield unit (HU)
Air	about –1000
Fat	about –100
Water	0 (reference)
Soft tissue	+20 to +70
Bone	greater than +400

2. From a single slice to a "sequential" series — acquisition technique

- ▶ **Conventional (incremental) CT**: the gantry completes one full rotation to acquire one axial slice; the patient table then steps a fixed distance and the next slice is acquired — repeated slice-by-slice through the region of interest, generating the classic **sequential set of separate axial images**.
- ▶ **Spiral (helical) CT**: the table moves continuously and smoothly while the tube rotates continuously, so the X-ray beam traces a spiral (helical) path through the body; this yields a continuous volumetric data set rather than discrete steps, acquired far faster (modern multislice helical scanners can image the whole body in a single breath-hold).
- ▶ Because the helical data set is volumetric, the computer can retrospectively generate **any number of closely-spaced or overlapping "sequential" axial slices**, and can also reformat the same data into sagittal, coronal or oblique planes — **multiplanar reconstruction (MPR)** — or into a 3-D surface-rendered image, all from one acquisition.
- ▶ Unwanted overlying structures can be digitally removed and the resulting images colour-coded to aid interpretation.
- ▶ A modern CT examination therefore virtually always uses helical acquisition, but the *output* is still presented and read as a **sequential stack of axial images**, supplemented by reconstructed coronal/sagittal sets — the term "sequential axial CT images" describes this display convention regardless of which acquisition mode produced it.



3. Convention for viewing a sequential axial series

- ▶ Axial CT (and MR) images are always viewed as if the observer is standing at the foot of a supine patient, looking towards the head — an "inferior view." Consequently the patient's right side appears on the *viewer's left* of the image, exactly as on a conventional chest radiograph.
- ▶ Coronal CT/MR images are viewed as if the patient is facing the observer; sagittal images are viewed as if standing at the patient's left side.
- ▶ A sequential series is conventionally read **from the most superior slice down to the most inferior** (or the reverse), and the observer mentally "tracks" a given structure — a vessel, duct, or lymph-node chain — as it appears, changes calibre, branches or disappears from one slice to the next; this continuity of tracking across slices is precisely what a *single* static section cannot provide.

4. Windowing — the same slice, different tissue contrast

- ▶ Because the HU scale spans roughly –1000 to +1000 (and beyond for metal/contrast), no single grey-scale display can show lung, soft tissue and bone optimally at once; the operator selects a "window" (**width and level**) centred on the HU range of interest for the tissue being studied.
- ▶ Standard windows used on the same sequential slices: **lung window** (wide width, centred near air, to show pulmonary parenchyma), **soft-tissue/mediastinal window** (narrow width, centred near 0–70 HU, to show viscera and vessels, usually after intravenous iodinated contrast), and **bone window** (wide width, high level, to show cortical detail and fractures).
- ▶ The same physical slice is therefore commonly displayed and reported at two or three different windows to extract full diagnostic value from one acquisition.

5. Worked example — a sequential axial CT series of the abdomen

Fig. 5.103 of Moore's Clinically Oriented Anatomy illustrates exactly this concept — six transverse CT scans of the abdomen (panels A–F) taken at **progressively more inferior levels**, showing the changing relationship of the body wall, viscera and blood vessels from slice to slice.

□ Fig 5.103 — Transverse (axial) CT images of abdomen. A–F. Scans at progressively inferior levels show (Moore — Clinically Oriented Anatomy — 9e, p.925)

Illustrative named levels within such a series (Moore, Fig. 5.104):

Level in the sequential series	Key structures demonstrated
T10 vertebra (oesophageal hiatus)	Lower oesophagus/cardia of stomach, crura of diaphragm
L1–L2 vertebra	Renal hila and renal vessels; neck/uncinate process of pancreas; origin of coeliac trunk and superior mesenteric artery near the transpyloric plane
L5 vertebra	Bifurcation of the abdominal aorta into the common iliac arteries

Analogous named "landmark" sequential levels are used to teach the thorax (e.g., upper T4 — arch of aorta; T5 — bifurcation of the pulmonary trunk and trachea) — each individual level is itself only meaningful when read as one frame of the whole superior-to-inferior sequence.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A candidate unable to reproduce the real plate should sketch **three or four stacked outline circles/ovals** (representing successive axial slices, superior at the top), each labelled with:

- ▶ **Vertebral body** (with pedicle/lamina/spinous process) and **vertebral canal contents**
- ▶ **Abdominal aorta and inferior vena cava**, shown changing position/calibre slice to slice
- ▶ **Major viscus at that level** (e.g., stomach/pancreas at a higher slice; kidneys/renal vessels at a mid slice; aortic bifurcation at the lowest slice)
- ▶ **Psoas major, quadratus lumborum, crura of diaphragm** as posterior landmarks present at every level
- ▶ An arrow beside the stack labelled "superior → inferior" to show the sequential direction, and a small inset gantry/tube-detector diagram to show the acquisition principle.

Applied / Clinical anatomy

- ▶ **Tracing continuity of tubular structures:** only a sequential series lets the radiologist follow the aorta and its branches, the ureter, the common bile duct or a lymph-node chain across multiple levels — essential for confirming that an abnormal shadow on one slice is a genuine continuous structure and not an artefact.
- ▶ **Tumour staging:** sequential slices through a suspected malignancy show its craniocaudal extent, relation to adjacent organs, vascular encasement and nodal involvement — the basis of TNM staging on cross-sectional imaging.

- ▶ **Vascular level differentiation:** because the coeliac trunk, superior mesenteric artery and renal arteries arise at successive, closely-spaced levels (T12/L1 → L1 → lower L1/upper L2), only a sequential series distinguishes a **suprarenal from an infrarenal abdominal aortic aneurysm**, which determines suitability for standard endovascular repair.
- ▶ **Multiplanar/3-D reconstruction:** modern helical acquisition of a sequential axial data set is retrospectively reformatted into coronal and sagittal images and 3-D volume renderings, improving surgical planning (e.g., vascular mapping before transplant or tumour resection).
- ▶ **CT-guided intervention:** a specific slice within the sequential series is used to plan and monitor needle placement for biopsy, drainage or ablation at a precisely localised level.
- ▶ **Trauma and whole-body protocols:** polytrauma "pan-scan" CT acquires a sequential axial series from the skull base to the pelvis in one pass, read systematically level by level to avoid missing injuries.
- ▶ **Windowing artefacts:** a lesion of intermediate density may be invisible on one window setting and obvious on another of the *same* slice — the examiner must review a sequential series at more than one window (lung, soft-tissue, bone) before excluding pathology.

High-yield exam pointers

- ▶ CT = Hounsfield, 1970; based on differential X-ray attenuation, computed as Hounsfield units (water = 0 HU, air ≈ -1000 HU, fat ≈ -100 HU, soft tissue +20 to +70 HU, bone > +400 HU).
- ▶ Conventional (incremental) CT = one slice per rotation + table step; spiral/helical CT = continuous table motion + continuous rotation = volumetric data, faster, allows multiplanar reconstruction (MPR).
- ▶ Axial CT/MR images are always viewed **as if from the patient's feet** (inferior view) — patient's right appears on the viewer's left.
- ▶ A "sequential axial CT series" = a stack of transverse slices read in order (superior→inferior or reverse), allowing structures to be tracked continuously across levels — the key advantage over a single isolated section.
- ▶ Windowing (lung/soft-tissue/bone window) lets the same slice display different tissue types optimally.
- ▶ Classic teaching levels illustrated in a sequential abdominal series: T10 (oesophageal hiatus), L1–L2 (renal hila, transpyloric plane, coeliac trunk/SMA origin), L5 (aortic bifurcation).
- ▶ Sequential/helical CT data can be reconstructed into coronal, sagittal or 3-D images from the same acquisition.
- ▶ Clinical value of "sequential" over a single image: tracing vessel/duct continuity, tumour staging, distinguishing suprarenal from infrarenal aortic pathology, and planning CT-guided intervention.

SOURCE & COVERAGE

Moore's Clinically Oriented Anatomy 9e (Medical Imaging Techniques — Computed Tomography; Sectional Medical Imaging of Abdomen, Figs 5.103–5.104); Gray's Anatomy (Standing) 41e (Technical aspects and applications of diagnostic radiology — Hounsfield scale, helical CT and multiplanar reconstruction); Vishram Singh — General Anatomy 4e (Radiological/Imaging Anatomy — conventional and spiral CT).

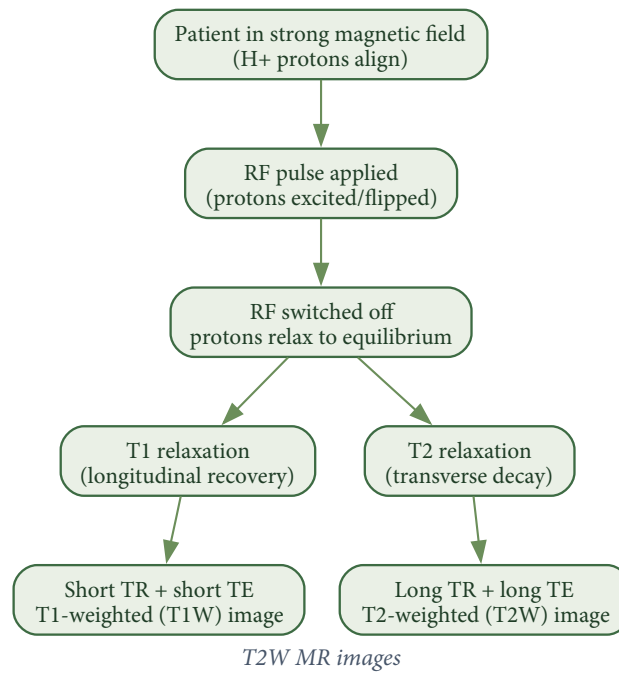
**T2W MR images**

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction Magnetic resonance imaging (MRI) is a non-ionising cross-sectional imaging technique that produces images from the behaviour of mobile hydrogen protons (of water and fat) when placed in a strong magnetic field and pulsed with radiofrequency (RF) energy. By varying how the RF pulses are sent and received, the same tissue can be shown with different contrast — these variants are called "weighted" images. A **T2-weighted (T2W) image** is one whose contrast is determined predominantly by the **T2 (transverse/spin-spin) relaxation time** of tissues rather than by T1 relaxation or proton density; on it, fluid and oedema appear characteristically **bright (high signal)**. T2W sequences are the workhorse of clinical and radiological anatomy for demonstrating CSF spaces, joint fluid, soft-tissue oedema, and disease.

Physical basis of MR signal and image weighting

- ▶ The human body is ~70–80% water; the **hydrogen proton** (a single spinning proton) behaves like a tiny bar magnet and is the ion exploited for MRI.
- ▶ The patient lies within a strong magnetic field; hydrogen protons align with (or against) this field. A **radiofrequency pulse** flips (excites) the aligned protons away from equilibrium.
- ▶ When the RF pulse is switched off, protons **relax** back to equilibrium, releasing the absorbed energy as a measurable RF signal that is spatially encoded by a computer into an image.
- ▶ Three tissue properties determine signal/contrast: **T1 relaxation** (recovery of longitudinal magnetisation), **T2 relaxation** (decay of transverse magnetisation) and **proton density**. Sequences are tuned (by varying repetition time, TR, and echo time, TE) to weight the image toward one of these:
 - **T1-weighted (T1W)**: short TR, short TE — fat/soft tissue bright, fluid dark; nicknamed the "anatomy weighting" because it best shows fine anatomical (fat/soft-tissue) detail.
 - **T2-weighted (T2W)**: long TR, long TE — fluid (and fat) give high signal; the sequence most sensitive to pathology (oedema, inflammation, tumour, effusion).
- ▶ Rapidly flowing blood characteristically shows a **signal void (black)** on conventional spin-echo sequences because excited protons move out of the imaging slice before their signal can be read.



T1-weighted vs T2-weighted images

Feature	T1-weighted (T1W)	T2-weighted (T2W)
Relaxation weighted	T1 (longitudinal) relaxation	T2 (transverse) relaxation
Scan parameters	Short TR, short TE	Long TR, long TE
CSF / free fluid	Low signal — dark	High signal — bright
Fat (routine, non-fat-suppressed)	High signal — bright	Intermediate-to-high signal — bright unless selectively fat-suppressed
Descriptive nickname	"Anatomy weighting" — best depicts fat and fine soft-tissue detail	Most sensitive to fluid, oedema and disease
Typical clinical role	Delineating normal anatomy	Detecting pathology — oedema, tumour, effusion, inflammation, thrombus

Signal characteristics of tissues on T2-weighted images

Tissue / fluid	Signal on T2W	Basis
CSF, joint effusion, cyst fluid, oedema, ascites	High (bright/white)	Long T2 of free (mobile) water
Fat (standard, non-fat-suppressed sequence)	Intermediate-to-high	Retains signal on routine T2W; selectively suppressed to low signal with fat-saturation (T2 FS) or STIR sequences
Skeletal muscle	Intermediate (grey)	Intermediate free-water content

Tissue / fluid	Signal on T2W	Basis
Cortical bone, air, ligaments/tendons, fibrous tissue	Low (dark/black)	Very few mobile protons / very short T2
Rapidly flowing blood	Low (signal void)	Time-of-flight effect — excited protons leave the slice before readout
Oedema, inflammation, tumour, thrombus (pathological states)	High	Increased free-water content

Fat-suppressed and contrast-enhanced modifications

- ▶ **T2 fat-saturation (T2 FS) / short tau inversion recovery (STIR):** selectively suppress the normally bright fat signal, making them highly sensitive for detecting the **soft-tissue or bone-marrow oedema** that almost invariably accompanies inflammation or tumours.
- ▶ **Gadolinium-enhanced T1 fat-saturated (T1FS) images** (a T1W, not T2W, technique) complement T2W studies by exquisitely highlighting **hypervascularity**, particularly in tumours, inflammation, and states where the blood–brain barrier is breached.
- ▶ **Metal artefact reduction sequences (MARS)** improve imaging of periprosthetic soft tissue around joint replacements or orthopaedic metalwork.
- ▶ Routine high-field MRI systems operate at **3–7 Tesla** (superconducting magnet, liquid-helium cooled); open/limb scanners for claustrophobic patients use permanent magnets of **0.2–0.75 T** (for comparison, Earth's own magnetic field is only 30–60 μT).

Regional anatomy best demonstrated on T2-weighted images

Region / structure	What T2W shows	Example
Brain — ventricular system & subarachnoid cisterns	CSF appears bright white, sharply outlining sulci, fissures and ventricles against grey/white matter	See diagram below
Dural venous sinuses	A thrombosed superior sagittal sinus and the adjacent venous infarct both show abnormally high signal	Cerebral venosinus thrombosis
Thyroid gland	Being highly vascular, the gland shows increased signal and intense contrast enhancement	—
Prostate	McNeal's zonal anatomy is best appreciated on T2W — the peripheral zone (70% of glandular tissue) is normally hyperintense; a prostate cancer typically appears as a focal low-signal lesion within this bright peripheral zone	See diagram below

Region / structure	What T2W shows	Example
Female pelvis (uterus)	Zonal anatomy of the uterus is defined on T2W: high-signal endometrium , a low-signal junctional zone (inner myometrium), and medium-to-high-signal outer myometrium; signal/thickness vary with the menstrual cycle. Zonal anatomy is indistinct before puberty and after menopause	Gray's Ch 77
Joints (knee, hip)	Fat-suppressed T2W arthrograms outline ligaments (e.g., anterior cruciate ligament, ligamentum teres) against bright joint fluid	—
Skeletal muscle	Denervated or oedematous muscle (e.g., after nerve injury) shows high signal on T2W	Anterior-compartment leg denervation

□ Fig 8.38 — Features of cerebral hemisphere on transverse MRI. CSF surrounding the (Moore — Clinically Oriented Anatomy — 9e, p.1428)

□ Fig 17.9 — ■ Axial T2-weighted MRI showing (A) benign (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.733)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled transverse (axial) T2-type MRI of the cerebral hemisphere at the level of the lateral ventricles, marking:

- ▶ **Frontal lobe cortex** (grey matter, intermediate signal)
- ▶ **Frontal lobe white matter** (intermediate signal, darker than CSF)
- ▶ **Anterior horn of lateral ventricle** — bright (CSF)
- ▶ **Head of caudate nucleus** — bordering the anterior horn
- ▶ **Septum pellucidum** — midline, separating the two anterior horns
- ▶ **Column of fornix**
- ▶ **Thalamus**
- ▶ **3rd ventricle** — midline, bright (CSF)
- ▶ **Choroid plexus** — within the ventricle
- ▶ **Posterior horn of lateral ventricle** — bright (CSF)
- ▶ **Splenium of corpus callosum**

A second, optional labelled diagram: an axial pelvic T2W image through the prostate showing the **pubic symphysis** (midline anteriorly), **central/transitional zone** (lower signal, periurethral), **peripheral zone** (bright, posterolateral — 70% of gland), **obturator internus muscle** (lateral wall), and **rectum** (posterior) — with a focal low-signal area in the peripheral zone marked as carcinoma.

Applied / Clinical anatomy

- ▶ **Safety and contraindications:** MRI is contraindicated in patients with a cardiac pacemaker or other implanted electro-inductive device, a ferromagnetic intracranial aneurysm clip, certain cardiac valve replacements, or an intraocular metallic foreign body — the strong static field carries a risk of device malfunction, clip displacement, or ocular injury. Loose metal objects, "MR-unfriendly" anaesthetic equipment, and credit cards must be excluded from the scan room; many extracranial vascular clips and orthopaedic prostheses are now "MRI-friendly" but may still cause local artefact.
- ▶ **Advantages over CT/ultrasound:** MRI uses no ionising radiation; provides true multiplanar (axial, sagittal, coronal, oblique) and 3-D imaging; and gives superior soft-tissue contrast, making it the first investigation of choice for detecting tumours of the brain and spinal cord and for assessing intervertebral disc prolapse.
- ▶ **Diagnostic uses specifically of the T2W sequence:** detection of cerebral/spinal-cord oedema, infarction and tumour; venous sinus thrombosis; joint effusions and ligament tears; pelvic organ zonal anatomy and tumours (e.g., prostate cancer within the peripheral zone); and soft-tissue/bone-marrow oedema when combined with fat suppression (T2 FS/STIR).
- ▶ **Terminology across modalities** (useful comparative table for viva/theory): plain radiograph — radiopaque/radiolucent; ultrasound — hyperechoic/hypoechoic; CT — high/low attenuation; MRI — high signal/low signal; nuclear scintigraphy — "hot"/"cold" areas.

- ▶ Gadolinium-based contrast (used with T1FS, not T2W, sequences) highlights hypervascular or inflamed tissue and breakdown of the blood–brain barrier, complementing the fluid-sensitivity of T2W in a combined MRI protocol.

High-yield exam pointers

- ▶ T2W = long TR + long TE; contrast reflects T2 (transverse/spin-spin) relaxation.
- ▶ On T2W, fluid/CSF/oedema = **bright**; T1W shows fluid as dark and is nicknamed the "anatomy weighting."
- ▶ Fat is intermediate-to-bright on routine (non-fat-sat) T2W; T2 FS/STIR selectively suppress fat to unmask underlying marrow/soft-tissue oedema.
- ▶ Cortical bone, air, ligaments/tendons and rapidly flowing blood give **low signal/signal void** on T2W.
- ▶ Cross-modality mnemonic: radiopaque/lucent (X-ray) ↔ hyperechoic/hypoechoic (US) ↔ high/low attenuation (CT) ↔ **high/low signal (MRI)** ↔ hot/cold (scintigraphy).
- ▶ **McNeal's prostate zones are best appreciated on T2W** — peripheral zone bright, cancer shows as a focal low-signal area within it.
- ▶ MRI is contraindicated with cardiac pacemakers, ferromagnetic aneurysm clips, certain valve prostheses, and intraocular metallic foreign bodies.
- ▶ Biggest edge of MRI over CT/US: **no ionising radiation, best soft-tissue contrast, true multiplanar imaging.**
- ▶ T2W is the sequence of first choice for brain/spinal-cord tumour and oedema, disc prolapse, joint effusion, and venous sinus thrombosis.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; Vishram Singh — General Anatomy 4e; Vishram Singh — Textbook of Anatomy Vol 2, 4e.

Coverage note: exact millisecond TR/TE values are not stated in the corpus; the standard long-TR/long-TE (T2W) vs short-TR/short-TE (T1W) relationship is given qualitatively only, as universally accepted MR-physics teaching.



Thyroid scanning

Asked in: Paper IV Oct 2008 — RGUHS MD/MS Anatomy

Definition / Introduction Thyroid scanning (thyroid scintigraphy) is a nuclear medicine (radionuclide) imaging technique in which a radiopharmaceutical selectively trapped by thyroid follicular cells is administered to the patient, and the gamma radiation it emits is recorded by a gamma camera to build up a two-dimensional image of the gland. Because the image reflects functional uptake of the tracer rather than tissue density, thyroid scanning uniquely reveals functioning thyroid tissue wherever it lies in the body — a property exploited both to define the surface anatomy and developmental variants of the gland (its lobes, isthmus, pyramidal lobe and ectopic remnants) and to characterise diffuse or focal thyroid disease. It complements, but is anatomically and physiologically distinct from, cross-sectional imaging (ultrasound/CT/MRI) of the gland.

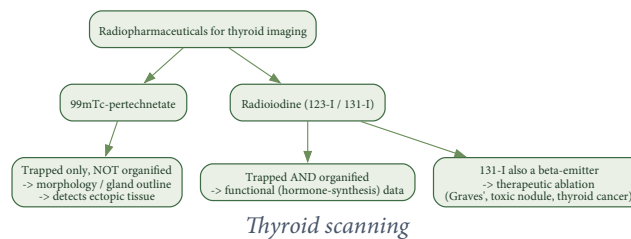
1. Principle of radionuclide (isotope) scanning

- ▶ Unlike conventional radiology, where an image is formed by passing energy through the body from an external source, nuclear medicine creates an image by measuring radiation emitted from a tracer administered internally (by intravenous injection, ingestion or inhalation).
- ▶ A **radiopharmaceutical** is a pharmaceutical carrier labelled with a radionuclide. Agents used for imaging emit a **gamma (γ) ray**, which is of high enough energy to pass through the body and be detected externally by a gamma camera; agents used for treatment emit a **beta (β) particle**, which travels only a short distance and deposits its dose locally in the target organ.
- ▶ Because a given isotope is selectively taken up by a particular organ, a lesion that concentrates **more** tracer than the surrounding gland produces a so-called "**hot**" **area** on the scan, while a lesion that **fails** to take up the tracer produces a "**cold**" **area** — the thyroid, together with the liver, is a classical example of an organ in which focal disease characteristically produces cold areas.
- ▶ Emitted radiation is captured on a **gamma camera** (planar scintigraphy) or by **SPECT/PET** systems; the functional data obtained can additionally be fused with the more anatomical detail of CT or MRI, combining anatomy and function in a single study.
- ▶ Nuclear imaging of the thyroid is one of the oldest applications of the specialty: radioactive iodine was first administered as an "**atomic cocktail**" to treat thyroid cancer, and nuclear medicine was recognised as a distinct diagnostic subspecialty only in the early 1970s.

2. Radiopharmaceuticals used in thyroid scanning

- ▶ **Technetium-99m (^{99m}Tc) pertechnetate** — readily available, being eluted from a molybdenum-99/technetium-99m generator kept in the department; it has a short half-life (about 6 hours), convenient for imaging and disposal, and emits gamma rays of suitable energy. It is **trapped by the thyroid in the same way as iodide but is not organified** (not incorporated into thyroglobulin), so it yields purely **morphological** information and is the agent of choice for demonstrating **ectopic thyroid tissue**.
- ▶ **Radioiodine ($^{123}\text{-iodine}$ or $^{131}\text{-iodine}$)** — trapped **and organified**, i.e. incorporated into thyroid hormone synthesis, so it yields genuine **functional** data on hormone-synthesising activity rather than gland outline alone.

- ▶ **^{131}I -iodine**, because it additionally emits a therapeutic beta particle, is also used to **treat** hyperfunctioning thyroid tissue, toxic nodules and differentiated thyroid cancer (e.g. ablation in Graves' disease), whereas $^{99\text{m}}\text{Tc}$ and ^{123}I remain purely diagnostic gamma emitters.



3. Anatomical basis relevant to reading the scan

- ▶ The gland lies anteriorly in the lower neck, level with the **fifth cervical to first thoracic vertebrae**, with right and left lobes joined by a median **isthmus**; it is ensheathed by the pretracheal layer of deep cervical fascia and covered anteriorly by sternothyroid, then sternohyoid, omohyoid and sternocleidomastoid — its superficial position also makes it an ideal organ for sonographic correlation alongside the scan.
- ▶ Normal weight is about **25 g**, greater in females and further enlarging in menstruation and pregnancy — a source of normal variation in the size/intensity of the scan image.
- ▶ Each lobe is about **5 cm long, 3 cm transverse and 2 cm anteroposterior**; the isthmus measures about **1.25 cm** transversely and vertically and lies anterior to the second and third tracheal cartilages — the dimensions the scan appearance is read against.
- ▶ A conical **pyramidal lobe** often ascends from the isthmus (more often from the left) toward the hyoid bone, occasionally attached by a fibromuscular band, the **levator glandulae thyroideae**; this is a normal variant commonly seen as a discrete extra focus of uptake above the isthmus and must not be mistaken for pathology.

4. Scanning technique and standard views

- ▶ The patient is positioned supine with the neck extended; the tracer (typically $^{99\text{m}}\text{Tc}$ -pertechnetate) is injected intravenously, and gamma-camera images are then acquired over the neck.
- ▶ A normal study comprises **four standard views**: an anterior "**marker**" (landscape) image that includes the lower face and upper thorax — showing the thyroid centrally with the **salivary glands** visible above it — together with close-up **anterior, right anterior oblique (RAO) and left anterior oblique (LAO)** images centred on the gland.
- ▶ On the normal scan the **right lobe, left lobe, isthmus** and, when present, the **pyramidal lobe** are outlined with symmetrical, homogeneous uptake.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the anterior close-up view of a normal thyroid scan (gamma-camera image) and label:

- ▶ **Right lobe of thyroid**
- ▶ **Left lobe of thyroid**
- ▶ **Isthmus** (joining the two lobes)
- ▶ **Pyramidal lobe** (ascending in the midline, usually from the left)
- ▶ **Salivary glands** (seen as separate foci of uptake above the thyroid on the anterior marker view)

5. Interpretation — patterns of uptake and their correlate

Pattern on scan	Description	Anatomical/clinical correlate
Diffuse increased uptake	Whole gland shows increased, homogeneous uptake	Graves' disease (diffuse toxic goitre) — no palpable nodules
Diffuse patchy/irregular uptake	Heterogeneous uptake throughout an enlarged gland	Multinodular goitre; autoimmune (Hashimoto's) thyroiditis
Focal "hot" nodule	Localised increased uptake, with suppression of the rest of the gland	Toxic (autonomously functioning) adenoma
Focal "cold" nodule	Localised reduced/absent uptake	Colloid nodule, cyst or haemorrhage — but also the pattern of a carcinoma, so it mandates further work-up
Ectopic focus with no gland at the normal site	Uptake seen away from the pretracheal site, absent centrally	Isolated ectopic (e.g. lingual) thyroid

6. Applied anatomical value — localising ectopic thyroid tissue

- ▶ The thyroid develops from an endodermal diverticulum at the **foramen caecum** of the tongue and migrates caudally along the **thyroglossal duct** to its adult pretracheal position; functioning thyroid tissue can therefore persist anywhere along this course. Ectopic thyroid tissue is rare but is described along the thyroglossal duct, laterally in the neck, and at distant sites such as the tongue (**lingual thyroid**), mediastinum and even sub-diaphragmatic organs.
- ▶ The **most frequent site of ectopic thyroid tissue is the base of the tongue at the foramen caecum**, and in a proportion of these cases it is the **only** thyroid tissue the patient possesses.
- ▶ Because a radionuclide scan images functioning tissue directly rather than merely showing a soft-tissue mass, it is the essential investigation before any surgery on a suspected thyroglossal duct cyst or midline tongue-base swelling: absent uptake at the normal pretracheal site with uptake instead at the ectopic focus confirms that the mass is the patient's functioning thyroid, so its removal would need to be avoided or followed by thyroid hormone replacement.

- ▶ Small detached masses of thyroid tissue may also occur above the lobes or isthmus as accessory thyroid nodules, and vestiges of the thyroglossal duct may persist as separate midline nodules or cysts — all identifiable as discrete extra foci of uptake distinct from the main gland.

embed: ![Fig 11.9 — Sublingual thyroid. A. Surface view. B. Technetium-99m scan showing su (Vishram Singh — Textbook of Clinical Embryology, p.140)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/7996c51caaa2e9bd.jpg)

7. Recent advances in thyroid scanning

- ▶ **Hybrid SPECT/CT and PET/CT** fuse the functional radionuclide map onto a simultaneously acquired CT dataset, giving precise anatomical localisation of an ectopic focus or of the downward (e.g. retrosternal) extent of an enlarging goitre — information planar scintigraphy alone cannot provide.
- ▶ **^{18}F -FDG PET/CT**, now routine for cancer staging, frequently shows incidental thyroid uptake: normal thyroid tissue has a standardised uptake value (SUV) around 1.3, with higher levels also seen in Graves' disease and chronic thyroiditis; a general SUV cut-off of 2.0–2.5 is used to separate benign from potentially malignant focal uptake, guiding which incidental thyroid findings on a PET study merit further evaluation.
- ▶ **Whole-body ^{131}I -iodine scanning** remains the standard post-thyroidectomy surveillance tool for metastatic differentiated thyroid carcinoma, exploiting the same trap-and-organify property used diagnostically.
- ▶ Non-radionuclide techniques — **high-resolution ultrasound** (now first-line for nodule characterisation and image-guided biopsy) and **elastography** — are used alongside, rather than instead of, isotope scanning, since the thyroid's superficial, highly vascular position also makes it an ideal sonographic organ.

Applied / Clinical anatomy

- ▶ **Thyrotoxicosis (toxic goitre)** is more common in women and presents with nervousness, weight loss, tachycardia, tremor and exophthalmos; its principal causes — **Graves' disease** (diffuse toxic goitre, no palpable nodules), **multinodular goitre**, and **toxic adenoma** — each produce a characteristic diffuse, patchy or focal-hot scan pattern respectively (Section 5).
- ▶ **Thyroiditis**, most importantly the autoimmune (lymphocytic) form (**Hashimoto's disease**), shows an enlarged gland infiltrated with lymphocytes and typically a patchy scan appearance.
- ▶ **Retrosternal (mediastinal) extension** of an enlarging goitre is limited superiorly by the attachment of sternothyroid to the thyroid cartilage, so the gland is instead forced downward into the thorax — relevant when a scan or cross-sectional study shows thyroid tissue extending below the thoracic inlet.
- ▶ Safe **thyroidectomy** depends on the relations demonstrated by pre-operative imaging: the superior thyroid artery lies close to the external laryngeal nerve at a high level and is therefore ligated close to the gland, while the inferior thyroid artery lies close to the recurrent laryngeal nerve near the gland and is ligated further away from it.

- ▶ **Graves' disease** may be treated definitively by radioiodine (^{131}I) ablation, which destroys most active follicular cells — a therapeutic application built on the identical trap-and-organify mechanism that the diagnostic scan demonstrates.

High-yield exam pointers

- ▶ $^{99\text{m}}\text{Tc}$ -pertechnetate is trapped but **not organified** → morphology only; $^{123}\text{I}/^{131}\text{I}$ are trapped **and organified** → true functional data — the classic distinction to state first.
- ▶ ^{131}I is additionally a **beta-emitter** used therapeutically (Graves', toxic nodule, thyroid cancer ablation); $^{99\text{m}}\text{Tc}$ and ^{123}I are purely diagnostic gamma-emitters.
- ▶ Four standard scan views: anterior marker (landscape), anterior, RAO, LAO; label right lobe, left lobe, isthmus, pyramidal lobe and salivary glands.
- ▶ "Hot" area = increased uptake (e.g. toxic adenoma); "cold" area = failed uptake — thyroid and liver are the textbook examples of organs where cold areas are the classical pathological pattern.
- ▶ Most frequent ectopic site = base of tongue at the **foramen caecum** (lingual thyroid), which may be the patient's **only** thyroid tissue — scanning is mandatory before excising a suspected thyroglossal remnant.
- ▶ Gland facts: weight ~25 g; level C5–T1; each lobe $5 \times 3 \times 2$ cm; isthmus 1.25 cm; pyramidal lobe more often on the left.
- ▶ Normal thyroid FDG-PET SUV ≈ 1.3 ; benign/malignant cut-off SUV 2.0–2.5.
- ▶ Graves' disease = diffuse increased uptake (no nodules); toxic adenoma = focal hot nodule; multinodular goitre/Hashimoto's thyroiditis = patchy/irregular uptake.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — General Anatomy 4e; Weir & Abrahams — Imaging Atlas of Human Anatomy 6e; Vishram Singh — Textbook of Clinical Embryology; IB Singh — Textbook of Anatomy Vol 3 6e; Ross Histology — A Text and Atlas 7e. Coverage note: Moore's Clinically Oriented Anatomy 9e (the specialty text listed for this Radiological topic) carries no dedicated thyroid-scan passage; the technique, radiopharmacology and applied-anatomy content above have been assembled from Gray's nuclear-medicine commentary and neck chapter, the Weir & Abrahams functional-imaging atlas, and the general/systemic anatomy texts, cross-checked for internal consistency.



Ultra sonography

Asked in: Paper IV Apr 2006 — RGUHS MD/MS Anatomy

Definition / Introduction Ultrasonography (USG, "ultrasound") is a non-invasive, real-time imaging technique that builds cross-sectional images of soft-tissue anatomy from the echoes of high-frequency mechanical sound waves reflected at interfaces between tissues of differing acoustic density. A piezoelectric transducer both emits the ultrasound beam and receives the returning echoes, and a scanner converts the strength and transit-time of each echo into a grey-scale (B-mode) or colour (Doppler) image. Unlike radiography, CT or PET, USG uses **no ionising radiation** — the World Health Organization (1988) declared diagnostic ultrasound safe, including for the developing foetus — which makes it the first-line, portable, bedside imaging modality of the abdomen, pelvis, obstetric and superficial anatomy.

1. Physical principle and instrumentation

- ▶ The transducer contains a **piezoelectric crystal** that converts an electrical stimulus into ultrasound of typical wavelength **2–18 MHz** (frequencies well above the 20 kHz upper limit of human hearing).
- ▶ A water-based coupling **gel** is applied between skin and probe to prevent an air gap, which would otherwise reflect virtually all the beam.
- ▶ The beam travels through tissue at roughly **1500 m/s**; at each interface of differing acoustic impedance part of the beam is reflected as an **echo**, which vibrates the transducer and is converted back into an electrical pulse.
- ▶ The scanner computes depth from **echo transit time** and brightness from **echo strength**, generating shades of grey that form the image (real-time **2-D** slice by mechanically sweeping/rotating the transducer; a stack of 2-D slices can be reconstructed into **3-D**, and sequential 3-D volumes into a moving "**4-D**" image).

□ Fig 1.54 — Technique for producing ultrasound image of upper abdomen. A. The imag (Moore — Clinically Oriented Anatomy — 9e, p.196)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Panel A (technique):** body in supine position → **transducer** on skin → **acoustic gel coupling agent** at the skin interface → **body wall** → cone of **ultrasound waves** (dotted lines) → target organ (**kidney**) → returning **echo** arrow back to transducer.
- ▶ **Panel B (B-mode grey-scale image):** label liver, **perirenal fat in renal sinus**, **cortex of kidney**, **psoas muscle**.
- ▶ **Panel C (Doppler image):** label **LK** (left kidney), **LRV** (left renal vein, blue — flow away from probe), **LRA** (left renal artery, red — flow toward probe), and the colour scale.

2. Modes of ultrasound display

Mode	Principle	Chief use
A-mode (amplitude)	Echoes shown as spikes of varying amplitude along one scan line; depth information only, no 2-D image	Historic — ocular biometry, echoencephalography
B-mode (brightness)	Echoes converted to dots of varying brightness across a 2-D plane; performed in real time; extendable to 3-D/4-D	Standard real-time anatomical/obstetric "sonogram"
M-mode (motion)	Records the changing position of one structure along a single line against a time axis	Cardiac valve motion, foetal heart-wall movement
Doppler	Frequency shift of echoes from moving reflectors (red blood cells) converted to velocity/colour data; continuous-wave or pulsed-wave; colour or power display	Vascular and cardiac flow, placental/foetal circulation

3. Types of scanning and probe selection

- ▶ **Transabdominal sonography** — performed across the anterior abdominal wall; used for upper-abdominal organs and later-trimester obstetric scanning.
- ▶ **Transvaginal (endovaginal) sonography** — probe introduced per vaginam, brought close to the uterus/adnexa/early gestational sac for higher-resolution first-trimester and gynaecological imaging.
- ▶ **Endosonography** (general term) — a miniaturised probe placed within a body orifice/cavity to image adjacent structures at high resolution, e.g. **endoanal ultrasound** of the anal sphincter complex.

Probe frequency band	Depth reached	Best suited to
High (10–15 MHz)	~2–4 cm	Superficial structures (thyroid, testis, breast, superficial vessels)
Mid (5–10 MHz)	~5–6 cm	Intermediate-depth soft tissue

Probe frequency band	Depth reached	Best suited to
Low (2–5 MHz)	~10 cm	Deep abdominal and obstetric scanning

- Image resolution falls as probe frequency (and hence penetration depth) is lowered — a fixed trade-off between depth and resolution.

4. Tissue echogenicity ("the grey scale")

Appearance	Screen colour	Example tissue/structure
Hyperechoic	White	Fat, cartilage
Hypoechoic	Grey	Muscle and most soft-tissue parenchyma
Anechoic	Black	Clear fluid — amniotic fluid, bile, urine, vessel lumen; also bone (which appears black deep to a bright hyperechoic surface rim, as ultrasound cannot penetrate it)
Acoustic shadowing	Black shadow deep to the structure	Gas and calculi, which reflect/absorb almost the entire beam

- Doppler colour convention commonly taught (not a fixed international standard): **BART** — **B**lue **A**way, **R**ed **T**oward the transducer.

5. Applications in embryology and obstetric imaging

- **Purpose of antenatal USG:** confirm pregnancy (gestational sac); estimate gestational age; detect multiple pregnancy; detect foetal anomalies; monitor foetal growth; detect ectopic pregnancy; guide invasive procedures (amniocentesis, chorionic villus sampling).
- **Classification of foetal sonographic examinations:** first-trimester (gestational sac number/size/location, yolk sac, foetal pole); second-/third-trimester (foetal well-being, presentation, liquor volume, cardiac activity, placental site, biometry); limited (a single targeted question, e.g. foetal heart activity in a bleeding patient); specialised (detailed anomaly scan for a suspected defect).

Biometric parameter	Landmarks / notes	Gestational window
Gestational sac	Grows ~1 mm/day; useful for dating up to a 14 mm mean diameter	Visible 3rd–5th week
Yolk sac	Visible 5th–6th week; maximal (~6 mm) by 10th week, then involutes	Confirms pregnancy only
Crown–rump length (CRL)	Highest point of skull to lowest point of buttock; single most accurate dating parameter	First trimester, up to 84 mm

Biometric parameter	Landmarks / notes	Gestational window
Biparietal diameter (BPD)	Axial plane through the foetal skull	Second–third trimester
Head circumference (HC)	Same plane as BPD, traced around the outer skull table	Second–third trimester
Abdominal circumference (AC)	Measured at the level of the portal-vein bifurcation/stomach	Second–third trimester
Femur length (FL)	Both condyles visualised; transducer perpendicular to the shaft; tip of greater trochanter to lateral epicondyle	Second–third trimester



Foetal CRL growth used for gestational dating (Sontakke, Human Embryology)

6. Applications in gross/systemic anatomy

- ▶ **Hepatobiliary** — USG is the investigation of choice for gallbladder disease; the gallbladder appears as an anechoic, oval/pear-shaped structure; the liver, pancreas and kidneys are assessed in the same sitting for pathology mimicking biliary disease.
- ▶ **Renal** — differentiates a solid mass (likely tumour) from a cystic mass (simple cyst); Doppler US demonstrates renal arterial and venous flow.
- ▶ **Urinary bladder and abdominal aorta** — fluid-filled and vascular structures are well seen.
- ▶ **Female pelvis** — uterus and ovaries are visualised for size, position and pathology (e.g. ovarian prolapse); serial USG is used to monitor ovulation.
- ▶ **Cardiovascular** — **echocardiography** (cardiac ultrasonography) assesses chamber size, wall motion and valves non-invasively; **Doppler echocardiography** demonstrates blood flow through the heart and great vessels.
- ▶ **Breast** — characterises a palpable lump not clearly seen on mammography (particularly in dense breast tissue), distinguishes a fluid-filled cyst from a solid mass, and guides biopsy needles.
- ▶ **Anal canal** — endoanal ultrasound images the internal and external anal sphincters at multiple axial levels.
- ▶ **Guided intervention** — USG guides amniocentesis (14–20 weeks), chorionic villus sampling (9–12 weeks) and percutaneous umbilical blood sampling, reducing the risk of foetal injury compared with unguided technique.

7. Advantages and limitations

Advantages	Limitations
Non-invasive, no ionising radiation — safe in pregnancy (WHO, 1988)	Operator-dependent; reproducibility varies
Real-time, dynamic imaging of motion and flow	Cannot penetrate bone — adult intracranial structures not assessable
Portable, relatively inexpensive, repeatable	Gas reflects/scatters the beam — bowel loops and lung are poorly visualised
Differentiates solid from cystic/fluid-filled lesions	Image quality falls with increasing patient girth/depth
Doppler adds functional (flow) data to structural imaging	Narrower field of view than CT/MRI; limited bony detail

Applied / Clinical anatomy

- ▶ Gallbladder USG is first-line for suspected cholelithiasis/cholecystitis; calculi are hyperechoic with posterior acoustic shadowing (gas/calculi block sound transmission).
- ▶ First-trimester **nuchal translucency (nuchal thickness)** and **nasal-bone** assessment on USG are used as anatomical markers in aneuploidy (Down syndrome) screening.
- ▶ Doppler ultrasound of renal and limb vessels non-invasively demonstrates arterial/venous flow (e.g. renal artery assessment, venous flow surveillance).
- ▶ Endovaginal scanning brings the probe close to the uterus/adnexa, giving higher-resolution first-trimester and gynaecological imaging than the transabdominal route.
- ▶ Neonatal cranial ultrasound through the still-membranous anterior fontanelle provides an acoustic window for the immature brain that is lost once the fontanelle ossifies — a direct correlate of the bone-blocking limitation above.
- ▶ Because bones appear anechoic with only a bright surface rim, USG complements but does not replace radiography/CT for skeletal detail.

High-yield exam pointers

- ▶ Piezoelectric transducer converts electrical energy to ultrasound (~2–18 MHz) and back; the image is built from echo strength and transit time.
- ▶ Four display modes: **A** (amplitude), **B** (brightness/real-time 2-D, extendable to 3-D/4-D), **M** (motion), **Doppler** (flow).
- ▶ Grey scale: hyperechoic-white (fat, cartilage), hypoechoic-grey (soft tissue/muscle), anechoic-black (fluid; also bone deep to its bright rim), acoustic shadowing (gas/calculi).
- ▶ Doppler convention commonly taught: **BART** — **B**lue **A**way, **R**ed **T**oward the probe.
- ▶ Frequency–depth trade-off: high-frequency probes (10–15 MHz) for superficial parts; low-frequency (2–5 MHz) for deep/obstetric scanning.
- ▶ No ionising radiation — WHO (1988) declared diagnostic USG safe, including in pregnancy.
- ▶ Investigation of choice for **gallbladder disease**.

- Obstetric dating: CRL is most accurate in the first trimester (up to 84 mm); BPD, HC, AC and FL are used together in the second–third trimester.
- Cannot penetrate bone or gas — the adult skull and gas-filled bowel/lung are poor USG windows.

SOURCE & COVERAGE

Sontakke — Textbook of Human Embryology (Ch. Clinical Applications and Ultrasonography in Embryology); Vishram Singh — General Anatomy 4e; IB Singh — Textbook of Anatomy Vol 1 6e; BD Chaurasia — Human Anatomy Vol 2 8e; Moore — Clinically Oriented Anatomy 9e; Larsen — Human Embryology 6e; Gray's Anatomy (Standring) 41e.



Write short notes on cholecystography

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction Cholecystography is a contrast radiographic technique for visualising the gallbladder and, indirectly, the extrahepatic biliary passages. The gallbladder is a soft-tissue viscus and is therefore radiolucent — it casts no useful shadow on a plain abdominal skiagram. Cholecystography exploits the one physiological property that makes the organ imageable: its capacity to concentrate bile. A radiopaque iodinated dye, taken orally or given intravenously, is excreted by the liver into the bile and is then concentrated many-fold within the gallbladder, rendering it opaque to X-rays. It has now been largely superseded by ultrasonography and other cross-sectional techniques but remains an important applied-anatomy question because it links gross anatomy, physiology and radiological anatomy of the biliary tree.

1. Anatomical basis — the extrahepatic biliary apparatus

The structure actually being demonstrated on a cholecystogram is the **extrahepatic biliary apparatus**, which has five components:

- Right and left **hepatic ducts** — emerge through the porta hepatis and unite to form the common hepatic duct.
- **Common hepatic duct** — descends about 2.5 cm and is joined on its right by the cystic duct.
- **Gallbladder** — a pear-shaped sac of 30–50 mL capacity lying in the fossa for the gallbladder on the inferior surface of the right lobe of the liver, along the right edge of the quadrate lobe. It measures about 10 cm in length and up to 3 cm in width, and has three parts:
 - **Fundus** — the blind, peritoneum-covered expanded end; it touches the anterior abdominal wall deep to the tip of the right 9th costal cartilage, at the point where the right linea semilunaris meets the costal margin.
 - **Body** — related above to the liver (bare area) and below, through peritoneum, to the second part of the duodenum.
 - **Neck** — continues into the cystic duct; its postero-medial wall shows **Hartmann's pouch**, a common site for impacted gallstones.

- ▶ **Cystic duct** — 3–5 cm long, its mucosa thrown into 5–10 crescentic folds forming the **spiral valve of Heister**, which keeps the duct patent so that bile can pass in both directions.
- ▶ **Bile duct (common bile duct)** — formed near the porta hepatis by union of the cystic and common hepatic ducts; about 7.5 cm long and 6 mm in diameter (anatomically not exceeding 8 mm; on ultrasound the normal upper limit is quoted as ≤ 7 mm, increasing slightly with age). It has supraduodenal, retroduodenal, infraduodenal (pancreatic) and intraduodenal parts, and joins the main pancreatic duct to form the **hepatopancreatic ampulla (of Vater)**, guarded by the sphincter of Oddi, opening on the major duodenal papilla.

The gallbladder is supplied by the **cystic artery** (usually from the right hepatic artery) and drained by the cystic vein into the portal vein; it is a key surgical/imaging landmark because contrast-filled ducts on a cholecystogram or cholangiogram trace exactly this five-part pathway.

□ Fig 8.12 — Components of the extrahepatic biliary apparatus. Note the sphincters around hepatopancreatic ampulla and terminal parts of the bile and main pancreatic ducts. (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.380)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label a diagram of the **extrahepatic biliary apparatus** as seen on a cholecystogram/cholangiogram:

- ▶ Right and left hepatic ducts → common hepatic duct
- ▶ Cystic duct (with spiral valve of Heister) joining at an acute angle
- ▶ Gallbladder — fundus, body, neck, Hartmann's pouch
- ▶ Bile duct — supraduodenal, retroduodenal, infraduodenal (pancreatic), intraduodenal parts
- ▶ Main pancreatic duct joining to form the hepatopancreatic ampulla (of Vater)
- ▶ Sphincter of Oddi and major duodenal papilla on the 2nd part of duodenum
- ▶ Cystic artery and portal vein (surgical/vascular landmarks)

2. Principle and technique of oral cholecystography

- ▶ **Principle:** an orally administered radiopaque iodine-containing dye is absorbed from the gut, taken up by hepatocytes, excreted into bile, and concentrated in the gallbladder by active mucosal reabsorption of water and electrolytes — the concentrated dye renders the gallbladder opaque.
- ▶ **Preparation:** the contrast is taken the previous evening; the patient remains fasting overnight.
- ▶ **Timing:** plain and contrast films are taken about 14–16 hours after ingestion of the dye, by which time the gallbladder has adequately concentrated the contrast.
- ▶ **Fatty test meal:** after the initial (fasting) films, a fatty meal is given to stimulate release of **cholecystokinin (CCK)** from the duodenal mucosa; CCK causes gallbladder contraction with reciprocal relaxation of the sphincter of Oddi, so a further film demonstrates the gallbladder's **contractility** and the free passage of concentrated bile into the duodenum.
- ▶ **Dependence on absorption:** because the dye must be absorbed from the intestine, the test is unreliable in vomiting, malabsorption, or hepatocellular dysfunction — a genuine limitation of the method.

- **Intravenous cholangiography** is a variant in which the dye is injected intravenously (bypassing intestinal absorption) to opacify the ducts and gallbladder when oral absorption cannot be relied upon.

3. What cholecystography demonstrates (anatomical/functional correlation)

Feature assessed	Anatomical/functional correlate
Size, shape and position of gallbladder shadow	Fundus/body/neck outline; confirms normal fossa-for-gallbladder location
Concentrating power	Mucosal active transport function of the gallbladder wall
Filling defects	Radiolucent (cholesterol) gallstones outlined by opaque bile
Contractility after fatty meal	CCK-mediated smooth-muscle contraction of the gallbladder wall
Patency of cystic duct	Passage of contrast from common hepatic duct into the gallbladder via the spiral valve of Heister
Non-visualisation of gallbladder	Cystic duct obstruction, chronic cholecystitis, or failure of hepatic excretion/absorption

4. Other/current methods of imaging the biliary tract

Because oral cholecystography depends on intestinal absorption and hepatic excretion, and gives no information on wall thickness or pericholecystic changes, it has been progressively replaced by the following:

Modality	Principle	What is demonstrated	Current status
Ultrasonography (USG)	Non-invasive real-time imaging	Gallbladder as a cystic, oval shadow with a narrow neck in the right upper quadrant; wall thickness; stones; sludge; bile duct and portal vein	Investigation of choice — has largely replaced cholecystography
Endoscopic retrograde cholangiopancreatography (ERCP)	Fibre-optic endoscope passes a catheter into the hepatopancreatic ampulla; contrast injected retrograde	Intrahepatic radicles, common hepatic/bile duct, pancreatic duct, gallbladder	Diagnostic and therapeutic (stone extraction, sphincterotomy, stenting)
Percutaneous transhepatic cholangiography (PTC/PTHC)	Direct percutaneous needle puncture of an intrahepatic duct under image guidance	Biliary tree opacified from above, when ERCP fails or cannot be performed	Used as a fallback to ERCP

Modality	Principle	What is demonstrated	Current status
Oral cholecystography	Oral iodinated dye concentrated in bile	Gallbladder shape, concentrating power, contractility	Obsolete/outdated as a routine test

5. Recent advances in biliary imaging

- ▶ **Magnetic resonance cholangiopancreatography (MRCP):** a heavily T2-weighted MR sequence exploits the long T2 of static bile to give a bright, non-invasive, contrast-free "cholangiogram-like" image of the whole biliary tree and pancreatic duct in one sitting; it has largely displaced diagnostic ERCP, reserving ERCP for therapeutic intervention.
- ▶ **Endoscopic ultrasound (EUS):** a high-frequency transducer at the tip of an endoscope placed in the duodenum/stomach gives high-resolution images of the distal common bile duct and ampullary region, useful for detecting small (microlithiasis) stones and ampullary/periampullary lesions missed by transabdominal USG.
- ▶ **Contrast-enhanced and 3D/4D ultrasonography:** improves characterisation of gallbladder wall lesions and dynamic assessment of gallbladder emptying, extending the old fatty-meal cholecystographic principle into real time.
- ▶ **CT cholangiography / multidetector CT with 3-D reconstruction:** used pre-operatively to map variant cystic-duct and cystic-artery anatomy (the artery's origin, number and course in the hepatobiliary triangle are notably variable) before laparoscopic cholecystectomy, reducing iatrogenic bile-duct injury.
- ▶ **Virtual cholangioscopy:** post-processed CT/MR data are rendered to simulate an endoluminal "walk-through" of the biliary tree, a non-invasive complement to ERCP-based cholangioscopy.
- ▶ Overall trend: invasive contrast cholangiography (oral cholecystography, and increasingly diagnostic ERCP) is being replaced by non-invasive, radiation-free cross-sectional techniques (USG, MRCP), while ERCP/PTC are retained chiefly for combined diagnosis-and-treatment.

Applied / Clinical anatomy

- ▶ **Cholelithiasis:** gallstones form typically in a "fat, fertile, flatulent female of forty" (the classical 5-F mnemonic); a stone impacted in Hartmann's pouch or the cystic duct is the commonest cause of non-visualisation on cholecystography and of acute cholecystitis.
- ▶ **Acute cholecystitis:** sudden right-hypochondrial pain referred to the inferior angle of the right scapula (visceral afferents, T7–T9) or the tip of the right shoulder (phrenic nerve, C3–C5 via subdiaphragmatic peritoneal irritation); a positive **Murphy's sign** (catch in breath on deep inspiration while palpating below the right costal margin at the 9th costal cartilage) is elicited clinically at the same surface point used to mark the gallbladder fundus.
- ▶ **Courvoisier's law:** obstructive jaundice with a distended, palpable gallbladder suggests an extrinsic cause (e.g., carcinoma of the head of pancreas); jaundice with a non-palpable, non-distended (fibrotic) gallbladder suggests an intrinsic cause such as impacted gallstones with prior chronic cholecystitis.

- ▶ **Biliary colic:** spasm of the gallbladder/duct smooth muscle attempting to expel an impacted calculus, referred to the right hypochondrium/epigastrium (T7–T9 dermatomes).
- ▶ **Calot's (cystohepatic) triangle:** bounded by the cystic duct, common hepatic duct, and inferior surface of liver, containing the cystic artery and the cystic lymph node of Lund (constantly enlarged in cholecystitis); careful dissection here during cholecystectomy avoids injury to the right hepatic artery or common hepatic/bile duct, especially when the right hepatic artery forms a looping "Moynihan's hump."
- ▶ **Accessory hepatic ducts** (~15% of cases) may open into the gallbladder, cystic duct, common hepatic duct, or bile duct and are a recognised cause of bile leak (biloma) after cholecystectomy.

High-yield exam pointers

- ▶ Cholecystography works because the gallbladder **concentrates** any radiopaque substance excreted in bile — the organ itself is radiolucent.
- ▶ Classical timing: dye taken the evening before; films taken 14–16 hours later; a fatty test meal is then given to assess contractility via CCK-mediated contraction.
- ▶ Ultrasonography is now the **investigation of choice** for the gallbladder and has largely replaced oral cholecystography.
- ▶ ERCP visualises the hepatopancreatic ampulla, bile duct, pancreatic duct and gallbladder via a retrograde endoscopic route; PTC is the fallback when ERCP fails.
- ▶ MRCP is now the leading non-invasive alternative for diagnostic biliary imaging.
- ▶ The extrahepatic biliary apparatus has five components: right/left hepatic ducts, common hepatic duct, gallbladder, cystic duct, bile duct.
- ▶ Applied correlates worth a line each: Murphy's sign, Courvoisier's law, Calot's triangle and its contents, referred pain pathways.

SOURCE & COVERAGE

Vishram Singh — Textbook of Anatomy Vol 2 (4e); BD Chaurasia — Human Anatomy Vol 2 (8e); IB Singh — Textbook of Anatomy Vol 1 (6e) and Vol 2 (6e); Gray's Anatomy (Standring) 41e.



Xero radiography

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

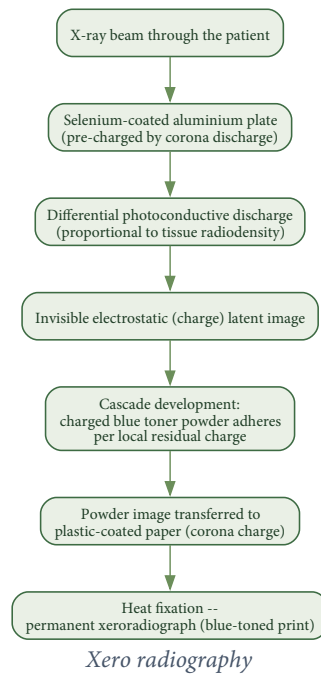
Definition / Introduction Xeroradiography is a variant of plain radiography in which the X-ray image is captured not on a silver-bromide film but on a reusable, electrically charged **selenium-coated aluminium plate**, using the same dry, powder-development (xerographic) principle popularised by the photocopier. The X-ray beam produces a pattern of differential electrostatic charge on the plate rather than a chemical latent image; this charge pattern is developed with a charged toner powder and permanently transferred onto plastic-coated paper. Because the process gives pronounced **edge enhancement** and a very **wide exposure latitude**, it was, for about two decades, the preferred technique for **breast imaging** (xeromammography) and for combined bone–soft-tissue surveys, before being superseded by dedicated screen–film and, later, digital mammography.

1. Principle of image formation

- ▶ Plain (film) radiography relies on differential absorption of the X-ray beam by tissues of different density, which is recorded as a **chemical latent image** on a silver-bromide emulsion and rendered visible by wet chemical development.
- ▶ Xeroradiography instead uses a **photoconductive selenium layer** on an aluminium base plate:
 - The plate is first uniformly charged (electrostatically, in the dark) by a corona-discharge unit, so that it carries a uniform surface charge.
 - When the X-ray beam (after passing through the patient) strikes the plate, the selenium becomes conductive **in proportion to the amount of radiation reaching it** — regions receiving more radiation (i.e., transmitted through less-dense tissue) discharge more, while regions under dense structures (bone) retain more charge.
 - This produces an invisible **electrostatic latent image** — a charge pattern that is the point-for-point analogue of the tissue radiodensity.
- ▶ The electrostatic image is thus formed by **differential photoconductive discharge**, not by a photochemical reaction — this is the fundamental physical difference from plain film radiography.

2. Procedure / technique of development

- ▶ The exposed plate is developed by "cascade development": a fine, electrically charged **blue toner powder** is dusted across the plate and adheres to it in proportion to the local residual charge, converting the invisible electrostatic image into a visible powder image.
- ▶ The powder image is then **electrostatically transferred** onto a sheet of plastic-coated paper (again using a corona charge) and permanently fixed onto it by heat lamination, yielding a durable, dry, blue-toned positive print — the **xeroradiograph**.
- ▶ Unlike film radiography, there is **no wet chemical processing** (no developer/fixer bath); the selenium plate itself is reusable after each exposure, once cleaned and recharged.



3. Characteristic features of the xeroradiographic image

- ▶ **Edge enhancement (boundary/fringe effect):** at any interface between two tissues of differing density, the lateral spread of charge accentuates the boundary, so the image shows bright and dark fringing lines at tissue margins — this markedly improves the conspicuity of fine soft-tissue outlines, calcifications, and lesion margins compared with plain film.
- ▶ **Wide exposure latitude:** because the process responds to a very broad range of radiation intensities without "saturating" (as film does when over- or under-exposed), a **single exposure can simultaneously display both bone and adjacent soft tissue** clearly in the same print — a genuine advantage over plain film, which typically requires separate bone- and soft-tissue-optimised exposures.
- ▶ The final print is a **positive image on opaque paper** (viewed by reflected light, like a photograph) rather than a transparency requiring a viewing box.

4. Xeroradiography vs conventional (film) radiography

Feature	Plain film radiography	Xeroradiography
Recording medium	Silver-bromide photographic film/emulsion	Selenium-coated aluminium plate (photoconductor)
Nature of latent image	Chemical (photographic)	Electrostatic (charge pattern)
Development	Wet chemical (developer, fixer)	Dry — charged powder ("cascade") development
Final image	Negative-type transparency, viewed on a light box	Positive print on plastic-coated paper, viewed by reflected light
Edge/contrast behaviour	Fixed contrast/latitude; edges not specifically enhanced	Marked edge enhancement + wide latitude (bone and soft tissue together)

Feature	Plain film radiography	Xeroradiography
Reusability of recording plate	Film is single-use (discarded after exposure)	Selenium plate is reusable after cleaning/recharging
Chief historical use	General skeletal and chest radiography	Breast (xeromammography) and bone–soft-tissue surveys

5. Clinical applications

- ▶ **Xeromammography** was the principal clinical application — the edge-enhancement effect made it particularly effective for detecting **breast tumours**, showing spiculated masses, architectural distortion and microcalcifications against the surrounding glandular parenchyma with better conspicuity than early screen–film systems of the same era.
- ▶ **Soft-tissue and combined bone–soft-tissue imaging of the extremities** — because a single xeroradiographic exposure could depict both cortical bone and adjacent soft-tissue planes (muscle, fat, oedema) without separate exposures, it was used for localisation of radiolucent soft-tissue foreign bodies (e.g., wood splinters, glass) and for soft-tissue swellings around joints.
- ▶ Occasionally used for laryngeal and paranasal sinus soft-tissue detail for the same edge-enhancement reason.

6. Advantages and disadvantages

Advantages	Disadvantages
Marked edge enhancement — better delineation of tissue margins, calcifications and masses	Historically required a higher radiation dose than dedicated low-dose screen–film mammography systems that were later developed specifically to compete with it
Wide exposure latitude — bone and soft tissue seen together in one exposure	Selenium plates and corona-charging/toner apparatus needed regular cleaning/maintenance; prone to dust and plate-defect artefacts
Dry process — no wet chemical development, faster turnaround	Equipment and running costs of dedicated xeroradiography units were relatively high
Reusable recording plate	Positive paper print is bulkier to store/archive than film, and cannot be post-processed the way a digital file can
Image can be read in ordinary room light (reflected-light paper print)	Superseded once dedicated low-dose mammography film–screen combinations, and subsequently digital detectors, matched or exceeded its diagnostic benefit without the dose penalty

7. Current status and recent advances

- ▶ Xeroradiography (and xeromammography in particular) is now essentially of **historical interest only** and has been abandoned in routine clinical practice.
- ▶ It was progressively displaced from the 1980s onward, first by **dedicated low-dose screen–film mammography** systems (purpose-built fine-grain film/intensifying-screen combinations giving

comparable soft-tissue detail at substantially lower radiation dose), and subsequently and completely by **digital imaging technologies**:

- **Full-field digital mammography (FFDM)** and **digital breast tomosynthesis (DBT)**, which use solid-state (flat-panel/CCD) detectors instead of a selenium plate, and reproduce (and exceed) the "edge enhancement" effect **algorithmically** by post-acquisition image processing (adjustable window/level, edge-sharpening filters) rather than a fixed physical property of the plate.
- **Computed radiography (CR)**, using photostimulable phosphor plates read by a laser scanner, and direct digital radiography (DR) with flat-panel detectors, which similarly give the wide dynamic range/latitude that xeroradiography once offered for combined bone–soft-tissue imaging, again without the dry-powder process or its dose penalty.
- ▶ Conceptually, xeroradiography remains important in the teaching of radiological anatomy as the historical bridge technology that first demonstrated the diagnostic value of **electronic/physical edge enhancement and wide dynamic range** — principles that are now achieved digitally and form the basis of modern computer-processed radiographic and mammographic images.
- ▶ *Coverage note: the working library does not contain a dedicated modern radiology text with cited figures for FFDM/DBT hardware; the "current status" points above reflect standard, universally accepted radiological-imaging teaching (that xeroradiography has been superseded by digital mammography/tomosynthesis) rather than a specific textbook citation, and are presented as such.*

Applied / Clinical anatomy

- ▶ The single most important applied point is **xeromammography for the detection of breast tumours** — its edge-enhancement property made spiculated malignant masses and microcalcification clusters stand out clearly against normal fibroglandular breast tissue, which is otherwise a technically difficult, low-inherent-contrast subject for plain radiography.
- ▶ Its ability to show **bone and soft tissue together in one film** made it historically useful for the anatomical evaluation of extremity trauma with suspected soft-tissue foreign bodies, and for delineating soft-tissue swellings (e.g., around a joint) relative to the underlying skeleton.
- ▶ As a teaching point for radiological anatomy, xeroradiography illustrates the general principle that the **diagnostic yield of an imaging technique** depends not only on differential tissue radiodensity (the anatomical basis common to all plain radiography) but also on how the recording medium **processes and displays** that differential signal — a concept now central to understanding digital image post-processing.

High-yield exam pointers

- ▶ Xeroradiography = **plain radiography variant** using a **selenium-coated, electrically charged aluminium plate** instead of film.
- ▶ Image formation: X-ray beam produces **differential photoconductive discharge** → **electrostatic latent image** (not a chemical latent image).
- ▶ Development is **dry**: charged **blue toner powder** ("cascade development") adheres per local charge, then is transferred to plastic-coated paper and heat-fixed — a permanent positive print.

- ▶ Two defining image properties: **edge enhancement** (boundary/fringe effect) and **wide exposure latitude** (bone + soft tissue in one exposure).
- ▶ Chief clinical use: **xeromammography** — **detection of breast tumours** (classic exam association).
- ▶ Also used for combined bone–soft-tissue surveys of the extremities (e.g., soft-tissue foreign-body localisation).
- ▶ Selenium plate is **reusable**, unlike film.
- ▶ Now **obsolete/historical** — superseded first by dedicated low-dose screen–film mammography, then completely by digital mammography/tomosynthesis and CR/DR systems, which reproduce edge enhancement digitally at lower dose.

SOURCE & COVERAGE

Vishram Singh — General Anatomy 4e; IB Singh — Textbook of Anatomy Vol 1, 6e (Introduction to Radiological Anatomy). Coverage note: xeroradiography receives only brief, focused coverage in the anatomy library (a short named section in Vishram Singh's General Anatomy, plus a confirmatory MCQ on its breast-imaging use); Gray's Anatomy (Standring) 41e and the other specialty texts have no dedicated section on this now-obsolete technique. The "Current status/recent advances" discussion is composed from standard, universally accepted radiological-imaging teaching rather than a specific cited textbook passage, as flagged above.



Applied & clinical anatomy



Branchial cyst

Asked in: Paper II Nov 2017 · Paper IV Oct 2006 (2×) — RGUHS MD/MS Anatomy

Definition/Introduction — A branchial cyst (lateral cervical cyst) is a congenital, epithelium-lined cystic swelling that results from failure of obliteration of the **cervical sinus of His**, the transient ectoderm-lined cavity formed when the rapidly-growing second pharyngeal arch buries the second, third and fourth pharyngeal clefts. It classically presents as a smooth, painless, slowly enlarging swelling along the anterior border of sternocleidomastoid (SCM) in a child or young adult, and forms a developmental continuum with the branchial sinus and fistula.

1. Embryological basis — formation and fate of the cervical sinus of His

- ▶ The pharynx is flanked by four pairs of **pharyngeal (branchial) arches**, separated externally by ectoderm-lined **pharyngeal clefts (grooves)** and internally by endoderm-lined **pharyngeal pouches**.
- ▶ The **second pharyngeal arch** proliferates and grows caudally over the third and fourth arches (as an "operculum") and fuses with the **epicardial ridge** (cardiac eminence) inferiorly.

- ▶ This overgrowth buries/traps the second, third and fourth clefts in a slit-like, ectoderm-lined cavity — the **cervical sinus (of His)** — lying between the operculum of the second arch superficially and the third/fourth (and vestigial sixth) arches deeply.
- ▶ Normally, the walls of the cervical sinus appose and fuse, and the cavity is obliterated as the neck elongates, giving the lateral neck a smooth contour.
- ▶ Only the **dorsal part of the first pharyngeal cleft persists** as a definitive structure — the external acoustic meatus and the cuticular (epithelial) layer of the tympanic membrane; the second, third and fourth clefts are normally obliterated along with the sinus.
- ▶ **Persistence of the cervical sinus, wholly or in part, gives rise to the branchial cyst/sinus/fistula group of anomalies** — the second most common congenital lesion of the head and neck in children.

□ Fig 17.27 — Normal and Abnormal Fates of the Pharyngeal Clefts (A–C) Three stages in normal development (Larsen — *Human Embryology* — 6e, p.1092)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw (i) a coronal/transverse schematic of the developing neck at three successive stages and (ii) a lateral neck outline, labelling:

- ▶ Pharyngeal clefts (1st–4th), 2nd pharyngeal arch expanding caudally over 3rd/4th arches
- ▶ Hypopharyngeal eminence, copula, median and lateral tongue buds, entrance to oesophagus (landmarks of the floor of the pharynx used to orient the section)
- ▶ **Lateral cervical sinus** — the trapped, ectoderm-lined cavity deep to the 2nd-arch operculum
- ▶ Four outcome panels: (a) isolated **lateral cervical cyst** (no communication), (b) cyst with **external fistula** only, (c) cyst with **internal fistula** only, (d) cyst with **both external and internal fistulae** (complete fistula)
- ▶ Lateral neck outline showing sternocleidomastoid muscle and the classic sites of aural (pre-auricular) and cervical (upper, mid third of SCM) cysts/fistulae

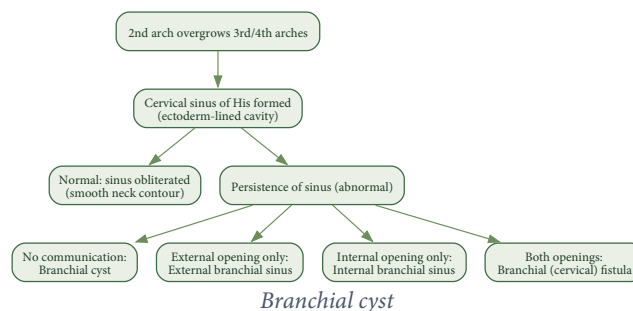
2. Pathogenesis and classification of cervical-sinus remnants

Depending on how much of the cervical sinus persists and whether it retains a communication with the skin (external, via the 2nd cleft) and/or the pharynx (internal, via rupture of the 2nd pharyngeal membrane into the tonsillar region), four clinical entities are described:

Anomaly	External opening (skin of neck)	Internal opening (pharynx/tonsillar fossa)	Embryological basis
Branchial (lateral cervical) cyst	Absent	Absent	Persistent, walled-off cervical sinus with no external or internal communication
External branchial sinus	Present, along anterior border of SCM	Absent	Cervical sinus retains its connection with the overlying skin

Anomaly	External opening (skin of neck)	Internal opening (pharynx/tonsillar fossa)	Embryological basis
Internal branchial sinus	Absent	Present, in the tonsillar fossa/palatine tonsil region	Cervical sinus communicates with the pharynx after rupture of the membrane between the 2nd cleft and 2nd pouch
Branchial (cervical) fistula	Present	Present	Both external and internal communications persist, connecting the pharynx to the skin of the neck

- ▶ A branchial cyst that ruptures onto the surface becomes a branchial sinus; thus cyst, sinus and fistula are a developmental continuum of the same defect rather than separate anomalies.
- ▶ Most (>90%) of these lesions arise from the **second pharyngeal cleft/pouch complex**; anomalies of the first, third and fourth clefts are much rarer variants of the same principle.



3. Site, age of presentation and clinical features

- ▶ **Site:** along the anterior border of sternocleidomastoid, classically at the junction of its upper one-third and lower two-thirds, just below and behind the angle of the mandible (though it may occur anywhere along the anterior SCM border).
- ▶ **Age:** usually **not evident at birth**; the cyst is asymptomatic in infancy and becomes clinically apparent as a lateral neck swelling in later childhood or early adulthood as it gradually enlarges.
- ▶ **Presentation:** a smooth, soft-to-firm, non-tender, slowly enlarging lateral neck mass; it characteristically **increases in size during an upper respiratory tract infection** (due to reactive hyperplasia of lymphoid tissue in its wall).
- ▶ Complications include recurrent infection/abscess formation and, if a sinus or fistula coexists, intermittent mucoid/salivary discharge onto the neck skin.

4. Histopathology

- ▶ The cyst wall is lined by either **stratified squamous epithelium** or, less commonly, **simple/pseudostratified columnar (ciliated) epithelium**, reflecting its origin from the ectodermal cervical sinus (and, in variants with pouch contribution, respiratory-type endoderm).

- ▶ The wall typically contains abundant **lymphoid tissue**, and the cyst fluid is characteristically a turbid or mucoid fluid.
- ▶ Recurrence after surgery is common if excision of the tract/wall is **incomplete**.

5. First branchial cleft cyst — a related but distinct entity

- ▶ Occasionally cysts/sinuses arise in relation to the **first** branchial cleft rather than the second; these are anatomically and clinically distinct because the first cleft's dorsal part contributes to the external acoustic meatus.
- ▶ Two types are described based on the level of the tract relative to the angle of the mandible/jaw line — **Type I** (opening above the jaw line, close to the external auditory meatus) and **Type II** (opening below the jaw line) — and these lesions run in close relation to the parotid gland and facial nerve, unlike second-cleft lesions which relate to the carotid vessels.

6. Genetic and molecular correlates (recent advances)

- ▶ Formation of the pharyngeal arches and their derivatives is driven by reciprocal endoderm–ectoderm–neural crest signalling; **fibroblast growth factor (FGF) signalling** from the pharyngeal pouch endoderm promotes chondrogenesis in the neural-crest-derived arch mesenchyme and also induces the **epibranchial placodes** (ectodermal thickenings at the dorsal ends of the 1st, 2nd and 4th clefts that later contribute neurons to the geniculate, petrosal and nodose sensory ganglia of cranial nerves VII, IX and X).
- ▶ **Branchio-oto-renal (BOR) syndrome** is the key genetic disorder linked to persistent branchial-cleft remnants: an **autosomal dominant** condition caused by mutation of **EYA1** (chromosome 8q13), a gene encoding a protein phosphatase used by conserved developmental pathways shared by the ear and kidney (the related gene **SIX1** interacts with EYA1 in the same pathway). It presents with cup-shaped/malformed external ears, pre-auricular pits/tags, mixed hearing loss, **branchial cysts and fistulae in the neck**, and renal anomalies (dysplasia, collecting-duct malformations).
- ▶ This genotype–phenotype link is why any child presenting with a branchial cystic anomaly together with ear or renal abnormalities warrants screening for BOR syndrome.

Applied / Clinical anatomy

- ▶ **Surgical relations:** during excision the cyst/tract lies in close relation to the **hypoglossal, glossopharyngeal and spinal accessory nerves**; a fistulous tract ascends from its cervical opening along the anterior border of SCM, traverses the platysma and cervical fascia to enter the **carotid sheath**, and then passes **between the internal and external carotid arteries** (the "carotid fork") en route to its internal opening in the tonsillar sinus — these relations must be protected during dissection.
- ▶ **Investigations:** ultrasonography and FNAC to characterise the swelling and exclude a solid/lymph-nodal lesion; CT/MRI or fistulography to delineate a fistulous tract before surgery.
- ▶ **Differential diagnosis:** thyroglossal cyst (midline, moves with tongue protrusion/deglutition), cystic hygroma (multiloculated, posterior triangle, transilluminant), tuberculous cervical lymphadenitis, and — importantly in adults over 40 — a **cystic metastatic lymph node** from an

occult tonsillar/base-of-tongue squamous carcinoma, which can closely mimic a branchial cyst and must be excluded before assuming a benign congenital diagnosis.

- ▶ **Treatment:** complete surgical excision of the cyst together with its sinus tract; incomplete removal is the principal cause of recurrence.

High-yield exam pointers

- ▶ Branchial cyst = persistence of the **cervical sinus of His** (2nd, 3rd, 4th cleft remnants buried by 2nd-arch overgrowth); lined by ectoderm.
- ▶ Site: anterior border of SCM, junction of upper 1/3–lower 2/3, below/behind angle of mandible.
- ▶ Not present at birth; appears in later childhood/early adulthood; enlarges with URTI.
- ▶ Cyst (no opening) → sinus (one opening, external or internal) → fistula (both openings) is a developmental continuum, not separate lesions.
- ▶ Histology: stratified squamous or columnar epithelium with lymphoid tissue in the wall.
- ▶ Only the 1st cleft has a definitive normal derivative (external acoustic meatus/tympanic membrane); 2nd–4th clefts are normally obliterated.
- ▶ Fistulous tract passes between internal and external carotid arteries to reach the tonsillar fossa; close to hypoglossal/glossopharyngeal/accessory nerves surgically.
- ▶ BOR syndrome (EYA1, 8q13, autosomal dominant) = branchial cysts/fistulae + ear anomalies + renal dysplasia — key gene–anomaly correlation for viva.
- ▶ Incomplete excision → recurrence; must differentiate from cystic nodal metastasis in an older patient.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Langman's Medical Embryology (Sadler) 14e; Larsen Human Embryology 6e; Moore The Developing Human 9e; Moore's Clinically Oriented Anatomy 9e; IB Singh Human Embryology (CBME 2021); Vishram Singh Textbook of Clinical Embryology; Sontakke Textbook of Human Embryology; Brijesh Kumar Embryology Text & Atlas; Thompson & Thompson Genetics in Medicine 8e.



Cervical Rib

Asked in: Paper I May 2010 · Paper IV Apr 2008 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction — A **cervical rib** is a congenital skeletal anomaly in which the **costal element of the transverse process of the seventh cervical vertebra** persists as a separate bony, cartilaginous or fibrous structure instead of fusing into the vertebra, producing an extra "rib" in the root of the neck. It usually runs from the C7 transverse process to the **first rib**, close to the insertion of **scalenus anterior**, and by narrowing the **scalene triangle** it may compress the **subclavian artery** and the **lower trunk of the brachial plexus (C8, T1)** — the classic cause of **thoracic outlet syndrome (TOS)**. The condition was first described by **Astley Cooper (1817)**, and most cervical ribs remain entirely asymptomatic.

1. Developmental basis

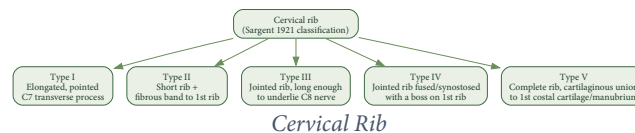
- ▶ Each typical cervical vertebra develops from a **centrum**, two **neural arch centres**, and an **anterior costal element** that normally fuses with the transverse process to form the anterior tubercle, the bar in front of the foramen transversarium, and part of the transverse process itself.
- ▶ At C7, this costal element is homologous with a true rib (as at thoracic levels) but is normally the **last cervical costal element to fuse**; if it fails to fuse and instead **enlarges and remains separate**, it forms a cervical rib.
- ▶ **Ossification**: a separate centre for the costal element appears during the **sixth month of intra-uterine life** and normally fuses with the body and transverse process during the **fifth to sixth year of life** (BD Chaurasia); persistence of a large, separate centre gives the spectrum of cervical rib seen radiologically.
- ▶ Gray's Anatomy notes that the **occasional co-occurrence of a cervical rib with a rudimentary or absent twelfth rib** points to a **homeotic shift** affecting a larger segment of the vertebral column during development — i.e. a mismatch between the morphological and positional identity of vertebrae at the cervicothoracic and thoracolumbar junctions.
- ▶ An analogous anomaly at the other end of the vertebral column is the **lumbar (gorilla) rib**, from a persistent costal element of L1; it is commoner than the cervical rib but usually asymptomatic and may mimic a fractured L1 transverse process radiologically.

2. Morphology and Sargent's classification

The cervical rib is **rarely symmetrical**, is **more often unilateral** than bilateral, and occurs **somewhat more frequently on the right side**. Its extent varies from a mere pointed elongation of the transverse process to a complete rib indistinguishable from a first thoracic rib. **Sargent (1921)**, cited in Gray's Anatomy, classified this spectrum into five types:

Type	Morphology
I	Prolongation and pointing of the C7 transverse process only
II	A short rib that articulates with the transverse process, continued by a fibrous band to the first rib
III	A jointed (articulated) rib long enough to carry/underlie the eighth cervical nerve

Type	Morphology
IV	A jointed rib whose free end is fused to, or forms a synchondrosis/synostosis with, a bony boss on the first rib, roughly at its mid-shaft
V	A complete seventh cervical rib with cartilaginous union to the first costal cartilage or to the manubrium



Only **types III–V** (a rib long enough to reach, or fuse with, the first rib) are of real clinical significance; a fibrous band alone (type II) can be just as compressive as a bony rib, since it is the **narrowing of the scalene triangle**, not the bone itself, that produces symptoms. Reported incidence of a cervical rib in the general population varies widely between sources — from **0.004% to 1%** (Gray's Anatomy) to **about 5%** of individuals when milder, radiologically-detected forms are included (Vishram Singh); the great majority are asymptomatic incidental findings.

3. Anatomical relations — the scalene triangle

Boundary	Structure
Anterior	Scalenus anterior
Posterior	Scalenus medius
Base (floor)	Upper surface of the first rib , on which the lower trunk of the brachial plexus rests

- ▶ Through this narrow gap pass the **subclavian artery** and the **roots/trunks of the brachial plexus**; a cervical rib (or a fibrous band from it) effectively **raises the floor of the triangle**, angulating and stretching these structures over its edge.
- ▶ On the first rib, scalenus anterior inserts on a tubercle; the **subclavian artery** lies in a groove **posterior** to this tubercle, and the **ventral ramus of T1/lower trunk** grooves the rib just posterior to the artery. The **subclavian vein**, by contrast, crosses the rib **anterior** to the scalenus anterior tubercle — which is why a cervical rib characteristically spares the vein and rarely causes venous thoracic outlet syndrome.
- ▶ Medial to scalenus anterior lies the **scalenovertebral triangle (triangle of the vertebral artery)** — bounded medially by longus colli, laterally by scalenus anterior, with its apex at the C6 transverse process and its base at the first part of the subclavian artery; the cervical pleura and lung apex project into it, which is why an unusually low apical pleura combined with a cervical rib can further crowd the outlet.

□ Fig 1.54 — Cervical rib causing pressure on the lower trunk of the brachial plexu (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.74)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a coronal/oblique view of the root of the neck and label:

- ▶ **Scalenus anterior** (anterior boundary of the scalene triangle) and its insertion tubercle on the first rib
- ▶ **Scalenus medius** (posterior boundary)
- ▶ **First rib** forming the floor/base of the triangle
- ▶ **Cervical rib** arising from the transverse process of C7, with a **fibrous band** running down to the first rib
- ▶ **Subclavian artery**, arched up and over the cervical rib/band (post-stenotic dilatation may be shown distally)
- ▶ **Subclavian vein**, running anterior to scalenus anterior — undisturbed
- ▶ **Lower trunk of the brachial plexus** (C8, T1 roots), angulated over the rib
- ▶ **Cervical (Sibson's) pleura and lung apex**, projecting up medial to scalenus anterior

4. Mechanism of neurovascular compression

- ▶ A long cervical rib (or its fibrous continuation) **narrows and raises the scalene triangle**, forcing the subclavian artery and the lower trunk of the brachial plexus to arch more sharply over a bony/fibrous edge instead of the smoothly-curved first rib.
- ▶ The **subclavian artery** is distorted and constricted by a leash formed by the tendon of scalenus anterior at the point of contact with the rib; **post-stenotic dilatation**, and even a true **aneurysm**, may develop just distal to the constriction.
- ▶ The **lower trunk** (C8, T1) is stretched/angulated over the same edge; chronic traction produces the neurological picture, which characteristically **s pares the upper and middle trunks** (C5–C7).
- ▶ Because the subclavian vein runs anterior to the scalenus anterior tubercle, it is **not directly related to the cervical rib**, so isolated cervical-rib-related **venous** thoracic outlet syndrome is uncommon (unlike costoclavicular or effort-related venous TOS/Paget-Schroetter syndrome, which are separate entities).

5. Clinical features

Feature	Arterial TOS (rare, dramatic)	Neurogenic TOS (much rarer with true motor loss)
Typical patient	Young woman	Young to middle-aged woman
Presenting symptom	Raynaud-like blanching, coldness, digital ischaemia/gangrene from embolisation	Pain along medial forearm and hand; paraesthesia
Pulse	Feeble/absent radial pulse; bruit/thrill over subclavian artery	Usually normal

Feature	Arterial TOS (rare, dramatic)	Neurogenic TOS (much rarer with true motor loss)
Motor findings	Usually none	Wasting of thenar and other intrinsic hand muscles; weak ulnar-innervated forearm flexors
Sensory findings	None	Blunted sensation over medial forearm/hand and little finger; little finger often shorter than normal
Danger	Thrombosis with distal embolisation; rarely embolisation proximally to carotid causing contralateral hemiplegia	Slow, often incomplete recovery even after decompression

Applied / Clinical anatomy

- **Diagnosis:** clinical suspicion from the classic triad of neck swelling/bony prominence, feeble/absent radial pulse, and pain along the C8/T1 dermatome; confirmed radiologically (a chest/cervicothoracic X-ray demonstrating the rib — a plain cervical spine film may look normal if it does not include the C7–T1 region) and, where vascular compromise is suspected, by **Doppler ultrasound, duplex scan, CT/MR angiography, and MRI/MR neurography** of the brachial plexus for the neurogenic form.
- **Adson's test:** the seated patient takes a deep breath, extends the neck and turns the face towards the affected side while the examiner palpates the radial pulse; a marked reduction or disappearance of the pulse is a **positive test**, supporting arterial compression at the scalene triangle.
- **Differential diagnosis:** cervical disc prolapse/spondylotic radiculopathy, a **Pancoast (superior sulcus) tumour** infiltrating the lower trunk, carpal tunnel syndrome (a far commoner cause of thenar wasting that was historically confused with cervical-rib syndrome), and syringomyelia.
- **Management:** asymptomatic cervical ribs need no treatment. Mild/early neurogenic symptoms are managed conservatively with physiotherapy and postural correction. Persistent or vascular cases require **surgical excision of the rib/fibrous band with decompression of the scalene triangle** (transaxillary, supraclavicular or posterior approaches, with or without first-rib resection and scalenectomy); the **periosteum of the excised rib must be stripped/removed** to prevent regrowth. Established aneurysm or thrombosis of the subclavian artery needs vascular reconstruction in addition to rib excision.
- **Complications if untreated:** progressive intimal damage, thrombosis and distal embolisation causing digital ischaemia/gangrene, aneurysm formation, and — rarely — proximal embolisation to the carotid circulation causing contralateral hemiplegia.

Recent advances

- A current literature review of **neurogenic thoracic outlet syndrome** notes that surgical decompression (transaxillary, supraclavicular or minimally invasive) remains standard for patients failing conservative therapy, and that **rib-sparing decompression techniques are**

increasingly favoured for their lower complication rates, with an emerging role for robotic-assisted approaches (Attaar & Pascarella, *Am Surg* 2025) [PMID: 40626394].

- ▶ A 17-year single-centre review of **62 first-rib resections** for TOS (including **7 cases with a cervical rib**) reported excellent/good symptom resolution in 84% of patients by Derkash's classification, confirming that first-rib resection can be performed safely with good outcomes even outside specialist tertiary units (Farquharson et al, *Ann R Coll Surg Engl* 2023) [PMID: 36779445].
- ▶ A cohort undergoing a **posterior intermuscular surgical approach** for neurogenic TOS caused specifically by an accessory rib or an elongated C7 transverse process showed marked improvement in DASH and pain scores by 3–6 months, supporting posterior decompression as an effective option when a bony anomaly is the underlying cause (Tolga et al, *Oper Neurosurg* 2023) [PMID: 37747340].
- ▶ In a paediatric/young-adult series, **first or cervical rib resection with scalenectomy via a supraclavicular approach** allowed 86% of operated patients to return to their pre-symptom sporting/activity level, underscoring that cervical rib-related TOS is not confined to adults (Bach et al, *J Hand Surg Am* 2024) [PMID: 38310509].
- ▶ **Magnetic resonance neurography** of the brachial plexus is refining pre-operative diagnosis of neurogenic TOS, directly visualising C8/T1 nerve-root or lower-trunk impingement by a cervical rib, rib synostosis or post-traumatic callus, and is increasingly used for surgical planning (Davidson et al, *Muscle Nerve* 2024) [PMID: 39253948].
- ▶ An Indian series specifically addressing cervical-rib-related TOS describes the **trans-cervical surgical approach** as a safe, effective option for rib/band excision, alongside a review of incidence, presentation and diagnostic manoeuvres relevant to Indian surgical practice (Kushwaha et al, *Indian J Otolaryngol Head Neck Surg* 2024) [PMID: 39130261].

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 [10.1177/00031348251358432](https://doi.org/10.1177/00031348251358432),
 [10.1308/rcsann.2023.0002](https://doi.org/10.1308/rcsann.2023.0002),
 [10.1227/ons.0000000000000922](https://doi.org/10.1227/ons.0000000000000922),
 [10.1016/j.jhsa.2023.12.013](https://doi.org/10.1016/j.jhsa.2023.12.013),
 [10.1002/mus.28246](https://doi.org/10.1002/mus.28246),
 [10.1007/s12070-024-04597-9](https://doi.org/10.1007/s12070-024-04597-9).)

High-yield exam pointers

- ▶ Cervical rib = persistent **costal element of the C7 transverse process**; ossification centre appears in the 6th intra-uterine month, normally fuses by the 5th–6th year of life.
- ▶ **Sargent's classification**: Type I (elongated TP) → Type V (complete rib with cartilaginous union to the manubrium/1st costal cartilage); a fibrous band (Type II) can compress just as effectively as bone.
- ▶ Structures at risk pass through the **scalene triangle** (scalenus anterior anteriorly, scalenus medius posteriorly, first rib as base): the **subclavian artery** and the **lower trunk of the brachial plexus** (C8, T1); the **subclavian vein is spared** as it lies anterior to the scalenus anterior insertion.

- ▶ Clinical picture = **thoracic outlet syndrome**: arterial form → feeble/absent radial pulse, bruit, Raynaud-like ischaemia, risk of aneurysm/embolisation and rare contralateral hemiplegia; neurogenic form → pain/paraesthesia along the medial forearm and hand, wasting of intrinsic hand muscles, short little finger.
- ▶ **Adson's test** — reduced/absent radial pulse on deep inspiration with neck extension and rotation to the affected side — supports the diagnosis.
- ▶ Diagnosis is confirmed by a chest/cervicothoracic radiograph (a cervical spine film alone may miss it) plus Doppler/duplex or CT/MR angiography (arterial) or MR neurography (neurogenic).
- ▶ Chief differentials: cervical disc prolapse, **Pancoast tumour**, and carpal tunnel syndrome (historically confused with cervical-rib wasting).
- ▶ Management: observation if asymptomatic; excision of the rib/band with the **periosteum stripped to prevent regrowth**, ± first-rib resection/scalenectomy, for persistent or vascular disease.
- ▶ Analogous anomaly: **lumbar (gorilla) rib** from a persistent L1 costal element — commoner, usually asymptomatic.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 1 8e and Vol 3-4 8e; Vishram Singh Textbook of Anatomy Vol 1 4e and Vol 3 4e; IB Singh Textbook of Anatomy Vol 2 6e.



Claw hand

Asked in: Paper IV May 2018 · Paper IV Oct 2008 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction — Claw hand (**main en griffe**) is the classic "**intrinsic-minus**" deformity of the hand: **hyperextension at the metacarpophalangeal (MCP) joints** combined with **flexion at the interphalangeal (IP) joints**, most marked in the ring and little fingers. It results from paralysis of the **interossei and the medial two lumbricals**, which normally flex the MCP joints and extend the IP joints; their loss leaves the long extensor and long flexor tendons of the fingers unopposed. It is the hallmark clinical sign of **ulnar nerve palsy**, and when the **median nerve** is also paralysed it becomes a **complete ("true") claw hand**.

1. Muscular basis of the deformity

- ▶ The **lumbricals** (arising from flexor digitorum profundus tendons) and the **palmar and dorsal interossei** insert into the **extensor expansion (dorsal digital expansion)** on the dorsum of each finger.
- ▶ Acting together, this "intrinsic" group produces a combined movement at each finger: **flexion of the MCP joint + extension of both IP joints** — the exact opposite of the pull of the long flexors (FDS, FDP) and long extensor (extensor digitorum).
- ▶ When the intrinsics are paralysed, the extensor digitorum is left to act **unopposed at the MCP joint**, producing **hyperextension**, while FDS and FDP act **unopposed at the IP joints**, producing

flexion — Gray's Anatomy terms this the "**intrinsic-minus**" hand, as opposed to the "**intrinsic-plus**" hand seen when the intrinsics act too strongly relative to the extensor.

- Because the **radial two lumbricals** (to the index and middle fingers) are supplied by the **median nerve** and are therefore spared in an isolated ulnar nerve lesion, clawing in ulnar palsy is **most marked in the ring and little fingers**; the index and middle fingers are relatively protected.

Muscle group	Nerve supply	Normal action	Effect of paralysis
Palmar & dorsal interossei (all 8)	Deep branch of ulnar nerve (C8, T1)	Flex MCP joints; extend IP joints; ab/adduct fingers	Loss of MCP flexion/IP extension → clawing; guttering of interosseous spaces; loss of finger ab/adduction
Medial 2 lumbricals (3rd, 4th)	Deep branch of ulnar nerve	Flex MCP, extend IP of ring & little fingers	Clawing of ring & little fingers
Lateral 2 lumbricals (1st, 2nd)	Median nerve	Flex MCP, extend IP of index & middle fingers	Spared in isolated ulnar palsy — index/middle less clawed
Adductor pollicis	Deep branch of ulnar nerve	Thumb adduction	Loss of thumb adduction — positive Froment's sign

2. Site of the ulnar nerve lesion and severity of clawing — the "ulnar paradox"

The ulnar nerve is most commonly injured **behind the medial epicondyle of the humerus** (cubital tunnel) at the elbow, or **in Guyon's canal (pisohamate tunnel)** at the wrist. Paradoxically, the deformity is **more marked with the more distal (wrist) lesion**:

Site of lesion	Additional muscles paralysed	Severity of clawing	Reason
Wrist (Guyon's canal, laceration in front of flexor retinaculum)	Only the intrinsics (interossei + medial 2 lumbricals); flexor carpi ulnaris and the ulnar half of flexor digitorum profundus (FDP) are spared	Marked ("true") claw hand	FDP to the ring and little fingers is intact, so its unopposed pull produces strong flexion at the DIP joints
Elbow (cubital tunnel syndrome, fracture-dislocation of medial epicondyle, tardy ulnar nerve palsy from cubitus valgus)	Intrinsics plus flexor carpi ulnaris and the ulnar half of FDP	Less marked clawing despite the higher lesion	FDP to the ring/little fingers is itself paralysed, so DIP flexion is weak — the " ulnar paradox ": the higher the lesion, the lesser the deformity

- With an elbow lesion, the flattened medial border of the forearm and inability of the FCU tendon to tighten on making a fist are additional pointers to the higher level of injury.

3. Complete ("true") claw hand — combined median + ulnar nerve palsy

- ▶ A combined lesion of the **median and ulnar nerves** (e.g. at the wrist, or in high lesions at the elbow/forearm) paralyses **all four lumbricals and all interossei**, producing clawing of **all four fingers (index to little)**, not just the ulnar two.
- ▶ Gray's Anatomy describes this as a "**full claw hand with thenar and hypothenar flattening and thumb adduction and flexion**" — the "**simian hand**" (ape-like appearance from loss of thenar bulk and thumb opposition/adduction).
- ▶ Sensory loss extends beyond the ulnar territory (medial one-third of palm, medial 1½ digits) to include the median territory (lateral 3½ digits, lateral two-thirds of palm).

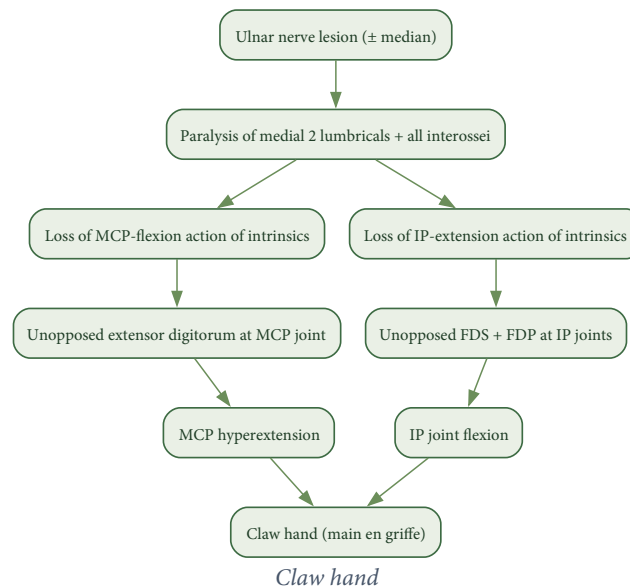
Feature	Isolated ulnar nerve palsy	Combined median + ulnar palsy (complete claw hand)
Fingers clawed	Ring and little mainly (index/middle spared by median-supplied lumbricals)	All four fingers
Thumb	Adduction lost (Froment's sign +ve); thenar bulk preserved	Thenar wasting + thumb adduction and flexion — simian hand
Sensory loss	Medial 1/3 palm, medial 1½ fingers (palmar + dorsal)	As above plus lateral 3½ fingers/lateral 2/3 palm (median territory)

4. Other causes of claw hand

- ▶ **Leprosy** — the single commonest cause of ulnar claw hand in the tropics; the ulnar nerve, easily palpable behind the medial epicondyle, is the peripheral nerve most frequently thickened and involved in leprosy.
- ▶ **Klumpke's paralysis** — traction injury to the **C8 and T1 roots/lower trunk** of the brachial plexus (breech delivery, sudden upward pull on an abducted arm, cervical rib, or a Pancoast tumour infiltrating the lower trunk); denervates the intrinsic hand muscles and produces clawing, often with an associated Horner's syndrome from T1 sympathetic fibre involvement.
- ▶ **Guyon's canal (pisohamate tunnel) compression** — ganglion, fracture of the hook of hamate, or chronic pressure (e.g. cyclist's/handlebar palsy).
- ▶ **Cubital tunnel syndrome / tardy ulnar nerve palsy** — chronic compression or a valgus deformity of the elbow following a malunited supracondylar or lateral condyle fracture.
- ▶ **Progressive/degenerative neurogenic disease** — motor neuron disease, syringomyelia, and hereditary motor-sensory neuropathies causing chronic denervation of the intrinsic muscles.
- ▶ **Volkman's ischaemic contracture** (an important differential, not a nerve palsy) — brachial artery injury/vasospasm after a supracondylar fracture of the humerus causes ischaemic fibrosis of the deep flexor compartment (FDP, FPL); this produces a **fixed flexion contracture** that can mimic clawing but is myogenic, not neurogenic, and is not correctable by nerve repair.

5. Clinical examination

- ▶ **Inspection:** hyperextension at MCP joints with flexion at IP joints (ring/little > index/middle in isolated ulnar palsy); **guttering/hollowing of the interosseous spaces** on the dorsum of the hand from interosseous wasting; **flattening of the hypothenar eminence**.
- ▶ **Sensory loss:** palmar and dorsal aspects of the medial one-third of the hand and medial 1½ fingers (little finger + ulnar half of ring finger); the skin over the ulnar dorsum is **spared in a wrist-level lesion** because the dorsal cutaneous branch of the ulnar nerve arises about 5 cm proximal to the wrist — a lesion more proximal (forearm/elbow) also abolishes dorsal sensation.
- ▶ **Vasomotor and trophic changes:** warm, dry skin (loss of sympathetic sudomotor supply) in long-standing cases, with dry scaly skin, cracked nails, and pulp atrophy of the fingers.
- ▶ **Bedside tests:**
 - **Card/paper test** — a card gripped between adjacent fingers is pulled away easily if the palmar interossei are paralysed.
 - **Froment's sign (book test)** — asked to grip a book between thumb and index finger, the patient flexes the terminal phalanx of the thumb (flexor pollicis longus, median nerve) to compensate for a paralysed adductor pollicis.
 - Dorsal interossei are tested by asking the patient to **abduct the fingers against resistance**.
 - Lumbricals/interossei together are tested by flexing the fingers at the MCP joint against resistance.



□ Fig 4.17 — Complete claw hand (BD Chaurasia — Human Anatomy Vol 1 — 8e, p.86)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a hand (dorsal view for the ring and little fingers, held out as in the figure above) and label:

- ▶ **Hyperextension at the metacarpophalangeal joints** of the ring and little fingers (label the joint and the direction of deformity)
- ▶ **Flexion at the proximal and distal interphalangeal joints** of the same fingers
- ▶ **Guttering/hollowing of the 2nd–4th intermetacarpal (interosseous) spaces** on the dorsum — from interosseous wasting
- ▶ **Flattened hypothenar eminence**
- ▶ Shade the **sensory loss zone**: medial one-third of the palm and dorsum + medial 1½ fingers (little finger and ulnar half of ring finger)
- ▶ If drawing the complete/true claw hand, additionally flatten the **thenar eminence** and show the **thumb adducted and flexed** (simian hand), and extend clawing to the index and middle fingers

Applied / Clinical anatomy

- ▶ **Splinting**: a **lumbrical-bar (knuckle-duster) splint** blocks MCP hyperextension while permitting IP flexion/extension, restoring a near-normal grip and preventing fixed contractures while awaiting nerve recovery.
- ▶ **Tendon transfer surgery**: once nerve recovery is unlikely, dynamic correction restores MCP-flexion/IP-extension using a donor tendon looped through the A1 pulley/flexor sheath or woven into the lateral bands — classic techniques include the **Stiles-Bunnell four-tailed flexor digitorum superficialis transfer**, the **Zancolli lasso procedure**, and **Brand's transfer** (extensor carpi radialis longus, lengthened with a tendon graft, into the lateral bands). Paul Brand's original description of paralytic claw hand and its surgical correction (1958) remains the foundational reference for these tendon-transfer principles.
- ▶ **Leprosy reconstructive surgery**: claw-hand correction is a major component of disability limitation in leprosy control programmes in India, since the ulnar (and often combined ulnar-median) nerve is the commonest site of leprosy neuritis in the upper limb.
- ▶ **Localising value**: the **level of clawing** (ulnar paradox), the **fingers involved** (ulnar two vs all four), and the **extent of sensory loss** (with or without dorsal sparing) together localise the lesion to the wrist, elbow, or a proximal/plexus level, and distinguish neurogenic clawing from the myogenic contracture of Volkmann's ischaemia.

Recent advances

- ▶ **Randomised comparison of tendon-transfer techniques for post-leprosy ulnar claw hand**: a prospective RCT (n = 50) comparing the **Modified Stiles-Bunnell (FDS four-tail) transfer** with the **Zancolli lasso procedure** found both significantly improved MCP range of motion and grip strength; the Zancolli lasso gave faster recovery and greater grip-strength gain (129% vs 117% of baseline), while the Stiles-Bunnell transfer gave marginally better claw correction — supporting an individualised choice of procedure (Chaudhuri et al, *Hand (N Y)* 2025) [PMID: 40851472].

- ▶ **A modification of Brand's classic transfer:** a four-tailed extensor carpi radialis brevis-to-lateral-band transfer was described in 9 patients with claw hand from chronic low ulnar palsy, reducing graft length and adhesion risk in the lumbrical canal while maintaining grip/pinch strength and MCP posture at 6-month follow-up (Wessel et al, *Hand (N Y)* 2024) [PMID: 38855947].
- ▶ **Distal nerve transfer as an alternative to tendon transfer:** distal **anterior interosseous nerve (AIN)-to-ulnar deep motor branch transfer** in 12 patients with proximal ulnar nerve injury restored intrinsic muscle strength (from universal M0 to M3/M4 in the majority of muscles), improved grasp/pinch strength to 80–82% of the normal side, and improved quality-of-life scores significantly at 24 months (Savić et al, *Brain Spine* 2026) [PMID: 42064350].
- ▶ **"Supercharged" and "turbocharged" double nerve transfers:** end-to-side AIN-to-ulnar-motor transfer (SETS), and a newer double transfer additionally rerouting the (expendable) abductor digiti minimi branch (STETS/TETS), produced significant gains in first dorsal interosseous strength and DASH scores in a retrospective series of 50 patients with severe ulnar neuropathy, suggesting an expanding surgical armamentarium for pre-empting clawing before it becomes fixed (Chi et al, *Hand (N Y)* 2024) [PMID: 39563002]; early/late reinnervation patterns after the standard SETS transfer were separately characterised electrophysiologically and clinically (Mitchell et al, *Hand (N Y)* 2024) [PMID: 39503214].
- ▶ **Refined electrodiagnosis of nerve-transfer contribution:** ultrasound-guided near-nerve needle stimulation of the AIN was used to directly confirm axonal contribution to reinnervated intrinsic muscles after an end-to-side AIN-to-ulnar transfer in chronic ulnar neuropathy at the elbow, offering a more precise tool to document reinnervation than routine nerve conduction studies (Meiling et al, *Muscle Nerve* 2026) [PMID: 41760087].

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 [10.1177/15589447251364568](https://doi.org/10.1177/15589447251364568),
 [10.1177/15589447241257558](https://doi.org/10.1177/15589447241257558),
 [10.1016/j.bas.2026.106054](https://doi.org/10.1016/j.bas.2026.106054), [10.1177/15589447241298720]
 (https://doi.org/10.1177/15589447241298720),
 [10.1177/15589447241286263](https://doi.org/10.1177/15589447241286263), [10.1002/mus.70194]
 (https://doi.org/10.1002/mus.70194).)

High-yield exam pointers

- ▶ Claw hand = **main en griffe** = MCP hyperextension + IP flexion, from paralysis of the **interossei and medial 2 lumbricals** (ulnar nerve, C8-T1) — the "**intrinsic-minus**" hand.
- ▶ Ring and little fingers are clawed most in **isolated ulnar palsy**, because the **lateral 2 lumbricals (index, middle) are median-supplied** and spared.
- ▶ **Ulnar paradox:** clawing is **more marked in a wrist lesion** (FDP intact → strong unopposed DIP flexion) than in an **elbow lesion** (FDP to ring/little also paralysed) — "the higher the lesion, the lesser the deformity."
- ▶ **Combined median + ulnar palsy** → **complete/true claw hand** (all 4 fingers) with thenar + hypothenar flattening and thumb adduction/flexion = **simian hand**.
- ▶ Sensory loss: medial 1/3 palm + medial 1½ fingers; **dorsum of hand spared only if the lesion is at the wrist** (dorsal cutaneous branch arises 5 cm proximal to wrist).

- ▶ Bedside tests: **card/paper test** (palmar interossei), **Froment's sign/book test** (adductor pollicis, compensated by median-supplied FPL).
- ▶ **Leprosy** is the commonest cause of ulnar claw hand in India; **Klumpke's paralysis** (C8, T1 root injury) and **Volkman's ischaemic contracture** (myogenic mimic, not neurogenic) are important differentials.
- ▶ Management: **lumbrical-bar (anti-claw) splinting** while awaiting nerve recovery; **tendon transfer** (Stiles-Bunnell, Zancolli lasso, Brand's transfer) or, increasingly, **distal nerve transfer** for irreversible palsy.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 1 8e; Vishram Singh Textbook of Anatomy Vol 1 4e; AK Datta Human Anatomy Vol 3 (Upper & Lower Limb).



Anal fistulas

Asked in: Paper IV Nov 2017 — RGUHS MD/MS Anatomy

Definition / Introduction. A **fistula-in-ano** is an abnormal, chronically epithelialised (granulation-tissue-lined) track connecting the anal canal internally to the perianal skin externally; it is called "complete" when it opens at both ends and "incomplete" (a sinus) when it opens at only one. The great majority are **cryptoglandular** in origin — infection of the intersphincteric anal glands that open into the anal crypts at the level of the anal valves — so the anatomy of the anal canal, its sphincter complex, and the perianal fascial spaces around it (ischiorectal fossa, perianal, submucous and supralelevator spaces) together dictate both the course a fistula takes and the surgical plan for its cure. Understanding this applied anatomy is essential because injudicious division of sphincter/anorectal-ring muscle during fistula surgery is the commonest cause of iatrogenic faecal incontinence.

1. Anatomy of the anal canal relevant to fistula formation

- ▶ The **anal canal** is the terminal ~4 cm of the gastrointestinal tract, lying in the anal triangle between the two ischiorectal (ischioanal) fossae, and is divided by the **pectinate (dentate) line** into upper (15 mm) and lower (23 mm) parts.
- ▶ **Anal columns (columns of Morgagni)**: 6–10 permanent longitudinal mucosal folds in the upper canal, each containing a radicle of the superior rectal vein.
- ▶ **Anal valves (valves of Morgagni)**: crescentic folds joining the lower ends of adjacent columns; their free edges, directed upward, together form the wavy **pectinate line** — the embryological site of the anal membrane and the "watershed" between hindgut (endoderm) above and proctodeum (ectoderm) below.
- ▶ **Anal sinuses**: vertical recesses above the valves, into whose floor the ducts of the **anal glands** open (**anal crypts**).
- ▶ **Anal glands**: branched, mucin-secreting tubular glands lying chiefly in the **intersphincteric space**; there is an average of about **twelve** intersphincteric anal glands in the adult canal, evenly distributed around the circumference, whose ducts cross the internal sphincter to open at the

anal valves. These glands are the **source of most anal fistulae** (cryptoglandular hypothesis of Parks, 1961).

Feature	Upper anal canal	Lower anal canal
Development	Hindgut (endoderm)	Proctodeum (ectoderm)
Epithelium	Simple columnar	Stratified squamous
Arterial supply	Superior rectal artery	Inferior rectal artery
Venous drainage	Superior rectal vein → portal system	Inferior rectal vein → caval system
Lymphatic drainage	Internal iliac nodes	Superficial inguinal nodes
Nerve supply	Autonomic (insensitive to touch/pain)	Somatic — inferior rectal n. (sensitive)
Haemorrhoids	Internal (painless)	External (painful)

2. Cryptoglandular pathogenesis

- ▶ Retrograde passage of bacteria from the anal lumen into an anal gland causes **cryptoglandular infection**; inflammatory occlusion of the gland duct prevents spontaneous drainage back into the canal.
- ▶ Pus collects first in the **intersphincteric space** (an intersphincteric abscess) and then tracks along the path of least resistance through or around the sphincter complex, discharging into one of the perianal fascial spaces and, ultimately, the skin — this is why the resulting track's anatomical course precisely mirrors the local muscular and fascial planes it has traversed.
- ▶ Because the internal opening is almost always at the level of an anal crypt at the **dentate line**, and the track is lined by chronic granulation tissue, the fistula rarely heals spontaneously and requires surgical division/laying open, drainage or seton placement.

3. Sphincteric anatomy and the anorectal ring

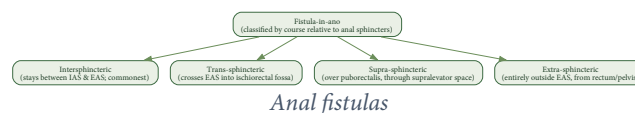
- ▶ **Internal anal sphincter** — thickened termination of the circular smooth muscle coat, autonomically innervated (involuntary), extending from the anorectal junction to the intersphincteric groove (white line of Hilton).
- ▶ **External anal sphincter** — striated muscle forming the bulk of the sphincter complex; classically described as deep, superficial and subcutaneous parts, but Gray's Anatomy (41st ed.) notes this three-part concept is "no longer valid" and the muscle is now regarded as a **single functional entity** of predominantly slow-twitch fibres.
- ▶ **Conjoint longitudinal muscle/coat**: continuation of the outer longitudinal muscle of the rectum, reinforced by fibres from levator ani, descending between the two sphincters; at the level of the white line it breaks up into fibroelastic septa — the most lateral forms the **perianal fascia** (bounding the perianal space), the most medial the **anal intermuscular septum** (attached at Hilton's line). These septa are the anatomical planes along which sepsis and fistula tracks preferentially spread.

- **Anorectal ring:** the palpable muscular ring at the anorectal junction, about 2.5 cm (an inch) above the anal margin, formed by the fusion of puborectalis, the deep part of the external sphincter and the internal sphincter — surgical division of this ring causes **incontinence**, making its identification and preservation the central surgical-anatomical concern in fistula surgery.

4. Anatomical classification of fistula-in-ano (relation to the sphincter complex)

Fistulae are classified by the anatomical relationship of the track to the internal and external anal sphincters:

Type	Course
Intersphincteric	Track stays in the intersphincteric plane, opening low near the anal verge; commonest type, follows the same path by which the primary cryptoglandular infection spread from the anal gland.
Trans-sphincteric	Track crosses the external sphincter at a variable height to reach the ischiorectal fossa before opening on the perineal skin.
Supra-sphincteric	Track passes up over the top of puborectalis (through the supralelevator space) before curving down through the ischiorectal fossa to the skin — sphincter complex and anorectal ring are both encircled.
Extra-sphincteric	Track runs entirely outside the external sphincter, from the rectum above the levator ani, through the ischiorectal fossa, to the perianal skin — usually the result of a pelvic (not cryptoglandular) source of sepsis or a penetrating injury.



5. Ischiorectal fossa and the horseshoe fistula

- The **ischiorectal (ischioanal) fossa** is a fat-filled, wedge-shaped space on each side of the anal canal, measuring roughly **5 cm vertically, 5 cm anteroposteriorly and 2.5 cm transversely**.
- **Boundaries:** apex (fusion of anal and obturator fascia), base (skin/superficial fascia), lateral wall (obturator fascia, obturator internus, ischial tuberosity), medial wall (levator ani above, external sphincter below); anterior recess (above the urogenital diaphragm) and posterior recess (between sacrotuberous and sacrospinous ligaments).
- The **lunate** and **perianal fasciae** subdivide the fossa into three compartments (suprategmental, ischiorectal proper, perianal) — each a potential plane for sepsis to track.
- **Contents:** ischiorectal fat pad; the **pudendal (Alcock's) canal** on the lateral wall carrying the internal pudendal vessels/nerve; inferior rectal vessels/nerve crossing the fossa; posterior scrotal/labial vessels and nerve anteriorly; perineal branch of S4 posteriorly.

- ▶ **Horseshoe fistula/abscess:** the right and left ischiorectal fossae communicate with one another **posterior to the anal canal** (via the deep postanal space); infection or a fistulous track can therefore spread from one side to the other, producing a bilateral, horseshoe-shaped abscess/fistula — a key applied point, since an apparently unilateral fistula may in fact have a horseshoe extension that must be drained/unroofed for cure.
- ▶ **Hiatus of Schwalbe:** an occasional gap between the tendinous origin of levator ani and the obturator fascia at the apex of the fossa, through which pelvic organs may rarely herniate (ischiorectal hernia) — a related but distinct applied point.

□ Fig 28.10 — Ischiorectal type of fistula in ano. Internally, it usually opens into one of anal crypt (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.442)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce a coronal section through the anal canal and both ischiorectal fossae, labelling in sequence:

- ▶ Anal columns, anal valves, anal sinuses and the **pectinate (dentate) line**
- ▶ An **anal gland** with its duct opening into an anal crypt, and the **intersphincteric abscess** it has produced
- ▶ **Internal and external anal sphincter** (single functional sleeve) with the **conjoint longitudinal muscle** between them
- ▶ The **fistulous track** crossing the lower external sphincter into the **ischiorectal fossa** and perianal skin (trans-sphincteric type)
- ▶ **Ischiorectal fossa** boundaries (obturator internus/fascia laterally, levator ani superomedially, ischial tuberosity) with the **pudendal (Alcock's) canal** on its lateral wall
- ▶ The **posterior communication** between the two fossae (deep postanal space) giving a horseshoe track

Applied / Clinical anatomy

- ▶ **Goodsall's rule:** predicts the internal opening from the external one — an anterior external opening tends to connect via a short, direct radial track, whereas a posterior external opening follows a curved track converging on a single posterior-midline internal opening (reflecting the posterior fascial communication described above).
- ▶ **Imaging correlate:** because the track's course relative to the sphincter complex determines prognosis and surgical approach, endoanal ultrasound and MRI are used routinely to map fistula anatomy pre-operatively along the same Parks-type planes.
- ▶ **Surgical principle:** a low intersphincteric/trans-sphincteric track (sparing sphincter bulk) can be laid open (fistulotomy); a high track encircling the anorectal ring/puborectalis needs a **seton** or staged approach, since dividing the ring causes incontinence.
- ▶ **Horseshoe extension** is managed by opening the deep postanal space in the midline rather than each limb separately, exploiting the same posterior communication that caused the spread.
- ▶ Fistula-in-ano is commoner in males; chronic tracks rarely undergo malignant change (fistula-associated carcinoma).

Recent advances

- ▶ **MRI remains the reference-standard modality for perianal fistula anatomy**, providing high-resolution mapping of the tract's origin, course and secondary extensions; cryptoglandular fistulas most commonly follow intersphincteric or trans-sphincteric planes, while Crohn-related fistulas often arise near the anorectal junction and extend beyond the conventional Parks planes with branching and proctitis (Lanier et al., *RadioGraphics*, 2026) [DOI: 10.1148/rg.250033].
- ▶ **A novel imaging-guided, anatomy-based classification of anorectal fistulas** (built on preoperative 3-D endoanal ultrasound with adjunctive MRI for complex tracks) has been validated in a multicentre retrospective cohort as a predictor of disease severity and surgical outcome, refining the traditional Parks anatomical categories for modern practice (Brillantino et al., *Annals of Coloproctology*, 2025) [PMID: 40598987].
- ▶ **3-D-printed anatomical models of cryptoglandular fistulas**, generated from patient MRI data, have been validated against the source imaging and are being explored as a tool for surgical planning and for teaching the intersphincteric/trans-sphincteric anatomy described above (Verkade et al., *Techniques in Coloproctology*, 2024) [DOI: 10.1007/s10151-024-02925-3].
- ▶ (*According to PubMed/Annals of Coloproctology/RadioGraphics search.*)

High-yield exam pointers

- ▶ **Fistula-in-ano** = chronic epithelialised track between anal canal and perianal skin; **cryptoglandular hypothesis (Parks, 1961)** — infection of one of the ~12 intersphincteric anal glands opening at the anal crypts/pectinate line.
- ▶ **Parks anatomical classification** (by relation to sphincters): **intersphincteric > trans-sphincteric > supra-sphincteric > extra-sphincteric** — commonest to rarest, and rising surgical risk to continence in that order.
- ▶ **Anorectal ring** (puborectalis + deep EAS + IAS), ~2.5 cm above the anal margin — division causes incontinence; must be identified and, where possible, preserved.
- ▶ **Gray's 41e**: the classical deep/superficial/subcutaneous division of the external anal sphincter is now considered a **single functional entity**.
- ▶ **Ischiorectal fossa**: ~5 cm × 5 cm × 2.5 cm; the two fossae **communicate posterior to the anal canal**, explaining **horseshoe abscess/fistula**.
- ▶ **Pudendal (Alcock's) canal** lies on the lateral wall of the ischiorectal fossa, carrying the internal pudendal vessels and nerve.
- ▶ **Hiatus of Schwalbe** (gap between levator ani origin and obturator fascia at the fossa apex) → rare ischiorectal hernia — a related but separate applied point.
- ▶ **Goodsall's rule** predicts internal opening from external opening site relative to a transverse anal line.
- ▶ Upper (endodermal) vs lower (ectodermal) anal canal differ in epithelium, blood/lymph supply and nerve supply — the **pectinate line** is the watershed for all of these and the usual site of the internal fistulous opening.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2 8e; Vishram Singh's Textbook of Anatomy Vol 2 4e; IB Singh's Textbook of Anatomy Vol 2 6e. Recent-advances section per RadioGraphics, Annals of Coloproctology and Techniques in Coloproctology (see DOIs/PMID above).



Anatomical basis of haemoptysis

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — Haemoptysis is the expectoration of blood or blood-streaked sputum originating from the lower respiratory tract (larynx, trachea, bronchi or lung parenchyma). Its anatomical basis lies chiefly in the lung's unique **dual arterial supply** — a low-pressure **pulmonary circulation** dedicated to gas exchange, and a high-pressure **systemic bronchial circulation** that nourishes the bronchial tree, connective tissue and visceral pleura. Because the two systems freely anastomose, chronic bronchopulmonary disease causes the systemic bronchial vessels to hypertrophy and become tortuous; being subjected to aortic pressure rather than the low pulmonary pressure, their rupture produces the torrential, difficult-to-control bleeding characteristic of massive haemoptysis. The segmental organisation of the lung further explains why bleeding is so often localised to one bronchopulmonary segment.

Dual arterial supply of the lung

Feature	Pulmonary arteries	Bronchial arteries
Origin	Pulmonary trunk (from right ventricle)	Descending thoracic aorta (directly, or via a posterior intercostal artery)
Blood carried	Deoxygenated (functional supply for gas exchange)	Oxygenated (nutrient supply)
Pressure	Low-pressure system	High (systemic/aortic) pressure
Course	Runs with the principal bronchus in the root of the lung; divides with it into lobar and segmental branches	Runs on the posterior aspect of the bronchial tree, following it to the respiratory bronchioles
Structures supplied	Alveolar capillary bed (gas exchange)	Bronchi and bronchioles, peribronchial connective tissue, bronchopulmonary lymph nodes, pulmonary artery/vein walls, visceral pleura (with pulmonary artery branches), lower oesophagus

Feature	Pulmonary arteries	Bronchial arteries
Venous return	Pulmonary veins (four, to left atrium)	Mostly via pulmonary veins; only proximal blood returns via true bronchial veins (azygos/hemiazygos system)
Contribution to haemoptysis	Uncommon source (~5%) — e.g. pulmonary infarction, arteriovenous malformation	Principal source (~90–95% of cases)

This division — pulmonary artery for oxygenation, bronchial artery for nutrition — is the key concept underlying the question: only the bronchial arteries carry systemic (aortic) pressure into the lung, so only they can produce brisk, high-volume bleeding when eroded or ruptured by disease.

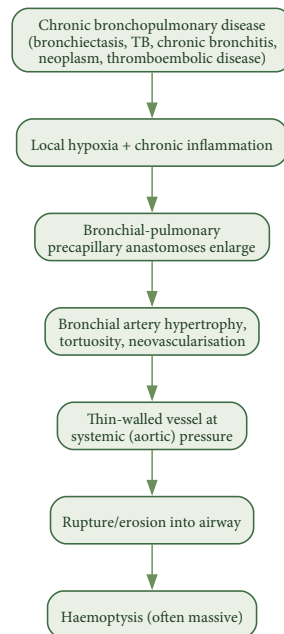
Bronchial artery anatomy

- ▶ **Number and origin** (classical description): usually **one right** bronchial artery and **two left** bronchial arteries.
 - The right bronchial artery has a variable origin — commonly as a common trunk with the **third right posterior intercostal artery**, occasionally from the aorta directly or from a left bronchial artery.
 - The two left bronchial arteries (superior and inferior) arise directly from the **descending thoracic aorta** — the upper opposite the body of the **fifth thoracic vertebra**, the lower just below the left principal bronchus.
- ▶ **Level**: bronchial arteries typically leave the aorta between the upper border of T5 and the lower border of T6.
- ▶ **Course and relations**: they pass posterior to the principal bronchus, ramify with the bronchial tree through the lobar and segmental divisions, terminate around the respiratory bronchioles, and give small oesophageal branches en route.
- ▶ **Distribution**: bronchial glands, walls of bronchi down to the respiratory bronchioles, adventitia of the pulmonary vessels, bronchopulmonary lymph nodes, and (via the hilar anulus) the visceral pleura.
- ▶ **Bronchial veins**: usually two per side. **Deep bronchial veins** drain intrapulmonary plexuses into the pulmonary veins/left atrium; **superficial bronchial veins** drain extrapulmonary bronchi, hilar nodes and pleura into the **azygos vein** (right) and **left superior intercostal/accessory hemiazygos vein** (left). Since much bronchial arterial blood returns via the pulmonary veins, a small physiological right-to-left shunt normally exists (with the thebesian veins).

Anastomoses and the mechanism of pathological bleeding

- ▶ At the hilum, bronchial arteries form a circle around the principal bronchus; their branches anastomose freely with branches of the **pulmonary arteries**, chiefly at the pre-capillary level in the bronchiolar wall and beneath the visceral pleura.
- ▶ Under normal conditions these connections are small; **they enlarge whenever the pulmonary arterial supply to a segment is obstructed or the bronchial tree is chronically inflamed** — the anatomical basis of collateral hypertrophy.

- In chronic suppurative/inflammatory disease (bronchiectasis, chronic bronchitis, lung abscess, active or healed tuberculous cavities) and in chronic pulmonary thromboembolic hypertension, repeated inflammation/hypoxia drive **neovascularisation and hypertrophy of the bronchial arteries**, which become dilated, tortuous and aneurysmal while still carrying aortic pressure (occasionally mimicking an aortic aneurysm).
- It is the **rupture of these thin-walled, high-pressure, hypertrophied systemic vessels** — not the low-pressure pulmonary vasculature — that produces the majority of clinically significant and massive haemoptysis.



Anatomical basis of haemoptysis

Bronchopulmonary segments — the basis of localised haemoptysis

- Each **bronchopulmonary segment** is a pyramidal, structurally independent unit of lung tissue aerated by its own segmental (tertiary) bronchus and supplied by its own segmental branch of the pulmonary artery; it is surrounded by connective-tissue septa, though intersegmental pulmonary veins and bronchial vessels cross these planes.
- There are **10 bronchopulmonary segments in the right lung**; the left lung is also described as having 10, but the apical and posterior segments of the upper lobe commonly fuse into an "apico-posterior" segment, and the anterior and medial basal segments of the lower lobe often fuse into an "antero-medial basal" segment — hence many texts describe only 8 separately identifiable segments on the left.
- Because each segment is an independent bronchovascular unit, **chronic disease (tuberculosis, bronchiectasis, aspergilloma, localised neoplasm)** is frequently confined to a single segment, explaining why haemoptysis is often segmental/localised rather than diffuse, and why **segmental resection** (rather than lobectomy or pneumonectomy) can be curative in localised bronchiectasis.
- The apical segment of the lower lobe (segment 6) arises from the most posterior/highest point of the lobar bronchus and is the classic site of aspiration pneumonia/localised sepsis in a supine patient — again a common substrate for chronic segmental disease and bleeding.

□ Fig 19.20 — Bronchopulmonary segments of the right lung, lateral and medial aspects (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.783)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce the above figure by hand (right lung, lateral and medial aspects), labelling:

- ▶ Outline of the right lung with **oblique** and **horizontal fissures**, demarcating upper, middle and lower lobes
- ▶ **Upper lobe segments**: apical, posterior, anterior
- ▶ **Middle lobe segments**: lateral, medial
- ▶ **Lower lobe segments**: superior (apical), medial basal, anterior basal, lateral basal, posterior basal
- ▶ Colour or shade each segment differently to show it is a separate bronchovascular unit
- ▶ Mark the **segmental bronchus** entering the apex of one representative segment, with its accompanying **segmental branch of the pulmonary artery**
- ▶ Indicate an **intersegmental pulmonary vein** running in the septum between two adjacent segments (to show it is *not* a complete vascular boundary)

Applied / Clinical anatomy

- ▶ **Source of bleeding**: in ~90–95% of cases haemoptysis arises from the **bronchial (systemic) arterial** circulation; only a minority (~5%) arise from the low-pressure **pulmonary arterial** circulation (e.g. pulmonary infarction from thromboembolism, arteriovenous malformation) or from non-bronchial systemic collaterals recruited through pleural adhesions.
- ▶ **Common causes**: chronic bronchitis, bronchiectasis, active or old healed pulmonary tuberculosis (including erosion of a bronchial-arterial pseudoaneurysm within a TB cavity), bronchogenic carcinoma eroding into a bronchus, lung abscess, pulmonary embolism/infarction, mitral stenosis (raised pulmonary venous pressure engorges bronchial submucosal veins), and fungal ball (aspergilloma) within a pre-existing cavity.
- ▶ **Massive haemoptysis** (variably defined, commonly >200–600 mL/24 h) is a surgical/interventional emergency because it is bronchial-arterial (systemic-pressure) bleeding; death is usually from airway flooding/asphyxiation, not exsanguination, given the small volume of the airway relative to total blood volume.
- ▶ **Bronchial artery embolisation (BAE)**: since haemoptysis is overwhelmingly a bronchial, not pulmonary, arterial problem, transfemoral catheterisation and embolisation of the culprit bronchial artery controls bleeding while sparing the gas-exchanging pulmonary circulation — a direct clinical application of the dual-supply anatomy.
- ▶ **Imaging correlate**: CT angiography of the thorax (increasingly extended from the neck to the upper abdomen) maps bronchial artery number, origin and course, and detects non-bronchial systemic collaterals (intercostal, internal thoracic, subclavian, phrenic) before embolisation.
- ▶ **Surgical correlate**: the bronchopulmonary segment as an independent bronchovascular unit underlies **segmental resection** for haemoptysis confined to localised bronchiectasis or a solitary cavity.

Recent advances in imaging/therapy of the bronchial circulation

- **CIRSE Standards of Practice on Bronchial Artery Embolisation** (Kettenbach J, Ittrich H, Gaubert JY, et al. *Cardiovasc Intervent Radiol* 2022;45:721–732, [DOI](https://doi.org/10.1007/s00270-022-03127-w)) formalised the classical **Cauldwell classification** of bronchial artery origin — Type 1 (2 left + 1 right as a right intercosto-bronchial trunk, ~41%), Type 2 (1 left + 1 right trunk, ~21%), Type 3 (2 left + 2 right, one as a trunk, ~21%), Type 4 (1 left + 2 right, ~10%) — and confirmed the culprit bed in massive haemoptysis is bronchial in ~90%, pulmonary in ~5%, non-bronchial systemic in ~5%; it recommends wide-field angio-CT "from the base of the neck to the renal arteries" to capture ectopic bronchial origins and non-bronchial collaterals before embolisation.
- A two-centre study (Ravetta P, Vouché M. *J Belg Soc Radiol* 2024;107(1), [DOI](https://doi.org/10.5334/jbsr.3097)) found high-quality pre-procedural CT angiography improved concordance between the bleeding lung and the angiographic culprit vessel (93.5% vs 75.0%, $p = 0.045$) and detected more non-bronchial systemic arteries than suboptimal imaging.
- A 2025 systematic review of bronchial artery embolisation (*BMC Pulmonary Medicine* 2025;25, [DOI](https://doi.org/10.1186/s12890-025-04000-5)) reaffirmed that recognising hypertrophied, tortuous bronchial arteries and recruited non-bronchial collaterals on cross-sectional imaging remains the anatomical key to procedural success and reduced recurrence.

(According to PubMed/CIRSE literature search.)

High-yield exam pointers

- Lung has a **dual arterial supply** — pulmonary artery (functional, low-pressure, gas exchange) and bronchial artery (nutritive, high-pressure, systemic) — this duality is the core anatomical basis of haemoptysis.
- Classical bronchial artery pattern: **1 right + 2 left**, arising from the descending thoracic aorta (left) or a right posterior intercostal artery/aortic common trunk (right), at the level of T5–T6.
- **Pre-capillary anastomoses** between bronchial and pulmonary arteries enlarge in chronic bronchopulmonary disease — the substrate for pathological bronchial artery hypertrophy.
- **~90–95% of haemoptysis originates from the bronchial (systemic) circulation**, not the pulmonary circulation, because only the bronchial vessels carry aortic pressure.
- **Bronchopulmonary segment** = independent bronchovascular unit (own segmental bronchus + segmental pulmonary artery branch) — the anatomical basis for segmental/localised disease, localised haemoptysis, and segmental resection.
- Right lung = 10 segments; left lung = 10 (often grouped as 8 due to apico-posterior and antero-medial basal fusion).
- Main causes: bronchiectasis, tuberculosis (including bronchial-artery pseudoaneurysm in a cavity), bronchogenic carcinoma, lung abscess, pulmonary infarction, mitral stenosis.
- **Bronchial artery embolisation** is the anatomy-based, first-line interventional treatment for massive haemoptysis; CT angiography from neck to upper abdomen maps ectopic bronchial origins and non-bronchial systemic collaterals beforehand.

- Bronchial veins largely drain into the **azygos/hemiazygos system**, but most bronchial arterial blood actually returns via the **pulmonary veins** — the anatomical basis of the small physiological right-to-left shunt.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 1 (8e); AK Datta's Human Anatomy Vol 1 — Thorax & Abdomen; Moore's Clinically Oriented Anatomy 9e; Vishram Singh's Textbook of Anatomy Vol 1 (4e); IB Singh's Textbook of Anatomy Vol 2 (6e).



Applied anatomy of the shoulder joint

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — The shoulder (glenohumeral) joint is a synovial, ball-and-socket articulation between the hemispherical head of the humerus and the shallow glenoid cavity of the scapula. It is the most mobile joint in the body, a mobility purchased at the price of bony stability — only about a quarter of the humeral head contacts the glenoid in any one position, and the head's surface area is roughly four times that of the socket. Because stability is maintained almost entirely by soft tissue (capsule, ligaments, labrum, rotator cuff) rather than by bony congruity, the joint is also the **most commonly dislocated joint in the body**, and its named weak points, its close neurovascular relations (axillary nerve, quadrangular space) and its periarticular musculotendinous cuff form the anatomical basis of nearly every clinically important shoulder lesion — dislocation, recurrent instability, nerve palsy, rotator-cuff disease and frozen shoulder.

Type, Articular Surfaces & Factors Maintaining Stability

- **Type:** synovial joint of the ball-and-socket variety (multiaxial, spheroidal).
- **Articular surfaces:** head of humerus (large, hemispherical) opposing the small, pear-shaped glenoid cavity of the scapula; both are hyaline-cartilage covered. The disproportion between the two surfaces is the single most important fact underlying the joint's instability.
- **Stability is maintained dynamically**, since the bony fit is inherently poor:

Stabilising factor	Contribution
Musculotendinous (rotator) cuff — subscapularis, infraspinatus, teres minor, supraspinatus	Most important stabiliser; compresses head into glenoid throughout range ("concavity compression")
Coracoacromial arch	Coracoid + acromion + coracoacromial ligament form a secondary bony-ligamentous socket superiorly, preventing upward escape of the head
Glenoidal labrum	Fibrocartilaginous rim deepening the glenoid fossa
Long heads of biceps and triceps	Check upward and downward displacement of the head
Atmospheric (negative intra-articular) pressure	Passive suction-effect stabiliser

Capsule, Weak Points & Bursae

- ▶ The **fibrous capsule** is loose, permitting a wide range of movement; medially it is attached to the scapula beyond the supraglenoid tubercle and labral margin, laterally to the anatomical neck of the humerus — except superiorly, where it is deficient for passage of the long head of biceps tendon, and inferomedially, where it extends down onto the surgical neck.
- ▶ The capsule is **least supported inferiorly**, which is why dislocation is almost always primarily **subglenoid**, and why the closely related **axillary nerve** is at risk.
- ▶ Anteriorly the capsule is reinforced by the superior, middle and inferior **glenohumeral ligaments**; the gap between the superior and middle glenohumeral ligaments is a recognised point of capsular weakness — the **foramen of Weitbrecht** — and a common site of **anterior dislocation** of the humeral head.
- ▶ **Bursae**: the subacromial/subdeltoid bursa (does not communicate with the joint, but is the largest bursa in the body and the site of subacromial impingement); the subscapularis bursa (communicates with the joint cavity); the infraspinatus bursa (may communicate).

Relations of the Joint

Aspect	Structures
Superior	Coracoacromial arch, subacromial bursa, supraspinatus, deltoid
Inferior	Long head of triceps; the quadrangular space , transmitting the axillary nerve and posterior circumflex humeral vessels
Anterior	Subscapularis, coracobrachialis, short head of biceps, deltoid
Posterior	Infraspinatus, teres minor, deltoid
Within the joint	Tendon of the long head of biceps brachii

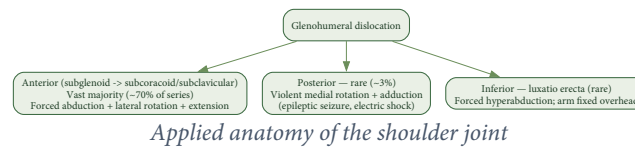
- ▶ **Quadrangular space** — boundaries: superiorly, subscapularis (in front), the loose inferior part of the joint capsule, and the inferior border of teres minor (behind); inferiorly, the superior border of teres major; medially, the lateral border of the long head of triceps; laterally, the surgical neck of the humerus. **Contents**: axillary nerve and posterior circumflex humeral vessels — the anatomical reason the axillary nerve is vulnerable in inferior/subglenoid dislocation and in surgical-neck fractures.

Blood Supply & Nerve Supply

- ▶ **Arteries**: anterior and posterior circumflex humeral, suprascapular and subscapular vessels — branches of the axillary artery/subclavian system forming a peri-articular anastomosis.
- ▶ **Nerves** (Hilton's law — nerves crossing a joint supply it): **axillary nerve** (anteroinferior capsule, via the quadrangular space), **suprascapular nerve** (postero-superior capsule) and **musculocutaneous nerve** (a minor articular contribution).

Types and Mechanism of Dislocation

Dislocation is the dominant applied topic for this joint. Because the capsule is weakest inferiorly, the head first slips **subglenoid**, then commonly migrates to a subcoracoid or subclavicular position.



- ▶ Clinically a dislocated shoulder loses its normal rounded contour: the humeral head lies anterior to the glenoid (sometimes beneath the coracoid), so the acromion — not the greater tubercle — becomes the most lateral bony point, giving a characteristic "squared-off" shoulder.
- ▶ **Posterior dislocation** classically follows violent, unilateral medial rotation/adduction forces such as an epileptic seizure or electric shock; the limb is held fixed in medial rotation and external rotation cannot be performed.
- ▶ **Luxatio erecta** (inferior dislocation) leaves the arm permanently fixed in abduction above the head; it is supported (and limited) by the inferior glenohumeral ligament and the long head of triceps, and the axillary nerve is again at risk because of its proximity to the inferior capsule.

□ Fig 6.11 — ■ Dislocation of the shoulder joint. Note the (Vishram Singh — *Textbook of Anatomy Vol 1 — 4e*, p.292)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A sagittal section through the shoulder joint (as in the classical exam figure), labelling: acromion and coracoacromial ligament; subacromial bursa; supraspinatus fused with the capsule superiorly; glenoid cavity with glenoidal labrum; head of humerus; fibrous capsule (thin inferiorly); superior/middle/inferior glenohumeral ligaments with the foramen of Weitbrecht between the superior and middle ligaments; long head of biceps tendon (intracapsular); subscapularis anteriorly; infraspinatus and teres minor posteriorly; and, inferiorly, the quadrangular space with the axillary nerve and posterior circumflex humeral vessels, bounded by teres minor above, teres major below, long head of triceps medially and the surgical neck of humerus laterally.

Recent advances in the applied/surgical anatomy of the shoulder joint

- ▶ A multicentre randomised controlled trial found that adding **remplissage** (tenodesis of infraspinatus tendon and posterior capsule into a Hill-Sachs defect) to arthroscopic Bankart repair resulted in significantly fewer redislocations and reoperations than isolated Bankart repair at medium-term (mean ~4-year) follow-up in patients with recurrent anterior instability and subcritical glenoid bone loss. The anatomical rationale is that an "off-track" Hill-Sachs lesion — assessed against the glenoid track on 3D CT — engages the antero-inferior glenoid rim during abduction-lateral rotation; remplissage converts it into an extra-articular, "on-track" lesion, reinforcing that stable reconstruction must address both the labral (Bankart) defect and the humeral-head (Hill-Sachs) defect together (Woodmass et al., *American Journal of Sports Medicine* 2024) [DOI](<https://doi.org/10.1177/03635465241254063>).
- ▶ A 2025 review consolidated current imaging insights into **quadrilateral (quadrangular) space syndrome**: MRI is now the diagnostic standard for confirming neurovascular compression of the

axillary nerve and posterior circumflex humeral vessels within the space, with denervation change (oedema, later fatty atrophy) in teres minor — occasionally extending to deltoid — as the characteristic finding, supplemented by venous engorgement/tortuosity at the space as an ancillary sign; the syndrome typically affects young overhead athletes whose sport repeatedly loads the abducted, externally rotated shoulder (Mishra et al., *Clinical Imaging* 2025) [DOI] (<https://doi.org/10.1016/j.clinimag.2025.110460>).

- ▶ A current-concepts review of **patient-specific (3D-printed) instrumentation and implants in reverse total shoulder arthroplasty** showed that CT-based pre-operative planning of glenoid version and inclination, translated into custom guides/baseplates, achieves markedly more accurate glenoid component position (mean deviation of only $\sim 1.8^{\circ}$ – 2° from the surgical plan) than standard instrumentation — a direct clinical application of the glenoid-version and glenohumeral-relation anatomy described above, particularly in cuff-arthropathy with glenoid bone loss (Wesorick et al., *JSES International* 2025) [DOI] (<https://doi.org/10.1016/j.jseint.2024.12.007>).

(According to PubMed.)

Applied / Clinical anatomy

- ▶ **Recurrent dislocation:** a first traumatic dislocation may be followed by repeated, sometimes self-reduced, dislocation with trivial force in young adults. Two anatomical lesions underlie this: the **Bankart lesion** — a tear of the antero-inferior glenoidal labrum, leaving a pouch-like defect in front of the glenoid neck into which the head slips — and the **Hill-Sachs lesion** — a compression defect on the postero-lateral head of humerus (from impaction against the glenoid rim during the first dislocation) that can hitch on the glenoid margin during abduction/lateral rotation.
- ▶ **Axillary nerve injury:** at risk in inferior/subglenoid dislocation and in fracture of the surgical neck of the humerus because of its course through the quadrangular space, closely applied to the medial aspect of the surgical neck just inferior to the capsule. Effects: loss of the rounded shoulder contour (deltoid wasting, prominent greater tubercle), weakness of abduction, and sensory loss over the lower half of deltoid in a badge-like area — the "**regimental badge**" patch (upper lateral cutaneous nerve of arm, a branch of the axillary nerve). Deltoid alone is not the sole abductor — initiation and much of the maintenance of abduction depends on the **suprascapular nerve** acting through supraspinatus/infraspinatus, so a rotator-cuff tear or suprascapular nerve lesion can mimic axillary palsy.
- ▶ **Bedside differentiation after reduction of a dislocated shoulder** (arm supported in a sling): ability to *initiate* abduction indicates an intact suprascapular nerve and intact rotator cuff; abnormal sensation over the deltoid patch indicates an axillary nerve lesion; and palpable contraction in the posterior deltoid fibres on gentle attempted extension confirms axillary nerve continuity even when abduction itself is limited.
- ▶ **Intramuscular injection into deltoid** is given in the middle of the muscle, well below its origin, to avoid the axillary nerve, which lies deep to the upper part of the muscle.
- ▶ **Rotator cuff disorders** are overall the commonest cause of shoulder pain: calcific supraspinatus tendinitis irritates the overlying subacromial bursa (subacromial bursitis); on abduction the inflamed bursa is caught under the acromion (subacromial impingement), producing pain typically between **60° and 120° of abduction** — the **painful arc syndrome**. Pressure over the

bursa just below the acromion reproduces pain with the arm adducted but not abducted, since the bursa slips under the acromion on abduction (**Dawbarn's sign**).

- ▶ **Frozen shoulder (adhesive capsulitis):** the two layers of synovial membrane become adherent, producing progressive pain and uniform restriction of all movements (especially lateral rotation, abduction and medial rotation) without radiological change, typically at 40–60 years of age; scapulohumeral rhythm is altered as scapular motion compensates for the reduced glenohumeral contribution. It is usually self-limiting over about two years, hastened by physiotherapy.
- ▶ **Referred "shoulder tip" pain:** irritation of the diaphragmatic pleura/peritoneum is referred to the shoulder because both the phrenic nerve (supplying this region) and the supraclavicular nerves (supplying the overlying shoulder skin) arise from the same C3–C4(–C5) spinal segments.
- ▶ **Aspiration (arthrocentesis)** of the joint is performed anteriorly, through the deltopectoral triangle medial to the humeral head and lateral to the coracoid process, or laterally just below the acromion.
- ▶ **Exclusion of shoulder joint disease:** the joint can be clinically excluded as a cause of symptoms if the patient can raise both arms fully overhead and appose the palms — confirming an intact deltoid, axillary nerve and rotator cuff mechanism.
- ▶ **Optimum position of immobilisation:** shoulder disease is splinted with the arm abducted 45°–90° to minimise the risk of disabling ankylosis.

High-yield exam pointers

- ▶ Shoulder (glenohumeral) joint = most mobile AND most commonly dislocated joint in the body; humeral head is ~4× the glenoid surface area.
- ▶ Stability = rotator cuff (SITS) + coracoacromial arch + glenoidal labrum + long heads of biceps/triceps + atmospheric pressure — NOT bony congruity.
- ▶ Capsule weakest inferiorly (subglenoid dislocation); anterior weak point = foramen of Weitbrecht (between superior and middle glenohumeral ligaments).
- ▶ Quadrangular space contents = axillary nerve + posterior circumflex humeral vessels; bounded by teres minor/teres major/long head of triceps/surgical neck of humerus.
- ▶ Dislocation: anterior (~70%, commonest) > posterior (~3%, seizure/electric shock) > inferior (luxatio erecta, rare, arm fixed overhead).
- ▶ Recurrent dislocation = Bankart lesion (antero-inferior labral tear) + Hill-Sachs lesion (postero-lateral humeral head defect).
- ▶ Axillary nerve injury → loss of shoulder contour, weak abduction, "regimental badge" sensory loss; deltoid is not the sole abductor (suprascapular nerve via supraspinatus/infraspinatus initiates abduction).
- ▶ Painful arc (60°–120°) = supraspinatus/subacromial impingement; Dawbarn's sign = subacromial bursitis; frozen shoulder = capsular adhesions, age 40–60.
- ▶ Referred shoulder-tip pain: phrenic + supraclavicular nerves share C3–C4(–C5) origin.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 1 (8e); AK Datta — Human Anatomy Vol 3 (Upper & Lower Limb); Vishram Singh — Textbook of Anatomy Vol 1 (4e); IB Singh — Textbook of Anatomy Vol 1 (6e); Moore's Clinically Oriented Anatomy 9e.



Applied anatomy of Thoracic inlet

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction

The **thoracic inlet** (superior thoracic aperture) is the narrow, obliquely-set osseo-cartilaginous ring that connects the thoracic cavity above with the root of the neck. Anatomists call it the **inlet** because air (trachea) and food (oesophagus) enter the thorax through it; clinicians call the same opening the **thoracic outlet**, because the great arteries and the T1 spinal nerve *emerge* from the thorax through it to reach the neck and upper limb — the source of the confusing but important synonym "thoracic outlet syndrome" for what is anatomically inlet pathology. Its small, crowded confines pack the trachea, oesophagus, apices of the lungs, great vessels, sympathetic trunks and the lower roots of the brachial plexus into a space sealed only by a thin fascial diaphragm (Sibson's fascia), making it one of the most clinically important cross-sections in the body — relevant to thoracic surgery, vascular access, regional anaesthesia and chest radiology alike.

Boundaries, dimensions and plane

Boundary	Structure
Anterior	Upper border (manubrial/jugular notch) of the manubrium sterni
Posterior	Anterior border of the superior surface of the body of the 1st thoracic vertebra (T1)
On each side	Medial border of the 1st rib and its costal cartilage

- **Shape:** reniform (kidney-shaped).
- **Dimensions:** transverse diameter $\approx$ 10–12.5 cm; antero-posterior diameter $\approx$ 5–6 cm.
- **Plane/obliquity:** the 1st rib slopes downward and forward from its posterior to its anterior end, so the anterior boundary lies about 3.7–4 cm **below** the posterior boundary; the plane of the inlet is therefore tilted at roughly **45° to the horizontal**, sloping down and forward. As a result, the upper border of the manubrium projects to the level of the **T2/T3 vertebral junction**.
- **Consequence of the obliquity:** the apex of each lung, capped by the cervical (dome of) pleura, is pushed upward through the inlet into the root of the neck rather than lying flush with it — this is why the lung apex and cervical pleura are vulnerable structures at the base of the neck.

Contents — structures crossing the inlet

Category	Structures
Viscera	Trachea, oesophagus, apices of both lungs with overlying (cervical) pleura, remnant of the thymus
Major arteries	Brachiocephalic trunk (right side only); left common carotid and left subclavian arteries
Minor arteries	Right and left internal thoracic arteries; right and left superior intercostal arteries
Veins	Right and left brachiocephalic veins ; right and left 1st posterior intercostal veins; inferior thyroid veins
Nerves	Right and left vagus nerves ; left recurrent laryngeal nerve ; right and left phrenic nerves ; right and left sympathetic trunks; right and left T1 spinal nerves ascending across the 1st rib to join the brachial plexus
Muscles	Sternohyoid, sternothyroid, longus colli (cervicis)
Lymphatics	Thoracic duct (arches into the root of the neck on the left)
Other	Anterior longitudinal ligament

□ Fig 15.9 — Structures passing through the thoracic inlet. (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.635)

Suprapleural membrane (Sibson's fascia)

- ▶ A tent-shaped fascial sheet that closes each half of the inlet on its own side; the two halves leave a median cleft for the trachea, oesophagus and great vessels.
- ▶ **Attachments:** apex → tip of the transverse process of C7; base → inner border of the **1st rib** and its costal cartilage.
- ▶ **Morphology:** represents the flattened, degenerated tendon of the vestigial **scalenus minimus (pleuralis)** muscle, reinforced by endothoracic fascia.
- ▶ **Relations:** superior surface related to the subclavian vessels and other root-of-neck structures; inferior surface fused to the **cervical pleura**, beneath which lies the apex of the lung.
- ▶ **Functions:** (1) protects and supports the cervical pleura and lung apex; (2) resists the swings of intrathoracic pressure during respiration, so that the root of the neck is not "puffed" in and out with each breath — i.e., it gives rigidity to the thoracic inlet.

Root-of-neck relations at the inlet

The **root of the neck** is the area of the neck immediately above the thoracic inlet, where the crowding of structures is greatest.

- ▶ **Scalene (interscalene) triangle** — a narrow gap above the 1st rib between **scalenus anterior** (anterior boundary) and **scalenus medius** (posterior boundary), with the 1st rib as its base. It transmits the **subclavian artery** and the **roots/trunks of the brachial plexus**.
- ▶ **Scalenovertebral triangle (triangle of the vertebral artery)** — bounded medially by longus colli, laterally by scalenus anterior, apex at the transverse process of C6, base formed by the 1st part of

the subclavian artery; its floor (from above down) is the transverse process of C7, the ventral ramus of C8, the neck of the 1st rib and the cupola of cervical pleura, and its roof is the carotid sheath. Contents: 1st part of the vertebral artery and its veins, the thyrocervical trunk and inferior thyroid artery, the sympathetic chain with the stellate ganglion, the thoracic duct arching laterally (left side), and the ansa subclavia.

- ▶ **Cervical pleura:** rises about 2.5 cm above the medial third of the clavicle and about 3–3.4 cm above the 1st costal cartilage, but not above the neck of the 1st rib (because of the rib's obliquity); it is strengthened externally by Sibson's fascia. Relations — anteriorly, subclavian artery and scalenus anterior; posteriorly, neck of the 1st rib; laterally, scalenus medius and the lower trunk of the brachial plexus; medially, vertebral bodies, trachea, oesophagus, the recurrent laryngeal nerve (in the tracheo-oesophageal groove) and, on the left, the thoracic duct.
- ▶ **Structures crossing the neck of the 1st rib, medial to lateral:** sympathetic chain → 1st posterior intercostal vein → superior intercostal artery → **T1 nerve** (large ascending branch of its ventral ramus).

□ Fig 12.8 — Scalene triangle. (Vishram Singh — *Textbook of Anatomy Vol 3 — 4e*, p.528)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a superior view of the thoracic inlet (kidney-shaped outline) and label:

- ▶ Boundaries: manubrium sterni (anterior), body of T1 vertebra (posterior), medial border of 1st rib + costal cartilage (each side)
- ▶ Midline viscera: trachea, oesophagus
- ▶ Right side: brachiocephalic trunk, right brachiocephalic vein, right vagus nerve, right phrenic nerve
- ▶ Left side: left common carotid artery, left subclavian artery, left brachiocephalic vein, left vagus nerve, left recurrent laryngeal nerve, left phrenic nerve, thoracic duct
- ▶ Each side: sympathetic trunk, T1 nerve crossing 1st rib, apex of lung capped by cervical pleura and Sibson's fascia
- ▶ Inset: scalene triangle (scalenus anterior/medius, subclavian artery, brachial plexus trunks) with a cervical rib shown arising from C7

Applied / Clinical anatomy

- ▶ **Cervical rib:** an enlarged costal element of the C7 transverse process, occurring in ~0.5% of people; may be complete (articulating with the 1st rib/manubrium) or incomplete (ending in a fibrous band). It raises the floor of the scalene triangle and stretches/compresses the lower trunk of the brachial plexus and the subclavian artery.
- ▶ **Thoracic outlet (scalene/cervical rib) syndrome:** compression of the lower brachial plexus trunk (C8, T1) and subclavian artery in the interscalene triangle — by a cervical rib or an anomalous scalenus anterior insertion — produces tingling/numbness and pain along the medial forearm and hand, progressive wasting of the small muscles of the hand (T1), and vascular features (weak or absent radial pulse, coldness, pallor of the limb).

- ▶ **Adson's test:** the radial pulse diminishes or is obliterated when the patient takes a deep breath with the neck extended and turned toward the affected side (tightens scalenus anterior over the subclavian artery) — used clinically to support a diagnosis of cervical rib/scalene syndrome.
- ▶ **Pancoast (superior sulcus) tumour:** an apical lung/pleural tumour growing at the crowded thoracic inlet compresses the lower brachial plexus (shoulder and arm pain, small-muscle wasting), invades the sympathetic chain/stellate ganglion causing **Horner's syndrome** (partial ptosis from paralysis of Müller's muscle, miosis from dilator pupillae paralysis, anhidrosis, enophthalmos, loss of the ciliospinal reflex), and may compress the subclavian vessels or recurrent laryngeal nerve (hoarseness).
- ▶ **Sibson's fascia and lung apex vulnerability:** the apex of the lung and cervical pleura lie superficial to Sibson's fascia at the root of the neck and are vulnerable to penetrating (stab) wounds there, producing an open pneumothorax; the same relation makes supraclavicular brachial plexus block and subclavian/internal jugular central-line placement carry a real risk of pleural puncture and iatrogenic pneumothorax.
- ▶ **Retrosternal (plunging) goitre:** an enlarged thyroid can extend caudally through the thoracic inlet into the superior mediastinum, compressing the trachea, oesophagus or great veins.
- ▶ **Coarctation of the aorta:** grossly dilated posterior intercostal and internal thoracic collateral vessels near the inlet produce characteristic rib notching, seen on chest radiographs.
- ▶ **Radiological correlate (thoracic-inlet region on chest X-ray/CT):** because the aerated lung apex overlaps only the lower part of the inlet region, a mediastinal mass that extends above the clavicles with a sharp margin is typically **posterior** in location, while one whose margin fades out at the clavicle is typically **anterior** — a bedside application of the same crowded-inlet anatomy to plain-film localisation of superior mediastinal masses.

High-yield exam pointers

- ▶ Superior thoracic aperture = anatomists' "**thoracic inlet**"; clinicians' "**thoracic outlet**" — same ring, opposite naming logic.
- ▶ Boundaries: manubrium (anterior) + T1 body (posterior) + 1st ribs (sides); reniform; obliquity ~45° down-and-forward.
- ▶ Right side has the **brachiocephalic trunk**; left side has **two** arterial branches (common carotid + subclavian) — a classic asymmetry to write explicitly.
- ▶ **Sibson's fascia** = degenerated tendon of scalenus minimus; apex C7 transverse process, base 1st rib; rigidifies the inlet.
- ▶ Scalene triangle (scalenus anterior/medius/1st rib) transmits subclavian artery + brachial plexus trunks — the key surgical triangle for cervical rib/TOS.
- ▶ Cervical rib (~0.5%) → thoracic outlet syndrome → C8/T1 sensory-motor signs + weak radial pulse; Adson's test positive.
- ▶ Pancoast tumour at the inlet → brachial plexus + sympathetic chain (Horner's syndrome) + subclavian vessels + recurrent laryngeal nerve, all in one clinical picture.
- ▶ Left recurrent laryngeal nerve and thoracic duct both cross the inlet on the **left** only — high-yield laterality point.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 1 8e; Vishram Singh — Textbook of Anatomy Vol 1 4e; Vishram Singh — Textbook of Anatomy Vol 3 4e; AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen).

Coverage note: the chest-radiograph "sharp margin above clavicle = posterior mass" localisation rule (final Applied/Clinical bullet) is standard cross-sectional/radiological teaching not verbatim in the retrieved corpus; included as universally-accepted applied anatomy for the Paper IV radiological-anatomy context.



Applied anatomy of thyroid gland

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction — The thyroid gland is a butterfly-shaped endocrine organ situated in the lower anterior neck opposite the C5–T1 vertebrae, consisting of two lateral lobes joined by an isthmus. It is unique among endocrine glands in being superficial (hence palpable and imaged directly), in depending on dietary iodine for hormone synthesis, and in storing its hormone extracellularly as colloid before release. Because it is intimately related to the trachea, oesophagus, carotid sheath, external and recurrent laryngeal nerves, and parathyroid glands, its gross and developmental anatomy underlies almost every clinical sign of thyroid disease and every step of thyroid surgery — making "applied anatomy" the natural framework for studying this gland.

Location, dimensions & capsule

- **Location and extent:** lies opposite C5, C6, C7 and T1 vertebrae, behind the sternohyoid and sternothyroid muscles, wrapping around the cricoid cartilage and upper tracheal rings. Each **lateral lobe** extends from the oblique line of the thyroid cartilage above to the 5th–6th tracheal ring below; the **isthmus** lies across the 2nd–4th tracheal rings. A **pyramidal lobe** may project upward from the isthmus (usually left of the midline), occasionally tethered to the hyoid bone by the **levator glandulae thyroideae**.
- **Dimensions/weight:** each lobe ~5 cm (long) × 2.5–3 cm (broad) × 2 cm (thick); isthmus ~1.2 cm in both diameters; gland weight ~15–25 g, larger in females and further enlarged in menstruation and pregnancy.
- **Capsule** — the gland has two coverings, and the relationship between them is the anatomical basis of safe thyroidectomy:

Capsule	Origin	Key feature
True capsule	Peripheral condensation of the gland's own fibrous stroma	A dense venous plexus lies deep to it (i.e., between true capsule and gland substance)

Capsule	Origin	Key feature
False capsule	Splitting of the pretracheal layer of deep cervical fascia	Thin over the posterior border, thick on the medial surface where it condenses into the suspensory ligament of Berry , binding the lobe to the cricoid cartilage

- ▶ Because the venous plexus lies **deep to the true capsule** (unlike the prostate, where the plexus lies **between** true and false capsules), the thyroid must be shelled out **along with its true capsule** to control haemorrhage.
- ▶ The false capsule/ligament of Berry anchors the gland to the larynx and hyoid bone — the anatomical reason the thyroid (and any thyroid swelling) **moves up and down on deglutition**, a clinical sign that distinguishes thyroid swellings from other neck masses.

Relations of the lobes and isthmus

Part	Feature	Relations
Apex	Directed upward and slightly laterally	Sandwiched between inferior constrictor (medially) and sternothyroid (laterally); related to the superior thyroid artery and external laryngeal nerve, which diverge near the apex
Base	At the 5th–6th tracheal ring	Inferior thyroid artery and recurrent laryngeal nerve
Lateral (superficial) surface	Convex	Sternohyoid, sternothyroid, superior belly of omohyoid; anterior border of sternocleidomastoid overlaps it inferiorly
Medial surface	—	Two tubes (trachea, oesophagus), two muscles (inferior constrictor, cricothyroid), two cartilages (cricoid, thyroid); external and recurrent laryngeal nerves ascend close to this surface
Posterolateral surface	—	Carotid sheath and its contents (common carotid artery, internal jugular vein, vagus); ansa cervicalis in the sheath's anterior wall; cervical sympathetic chain behind the sheath, in front of prevertebral fascia
Anterior border	Thin	Anterior branch of superior thyroid artery

Part	Feature	Relations
Posterior border	Thick, rounded	Longitudinal anastomosis between superior and inferior thyroid arteries; parathyroid glands
Isthmus, anterior surface	—	Sternohyoid and sternothyroid; anterior jugular veins
Isthmus, posterior surface	—	2nd–4th tracheal rings
Isthmus, superior border	—	Anastomosis of the two anterior branches of the superior thyroid arteries
Isthmus, inferior border	—	Inferior thyroid vein emerges; thyroidea ima artery (when present) enters

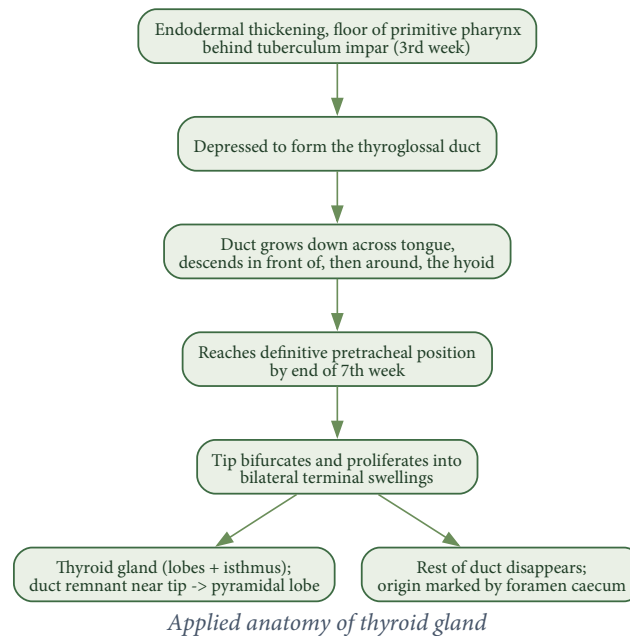
Blood supply, venous drainage, lymphatics & nerve supply

- **Superior thyroid artery** (first branch of the external carotid artery) descends with the **external laryngeal nerve**, from which it diverges near the apex, dividing into anterior and posterior branches; supplies the upper one-third of the lobe and upper half of the isthmus.
- **Inferior thyroid artery** (branch of the thyrocervical trunk of the subclavian artery) ascends along scalenus anterior, then turns medially behind the carotid sheath to reach the back of the lobe, where its relation to the **recurrent laryngeal nerve is markedly variable** (in front of, behind, or between its branches); supplies the lower two-thirds of the lobe, the lower half of the isthmus, and gives an ascending branch to the parathyroid glands.
- **Thyroidea ima artery** (an inconstant minority, quoted variably across texts) arises from the brachiocephalic trunk or aortic arch and enters the isthmus from below; **accessory thyroid arteries** arise from tracheal and oesophageal vessels.
- **Venous drainage** is by three sets of veins — superior and middle thyroid veins draining into the internal jugular vein, and inferior thyroid vein(s) forming a pretracheal plexus that drains into the left brachiocephalic vein; an inconstant fourth vein (of Kocher) may drain into the internal jugular vein.
- **Lymphatics** follow the arteries: an upper group to the prelaryngeal and upper deep cervical (jugulodigastric) nodes, and a lower group to the pretracheal, lower deep cervical nodes and nodes along the recurrent laryngeal nerve; lymph from the lower isthmus may reach retrosternal/brachiocephalic nodes in the superior mediastinum.
- **Nerve supply** is chiefly **sympathetic**, from the superior, middle and inferior cervical ganglia (mainly the middle), reaching the gland along the arteries as vasomotor fibres; a parasympathetic contribution travels with the vagus and recurrent laryngeal nerve.

Development and congenital anomalies

The thyroid begins as a median endodermal thickening in the floor of the primitive pharynx, immediately behind the tuberculum impar, in the 3rd week of intrauterine life. This is depressed to form the **thyroglossal duct**, which grows down across the tongue and descends in front of the neck, passing

in front of and then winding around the lower border of the hyoid bone (becoming retrohyoid), before reaching its definitive pretracheal position by the end of the 7th week, where its tip bifurcates and proliferates into bilateral terminal swellings that expand to form the gland. A remnant of the duct near its tip may persist as the pyramidal lobe; the rest of the duct disappears, its origin marked in the adult by the **foramen caecum** at the junction of the anterior two-thirds and posterior one-third of the tongue. The thyroid is the earliest endocrine gland to develop and is functional by the third month.



Congenital anomalies traceable to this descent include: **thyroglossal cyst/fistula** (persistence of the duct); **ectopic thyroid** — at the base of the tongue (**lingual thyroid**, lying just beneath the foramen caecum, occasionally causing infantile dysphagia) or at a supra-, retro-, or infrahyoid site along the duct's path; absence of one lobe or of the isthmus; **retrosternal thyroid** (descent beyond the normal position into the superior mediastinum); and **aberrant thyroid** tissue found away from the duct's course (in relation to the carotid sheath, mediastinum, or pericardium).

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 8.5 — Deep relations of the thyroid gland (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.174)

Reproduce this figure by hand with the following labels:

- ▶ Hyoid bone and thyrohyoid membrane
- ▶ Thyroid cartilage and cricothyroid muscle
- ▶ Cricoid cartilage
- ▶ Inferior constrictor muscle
- ▶ Superior laryngeal nerve and superior thyroid artery (above), dividing into internal laryngeal nerve + superior laryngeal artery and external laryngeal nerve
- ▶ Outline of the lobe of the thyroid gland
- ▶ Outline of the isthmus of the thyroid gland
- ▶ Oesophagus (left of trachea)
- ▶ Trachea
- ▶ Recurrent laryngeal nerve, ascending in the tracheo-oesophageal groove close to the posterior border of the lobe

Recent advances in the applied/surgical anatomy of the thyroid

- ▶ A systematic review and meta-analysis of 8 randomised controlled trials (1,620 patients) found that intraoperative **near-infrared autofluorescence (NIRAF)** imaging for locating the parathyroid glands during thyroidectomy significantly lowered postoperative hypocalcaemia (OR 0.56, 95% CI 0.36–0.89) and persistent hypoparathyroidism (OR 0.44, 95% CI 0.22–0.89), exploiting the intrinsic autofluorescence of parathyroid tissue to keep dissection along a plane that spares its blood supply from the ascending branch of the inferior thyroid artery (Javed et al., *Clinical Otolaryngology* 2025) [DOI](<https://doi.org/10.1111/coa.14313>).
- ▶ A meta-analysis of 17 studies quantified the surgical risk of the **non-recurrent laryngeal nerve** (a variant in which the nerve leaves the vagus directly and enters the larynx without "recurring," almost always on the right): pooled injury risk was 7%, nearly four times that of a normal recurrent laryngeal nerve (risk ratio 3.8). The variant is strongly linked to an **aberrant right subclavian artery**, which is radiologically predictable pre-operatively, reinforcing the applied teaching that imaging plus intraoperative nerve monitoring (rather than reliance on the inferior thyroid artery as a landmark) is needed when this anomaly is suspected (So & Thompson, *Clinical Otolaryngology* 2025) [DOI](<https://doi.org/10.1111/coa.14312>).
- ▶ A meta-analysis comparing **transoral endoscopic thyroidectomy** approaches (submental vestibular vs vestibular-only vs conventional open surgery) for early papillary thyroid carcinoma showed the submental-vestibular route achieved shorter operating time, more resected lymph nodes and less mandibular numbness, illustrating how modern minimal-access surgery re-routes dissection through the lingual/submental and vestibular planes to reach the gland without a visible neck incision, while still respecting the same capsular and neurovascular anatomy described above (Hindawi et al., *Langenbeck's Archives of Surgery* 2024) [DOI](<https://doi.org/10.1007/s00423-024-03377-x>).

(According to PubMed.)

Applied / Clinical anatomy

- ▶ **Clinical distinguishing sign:** because the false capsule/ligament of Berry fixes the gland to the larynx and hyoid, thyroid swellings — unlike other neck swellings — move up and down with deglutition; the gland is classically **palpated from behind**.
- ▶ **Posterior extension of tumours:** since the capsule is thin posteriorly, a thyroid tumour may extend backwards and compress the trachea, oesophagus or carotid sheath without producing an obvious anterior neck swelling.
- ▶ **Goitre and the "3 D's":** any thyroid enlargement other than during menstruation/lactation is a goitre; simple (puberty) goitre reflects iodine-deficiency-driven, TSH-mediated hyperplasia. Because the gland is fixed above by its fascial sheath and sternothyroid attachment to the thyroid cartilage, massive enlargement can only expand backwards or downwards, producing **dyspnoea** (tracheal compression), **dysphagia** (oesophageal compression) and **dysphonia** (recurrent laryngeal nerve compression in the tracheo-oesophageal groove). Downward extension behind the sternum (**retrosternal goitre**) can cause dangerous dyspnoea and venous congestion from great-vein compression.
- ▶ **Thyroidectomy and the capsular plane:** total thyroidectomy removes the gland with its true capsule (to control the venous plexus deep to it); **subtotal thyroidectomy** deliberately leaves the posterior parts of both lobes behind, protecting the parathyroid glands from inadvertent removal and reducing the risk of postoperative myxoedema.
- ▶ **Nerve-safe arterial ligation:** the superior thyroid artery is ligated close to the apex of the lobe (where it has already diverged from the deeper external laryngeal nerve), while the trunk of the inferior thyroid artery is ligated away from the base of the gland — or its glandular branches ligated individually close to the capsule — because its relation to the recurrent laryngeal nerve near the base is too variable to rely on visually; this also preserves the ascending branch supplying the parathyroids. The ligament of Berry, closely related to the recurrent laryngeal nerve, is a further site of nerve risk during mobilisation of the lower pole.
- ▶ **Parathyroid injury:** inadvertent removal of the parathyroid glands (lying on the posterior border of the lobes) causes hypoparathyroidism and tetany from hypocalcaemia, presenting with carpopedal spasm.
- ▶ **Tumour behaviour:** benign thyroid tumours displace or compress adjoining structures; malignant tumours invade them, producing pressure symptoms and nerve palsies.
- ▶ **Imaging correlate:** the gland's superficial position makes it ideally suited to ultrasonography (nodules, gland volume) and fine-needle aspiration cytology; it enhances well on contrast CT/MRI, and radionuclide scanning (^{99m}Tc -pertechnetate/ ^{123}I) exploits its iodine-trapping to assess function and to localise ectopic tissue such as a lingual thyroid before any excision (since it may be the patient's only functioning thyroid tissue).
- ▶ **Lymphatic spread in carcinoma:** because lymphatics follow the arterial pedicles, papillary carcinoma characteristically spreads first to the central (pretracheal/paratracheal) compartment before the lateral deep cervical nodes, the rationale for central-compartment neck dissection.

High-yield exam pointers

- ▶ Thyroid = only superficial, palpable endocrine gland; moves with deglutition because of the false capsule/ligament of Berry attaching it to the larynx and hyoid.
- ▶ True capsule removed at thyroidectomy (venous plexus lies deep to it); false capsule = split pretracheal fascia, thickened medially as ligament of Berry.
- ▶ Apex related to superior thyroid artery + external laryngeal nerve (nerve deep, diverges near apex); base related to inferior thyroid artery + recurrent laryngeal nerve (variable relation).
- ▶ Superior thyroid artery = branch of external carotid; inferior thyroid artery = branch of thyrocervical trunk; thyroidea ima (inconstant) = from brachiocephalic trunk/aortic arch.
- ▶ Lymphatics follow the arteries — upper group to prelaryngeal/upper deep cervical nodes, lower group to pretracheal/lower deep cervical nodes.
- ▶ Develops from the thyroglossal duct (3rd week, behind tuberculum impar); foramen caecum marks its site of origin; functional by the 3rd month.
- ▶ Congenital anomalies: thyroglossal cyst/fistula, lingual thyroid, retrosternal thyroid, absent lobe/isthmus.
- ▶ Goitre pressure triad — dyspnoea, dysphagia, dysphonia ("3 D's") — because the gland cannot expand upward.
- ▶ Subtotal thyroidectomy spares the posterior parts of both lobes to protect the parathyroids and avoid myxoedema.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Textbook of Anatomy Vol 3 (4e); BD Chaurasia's Human Anatomy Vol 3–4 (8e).



Applied aspects of innervations of urinary bladder

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction The urinary bladder receives a triple nerve supply — **sympathetic**, **parasympathetic** and **somatic** — that reciprocally controls the detrusor muscle and the two urethral sphincters so that the bladder alternates between a low-pressure storage phase and a coordinated voiding phase. Storage and voiding are integrated by a **spinal (sacral) micturition reflex**, itself supervised by a **pontine micturition centre** and, ultimately, by the **cerebral cortex**, which imposes voluntary control. Because this pathway runs from cortex to pelvic plexus, a lesion at almost any level — cortical, spinal, or peripheral — produces a distinctive, localisable pattern of bladder dysfunction (**neurogenic bladder**), and the anatomy also explains referred bladder pain, retrograde ejaculation, and the risks of pelvic surgery. This makes bladder innervation one of the most clinically productive topics in applied neuroanatomy.

1. Motor (efferent) innervation

Nerve	Preganglionic origin	Course / relay	Chief action
Parasympathetic — pelvic splanchnic nerves (nervi erigentes)	S2, S3, S4 (sacral/spinal micturition centre)	Inferior hypogastric (pelvic) plexus → vesical plexus → intramural ganglia in the bladder wall	Motor to detrusor muscle ; relaxes/inhibits the internal urethral sphincter (sphincter vesicae) → EMPTYING
Sympathetic — hypogastric nerve	Lower thoracic–upper lumbar segments (T10/T11–L2)	Relay in inferior mesenteric ganglion / superior & inferior hypogastric plexuses → vesical plexus	Inhibitory to the detrusor; motor to sphincter vesicae/trigone → FILLING/continence ; in the male, closes the bladder neck during emission to prevent retrograde ejaculation
Somatic — pudendal nerve	S2, S3, S4 (Onuf's nucleus, anterior grey horn)	Pudendal nerve → external urethral sphincter	Voluntary motor control of the external urethral sphincter

- ▶ Working rule: **sympathetic = fills, parasympathetic = empties, somatic (pudendal) = voluntary control** of micturition.
- ▶ The sympathetic contribution to continence is minor at rest; its chief physiological role is closing the internal sphincter during ejaculation.

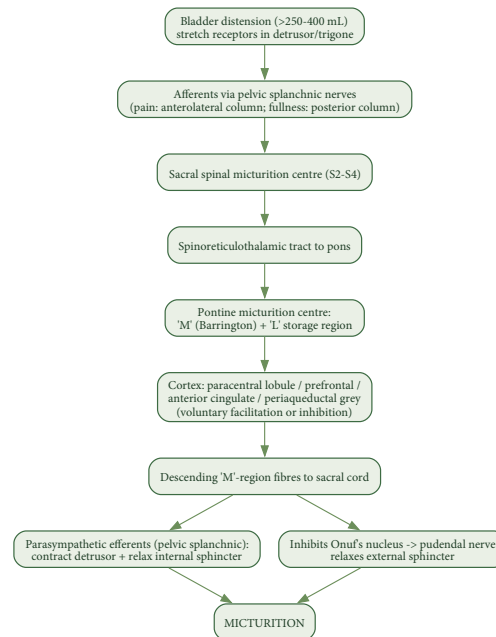
2. Sensory (afferent) innervation

- ▶ Two functionally distinct groups of afferents travel centrally with **both** the parasympathetic (pelvic splanchnic) and sympathetic (hypogastric) pathways, but ascend the cord by different routes:
 - Fibres carrying **conscious bladder fullness/distension** ascend in the **posterior (dorsal) white column**.

- Fibres carrying **bladder pain** ascend in the **anterior and lateral (anterolateral) white columns**.
- ▶ Referred pain of bladder distension or spasm (e.g. carcinoma, cystitis) is felt over the cutaneous areas supplied by **T10–L2 and S2–4** — the suprapubic/hypogastric region, perineum and penis.

3. Micturition reflex — spinal, pontine and cortical integration

- ▶ Bladder filling beyond about 250–400 mL stimulates stretch receptors in the detrusor and trigonal mucosa.
- ▶ Afferent impulses travel chiefly via the pelvic splanchnic nerves to the **sacral spinal micturition centre (S2–S4)**, and ascend further via **spinoreticulothalamic fibres** to the brainstem and thalamus.
- ▶ In the pons, a **micturition control centre** occupies the dorsolateral pontine tegmentum on each side, and comprises a medially placed '**M**' (**micturition, Barrington's**) **region** and a laterally placed '**L**' (**storage**) **region**.
- ▶ Higher control is exerted by the **paracentral lobule/inferior frontal gyrus, right prefrontal and anterior cingulate cortex, preoptic nucleus and periaqueductal grey matter**, which allow voluntary facilitation or inhibition of the pontine centres.
- ▶ When voiding is willed, descending fibres from the '**M**' region drive the **sacral parasympathetic neurones** (contracting detrusor, relaxing the internal sphincter) and simultaneously inhibit **Onuf's nucleus**, relaxing the external sphincter via the pudendal nerve — producing coordinated micturition.
- ▶ If voiding is deferred, the '**L**' region and cortex increase pudendal (Onuf's) tone to keep the external sphincter closed and inhibit the '**M**' region, permitting continued storage.
- ▶ In infancy, micturition is a pure **sacral spinal reflex** — the bladder empties automatically on filling — because the corticospinal fibres to the sacral cord are not yet myelinated; **voluntary cortical control matures by about 3–6 years of age**, the anatomical basis of physiological enuresis before this age.



Applied aspects of innervations of urinary bladder

4. Innervation of the bladder — labelled anatomy

□ Fig 16.9 — Innervation of the urinary bladder (sympathetic innervation: blue lines; parasympathetic innervation: red lines; somatic innervation: black lines) (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.696)

Diagram to draw

A schematic of the bladder with its three nerve supplies in different colours, labelling:

- ▶ **Bladder (detrusor muscle), trigone, internal urethral sphincter (sphincter vesicae), external urethral sphincter**
- ▶ **Parasympathetic:** S2–S4 sacral outflow → **pelvic splanchnic nerves (nervi erigentes)** → inferior hypogastric plexus → **vesical plexus** → detrusor (motor) and internal sphincter (inhibitory)
- ▶ **Sympathetic:** T10/T11–L2 outflow → sympathetic chain/lumbar splanchnic → inferior mesenteric ganglion → **superior and inferior hypogastric plexus (hypogastric nerve)** → vesical plexus → sphincter vesicae (motor) and detrusor (inhibitory)
- ▶ **Somatic:** S2–S4 (Onuf's nucleus) → **pudendal nerve** → external urethral sphincter
- ▶ Arrows showing afferents for pain (anterolateral column) and fullness (posterior column) travelling back with both autonomic routes

Applied / Clinical anatomy

A. Neurogenic bladder — classified by site of lesion

Type	Site of lesion	Mechanism	Clinical picture
Atonic bladder	Acute spinal shock just after cord transection above the sacral segments	Detrusor flaccid; internal sphincter tightly contracted (loss of higher inhibition); external sphincter relaxed	Bladder distends progressively → overflow

Type	Site of lesion	Mechanism	Clinical picture
Automatic (reflex) bladder — UMN type	Complete cord lesion above S2–S4 , involving the pyramidal (corticospinal) tract, after recovery from spinal shock	Voluntary initiation/inhibition lost; sacral reflex arc intact	Detrusor contracts reflexly every 1–4 hours , as in early infancy — "automatic" or "reflex" bladder
Autonomous bladder — LMN type	Destruction of S2–S4 segments/conus medullaris or cauda equina	Both reflex and voluntary pathways lost; bladder wall flaccid	Greatly increased capacity; continuous dribbling (overflow incontinence) ; may be emptied by manual (Credé) compression or abdominal straining
Atonic (sensory) neurogenic bladder	Interruption of the sensory limb only — posterior column disease (e.g. tabes dorsalis, diabetic neuropathy)	Large residual volume accumulates without reflex detrusor contraction	Painless retention with loss of the sensation of fullness
Uninhibited neurogenic bladder	Bilateral lesion of the medial frontal cortex/paracentral lobule (e.g. parasagittal meningioma, superior sagittal sinus thrombosis, anterior cerebral artery occlusion, dementia)	Loss of cortical inhibition of the pontine micturition centre	Triad of hesitancy, urgency and precipitancy

- **Pain vs fullness dissociation:** bilateral **anterolateral cordotomy** relieves intractable bladder pain (e.g. of carcinoma bladder) without abolishing the sensation of bladder fullness, since the two travel in different spinal columns.
- **Presacral neurectomy** (division of the sympathetic supply alone) does **not** relieve bladder pain, because pain fibres travel with both sympathetic and parasympathetic pathways.
- **Retrograde ejaculation:** injury to the sympathetic (hypogastric) supply of the bladder neck — e.g. retroperitoneal lymph-node dissection, lumbar sympathectomy, diabetic autonomic neuropathy — prevents bladder-neck closure during emission, so semen refluxes into the bladder instead of being expelled.
- **Iatrogenic pelvic-plexus injury:** the inferior hypogastric (pelvic) plexus lies on the pelvic side-wall close to the cervix/rectum/prostate and is vulnerable during **radical hysterectomy, abdominoperineal resection and radical prostatectomy**, causing post-operative detrusor atony, retention or incontinence; contemporary **nerve-sparing pelvic surgery**, guided by intraoperative neurostimulation mapping, aims to preserve the plexus and reduce this risk.
- **Trabeculated bladder:** chronic bladder-outflow obstruction (benign prostatic hyperplasia, urethral stricture) produces detrusor hypertrophy with an interlacing "open-weave" muscular pattern.

- ▶ **Detrusor–sphincter dyssynergia:** suprasacral spinal cord lesions can uncouple pontine 'M'-region–sacral cord coordination, so the detrusor contracts against a still-closed external sphincter, generating high intravesical pressures with risk of vesico-ureteric reflux and hydronephrosis — an indication for urodynamic surveillance in spinal cord injury/spina bifida patients.
- ▶ **Sacral neuromodulation** (chronic stimulation of the S3 nerve root) and **intradetrusor onabotulinumtoxinA injection** exploit this segmental anatomy to treat neurogenic detrusor overactivity refractory to anticholinergic therapy.
- ▶ **Suprapubic cystostomy** uses the extraperitoneal position of the distended bladder against the anterior abdominal wall for safe access without breaching the peritoneal cavity.

High-yield exam pointers

- ▶ Sympathetic (T10/T11–L2, hypogastric nerve) = fills; parasympathetic (S2–S4, pelvic splanchnic/nervi erigentes) = empties; pudendal nerve (S2–S4, Onuf's nucleus) = voluntary control of the external sphincter.
- ▶ Sensory dissociation: pain → anterolateral columns; fullness/distension → posterior columns — basis of pain-relieving cordotomy without loss of fullness sensation.
- ▶ **Presacral neurectomy does not relieve bladder pain** — pain also travels with parasympathetic fibres.
- ▶ **Pontine micturition centre** = 'M' region (Barrington's nucleus, medial) + 'L' storage region (lateral), in the dorsolateral pontine tegmentum.
- ▶ Four clinical types of neurogenic bladder: **atonic (spinal shock)** → **automatic/reflex** (UMN, suprasacral) → **autonomous** (LMN, sacral/cauda equina) → **uninhibited** (bilateral frontal cortex) — plus the sensory (tabetic) atonic bladder.
- ▶ **Onuf's nucleus** (S2–S4 anterior horn) is the somatic motor nucleus for the external urethral (and anal) sphincter via the pudendal nerve; it is characteristically spared in motor neuron disease.
- ▶ **Enuresis is physiological up to 3–6 years** — corticospinal fibres to the sacral cord are not yet myelinated.
- ▶ **Retrograde ejaculation** follows sympathetic (hypogastric) nerve injury; nerve-sparing pelvic surgery protects the inferior hypogastric plexus during radical pelvic operations.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Textbook of Anatomy Vol 2 4e; Vishram Singh — Clinical Neuroanatomy 4e; IB Singh — Textbook of Human Neuroanatomy; Snell — Clinical Neuroanatomy 7e.



Applied aspects of venous drainage of lower limb

Asked in: Paper IV 14-Jul-2023 — RGUHS MD/MS Anatomy

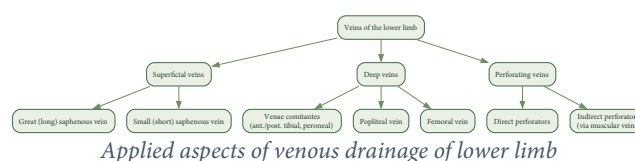
Definition / Introduction The venous drainage of the lower limb is of great clinical and surgical importance because venous blood must ascend against gravity in the erect posture. The veins are classified into **superficial, deep and perforating** groups. Superficial veins are more numerous in valves distally and drain, via perforators, into the deep veins, which are the true "workhorse" channels aided by muscular contraction. Failure of any component of this system — valves, muscle pump, or fascial support — underlies the two commonest applied conditions of the limb: **varicose veins** and **deep vein thrombosis (DVT)**.

1. Classification of veins and factors aiding venous return

The veins of the lower limb are classified anatomically and functionally as:

- **Superficial veins** — great (long) and small (short) saphenous veins and their tributaries, lying in the superficial fascia.
- **Deep veins** — venae comitantes of the plantar, tibial and peroneal arteries, the popliteal vein and the femoral vein, lying deep to the deep fascia alongside the arteries.
- **Perforating veins (perforators)** — connect superficial to deep veins, piercing the deep fascia; their valves permit **one-way flow only, from superficial to deep**.

Factor group	Components
General factors	Negative intrathoracic pressure (more negative on inspiration); arterial pressure/capillary overflow; compression of veins by adjacent arterial pulsation; valves dividing the long blood column into shorter segments and maintaining unidirectional flow
Local — venous	Lower-limb veins are more muscular and valve-rich than veins elsewhere; superficial veins connect to deep veins via perforators
Local — muscular	Contraction of calf muscles ("calf pump/peripheral heart") compresses deep veins and drives blood upward; the soleus contains venous sinuses (soleal sinuses) that are squeezed into the deep veins on contraction and refill from superficial veins on relaxation
Local — fascial	The tight sleeve of deep fascia limits outward muscle bulging, making the calf-pump action more effective



2. Superficial veins — great and small saphenous veins

The **great saphenous vein (GSV)** — the longest vein in the body and the preaxial vein of the limb — begins by union of the medial end of the dorsal venous arch with the medial marginal vein of the great

toe. It runs ~2.5 cm anterior to the medial malleolus (accompanied here by the **saphenous nerve**), crosses obliquely across the lower third of the medial tibial surface, ascends behind the medial border of the tibia, passes about a hand's-breadth posterior to the patella at the knee, and ascends the medial thigh to pierce the cribriform fascia at the **saphenous opening**, draining into the femoral vein. Its tributaries include the medial marginal vein; communicating veins and the **posterior arch vein** ("vein of Leonardo da Vinci") in the leg; anterior and posteromedial (accessory saphenous) veins in the thigh; and, just before termination, the superficial epigastric, superficial circumflex iliac and superficial external pudendal veins, with the deep external pudendal vein as the last tributary. The **thoracoepigastric vein** links the superficial epigastric vein to the lateral thoracic vein, forming a natural communication between the upper- and lower-limb venous systems. The GSV contains **10–20 valves**, the most important being the **saphenofemoral valve**, ~3.5–4 cm inferolateral to the pubic tubercle; in ~80% of people the external iliac vein also has a valve protecting this junction from high venous pressure — the remaining 20% are predisposed to varicose veins starting at the saphenofemoral junction.

The **small (short) saphenous vein (SSV)** — the postaxial vein — is formed behind the lateral malleolus by union of the lateral end of the dorsal venous arch with the lateral marginal vein, ascends along the lateral border of the tendocalcaneus and the midline of the calf (accompanied by the **sural nerve**), pierces the deep fascia in the lower popliteal fossa and drains into the **popliteal vein**. It carries 7–13 valves.

Feature	Great saphenous vein	Small saphenous vein
Origin	Medial end of dorsal venous arch	Lateral end of dorsal venous arch
Relation at ankle	Anterior to medial malleolus	Posterior to lateral malleolus
Accompanying nerve	Saphenous nerve	Sural nerve
Valves	10–20	7–13
Termination	Femoral vein (at saphenous opening)	Popliteal vein

3. Deep veins

The deep veins — medial and lateral plantar, dorsalis pedis, anterior and posterior tibial, peroneal, popliteal and femoral veins — accompany the corresponding arteries as paired *venae comitantes* below the knee, uniting into single large trunks above the knee. They are more valve-rich than superficial veins and are the principal channel for venous return once activated by the calf pump. Notably, the venous blood of the **thigh and leg flows from superficial to deep** (directed by perforator valves), whereas in the **foot** it flows from **deep (sole) to superficial (dorsum)** — an important functional reversal.

4. Perforating veins

Perforators are classified as **indirect** (connecting superficial to deep veins through intervening muscular veins) and **direct** (connecting the two systems directly); the great and small saphenous veins themselves are the largest direct perforators. About five to six named perforators are constant:

Named perforator	Connection
Adductor canal (Hunterian) perforator	GSV → femoral vein, in the lower adductor canal
Knee (Boyd's) perforator	GSV/posterior arch vein → posterior tibial vein, just below knee
Three medial ankle perforators (of Cockett) — upper, middle, lower	Posterior arch vein → posterior tibial vein, between mid-calf and medial malleolus
Lateral ankle perforator	SSV (or tributary) → peroneal vein, at junction of middle/lower third of leg

□ Fig 11.2b — Tributaries and perforating veins of the great saphenous vein (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.179)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled schematic of the venous system of the lower limb, showing:

- ▶ Dorsal venous arch (medial and lateral ends; medial and lateral marginal veins)
- ▶ Great saphenous vein — course anterior to medial malleolus → medial tibial surface → behind knee → saphenous opening → femoral vein; saphenofemoral valve
- ▶ Small saphenous vein — course behind lateral malleolus → midline of calf → popliteal fossa → popliteal vein
- ▶ Perforators labelled by name: Hunterian (adductor canal), Boyd's (knee), three Cockett's (medial ankle), lateral ankle perforator — with arrows showing one-way superficial→deep flow
- ▶ Deep veins: posterior tibial, anterior tibial, peroneal, popliteal, femoral
- ▶ Saphenous and sural nerves alongside their respective veins

Applied / Clinical anatomy

- ▶ **Venesection (cut-down):** The GSV in front of the medial malleolus is the most preferred site for surgical cut-down when peripheral veins elsewhere are collapsed/invisible, to secure IV access for fluids/blood. The saphenous nerve lies anterior to the vein here and must be identified and preserved.
- ▶ **Coronary artery bypass grafting (CABG):** A segment of GSV is harvested and used as an aortocoronary graft; it must be **reversed** before anastomosis so that its valves do not obstruct the new (arterial-direction) blood flow.
- ▶ **Varicose veins:** Defined as dilated, tortuous, superficial veins. Pathogenesis: incompetence of valves in the perforating veins converts them into "high-pressure leaks" that transmit deep-venous (muscle-pump) pressure to the superficial system, causing dilatation; alternatively, incompetence of the saphenofemoral valve allows reflux from the femoral vein, with varicosity beginning at the saphenofemoral junction and extending distally. Prolonged standing (bus conductors, traffic police, nurses) and pregnancy (gravid uterus compressing the iliac veins, usually resolving post-partum) are classic predisposing settings.
 - **Trendelenburg test:** Limb is elevated to empty the veins; pressure is applied over the saphenofemoral junction; on standing, quick refilling on releasing pressure indicates

superficial (valvular) incompetence, while gradual filling with pressure maintained indicates perforator incompetence.

- **Perthes' (tourniquet) test:** A tourniquet occludes the saphenous vein (not the femoral vein) at the thigh; the patient walks briskly — shrinking of varicosities implies patent, competent deep/perforating veins, while increased distension implies deep venous obstruction. Only superficial veins and perforators can be tested this way; deep veins cannot be assessed directly by these tests.
- **Management:** Sclerotherapy, laser ablation, or perforator ligation/stripping of the GSV when multiple perforators are defective.
- ▶ **Deep vein thrombosis (DVT):** The **soleal venous sinuses** are a common site of stasis-related thrombosis, particularly during prolonged bed rest or immobility (e.g., post-operative patients), since the calf pump is inactive. Dislodged thrombus fragments are carried in the venous return to cause life-threatening **pulmonary embolism**. Thrombosed perforators that later recanalise do so **without their valves**, predisposing to subsequent reflux and secondary varicosity.
- ▶ **Venous (varicose) ulcers:** Chronic venous stasis causes leakage of red cells into peri-venous tissue; breakdown of these cells deposits haemosiderin, producing brown pigmentation, while stasis-oedema renders the skin — classically over the lower leg and around the medial malleolus, the territory of the defective medial ankle perforators — unhealthy and prone to ulceration, especially after minor trauma.
- ▶ **Surface marking correlates:** Knowledge of the GSV's course (2.5 cm anterior to medial malleolus; a hand's-breadth posterior to the patella at the knee; saphenofemoral junction 3.5–4 cm inferolateral to the pubic tubercle) guides both venesection and identification of the site of surgical high-tie/ligation in varicose vein surgery.

High-yield exam pointers

- ▶ Veins of lower limb: **superficial, deep, perforating** — perforator valves permit superficial→deep flow only.
- ▶ GSV = longest vein in body; preaxial; anterior to medial malleolus; saphenous nerve accompanies it; 10–20 valves; ends in femoral vein at saphenous opening.
- ▶ SSV = postaxial; posterior to lateral malleolus; sural nerve accompanies it; ends in popliteal vein.
- ▶ Named perforators: **Hunterian** (adductor canal), **Boyd's** (knee), **Cockett's** (three medial ankle), lateral ankle perforator.
- ▶ **Soleus** = "**peripheral heart**" — soleal sinuses are the classic site of DVT origin and source of pulmonary embolism.
- ▶ Varicose veins: incompetent perforator/saphenofemoral valves → high-pressure leak → dilated, tortuous superficial veins; tested by **Trendelenburg** and **Perthes'** tests.
- ▶ GSV is the preferred site for venesection and is used (reversed) as a CABG graft.
- ▶ Foot is the exception: venous flow there runs deep (sole) → superficial (dorsum).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2, 8e; Vishram Singh — Textbook of Anatomy Vol 2, 4e.



Blood supply of Thyroid gland and its clinical importance

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction — The thyroid gland, though weighing only about 25 g, is one of the most vascular organs in the body, supplied by paired **superior** and **inferior thyroid arteries** (and, inconstantly, a **thyroid ima artery**), drained by three sets of thyroid veins into the internal jugular and brachiocephalic veins, and possessing rich lymphatics that follow the arterial pedicles. Because the recurrent and external laryngeal nerves run in intimate, variable relation to these vessels, the vascular anatomy of the thyroid is the anatomical basis of virtually every major complication of thyroid surgery — making this one of the most clinically loaded topics in head-and-neck anatomy.

Arterial supply

Artery	Origin	Course	Distribution	Key relation
Superior thyroid artery	First (anterior) branch of the external carotid artery	Descends with the external laryngeal nerve ; pierces pretracheal fascia at the apex of the lobe, where the nerve deviates medially and the artery divides into anterior/posterior branches	Anterior branch → anterior surface + upper border of isthmus (anastomoses with its fellow); posterior branch → lateral/medial surface (anastomoses with ascending branch of ITA). Supplies upper 1/3 of lobe, upper half of isthmus	External laryngeal nerve lies deep to the artery near the apex
Inferior thyroid artery	Branch of the thyrocervical trunk (subclavian artery)	Ascends along medial border of scalenus anterior, turns medially behind the carotid sheath and middle cervical ganglion, in front of the vertebral vessels, to the back of the lobe	4–5 glandular branches → inferior/posterior surface + lower half of isthmus; ascending branch anastomoses with posterior branch of STA and supplies the parathyroid glands	Recurrent laryngeal nerve relation highly variable — anterior to, posterior to, or between its branches

Artery	Origin	Course	Distribution	Key relation
Thyroid ima artery (inconstant; quoted incidence ~3–8% across texts)	Brachiocephalic trunk, or directly from arch of aorta	Ascends in front of the trachea	Enters the isthmus from below	Hazard during emergency tracheostomy
Accessory thyroid arteries	Tracheal and oesophageal arteries	—	Minor supplementary supply	—

The arteries are large relative to gland size, and their branches anastomose profusely both on and within the substance of the gland — ipsilaterally and contralaterally — accounting for the gland's characteristic high vascularity and the free bleeding encountered if surgical haemostasis is imprecise.

Venous drainage

- ▶ **Superior thyroid vein** — emerges at the upper pole, runs with the superior thyroid artery towards the carotid sheath, and drains into the **internal jugular vein**.
- ▶ **Middle thyroid vein** — a short, wide vessel emerging from the lateral surface at the middle of the lobe; drains directly into the **internal jugular vein**. Being short and unsupported, it is easily torn during mobilisation of the gland and is a frequent source of intraoperative bleeding if not ligated early.
- ▶ **Inferior thyroid vein(s)** — arise from a glandular venous plexus at the lower border of the isthmus, forming a **pretracheal venous plexus**; the left descends to join the **left brachiocephalic vein**, and the right crosses obliquely to join the **right brachiocephalic vein**/superior vena cava junction. They often open by a common trunk and have valves at their termination.
- ▶ **Vein of Kocher** (inconstant fourth thyroid vein) — emerges between the middle and inferior veins and drains into the internal jugular vein.
- ▶ A dense **venous plexus lies deep to the true (inner) capsule** of the gland, between the true and false (pretracheal fascial) capsules — an arrangement comparable to the venous plexus around the prostate. This is precisely why thyroidectomy is performed within the true capsule: the plane of cleavage leaves the plexus, and the parathyroid blood supply running with it, undisturbed on the tracheal wall.

Lymphatic drainage and nerve supply

- ▶ **Upper group** of lymphatics (following the superior thyroid vessels) drains to the **prelaryngeal (Delphian)** node and the **upper deep cervical (juglodigastric)** nodes.
- ▶ **Lower group** (following the inferior thyroid vessels) drains to the **pretracheal and paratracheal** nodes, nodes along the recurrent laryngeal nerves, and the **lower deep cervical** nodes.
- ▶ Lymph from the lower part of the isthmus may drain to **retrosternal/brachiocephalic nodes** in the superior mediastinum; occasionally thyroid lymphatics drain directly into the thoracic duct without an intervening node.
- ▶ **Nerve supply** is chiefly **sympathetic** — from the superior, middle (the largest contribution) and inferior cervical ganglia, reaching the gland along the course of the thyroid arteries; a parasympathetic contribution accompanies the vagus/recurrent laryngeal nerve. These fibres are

principally **vasomotor**, regulating glandular blood flow; hormone secretion itself is controlled by TSH, not by autonomic innervation.

Surgical anatomy of the vascular pedicle — the basis of "clinical importance"

This is the crux of why the blood supply of the thyroid is examined so heavily: the two named nerves that determine voice quality and airway safety travel with the two named arteries.

- ▶ **External laryngeal nerve** (branch of the superior laryngeal nerve, vagus) supplies cricothyroid, the tensor of the vocal fold. It runs with the superior thyroid artery but diverges near the apex, where the nerve lies **deep** and the artery **superficial**. Hence the **superior thyroid artery is ligated close to the gland (at the apex)**, not away from it — ligating high and away from the gland risks the nerve. Injury causes a subtle deficit — voice fatigue and loss of the higher register — rather than frank hoarseness.
- ▶ **Recurrent laryngeal nerve** supplies all intrinsic laryngeal muscles except cricothyroid and carries sensation below the vocal folds. Its relation to the inferior thyroid artery near the base is **markedly variable** (anterior to, posterior to, or between its branches), so this "danger zone" cannot be relied upon visually. Operative practice therefore avoids ligating the **main trunk** of the ITA in this variable zone: the trunk is ligated **well proximal to the gland** (still away from the nerve), or its **glandular branches ligated separately close to the capsule** (distal to where the nerve usually crosses) — both strategies spare the nerve and keep the ascending anastomotic branch to the **parathyroid glands** intact.
- ▶ The posterior part of the false capsule condenses into the **ligament of Berry**, binding the lobe to the cricoid cartilage; the recurrent laryngeal nerve lies close to it and is at particular risk of traction injury as the ligament is divided at the lower pole.
- ▶ An anomalous **non-recurrent laryngeal nerve** occurs almost exclusively on the right, associated with an aberrant right subclavian artery (arteria lusoria) from a left aortic arch; the nerve leaves the vagus directly and enters the larynx without "recurring," raising the risk of inadvertent transection.
- ▶ Because the gland is so richly vascular with free anastomoses, stepwise ligation of named vessels close to the capsule (rather than blunt dissection) is the operative principle that limits blood loss and nerve injury.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- Fig 8.7 — Arterial supply of the surfaces of thyroid gland. Sites of ligatures of the superior and inferior thyroid arteries are shown (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.175)

Reproduce this figure by hand with the following labels:

- ▶ Outline of thyroid gland (lobe)
- ▶ Superior thyroid artery, with its **site of ligation** marked close to the apex
- ▶ Anterior branch and posterior branch of the superior thyroid artery
- ▶ Anastomosing branch (across the upper border of the isthmus)
- ▶ External laryngeal nerve — running alongside, then diverging deep to, the superior thyroid artery near the apex
- ▶ Thyrocervical trunk arising from the subclavian artery, with scalenus anterior, transverse cervical and suprascapular arteries shown for origin context
- ▶ Inferior thyroid artery, with its ascending branch anastomosing with the posterior branch above
- ▶ Inferior laryngeal artery (terminal branch of the inferior thyroid artery)
- ▶ Recurrent laryngeal nerve — shown close to the lower/posterior aspect of the gland, near the terminal branches of the inferior thyroid artery

Recent advances in vascular/neural mapping during thyroid surgery

- ▶ **Intraoperative neuromonitoring (IONM) of the recurrent laryngeal nerve:** a meta-analysis of RCTs (2,521 patients, 4,977 nerves at risk) found IONM did not significantly lower RLN injury versus visualisation alone (2.3% vs 3.2%, $p = 0.06$), but it remains valuable for real-time confirmation and for detecting anomalies such as the non-recurrent laryngeal nerve, prevalence ~0.7% right/0.04% left, linked to an aberrant subclavian artery (Davey et al, *Am J Surg* 2022 [DOI](<https://doi.org/10.1016/j.amjsurg.2022.03.036>); Inversini et al, *J Investig Med High Impact Case Rep* 2024 [DOI](<https://doi.org/10.1177/23247096241273099>)).
- ▶ **Indocyanine green (ICG) near-infrared angiography** now maps the feeding vessels of the parathyroid glands before dissection, so the surgeon can preserve a well-perfused gland supplied via the ascending branch of the inferior thyroid artery (Moreno-Llorente et al, *Front Surg* 2023) [DOI](<https://doi.org/10.3389/fsurg.2023.1217764>).
- ▶ A controlled trial combining **near-infrared autofluorescence with pre-resection ICG angiography** during total/completion thyroidectomy cut one-year hypoparathyroidism from 12.3% to 6.5% (adjusted OR 0.16, 95% CI 0.05–0.56) (Michaelsen et al, *Surgery* 2025) [DOI](<https://doi.org/10.1016/j.surg.2025.109623>).

(According to PubMed.)

Applied / Clinical anatomy

- ▶ **Thyroidectomy planes:** total thyroidectomy removes the gland with its true capsule; **subtotal thyroidectomy** deliberately leaves the posterior parts of both lobes (with their parathyroid-supplying vessels) behind, avoiding hypoparathyroidism/hypocalcaemia and post-operative myxoedema.

- ▶ **Nerve palsies:** unilateral RLN injury causes hoarseness (cord paramedian); bilateral injury apposes both cords near the midline, causing stridor/airway obstruction needing emergency tracheostomy. External laryngeal nerve injury gives a weak, easily-fatigued voice with loss of the higher register — often missed since gross hoarseness is absent.
- ▶ **Goitre and pressure effects:** fixed superiorly by its fascial sheath and sternothyroid, the gland enlarges backwards/downwards, producing the classic 3 D's — dyspnoea (tracheal), dysphagia (oesophageal), dysphonia (RLN, in the tracheo-oesophageal groove); downward extension as **retrosternal goitre** can additionally compress the great veins, causing venous engorgement.
- ▶ **Tracheostomy hazard:** an inconstant thyroid ima artery crossing in front of the trachea below the isthmus must be sought for and controlled to avoid brisk haemorrhage.
- ▶ **Imaging correlate:** the gland's superficial position and high vascularity make it ideal for ultrasound (gland volume, nodules); it shows intense CT contrast enhancement and increased T2-MRI signal, while radionuclide imaging (^{99m}Tc -pertechnetate, $^{123}\text{I}/^{131}\text{I}$) exploits its iodine trapping to assess function and detect ectopic tissue.
- ▶ **Nodal spread in carcinoma:** since lymphatics follow the arterial pedicles, papillary carcinoma spreads first to the central (pretracheal/paratracheal, "level VI") compartment before lateral deep cervical nodes — the rationale for central-compartment clearance in thyroid cancer surgery.

High-yield exam pointers

- ▶ Superior thyroid artery = first branch of external carotid; inferior thyroid artery = branch of thyrocervical trunk of subclavian; thyroid ima artery (inconstant) = from brachiocephalic trunk/aortic arch.
- ▶ External laryngeal nerve is intimately related to the superior thyroid artery near the apex (nerve deep, artery superficial) — ligate the artery close to the gland.
- ▶ Recurrent laryngeal nerve has a highly variable relation to the inferior thyroid artery near the base — never rely on the artery as a landmark; identify the nerve directly.
- ▶ Ascending branch of the inferior thyroid artery is the main supply to the parathyroid glands — must be preserved.
- ▶ Three thyroid veins (superior, middle, inferior) $\pm$ inconstant vein of Kocher; middle vein drains directly and shortly into the IJV and tears easily.
- ▶ Dense venous plexus deep to the true capsule dictates the surgical plane of thyroidectomy (compare prostatic capsule).
- ▶ Lymphatics follow the arteries — upper group to prelaryngeal/upper deep cervical nodes, lower group to pretracheal/paratracheal/lower deep cervical nodes.
- ▶ Classic pressure triad of goitre: dyspnoea, dysphagia, dysphonia (the "3 D's").
- ▶ Non-recurrent laryngeal nerve (right-sided anomaly with aberrant subclavian artery) is a recognised operative pitfall.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3–4 (8e); Vishram Singh's Textbook of Anatomy Vol 3 (4e); IB Singh's Textbook of Anatomy Vol 3 (6e).



Branches of vagus nerve in the thorax and neck

Asked in: Paper IV 14-Jul-2023 — RGUHS MD/MS Anatomy

Definition / Introduction The **vagus nerve (CN X)** is the tenth cranial nerve and the longest-coursing of all cranial nerves, extending from the medulla oblongata through the neck and thorax into the abdomen as far as the distal third of the transverse colon. It is a mixed nerve containing **general somatic afferent (GSA)**, **general visceral afferent (GVA)**, **general visceral efferent (GVE, parasympathetic)** and **special visceral/branchial efferent (SVE)** fibres, and it also carries the functional (cranial) root of the accessory nerve, distributed through its pharyngeal and recurrent laryngeal branches. It exits the skull through the **jugular foramen** bearing two sensory ganglia — the **superior (jugular) ganglion** and the **inferior (nodose) ganglion** — and gives off a graded series of branches as it descends through the neck and thorax before reaching the oesophageal hiatus of the diaphragm.

Origin, ganglia and course overview

- ▶ **Nuclei of origin:** dorsal (motor) nucleus of vagus (GVE — parasympathetic to thoracic/abdominal viscera), nucleus ambiguus (SVE — striated muscle of pharynx, larynx, upper oesophagus), and nucleus tractus solitarius/spinal trigeminal nucleus (GVA/GSA).
- ▶ **Exit:** a series of rootlets in the groove between the olive and inferior cerebellar peduncle → jugular foramen (in a common dural/arachnoid sheath with the accessory nerve).
- ▶ **Superior (jugular) ganglion:** small, round (~4 mm), within the jugular foramen; mainly somatic (GSA) neurones; gives the meningeal and auricular branches.
- ▶ **Inferior (nodose) ganglion:** larger, cylindrical (~25 mm × 5 mm), just below the foramen; site of most visceral afferent (GVA) cell bodies (heart, larynx, lungs, alimentary tract to transverse colon; taste from vallecula/epiglottis).
- ▶ The **cranial root of the accessory nerve** joins the vagus just below the inferior ganglion and is distributed in its pharyngeal and recurrent laryngeal branches.
- ▶ **Course in the neck:** descends vertically within the **carotid sheath**, between the internal jugular vein (laterally) and the internal, then common, carotid artery (medially), to the root of the neck.
- ▶ **Entry into the thorax** differs on the two sides (detailed below) — this asymmetry, and its consequence for the recurrent laryngeal nerve, is the single most examination-relevant fact about this topic.

Branches in the neck

Branch	Origin	Course	Distribution
Meningeal branch	Superior (jugular) ganglion	Passes back through the jugular foramen	Dura mater of the posterior cranial fossa
Auricular branch (Arnold's nerve)	Superior ganglion (joined by a twig from the inferior ganglion of IX)	Mastoid canaliculus → crosses the facial canal ~4 mm above the stylomastoid foramen (gives ascending twig to facial nerve) → tympanomastoid fissure	Skin of the auricle and floor/posterior wall of the external acoustic meatus — the only cutaneous sensory branch of CN X
Pharyngeal branch	Upper part of the inferior (nodose) ganglion	Passes between the internal and external carotid arteries to the upper border of middle constrictor; joins glossopharyngeal and sympathetic twigs to form the pharyngeal plexus	Chief motor nerve of the pharynx (all pharyngeal muscles) and soft palate, except stylopharyngeus (IX) and tensor veli palatini (mandibular nerve)
Branch to carotid body	Variable — from the inferior ganglion, or travelling in the pharyngeal or superior laryngeal nerve	Joins glossopharyngeal rami and sympathetic branches	Chemoreceptor plexus of the carotid body
Superior laryngeal nerve	Middle of the inferior ganglion	Descends alongside the pharynx (posterior, then medial, to the internal carotid artery) and divides at the level of the hyoid into internal and external laryngeal nerves	See below
— Internal laryngeal nerve	Larger division	Pierces the thyrohyoid membrane with the superior laryngeal vessels	Sensory to laryngeal mucosa above the vocal folds, epiglottis, vallecula; afferents from laryngeal stretch receptors
— External laryngeal nerve	Smaller division	Descends behind sternohyoid with the superior thyroid artery, curves round the inferior thyroid tubercle	Motor to cricothyroid only (the one laryngeal muscle <i>not</i> supplied by the recurrent laryngeal nerve)
Cervical cardiac branches (superior + inferior)	Superior branch high in the neck, inferior branch low in the neck	Descend along the carotid sheath and enter the thorax through the thoracic inlet	Join the (superficial/deep) cardiac plexus ; carry preganglionic parasympathetic fibres to the heart

Branch	Origin	Course	Distribution
Right recurrent laryngeal nerve	Arises from the right vagus as it crosses anterior to the first part of the right subclavian artery	Hooks backwards and upwards below then behind the subclavian artery, ascends in the tracheo-oesophageal groove, related to the inferior thyroid artery near the thyroid lower pole	Motor to all intrinsic laryngeal muscles except cricothyroid; sensory to mucosa below the vocal folds. Unlike the left, it is given off entirely in the neck/root of neck and never enters the thorax

Branches in the thorax

The right and left vagi differ markedly in their thoracic course because of the asymmetric development of the aortic arch system.

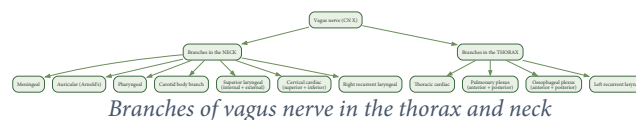
Feature	Right vagus	Left vagus
Entry into thorax	Crosses anterior to the first part of the right subclavian artery , posterior to the right brachiocephalic vein	Passes between the left common carotid and left subclavian arteries, posterior to the left brachiocephalic vein
Key thoracic branch	Contributes only cardiac, pulmonary and oesophageal branches (recurrent laryngeal already given off in the neck)	Crosses the left side of the arch of the aorta and here gives off the left recurrent laryngeal nerve , which hooks below and behind the arch, immediately behind the attachment of the ligamentum arteriosum , and ascends in the tracheo-oesophageal groove to the larynx
Relation to lung root	Passes posterior to the root of the right lung	Passes posterior to the root of the left lung (also contributing anteriorly)
Relation to oesophagus	Continues on the posterior surface of the oesophagus	Continues on the anterior surface of the oesophagus

Branches common to both vagi in the thorax:

- **Thoracic cardiac branches** — join the **deep (dorsal) part of the cardiac plexus**, lying between the arch of the aorta and the tracheal bifurcation, along with sympathetic cardiac branches and (on the left) a twig from the recurrent laryngeal nerve.
- **Pulmonary branches** — form the **anterior pulmonary plexus** (smaller, anterior to the lung root) and **posterior pulmonary plexus** (larger, posterior to the lung root); motor (bronchoconstrictor) to bronchial smooth muscle and secretomotor to bronchial mucous glands.
- **Oesophageal branches** — surround the oesophagus below the level of the lung roots as the **oesophageal plexus**; motor to the smooth muscle of the lower oesophagus and secretomotor to its mucous glands.
- **Left recurrent laryngeal nerve** (left side only, as above) — gives cardiac filaments to the deep cardiac plexus as it hooks round the aortic arch.

Formation of the vagal trunks

- ▶ Below the level of the lung roots, vagal fibres condense around the oesophagus into an **anterior oesophageal plexus** (formed mainly by the **left vagus**) and a **posterior oesophageal plexus** (formed mainly by the **right vagus**).
- ▶ These converge into the **anterior vagal trunk** (mainly left-vagus fibres) and **posterior vagal trunk** (mainly right-vagus fibres).
- ▶ This left-anterior/right-posterior arrangement results from the embryonic **90° clockwise rotation of the stomach** about its craniocaudal axis, which carries the originally left-sided vagal plexus ventrally and the right-sided plexus dorsally.
- ▶ Both trunks pass through the **oesophageal opening of the diaphragm (T10)** into the abdomen: the posterior (right) trunk supplies the posterior stomach and, via a large coeliac branch, the liver, kidneys and gut up to the distal transverse colon (coeliac, superior mesenteric and renal plexuses); the anterior (left) trunk supplies the stomach, liver, and upper duodenum/head of pancreas.



□ Fig 10.16 — Distribution of vagus nerve (CN X). A. Overview. After supplying the p (Moore — Clinically Oriented Anatomy — 9e, p.1719)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the vagus emerging from the jugular foramen with its superior and inferior ganglia, then a single vertical trunk in each of the neck and thorax with branches labelled off it:

- ▶ Jugular foramen; **superior ganglion**; **inferior (nodose) ganglion**; cranial root of XI joining the vagus
- ▶ Neck branches (label each as a side-twig): meningeal; auricular (Arnold's); pharyngeal (→ pharyngeal plexus); carotid body branch; superior laryngeal nerve dividing into internal + external laryngeal nerves; superior and inferior cervical cardiac branches; **right recurrent laryngeal nerve hooking under the right subclavian artery**
- ▶ Root of neck: right vagus crossing anterior to the right subclavian artery; left vagus passing between left common carotid and left subclavian arteries
- ▶ Thorax: left vagus crossing the arch of the aorta giving the **left recurrent laryngeal nerve hooking below the ligamentum arteriosum**; both vagi giving thoracic cardiac branches to the cardiac plexus, pulmonary branches to the anterior/posterior pulmonary plexus at the lung root, and oesophageal branches forming the oesophageal plexus
- ▶ Convergence below the lung roots into the **anterior vagal trunk** (left, anterior to oesophagus) and **posterior vagal trunk** (right, posterior to oesophagus) passing through the oesophageal hiatus

Applied / Clinical anatomy

- ▶ **Recurrent laryngeal nerve palsy**: unilateral injury → hoarseness/dysphonia (cord fixed in paramedian position); bilateral acute injury → aphonia with inspiratory stridor, a surgical emergency. The right RLN is vulnerable in the **neck** near the inferior thyroid artery/ligament of Berry during thyroidectomy; the **left RLN**, being entirely intrathoracic in its origin, is characteristically involved by mediastinal disease — aortic arch aneurysm, left atrial enlargement, bronchogenic or oesophageal carcinoma, enlarged para-aortic nodes (**cardiovocal/Ortner syndrome**).
- ▶ **External laryngeal nerve injury** (e.g., during superior thyroid vessel ligation) paralyses cricothyroid → weak, easily-tiring voice, initially compensated by the opposite cricothyroid.
- ▶ **Auricular branch (Arnold's nerve)**: mechanical stimulation of the external acoustic meatus (syringing, otoscopy) can trigger a vasovagal reflex — cough (Arnold's/ear-cough reflex), bradycardia, or syncope.
- ▶ **Vagotomy** (truncal, selective, or highly selective/parietal-cell) for peptic ulcer disease divides the anterior and/or posterior vagal trunks near the oesophageal hiatus; truncal vagotomy denervates the pylorus and requires a drainage procedure (pyloroplasty/gastrojejunostomy) to prevent gastric stasis, and may cause post-vagotomy diarrhoea.
- ▶ **Cardiac branches** mediate the vagal (parasympathetic) limb of reflex bradycardia (carotid sinus massage, Bezold–Jarisch reflex, vasovagal syncope) and are the target of vagal nerve stimulation therapies.
- ▶ **Pharyngeal branch loss** (bilateral vagal lesion) causes palatal asymmetry — uvula/soft palate is drawn towards the *normal* side on phonation ("curtain sign").

High-yield exam pointers

- ▶ CN X is the **only cranial nerve** with a course extending beyond the head and neck into the thorax and abdomen.
- ▶ Two ganglia: **superior (jugular)** — somatic, gives meningeal + auricular branches; **inferior (nodose)** — visceral, site of most GVA cell bodies, gives pharyngeal, laryngeal, cardiac, pulmonary and oesophageal branches.
- ▶ **Cranial root of XI** functionally travels with the vagus, distributed via its pharyngeal and recurrent laryngeal branches to soft palate, pharynx and larynx.
- ▶ **Right RLN loops under the subclavian artery in the root of the neck; left RLN loops under the arch of the aorta (ligamentum arteriosum) in the thorax** — the single most-tested fact, explaining why the left nerve has the longer intrathoracic course and greater surgical/pathological vulnerability.
- ▶ **External laryngeal nerve** → cricothyroid only; **recurrent laryngeal nerve** → all other intrinsic laryngeal muscles.
- ▶ **Auricular branch (Arnold's nerve)** = the only cutaneous sensory territory of the vagus.
- ▶ Thoracic branches of both vagi: **cardiac** → deep cardiac plexus; **pulmonary** → anterior/posterior pulmonary plexus; **oesophageal** → oesophageal plexus.
- ▶ **Anterior vagal trunk** = mainly left vagus; **posterior vagal trunk** = mainly right vagus — consequence of the 90° embryonic rotation of the stomach; both traverse the oesophageal hiatus (T10) into the abdomen.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Moore's Clinically Oriented Anatomy 9e; Snell's Clinical Neuroanatomy 7e; BD Chaurasia Vol 3–4 8e; IB Singh Textbook of Anatomy Vol 2 & Vol 3 6e and Textbook of Human Neuroanatomy; Vishram Singh Textbook of Anatomy Vol 3 4e; Larsen Human Embryology 6e (recurrent laryngeal nerve embryology).



Cardiac plexus

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction The **cardiac plexus** is a mixed autonomic (sympathetic + parasympathetic) nerve plexus lying in the superior and posterior mediastinum, formed by cardiac branches of the vagus nerves and the cervical/upper thoracic sympathetic trunks, which converge on the great vessels at the root of the heart. It is conventionally described as a **superficial (ventral)** part below the arch of the aorta and a larger **deep (dorsal)** part in front of the tracheal bifurcation, each continuing onto the heart as coronary, pulmonary and atrial extensions. Initiation of the cardiac cycle is myogenic (sino-atrial node), but its rate and force are harmonised by this plexus, which also carries the visceral afferents responsible for cardiac reflexes and referred (anginal) pain.

1. Location and gross relations

Feature	Superficial (ventral) part	Deep (dorsal) part
Position	Below the arch of the aorta, in front of the right pulmonary artery, just to the right of the ligamentum arteriosum	In front of the bifurcation of the trachea , above the bifurcation of the pulmonary trunk, behind the arch of the aorta
Size	Small	Larger; forms right and left halves
Special feature	A small cardiac ganglion (of Wrisberg) usually lies here, close to the ligamentum arteriosum	Right half surrounds the brachiocephalic trunk; left half surrounds the aortic arch
Connections	Continuous with the deep part, the right coronary plexus, and the left anterior pulmonary plexus	Continuous with the superficial part on the left side; gives right/left coronary and pulmonary plexuses

2. Formation — sympathetic contribution

Preganglionic sympathetic axons arise in the intermediolateral cell column of the **upper four to five thoracic spinal segments (T1–T5)**; some synapse in the corresponding upper thoracic ganglia, others ascend the sympathetic trunk to synapse in the cervical ganglia. Postganglionic fibres form the sympathetic (cardiopulmonary splanchnic) cardiac nerves:

Sympathetic cardiac nerve	Ganglion of origin	Joins
Superior cervical cardiac branch	Superior cervical ganglion	Left → superficial plexus ; Right → deep plexus
Middle cervical cardiac branch	Middle cervical ganglion	Deep plexus (both sides)
Inferior cervical cardiac branch	Inferior cervical (stellate) ganglion	Deep plexus (both sides)
Thoracic cardiac branches	Upper thoracic ganglia (approx. T2–T5)	Deep plexus (both sides)

Sympathetic stimulation is **cardio-accelerator**: it increases heart rate, conduction velocity and force of contraction, and dilates the coronary arteries (mediated chiefly by β -adrenoceptors on the vessel wall).

3. Formation — parasympathetic (vagal) contribution

Preganglionic parasympathetic axons arise from neurones of the **dorsal nucleus of the vagus** (and cells near the nucleus ambiguus), and travel in vagal cardiac branches to relay in the cardiac plexus and in intrinsic ganglia within the atrial walls:

Vagal cardiac nerve	Joins
Superior cervical cardiac branch of vagus	Deep plexus (both sides)
Inferior cervical cardiac branch of vagus	Left → superficial plexus ; Right → deep plexus
Thoracic cardiac branches of vagus	Deep plexus
Branches from the recurrent laryngeal nerve	Deep plexus

Parasympathetic (vagal) stimulation is **cardio-inhibitory**: it slows heart rate and conduction, reduces contractile force, and constricts the coronary arteries.

Key formation rule (high-yield): the superficial cardiac plexus is formed by only **two** nerves, and both are from the **left side** — the superior cervical (sympathetic) cardiac branch and the inferior cervical (vagal) cardiac branch. Every other cardiac branch, from both sides, joins the deep plexus.

embed: ![Fig 21.25 — ■ Superficial cardiac plexus. (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.860)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/5431855623aaa0c0.jpg)

embed: ![Fig 21.26 — ■ Deep cardiac plexus. (A) Parasympathetic (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.861)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/72ad0b579eddc108.jpg)

4. Distribution and extensions

- ▶ **Superficial plexus** → sends fibres to (a) the deep plexus, (b) the right coronary plexus, and (c) the **left anterior pulmonary plexus**.
- ▶ **Deep plexus — right half**: surrounds the brachiocephalic trunk; fibres passing anterior to the right pulmonary artery (the more numerous) supply the right anterior pulmonary plexus and continue into the **right coronary plexus**; fibres passing posterior to the right pulmonary artery supply the right atrium and continue into the **left coronary plexus**.
- ▶ **Deep plexus — left half**: connected to the superficial part; supplies the left atrium and left anterior pulmonary plexus, and forms most of the **left coronary plexus**.
- ▶ **Right coronary plexus**: formed from both superficial and deep parts; accompanies the right coronary artery to supply the right atrium and ventricle.
- ▶ **Left coronary plexus**: larger than the right; formed mainly from the left half of the deep plexus with a few fibres from the right half; accompanies the left coronary artery to supply the left atrium and ventricle.

- ▶ **Atrial plexuses:** derivatives of the right and left coronary-plexus continuations, distributed to the corresponding atria, overlapping the coronary supply.
- ▶ **Anterior and posterior pulmonary plexuses:** the anterior pulmonary plexus is an extension of the deep cardiac plexus; the posterior pulmonary plexus is formed independently from vagal and T2–T5 sympathetic branches.

5. Ganglion cells within the plexus

- ▶ **Cardiac ganglion (of Wrisberg):** a small ganglion in the superficial part, close to the ligamentum arteriosum.
- ▶ **Intrinsic cardiac ganglia:** confined largely to the atria and interatrial septum, most numerous in the subepicardial connective tissue near the sino-atrial and atrioventricular nodes; their axons are believed to be largely, if not exclusively, **postganglionic parasympathetic**. These ganglia are not simple relay stations — they integrate extrinsic autonomic input and may support local cardiac reflexes.

6. Functional/density pattern of innervation

- ▶ Cholinergic (vagal) and adrenergic (sympathetic) fibres arising in or traversing the cardiac plexus are distributed **most profusely to the sino-atrial and atrioventricular nodes**; the supply to atrial and ventricular working myocardium is much less dense.
- ▶ Adrenergic fibres also supply the coronary arteries and cardiac veins directly.
- ▶ Rich subendocardial and valvular-leaflet plexuses contain cholinergic, adrenergic and peptidergic (e.g. neuropeptide Y) fibres.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label a single composite scheme of the cardiac plexus (as classically drawn from an anterior dissection of the superior/posterior mediastinum after removing the ascending aorta):

- ▶ Trachea and its bifurcation; arch of aorta; pulmonary trunk and its bifurcation; ligamentum arteriosum
- ▶ Right and left vagus nerves, with superior cervical, inferior cervical and thoracic cardiac branches labelled; right and left recurrent laryngeal nerves
- ▶ Right and left sympathetic trunks with superior, middle and inferior (stellate) cervical ganglia and upper thoracic ganglia; their cardiac (cardiopulmonary splanchnic) branches
- ▶ **Superficial cardiac plexus** (below aortic arch, right of ligamentum arteriosum) with the cardiac ganglion of Wrisberg
- ▶ **Deep cardiac plexus** (in front of tracheal bifurcation, behind aortic arch), shown as right and left halves
- ▶ Arrows/labels for right and left coronary plexuses, anterior/posterior pulmonary plexuses, and atrial plexuses continuing onto the heart

Applied / Clinical anatomy

- ▶ **Cardiac referred pain (angina pectoris):** ischaemic pain impulses travel centrally along the sympathetic (middle/inferior cervical and thoracic) cardiac nerves to reach spinal segments T1–

T5, chiefly through the left-sided dorsal root ganglia. Because these same ganglia also receive somatic afferents from the medial arm/forearm (via the medial cutaneous nerve of the arm) and anterior chest wall, pain is referred to the precordium, left shoulder and medial upper limb; bilateral spinal (commissural) connections occasionally refer pain to the neck, jaw, right side or back.

- ▶ **Cardiovascular reflexes:** vagal (parasympathetic) afferents from the heart run in cardiac branches to the reticular formation, mediating reflex bradycardia/hypotension — the anatomical basis of vasovagal responses and of the bradycardia sometimes seen with inferior-wall myocardial ischaemia.
- ▶ **Ortner's (cardiovocal) syndrome:** gross enlargement of the left atrium (e.g. mitral stenosis) can compress the left recurrent laryngeal nerve as it hooks below the aortic arch close to the superficial cardiac plexus and ligamentum arteriosum, producing hoarseness of voice — a direct clinical correlate of the plexus's close relations.
- ▶ **Stellate ganglion block / thoracic sympathectomy:** interrupts sympathetic cardiac afferents and is used for intractable angina and some arrhythmias, exploiting the fact that cardiac pain fibres travel exclusively in the sympathetic (not vagal) pathway.
- ▶ **Surgical relevance:** the deep cardiac plexus, lying immediately anterior to the tracheal bifurcation and posterior to the great vessels, is vulnerable during mobilisation of the aortic arch, pulmonary trunk and hilar dissection; the superficial plexus and cardiac ganglion of Wrisberg lie close to the ligamentum arteriosum, relevant during PDA ligation.
- ▶ The heart itself is **insensitive to touch, cutting, heat or cold**; only ischaemia and accumulated metabolic products excite the nociceptive afferents carried in this plexus — explaining the classically "silent" nature of direct cardiac trauma versus the severe pain of ischaemia.

High-yield exam pointers

- ▶ Superficial cardiac plexus = only 2 nerves, both from the **left**: left superior cervical (sympathetic) + left inferior cervical (vagal) cardiac branches.
- ▶ Deep cardiac plexus = **all remaining** cardiac branches of both vagi, both sympathetic trunks (cervical + upper thoracic), and the recurrent laryngeal nerves.
- ▶ Location: superficial — below aortic arch, right of ligamentum arteriosum; deep — in front of tracheal bifurcation, behind aortic arch.
- ▶ Cardiac ganglion of **Wrisberg** sits in the superficial plexus near the ligamentum arteriosum; **intrinsic ganglia** cluster near the SA/AV nodes.
- ▶ Sympathetic = T1–T5 preganglionic → cardio-accelerator + coronary vasodilator; vagal = dorsal vagal nucleus → cardio-inhibitory + coronary vasoconstrictor.
- ▶ Innervation density: SA/AV nodes >> atrial/ventricular myocardium.
- ▶ Right coronary plexus from both superficial + deep parts; left coronary plexus mainly from the deep plexus's left half.
- ▶ Pain fibres from the heart travel only via the **sympathetic** route to T1–T5 segments — the anatomical basis of anginal referred pain.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh — Textbook of Anatomy Vol 1 4e; BD Chaurasia — Human Anatomy Vol 1 8e; BD Chaurasia — Human Anatomy Vol 3-4 8e; Moore's Clinically Oriented Anatomy 9e.



Clinical anatomy of femoral canal

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction

The femoral canal is the medial, smallest and most clinically important of the three compartments of the femoral sheath — the funnel-shaped fascial tube that carries the femoral vessels from the abdomen into the front of the thigh, deep to the inguinal ligament. It is a short, conical, fat- and lymph-node-containing passage lying just medial to the femoral vein, closed above by the femoral septum and shut off below by fusion of its walls. Though functionally it exists only to give the femoral vein room to expand, the femoral canal is the single most important site of potential weakness in the groin, being the pathway through which a **femoral hernia** protrudes — an acquired, female-predominant hernia with a notoriously high risk of strangulation. Its precise boundaries, contents and relations are therefore high-yield both for gross anatomy and for surgical/clinical correlation.

Femoral sheath — formation, extent and compartments

- ▶ The **femoral sheath** is a funnel-shaped fascial sleeve enclosing the upper 3–4 cm of the femoral vessels as they pass deep to the inguinal ligament from the abdomen into the femoral triangle.
- ▶ **Formation:** it is a downward prolongation of the two fasciae lining the abdominal wall —
 - **Anterior wall** = **fascia transversalis** (lining the transversus abdominis).
 - **Posterior wall** = **fascia iliaca** (covering iliacus and psoas major).
- ▶ Inferiorly the sheath disappears by blending with the tunica adventitia of the femoral vessels, about 4 cm below the inguinal ligament.
- ▶ The sheath is **asymmetrical**: its lateral wall is vertical while its medial wall slopes downward and laterally — this obliquity is what directs an enlarging femoral hernia forward and then upward.
- ▶ Two anteroposterior **septa** subdivide the sheath into three compartments:

Compartment	Position	Contents
Lateral (arterial)	Most lateral	Femoral artery + femoral branch of the genitofemoral nerve
Intermediate (venous)	Middle	Femoral vein
Medial (lymphatic) = femoral canal	Most medial; smallest	Femoral canal (described below)

- ▶ The **femoral nerve** lies lateral to the artery in the groove between iliacus and psoas major, **outside** the femoral sheath altogether (it lies behind the fascia iliaca, which forms the sheath's posterior wall) — a frequently tested point of contrast with the femoral vessels.

Femoral canal — dimensions, femoral ring and contents

- ▶ **Shape and size:** a short, conical fascial tube, wide above and tapering to a blind lower end; approximately 1.25–1.5 cm long and up to 1.5 cm wide at its base.
- ▶ Below the inguinal ligament the canal lies **posterior** to the saphenous opening/cribriform fascia and **anterior** to the fascia covering pectineus.
- ▶ The **upper, wider end** of the canal — the point where it opens into the abdominal cavity — is the **femoral ring**, whose boundaries are:

Boundary	Structure
Anterior	Inguinal ligament
Posterior	Pecten pubis (superior ramus of pubis), covered by pectineus and its fascia
Medial	Sharp, concave (free) margin of the lacunar ligament
Lateral	Septum separating the ring from the femoral vein

- ▶ The **inferior epigastric vessels** lie close to the junction of the anterior and lateral walls of the ring — relevant when the ring is enlarged surgically.
- ▶ The femoral ring is normally sealed by a condensation of extraperitoneal connective tissue, the **femoral septum**; the parietal peritoneum draping this septum from above produces a shallow depression, the **femoral fossa**.
- ▶ **Contents of the canal:** loose areolar/fatty tissue, lymphatic vessels, and the middle of the **three deep inguinal lymph nodes** — the **node of Cloquet (Rosenmüller's node)** — draining the glans penis/clitoris and communicating upward with the external iliac nodes through the femoral septum. (Of the three deep inguinal nodes, the lowest lies below the saphenofemoral junction, the middle — Cloquet's node — lies in the canal, and the highest lies at the ring.)
- ▶ **Function:** the canal is essentially a reserved potential space that allows the femoral vein to distend when venous return rises or intra-abdominal pressure is transiently raised (e.g. Valsalva manoeuvre, coughing) — and it is precisely this "give" that is exploited when abdominal contents herniate into it.

□ Fig 23.18 — ■ *Boundaries of femoral ring.* (Vishram Singh — *Textbook of Anatomy Vol 2* — 4e, p.969)

□ Fig 3.18 — *Femoral canal and the course of a femoral hernia* (BD Chaurasia — *Human Anatomy Vol 2* — 8e, p.84)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Cross-section at the level of the femoral ring** (as in the first plate above) — label: lateral cutaneous nerve of thigh; fascia iliaca; inguinal ligament; iliacus; femoral nerve; iliopectineal arch; psoas major and psoas fascia; femoral artery; femoral vein; pectineus; pecten pubis; lacunar ligament; femoral ring.
- ▶ **Sagittal section through the groin/femoral canal** (as in the second plate above) — label: skin, superficial fascia; external oblique aponeurosis, internal oblique, transversus abdominis; fascia transversalis; peritoneum; fascia iliaca; inguinal ligament; spermatic cord; femoral fossa; pectineal fascia; femoral septum; lymph node of Cloquet; pectineus; femoral canal; cribriform fascia; course of femoral hernia (arrow); fascia lata; adductor longus.

Anatomical basis, course and coverings of a femoral hernia

- ▶ **Anatomical basis:** the femoral ring is a fixed-size, rigid-walled defect (bone posteriorly, ligaments anteriorly and medially, vein laterally) in the floor of the abdomen. Any factor that raises intra-abdominal pressure or widens the ring (pregnancy, chronic cough, straining, obesity) can force a peritoneal sac, carrying a loop of intestine or omentum, into the canal — a **femoral hernia**.
- ▶ **Course of the hernial sac** is typical and testable:

Step	Direction	Structure traversed
1	Downwards	Through the femoral canal
2	Forwards	Through the saphenous opening, bulging through the cribriform fascia
3	Upwards	Along the superficial epigastric and superficial circumflex iliac vessels, in the superficial fascia of the thigh (may make the swelling U-shaped if it enlarges further)

- ▶ Manual reduction of the hernia follows this course **in reverse**.
- ▶ **Coverings of the sac**, superficial to deep: skin → superficial fascia → cribriform fascia → femoral sheath → femoral septum (with peritoneum forming the sac itself).
- ▶ **Why more common in females:** a wider pelvis, a relatively larger femoral ring/canal, and smaller femoral vessels together give women a roomier femoral canal than men — femoral hernia is markedly commoner in women, though inguinal hernia remains the commonest groin hernia overall in both sexes.
- ▶ **Femoral hernia is never congenital** — unlike indirect inguinal hernia, it has no embryological (processus vaginalis) basis and is always acquired.
- ▶ **Strangulation** is disproportionately common because the ring's boundaries — especially the sharp, unyielding free margin of the lacunar ligament — do not stretch; the surgeon relieves strangulation by **incising the lacunar ligament** to enlarge the ring. This is usually safe, but in

roughly **1 in 5 individuals** an anomalous ("replaced" or "accessory") obturator artery — an enlarged pubic branch of the inferior epigastric artery substituting for or supplementing the obturator artery — runs close to the medial margin of the ring along the free edge of the lacunar ligament, and can be cut inadvertently with alarming haemorrhage.

Femoral vs inguinal hernia — differentiating points

Feature	Femoral hernia	Inguinal hernia
Relation to pubic tubercle	Below and lateral	Above and medial
Sex predominance	Female	Male
Congenital form	Never congenital	Indirect type may be congenital
Neck	Narrow, rigid	Wider (direct) / narrow (indirect)
Risk of strangulation	High (rigid lacunar ligament margin)	Indirect type more liable to obstruction (narrow neck)
Key clinical landmark	Pubic tubercle is decisive for distinguishing the two	—

Recent advances in imaging and surgical anatomy of the femoral canal

- **Occult hernia imaging:** when examination is equivocal (common in women), MRI outperforms ultrasonography for confirming an occult femoral/inguinal hernia, and multidetector CT now defines the exact fascial plane pre-operatively (According to PubMed, Shakil et al, *Am Fam Physician* 2020) [PMID: 33064426].
- **Laugier's hernia** — sac herniating directly through the substance of the lacunar ligament rather than the ring proper — has characteristic MDCT features (laterally-displaced femoral vein) permitting pre-operative distinction from typical femoral hernia (According to PubMed, Miyamoto et al, *Langenbecks Arch Surg* 2020) [DOI: 10.1007/s00423-020-01897-w].
- **De Garengot hernia** (appendix within a femoral sac, first described 1731) is still under-diagnosed pre-operatively (imaging confirmed only ~31% of a pooled 222-case series) and now has a proposed morphology-based classification (According to PubMed, Guenther et al, *Surg Endosc* 2020) [DOI: 10.1007/s00464-020-07934-5].
- **Laparoscopic repair**, long reserved for adults, is increasingly reported for **paediatric femoral hernia**; a 2024 scoping review found no recurrences among 42 laparoscopic repairs, reinforcing its dual diagnostic/therapeutic role when groin exploration for suspected inguinal hernia proves negative (According to PubMed, Chen et al, *J Laparoendosc Adv Surg Tech A* 2024) [DOI: 10.1089/lap.2023.0372].
- A **new nine-grade groin hernia classification**, combining anatomical type with clinical severity, has been proposed to standardise urgency-of-repair decisions and outcome audits (According to PubMed, Yang et al, *Hernia* 2024) [DOI: 10.1007/s10029-024-03000-4].
- With rising **transfemoral TAVI**, an unsuspected femoral hernia at the vascular access site is now a recognised peri-procedural hazard in the same elderly population both conditions favour, prompting calls for routine pre-procedural groin assessment (According to PubMed, Marciniuk et al, *BMC Surg* 2020) [DOI: 10.1186/s12893-020-0693-3].

Applied / Clinical anatomy

- ▶ **Femoral venous access:** because the femoral vein lies immediately lateral to the canal within the intermediate compartment of the sheath, it is a standard site for central venous cannulation, angiographic catheterisation and fluid administration — the canal itself is deliberately avoided as it carries no vessel to cannulate.
- ▶ **Lymphatic sentinel node:** Cloquet's/Rosenmüller's node, lying within the canal, is the most proximal deep inguinal node and a key sentinel for lymphatic spread from the external genitalia and lower limb; enlargement here can itself mimic (or mask) a femoral hernia.
- ▶ **Psoas abscess** may track along the iliopsoas fascia (posterior wall of the sheath) into the femoral triangle as a swelling below the inguinal ligament — a differential for femoral hernia.
- ▶ **Surgical approaches** exploit this anatomy: a **low (infra-inguinal)** approach opens the sac below the inguinal ligament; a **high (extraperitoneal)** approach controls the neck and any anomalous obturator vessel from above; laparoscopic (TAPP/TEP) repair treats the whole **myopectineal orifice** — femoral, direct and indirect defects together — with one mesh.
- ▶ **Meralgia paraesthetica** — entrapment of the lateral cutaneous nerve of the thigh at the inguinal ligament (the anterior boundary of the ring) — is a related but distinct entity in the same surgical field.

High-yield exam pointers

- ▶ Femoral canal = medial (smallest) compartment of the femoral sheath; sheath formed by fascia transversalis (anterior) + fascia iliaca (posterior), enclosing the upper 3–4 cm of femoral vessels.
- ▶ Three compartments, lateral to medial: **artery** (+ genitofemoral femoral branch) → **vein** → **canal** (lymphatics/node of Cloquet).
- ▶ Canal ≈ 1.25–1.5 cm long, conical, tapering downward; its wide upper end is the **femoral ring**.
- ▶ Femoral ring boundaries: **anterior** = inguinal ligament; **posterior** = pecten pubis/pectineus; **medial** = lacunar ligament (sharp free margin); **lateral** = femoral vein.
- ▶ Ring closed by the **femoral septum**; peritoneal dimple above it = **femoral fossa**.
- ▶ Contents of canal: fat, lymphatics, and **Cloquet's/Rosenmüller's node**.
- ▶ Femoral hernia: never congenital; commoner in females (wider pelvis, larger canal, smaller vessels); course = down → forward (saphenous opening) → up; high strangulation risk because of the rigid lacunar-ligament margin.
- ▶ Enlarging the ring at surgery = cut the lacunar ligament — beware an anomalous obturator artery (~20%) running along its free edge.
- ▶ Pubic tubercle is the key landmark: femoral hernia lies below-and-lateral, inguinal hernia lies above-and-medial to it.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; BD Chaurasia — Human Anatomy Vol 3-4 8e; AK Datta — Human Anatomy Vol 3 (Upper & Lower Limb); Vishram Singh — Textbook of Anatomy Vol 2 4e; Moore's Clinically Oriented Anatomy 9e. Recent-advances citations retrieved from PubMed (2020–2024).



Clinical anatomy of peritoneal recesses

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction

A peritoneal recess (fossa) is a small pocket or diverticulum of the peritoneal cavity that is partly or wholly separated from the main compartments by an inconstant fold of peritoneum. Most arise during fetal life at transitional zones between the mobile, mesentery-bearing segments of the gut and the fixed (retroperitoneal) segments produced by rotation and fusion; many are best developed in the fetus and are progressively obliterated with age. Clinically they matter for three reasons: they are potential sites of **internal herniation and strangulation**, they act as **gutters and dependent pockets** along which ascites, blood, pus or malignant peritoneal fluid tracks and pools, and several serve as **landmarks for percutaneous drainage, paracentesis, culdocentesis and surgical access**. This answer classifies the named recesses by their compartment, describes each with its clinically testable features, and closes with their applied anatomy.

1. General organisation of the peritoneal cavity

- ▶ The peritoneal cavity has two parts: the **greater sac** (main cavity) and the **lesser sac (omental bursa)**, a diverticulum behind the stomach and lesser omentum; the two communicate through the **epiploic foramen (of Winslow)**.
- ▶ For clinical description the greater sac is divided by the transverse colon and transverse mesocolon into a **supramesocolic (supracolic)** compartment above and an **inframesocolic (infracolic)** compartment below.
- ▶ The **supramesocolic compartment** is arbitrarily divided into right and left supramesocolic spaces: the right contains the right subphrenic space, the right subhepatic space and the lesser sac; the left contains the left subphrenic space and the left perihepatic space.
- ▶ The **inframesocolic compartment** is divided unequally by the oblique root of the mesentery of the small intestine into right and left infracolic spaces, and also contains the right and left **paracolic gutters** lateral to the ascending and descending colon.
- ▶ The **pelvic peritoneum** forms further recesses/pouches that differ between the sexes (below).



Clinical anatomy of peritoneal recesses

2. Recesses of the supramesocolic compartment

- ▶ **Right subphrenic space** — between the diaphragm and the anterior/superior/right-lateral surfaces of the right lobe of liver; bounded on the left by the falciform ligament, posteriorly by the upper layer of the coronary ligament. A common site of infected collection following perforated appendicitis or duodenal ulcer (clockwise flow of peritoneal fluid carries infection here).
- ▶ **Right subhepatic space (hepatorenal pouch of Morison)** — between the inferior surface of the right liver lobe and the upper pole of the right kidney; bounded superiorly by the lower layer of the coronary ligament, inferomedially by the hepatic flexure, transverse mesocolon, second part of duodenum and head of pancreas. In the **supine** position it is the most dependent part of the peritoneal cavity in the upper abdomen — the commonest site of a subphrenic abscess.
- ▶ **Left subphrenic space** — larger than the right, subdivided into anterior/posterior subphrenic and a left perihepatic space; bounded medially by phrenicocolic, splenorenal and gastrosplenic ligaments. The **phrenicocolic ligament** partially obstructs flow from the left paracolic gutter, which is why left-sided subphrenic collections are less common than right-sided ones.
- ▶ **Lesser sac (omental bursa)** — closed except at the **epiploic foramen**, a vertical slit about 3 cm high behind the free right border of the lesser omentum, at the level of the **12th thoracic vertebra**. Its boundaries: anterior = free edge of lesser omentum (bile duct anteriorly-right, hepatic artery anteriorly-left, portal vein posteriorly); posterior = inferior vena cava; superior = caudate process of liver; inferior = first part of duodenum. A prominent gastropancreatic fold (raised by the left gastric and common hepatic arteries) divides the sac into a **superior recess** (behind the lesser omentum/caudate lobe, extending into the fissure for the ligamentum venosum) and a larger **inferior recess** (between stomach and pancreas, within the greater omentum); the part between the gastrosplenic and splenorenal ligaments is the **splenic recess**.
- ▶ **Clinical:** a posterior gastric ulcer may perforate into the lesser sac, with leaking fluid tracking through the epiploic foramen into the hepatorenal pouch; if the foramen seals by adhesion, the sac distends and requires drainage through the lesser omentum. Because the epiploic foramen cannot safely be enlarged (vital structures on all sides), a strangulated hernia through it is approached via the greater omentum.

□ Fig 5.29 — Omental (epiploic) foramen and omental bursa. The index finger is passing from the greater sac into the lesser sac. (Moore — Clinically Oriented Anatomy — 9e, p.768)

3. Duodenal recesses

These occur around the duodenojejunal flexure/fourth part of duodenum as minor aberrations of gut rotation and fixation; several are potential sites of a **paraduodenal (left paraduodenal) hernia**, the commonest internal hernia.

Recess	Incidence	Level / position	Depth	Orifice faces
Superior duodenal recess	~50%	Left of 4th part of duodenum, at L2, behind the superior duodenal fold	~2 cm	Downwards

Recess	Incidence	Level / position	Depth	Orifice faces
Inferior duodenal recess	~75%	Left of 4th part, at L3, behind the (avascular) inferior duodenal fold	~3 cm	Upwards
Paraduodenal recess	~20%	Behind a falciform fold carrying the inferior mesenteric vein + ascending left colic artery	Variable	To the right
Retroduodenal recess	Rare, largest	Behind 3rd/4th parts of duodenum, in front of aorta	8–10 cm	To the left (wide orifice)
Duodenojejunal (mesocolic) recess	~20%	Left of aorta, between duodenojejunal junction and root of transverse mesocolon; bounded above by pancreas, laterally by kidney, below by left renal vein	~3 cm	Down and to the right
Mesentericoparietal fossa (of Waldeyer)	~1%	Below 3rd part of duodenum, behind a fold raised by the superior mesenteric artery	—	To the left

- The superior and inferior duodenal recesses often share a common orifice; the paraduodenal recess (in the left colic mesentery, containing the inferior mesenteric vein in its free edge) is the classic site of a **left paraduodenal hernia**.

□ Fig 63.9 — The superior and inferior duodenal recesses. Note that the transverse (Gray's Anatomy — Standring — 41e, p.1534)

4. Caecal, paracolic and intersigmoid recesses

Peritoneal folds around the caecum form several named recesses, all potential sites of internal herniation and post-appendicectomy abscess.

Recess	Boundaries	Orifice faces	Clinical note
Superior ileocaecal recess	Front — vascular fold (anterior caecal vessels); behind — ileal mesentery; below — terminal ileum; right — ileocaecal junction	Left	Best developed in children
Inferior ileocaecal recess	Bounded by the ileocaecal fold ("bloodless fold of Treves"); above — terminal ileum/mesentery; right — caecum; behind — upper mesoappendix	Down and to the left	May be mistaken for mesoappendix if inflamed
Retrocaecal recess	In front — caecum ($\pm$ ascending colon); behind — parietal peritoneum; sides — caecal (parietocolic) folds	Downwards	Frequently lodges the vermiform appendix (retrocaecal appendix)
Paracaecal/paracolic recesses	Shallow depressions within the right paracolic gutter	—	Common site of post-appendicectomy abscess

- **Paracolic gutters:** right (deeper) and left grooves lateral to the ascending/descending colon, continuous above with the hepatorenal pouch/lesser sac (right) and below with the pelvis; a route for spread of infection, ascites and peritoneal metastases between the pelvis and subphrenic spaces.
- **Intersigmoid recess:** present constantly in the fetus and early infancy, often disappearing later; lies behind/inferior to the apex of the V-shaped sigmoid mesocolon attachment; its posterior wall is the parietal peritoneum overlying the **left ureter** as it crosses the bifurcation of the left common iliac artery — a rare but described site of internal (intersigmoid) hernia.

□ Fig 63.10 — The peritoneal folds and recesses in the caecal region. (Gray's Anatomy — Standring — 41e, p.1536)

5. Pelvic peritoneal recesses (pouches)

- **Male pelvis:** peritoneum reflects from the anterior rectal surface, over the seminal vesicles, onto the posterior bladder to form a single **rectovesical pouch**, limited laterally by sacrogenital folds; on either side of the bladder lie shallow **paravesical fossae**, and lateral to the rectum, **pararectal fossae**.
- **Female pelvis:** the uterus and vagina interpose to create **two** pouches instead of one — a deep **recto-uterine pouch (pouch of Douglas)** between rectum and posterior vaginal fornix/uterus, and a shallow **vesico-uterine pouch** between uterus and bladder; pararectal and paravesical fossae are limited laterally by peritoneum over the uterosacral and round ligaments respectively.
- **Dependency and measurements:** with the body erect or sitting, the pelvic pouches (rectovesical/rectouterine) become the **most dependent part of the entire peritoneal cavity**, more so than Morison's pouch — hence pus, blood or malignant ascites gravitates here. The floor

of the rectouterine pouch lies about **5.5 cm** from the anal verge (accessible per rectum or per vaginam); the rectovesical pouch in the male lies about **7.5 cm** from the anus.

- ▶ The **ovarian fossa**, a shallow depression on the lateral pelvic wall bounded by the obliterated umbilical artery (anteriorly), ureter (posteriorly) and external iliac vessels (above), usually lodges the ovary in nulliparous women.

□ Fig 18.30 — Morrison's or hepatorenal pouch with rectouterine or Douglas pouch (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.315)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Duodenal recesses** (as in the first plate) — label: inferior mesenteric vein, superior duodenal fold, superior duodenal recess, inferior duodenal recess, inferior duodenal fold, left colic artery, transverse mesocolon, duodenojejunal flexure.
- ▶ **Caecal region recesses** (as in the second plate) — label: ascending colon, vascular fold of caecum, superior ileocaecal recess, ileocaecal fold, inferior ileocaecal recess, ileum, mesoappendix, vermiform appendix, caecum, retrocaecal recess.
- ▶ **Midline sagittal section of male and female pelvis** — label (male): bladder, rectovesical pouch, rectum, sacrogenital fold, seminal vesicle; label (female): bladder, vesicouterine pouch, uterus, rectouterine pouch (of Douglas), posterior fornix of vagina, rectum. Add an inset arrow showing the **clockwise flow of peritoneal fluid** from pelvis → right paracolic gutter → hepatorenal pouch → right subphrenic space.

Recent advances in imaging and management of peritoneal-recess pathology

- ▶ A comprehensive RadioGraphics review has re-mapped peritoneal compartment boundaries against modern cross-sectional imaging to make disease-spread patterns (fluid along fascial planes vs multifocal tumour spread) more predictable for reporting radiologists (According to PubMed, Gaballah AH et al., *Radiographics* 2024) [DOI](<https://doi.org/10.1148/rg.230216>).
- ▶ A 2026 companion RadioGraphics review extends this compartmental mapping to the retroperitoneum and pelvic extraperitoneum, clarifying how disease crosses from peritoneal recesses into extraperitoneal planes (According to PubMed, Gaballah AH et al., *Radiographics* 2026) [DOI](<https://doi.org/10.1148/rg.250022>).
- ▶ A 2025 review catalogues benign and inflammatory "mimics" of peritoneal carcinomatosis that localise to the same recesses and gutters, aiding differential diagnosis on CT/MRI (According to PubMed, Ambrosetti MC et al., *Diagnostics* 2025) [DOI](<https://doi.org/10.3390/diagnostics15091163>).
- ▶ A 2025 case report of bowel obstruction through the **intersigmoid recess** underlines how preoperative CT diagnosis of this rare internal hernia remains difficult, with confirmation typically only at emergency laparotomy (According to PubMed, Soussan H et al., *Cureus* 2025) [DOI](<https://doi.org/10.7759/cureus.77996>).
- ▶ A case series of paraduodenal hernias confirms the left-sided variant (paraduodenal recess) is roughly **three times commoner** than the right-sided (mesentericoparietal/Waldeyer) variant, and demonstrates that laparoscopic repair is safe and effective in selected cases (According to

PubMed, Giri OA et al., *Surg Endosc* 2023) [DOI](<https://doi.org/10.1007/s00464-023-10513-z>); a separate report describes successful reduced-port laparoscopic repair of a right paraduodenal hernia (According to PubMed, Oshita K et al., *Asian J Endosc Surg* 2021) [DOI](<https://doi.org/10.1111/ases.12908>).

- Therapeutically, the peritoneal cavity and its recesses are increasingly exploited for direct drug delivery: a systematic review/meta-analysis of intraperitoneal chemotherapy (including pressurised intraperitoneal aerosol chemotherapy, PIPAC) for gastric-cancer peritoneal metastases found it safe and associated with improved survival compared with historical controls (According to PubMed, Guchelaar NAD et al., *Br J Surg* 2024) [DOI](<https://doi.org/10.1093/bjs/znae116>).

Applied / Clinical anatomy

- **Internal hernia:** any peritoneal recess, foramen or cul-de-sac can trap a loop of bowel; overall the **paraduodenal** site is commonest, followed by **pericaecal** recesses, then hernia through the **epiploic foramen**. The neck of the recess does not stretch, so strangulation is a real risk; repair requires care regarding vessels in the fold (inferior mesenteric vein/left colic artery in the paraduodenal fold; superior mesenteric artery in Waldeyer's fold).
- **Spread of infection/fluid:** peritoneal fluid flows predominantly **clockwise**; in the supine position it ascends preferentially along the (deeper) **right paracolic gutter** to the hepatorenal pouch and right subphrenic space, explaining why appendicular or duodenal-ulcer infection commonly seeds a **right subphrenic abscess**; on sitting/erect posture, fluid gravitates to the pelvic pouches (rectovesical/rectouterine).
- **Peritoneal metastases:** malignant cells are trapped in dependent recesses and in the "milky spots" of the greater omentum (producing an "omental cake"); ovarian and other pelvic cancers characteristically drop metastases into the **pouch of Douglas**, palpable on rectal/vaginal examination.
- **Retrocaecal appendix:** lying in the retrocaecal recess, it can cause atypical, less-localised right-iliac-fossa pain and is more prone to a "silent" perforation walled off by the caecal folds.
- **Culdocentesis** (needle aspiration through the posterior vaginal fornix) samples the rectouterine pouch — used to detect haemoperitoneum (e.g. ruptured ectopic pregnancy) or pelvic abscess.
- **Image-guided/percutaneous drainage** of subphrenic, subhepatic (Morison's) and pelvic collections has now largely replaced open surgical drainage, exploiting the same dependent-recess anatomy.
- **Ascitic paracentesis** is safely performed in the lower paracolic gutters, away from the mobile small bowel.

High-yield exam pointers

- Peritoneal cavity = greater sac + lesser sac, joined by the **epiploic foramen** (T12 level, ~3 cm).
- Compartments: **supramesocolic** (subphrenic, subhepatic/Morison, lesser sac) and **inframesocolic** (paracolic gutters, duodenal, caecal, intersigmoid recesses), divided by the transverse mesocolon.

- ▶ **Morison's pouch (hepatorenal)** = most dependent recess of the upper abdomen supine; commonest site of subphrenic abscess.
- ▶ **Duodenal recesses:** superior (~50%, L2, 2 cm), inferior (~75%, L3, 3 cm), paraduodenal (~20%, left paraduodenal hernia site), retroduodenal (rare, 8–10 cm, largest), duodenojejunal/mesocolic (~20%), Waldeyer's mesentericoparietal fossa (~1%, right paraduodenal hernia).
- ▶ **Caecal recesses:** superior/inferior ileocaecal, retrocaecal (lodges appendix), paracaecal — sites of post-appendicectomy abscess.
- ▶ **Intersigmoid recess** overlies the left ureter at the common iliac bifurcation; present in the fetus, usually obliterated in adults.
- ▶ **Pelvic pouches:** single rectovesical pouch in males; rectouterine (Douglas, 5.5 cm from anus) + vesicouterine pouches in females — most dependent site erect/sitting.
- ▶ Commonest internal hernia site overall = **paraduodenal**, then pericaecal, then epiploic foramen.
- ▶ Fluid/pus tracks clockwise via the (deeper) right paracolic gutter to the right subphrenic space; malignant cells lodge in recesses and omental milky spots.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2 8e; Moore's Clinically Oriented Anatomy 9e. Recent-advances citations retrieved from PubMed (2021–2026).



Clinical anatomy of Prostate

Asked in: Paper IV 17-Apr-2026 — RGUHS MD/MS Anatomy

Definition / Introduction

The prostate is the largest accessory genital gland of the male reproductive system — a pyramidal, fibromuscular-glandular organ that surrounds the prostatic urethra from the neck of the urinary bladder above to the external urethral sphincter/membranous urethra below. It lies in the lesser pelvis behind the pubic symphysis and in front of the rectal ampulla, embraced on each side by levator ani. Its secretions (rich in acid phosphatase, citric acid, fibrinolysin, amylase and prostate-specific antigen, PSA) contribute the bulk of the seminal fluid. The gland's zonal and capsular anatomy underlies its two commonest diseases — benign prostatic hyperplasia (BPH) and carcinoma prostate — making it one of the highest-yield "clinical anatomy" topics in the pelvis.

Situation, shape, size and external features

- ▶ **Situation:** below the neck of the urinary bladder, behind the lower border of the pubic symphysis and pubic arch, above the urogenital diaphragm/deep perineal pouch, and in front of the ampulla of the rectum.
- ▶ **Shape:** resembles an inverted cone/chestnut. A normal, non-hypertrophied gland is described as **croissant-shaped** (short anterior commissure, prominent apical notch); with BPH it becomes **doughnut-shaped** — a distinction that matters when planning the incision at radical prostatectomy to avoid the external urethral sphincter.

- **Size:** base 4 cm transversely, 3 cm vertically, 2 cm anteroposteriorly.
- **Weight:** ~8 g in a young adult; almost invariably enlarges with BPH after the fifth decade, commonly to ~40 g and occasionally 150 g or more.
- **External features:** an **apex** (inferior, at the prostatomembranous urethral junction), a **base** (superior, continuous with the bladder neck, marked by a circular groove lodging vesicoprostatic venules), and **four surfaces** — anterior, posterior, and two inferolateral.

Relations and capsules of the prostate

□ Fig 17.2 — ■ Location, features and relations of the prostate gland: (A) as seen (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.720)

Surface/border	Relation	Clinical note
Anterior	Pubic symphysis, separated by the retropubic space (of Retzius) and the dorsal vascular complex (Santorini's plexus) ; upper part tethered by puboprostatic ligaments	Retropubic (Millin) prostatectomy uses this plane
Posterior	Ampulla of the rectum, separated by fascia of Denonvilliers (an obliterated rectovesical peritoneal pouch); pierced near its upper border by the two ejaculatory ducts	Palpable on digital rectal examination, ~4 cm from the anal verge
Inferolateral (×2)	Pelvic side wall/levator ani, which embraces the gland as the pubourethral (levator prostatae) sling , separated by a thin fascial layer and the prostatic venous plexus	Neurovascular bundles run in this plane
Base (superior)	Bladder neck (structurally continuous)	Circular groove for venous plexus
Apex (inferior)	Rectourethralis (Y-shaped muscle) posteriorly; external urethral sphincter; separated from the anal canal by the perineal body	Apex–sphincter relationship dictates the enucleation/anastomosis plane at radical prostatectomy

Capsules and supports

- **True capsule:** a fibromuscular condensation of the peripheral gland substance, continuous with its stroma.
- **False capsule (prostatic sheath):** derived from the endopelvic/parietal pelvic fascia, lying outside the true capsule.
- The **prostatic venous plexus** lies between the true and false capsules — the surgical plane of enucleation of a BPH adenoma therefore lies *deep to both* capsules (contrast the thyroid, where the venous plexus lies outside both capsules).

- **Ligamentous supports:** two pairs of **puboprostatic ligaments** (medial pair near the apex, lateral pair near the base) connecting the false capsule to the pubic bones; the superior fascia of the urogenital diaphragm supports the apex; posteriorly the false capsule adheres to the fascia of Denonvilliers.

Lobes and McNeal's zonal anatomy

□ Fig 17.5 — ■ McNeal's zones of prostate. (Vishram Singh — *Textbook of Anatomy Vol 2 — 4e, p.725*)

- The prostate was classically described as having **five lobes** — anterior (isthmus), posterior, median, and two lateral — but five lobes are distinguishable only in the **fetal gland before 20 weeks' gestation**. From then until the onset of BPH, only **three lobes** remain recognisable clinically: two lateral lobes and a median lobe.
- **McNeal's zonal concept** has replaced the lobar description for clinical/radiological purposes, dividing the glandular tissue into three zones plus a non-glandular region:

Zone	Location	% of glandular volume	Embryological origin	Clinical significance
Peripheral zone	Cup-shaped, encloses the gland posteriorly and posterolaterally	~70%	Urogenital sinus	Site of most carcinomas ; directly palpable on PR examination
Central zone	Conical, surrounds the ejaculatory ducts, apex at the verumontanum	~25%	Wolffian (mesonephric) duct system	Rarely involved in disease
Transitional zone	Around the distal preprostatic urethra	~5%	Urogenital sinus	Site of BPH ; enlarges to form the bulk of an obstructed gland
Anterior fibromuscular stroma	Anterior, non-glandular	—	Smooth + striated muscle	Continuous with the bladder-neck detrusor apron and external sphincter

- On **T2-weighted MRI**, the peripheral zone shows high signal while the central and transitional zones (together the "central gland") show low-intermediate signal; the interface between a BPH-hypertrophied transitional zone and the compressed peripheral zone forms the **surgical pseudocapsule**.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Sagittal-section relations diagram** (as in the plate above) — label: urinary bladder and its neck; prostate (base, apex, anterior and posterior surfaces); symphysis pubis, retropubic space of Retzius and puboprostatic ligaments; prostatic urethra; ejaculatory ducts; seminal vesicle and ampulla of vas deferens; rectovesical pouch of peritoneum; fascia of Denonvilliers; ampulla of rectum; levator ani (pubourethral sling); external urethral sphincter/membranous urethra; perineal body.
- ▶ **McNeal's zonal diagram** (coronal/horizontal section, as in the plate above) — label: peripheral zone; central zone; transitional zone; anterior fibromuscular stroma; preprostatic urethra; verumontanum (colliculus seminalis); prostatic urethra distal to the verumontanum; ejaculatory ducts entering the central zone.

Structures within the prostate and prostatic urethra

- ▶ **Prostatic urethra** traverses the gland vertically at the junction of its anterior one-third with its posterior two-thirds, emerging from the anterior surface just above the apex.
- ▶ **Prostatic utricle**: a small blind mucosal sac opening at the summit of the verumontanum; it is a remnant of the fused paramesonephric (Müllerian) ducts — the *vagina masculina*.
- ▶ **Ejaculatory ducts** (×2) pierce the posterior surface near its upper border, run through the central zone, and open into the prostatic urethra on either side of the utricular opening.
- ▶ Landmarks on the **posterior wall of the prostatic urethra**: the **urethral crest** (median mucosal fold); the **colliculus seminalis/verumontanum** (its rounded mid-elevation, bearing the utricular and ejaculatory-duct openings); and the **prostatic sinuses**, grooves on either side of the crest into which the main prostatic ducts open.
- ▶ A crescentic mass of **striated (external urethral sphincter) muscle** lies anterior to the smooth muscle of the gland, continuous inferiorly with the sphincter of the deep perineal pouch; its contraction can compress the urethra or, by displacing the urethral crest, help expel glandular secretion into the urethra before ejaculation.

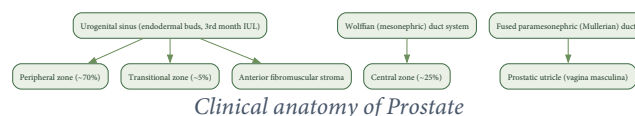
Blood supply, lymphatic drainage and nerve supply

System	Details
Arterial	Branches of the inferior vesical, middle rectal and internal pudendal arteries (all from the internal iliac artery), reaching the gland along a posterolateral line as urethral branches (entering at the prostatovesical junction, chiefly at the 5 and 7 o'clock positions, also at 1 and 11 o'clock) and capsular branches (running posterolaterally in the neurovascular bundle; the constant apical perforator is a key landmark at radical prostatectomy).

System	Details
Venous	The prostatic venous plexus occupies the space between the true and false capsules, receiving the deep dorsal vein of the penis anteriorly; it communicates with the vesical plexus and internal pudendal vein and drains into the vesical and internal iliac veins . It also has valveless communications with the internal vertebral (Batson's) venous plexus — the anatomical basis for haematogenous spread of prostatic carcinoma to the vertebral column and skull, bypassing the caval/pulmonary circulation.
Lymphatic	Chiefly to the internal iliac and sacral nodes , with additional drainage to the external iliac and obturator nodes — the first-echelon nodes sampled during pelvic lymphadenectomy for staging carcinoma prostate.
Nerve supply	From the inferior hypogastric (pelvic) plexus via the prostatic plexus. Sympathetic fibres arise from L1–L2 (superior hypogastric plexus); parasympathetic fibres arise from S2–S4 (pelvic splanchnic nerves). The autonomic cavernous nerves ("neurovascular bundles of Walsh") lie posterolateral to the capsule and continue to the corpora cavernosa; the somatic pudendal nerve supplies the external urethral sphincter, entering at the 5 and 7 o'clock positions.

Microanatomy, development and age changes

- **Microanatomy:** fibromuscular stroma (~30%) and tubulo-alveolar glandular tissue (~70%); glands are lined by columnar/pseudostratified epithelium and drain via 12–20 main ducts into the prostatic sinuses; small eosinophilic **corpora amylacea (amyloid bodies)** accumulate in the lumina with age.
- **Development:** the glandular parenchyma arises in the **3rd month of intra-uterine life** as a series of **endodermal buds** from the primitive urethra and adjoining urogenital sinus; the surrounding **stroma** condenses from splanchnic mesenchyme in the 4th month. The **central zone** is thought to derive instead from the **Wolffian (mesonephric) duct system**, like the epididymis, vas deferens and seminal vesicles. The **prostatic utricle** develops from the fused caudal ends of the paramesonephric (Müllerian) ducts at the site of the Müllerian tubercle.



- **Age changes:** quiescent in childhood → rapid follicular growth and gland-doubling at **puberty (14–18 years)** → continued glandular proliferation through the third decade → size stable from the **fourth decade**, with epithelial involution and increasing corpora amylacea from **45–50 years** onward, after which most men develop some degree of **BPH**.

Recent advances in prostate imaging and surgical anatomy

- ▶ **Zonal mpMRI/PI-RADS:** PI-RADS v2-scored multiparametric MRI, exploiting the McNeal zonal signal pattern (high-signal peripheral zone vs low-signal central gland), is now the road-map for targeted biopsy; deep-learning models trained with zonal-segmentation priors approach expert-radiologist sensitivity for clinically significant lesions (According to PubMed, Hosseinzadeh et al, *Eur Radiol* 2022) [DOI: 10.1007/s00330-021-08320-y].
- ▶ **Zone-specific PSA metrics:** transition-zone PSA density and TZ-volume ratio outperform whole-gland PSA density in triaging equivocal PI-RADS-3 lesions for biopsy (According to PubMed, Wang et al, *Sci Rep* 2025) [DOI: 10.1038/s41598-025-18336-9].
- ▶ **Medical therapy alters zonal imaging:** 5 α -reductase inhibitors for BPH raise ADC values and reduce lesion conspicuity specifically in the **peripheral zone** on mpMRI, a confounder radiologists must allow for (According to PubMed, Das et al, *BJU Int* 2025) [DOI: 10.1111/bju.70067].
- ▶ **PSMA PET/CT,** imaging prostate-specific membrane antigen on glandular epithelium, is now the most accurate single test for extracapsular extension, seminal vesicle invasion, pelvic nodal staging and low-PSA biochemical recurrence (According to PubMed, Shen et al, *J Cancer Res Clin Oncol* 2025 [DOI: 10.1007/s00432-025-06184-z]; Jochumsen & Bouchelouche, *Semin Nucl Med* 2023 [DOI: 10.1053/j.semnuclmed.2023.07.001]).
- ▶ **Retzius-sparing robot-assisted radical prostatectomy (RS-RARP)** approaches the gland posteriorly through the pouch of Douglas, preserving the anterior support complex (puboprostatic ligaments, dorsal venous/Santorini complex, endopelvic fascia) that conventional anterior RARP divides — explaining its earlier return of continence, and now feasible even in the distorted anatomy left by prior TURP (According to PubMed, Lumen et al, *J Vis Exp* 2022 [DOI: 10.3791/63592]; Schütz et al, *World J Urol* 2025 [DOI: 10.1007/s00345-025-06112-3]).

Applied / Clinical anatomy

- ▶ **Benign prostatic hyperplasia (BPH):** nodular hyperplasia of the **transitional zone/median ($\pm$ lateral) lobe** after the fifth decade; enlargement projects into the bladder floor and forms a valve-like flap over the internal urethral orifice, so straining worsens obstruction; PR examination reveals a smooth, firm, symmetrically enlarged gland. Surgical enucleation (prostatectomy) leaves both capsules and the intervening venous plexus behind and can be performed via the **transurethral (TURP), transvesical, retropubic or perineal (through Denonvilliers' fascia)** routes.
- ▶ **Carcinoma prostate:** arises chiefly in the **peripheral zone/posterior lobe**; PR examination reveals a hard, irregular, fixed nodule with an obliterated median sulcus. Because Denonvilliers' fascia is only rarely breached, direct rectal invasion is late. Spread occurs by direct extension, via the **internal iliac/sacral lymph nodes**, and — most distinctively — via the **valveless prostatic-vertebral (Batson's) venous plexus** to the vertebral column and skull, producing osteosclerotic secondaries without necessarily involving the lung or liver.
- ▶ **Radical prostatectomy and nerve-sparing surgery:** the posterolateral **neurovascular bundles (cavernous nerves of Walsh)** are deliberately identified and preserved to retain erectile function;

the apex–external-sphincter relationship (croissant vs doughnut shape) guides the incision to preserve continence.

- ▶ **Retrograde ejaculation:** iatrogenic damage to the preprostatic sphincter (e.g. during TURP) allows semen to enter the bladder rather than being expelled through the urethra, causing post-surgical sterility.
- ▶ **Prostatitis:** acute prostatitis usually follows gonococcal urethritis; chronic prostatitis may be secondary to tuberculous infection spreading from the epididymis, seminal vesicle or bladder.
- ▶ **Digital rectal examination (DRE):** the posterior surface/peripheral zone lies directly against the anterior rectal wall, roughly 4 cm from the anal verge, making it the single most accessible structure for screening and staging; transrectal ultrasound exploits the same hypoechoic-transition/echogenic-peripheral zonal contrast to guide systematic and MRI-fusion biopsy.
- ▶ **Prostatic utricle anomalies:** cystic dilatation of this Müllerian remnant can obstruct the urethra or predispose to recurrent urinary infection in boys, demonstrable on micturating cystourethrography.

High-yield exam pointers

- ▶ Largest accessory genital gland; ~8 g, 4 × 3 × 2 cm; surrounds the prostatic urethra from bladder neck to external sphincter.
- ▶ Five fetal lobes (anterior/isthmus, posterior, median, two lateral) reduce to three adult lobes (median + two lateral); replaced clinically by **McNeal's zones**.
- ▶ McNeal's zones: **peripheral 70%** (carcinoma), **central 25%** (spared; Wolffian origin), **transitional 5%** (BPH), plus non-glandular anterior fibromuscular stroma.
- ▶ Two capsules — **true** (fibromuscular) and **false** (endopelvic fascia) — with the **prostatic venous plexus sandwiched between them**; enucleation plane lies deep to both.
- ▶ Posterior relation = **fascia of Denonvilliers**, the obliterated rectovesical pouch — the barrier that delays direct rectal invasion by carcinoma.
- ▶ Arterial supply: **inferior vesical, middle rectal, internal pudendal**. Venous drainage: prostatic plexus → vesical/internal iliac veins, with **valveless communication to Batson's vertebral venous plexus** (vertebral/spinal metastasis).
- ▶ Lymphatic drainage: chiefly **internal iliac and sacral** nodes.
- ▶ Nerve supply: inferior hypogastric plexus; sympathetic **L1–L2**, parasympathetic **S2–S4**; posterolateral **neurovascular bundles of Walsh** spared in nerve-sparing prostatectomy.
- ▶ PR examination is diagnostic: smooth firm enlargement = BPH; hard, irregular, fixed nodule = carcinoma.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2 8e; Vishram Singh — Textbook of Anatomy Vol 2 4e. Recent-advances citations retrieved from PubMed (2022–2025).



Clinical anatomy of thoracoabdominal diaphragm

Asked in: Paper IV 14-Jul-2023 — RGUHS MD/MS Anatomy

Definition / Introduction The diaphragm is a dome-shaped musculotendinous septum that separates the thoracic cavity from the abdominal cavity, giving it the name "thoracoabdominal diaphragm." It is the chief muscle of quiet respiration, contributing roughly two-thirds of the tidal volume of quiet breathing. Its muscular periphery arises from the circumference of the inferior thoracic aperture and converges on a central tendon. Although it comes to lie at the thoracoabdominal junction in the adult, it develops opposite the third to fifth cervical segments, so its motor nerve — the phrenic nerve (C3, C4, C5) — is dragged down with it, giving the nerve its characteristically long intrathoracic course.

Attachments — origin and insertion

Origin (three parts):

- ▶ **Sternal part** — two fleshy slips from the posterior surface of the xiphoid process.
- ▶ **Costal part** — fleshy slips from the inner surfaces of the lower six costal cartilages/ribs each side, interdigitating with **transversus abdominis**.
- ▶ **Lumbar part** — by two crura and two aponeurotic arches: **right crus** from the upper **three** lumbar vertebral bodies/discs (longer/stronger — pulls against the liver, and its fibres split to encircle the oesophagus); **left crus** from the upper **two**; **medial arcuate ligament** (thickened psoas fascia, L1/L2 body to L1 transverse process); **lateral arcuate ligament** (thickened quadratus lumborum fascia, L1 transverse process to 12th rib); **median arcuate ligament** (the crura's meeting medial margins, arching anterior to the aorta at T12/L1).

Insertion — fibres converge on the **central tendon**, a trifoliate aponeurosis fused below the fibrous pericardium — triangular middle leaflet towards the xiphoid, tongue-shaped right and left leaflets curving posterolaterally (left narrower) — with four diagonal bands decussating anterior to the oesophagus and left of the IVC.

□ Fig 26.1 — The diaphragm as seen from below (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.418)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Diaphragm viewed from below — label: central tendon (middle, right and left leaflets), right crus and left crus, median/medial/lateral arcuate ligaments, sternal slips (xiphoid), costal slips (lower six ribs), 12th rib, psoas major and quadratus lumborum, vena caval opening (T8) with IVC, oesophageal opening (T10) with oesophagus encircled by right crus fibres, aortic opening (T12) with aorta/thoracic duct/azygos vein, sympathetic chain behind medial arcuate ligament, greater/lesser splanchnic nerves piercing the crura.

Openings in the diaphragm

Major openings (mnemonic — "I 8 eggs 10 AT 12"):

Opening	Vertebral level	Shape	Structures transmitted	Effect of contraction
Vena caval	T8 (junction of central and right leaflets of central tendon)	Quadrilateral	IVC, branches of right phrenic nerve, lymphatics from liver	Dilates — aids venous return
Oesophageal	T10 (in muscular right crus)	Elliptical	Oesophagus, right and left vagal trunks, oesophageal branches of left gastric vessels	Constricts — "pinch-cock"/sphincteric action
Aortic	T12 (behind median arcuate ligament)	Rounded	Aorta, thoracic duct, azygos vein	No effect — lies posterior to the muscle

Minor openings: space of Larrey/foramen of Morgagni (between sternal and costal slips — superior epigastric vessels, lymphatics); **musculophrenic vessels** (near 9th costal cartilage); **lower five intercostal and subcostal nerves/vessels** (through costal interdigitations, subcostal bundle also behind the lateral arcuate ligament); **sympathetic trunk** (behind the medial arcuate ligament); **greater/lesser/least splanchnic nerves** (piercing the corresponding crus); **hemiazygos vein** (pierces the left crus).

Relations

- **Superior surface** — pleura and lung bases on each side; fibrous pericardium (fused to the central tendon, the "cardiac plateau") in the midline. The right dome is higher/broader than the left (right at the 4th costal cartilage, left one rib lower, in full expiration); domes descend up to 10 cm on deep inspiration. On an erect PA chest radiograph the right hemidiaphragm lies at the anterior end of the 6th rib, the left 1.5–2.5 cm lower; the level is highest supine, lowest sitting.
- **Inferior surface** (peritoneum-covered) — right: right lobe of liver, right kidney, right suprarenal; left: left lobe of liver, gastric fundus, spleen, left kidney, left suprarenal.

Blood supply and lymphatic drainage

- **Arteries** (profuse anastomotic supply): **superior phrenic** (thoracic aorta, upper surface); **inferior phrenic** (abdominal aorta/coeliac trunk — the major supply, lower surface); **pericardiophrenic** and **musculophrenic** (both from internal thoracic artery); **superior epigastric** (internal thoracic terminal branch); **lower five intercostal and subcostal arteries** (costal margin).
- **Veins** — superior surface via musculophrenic/pericardiophrenic veins to the internal thoracic vein; inferior surface via right and left inferior phrenic veins to the IVC (left may drain to left suprarenal/renal/hepatic vein instead).
- **Lymph nodes** — anterior (behind xiphoid), posterior (near aortic opening), right lateral (near caval opening), left lateral (near oesophageal opening), draining onward to parasternal, posterior mediastinal and brachiocephalic nodes.

Nerve supply

- ▶ **Motor** — the **phrenic nerves** (ventral rami C3, C4, C5) are the **sole** motor supply. The right nerve traverses the central tendon at/near the caval opening; the left pierces the muscular part anterior to the central tendon. Each divides into anterior (sternal), anterolateral and posterior (crural) rami; the right crus is supplied by the right phrenic, the left crus and the left part of the right crus by the left phrenic.
- ▶ **Sensory** — phrenic nerves to the central part (mediastinal/diaphragmatic pleura, pericardium, central peritoneum); **lower six intercostal (and subcostal) nerves** to the peripheral part.
- ▶ The nerve's long intrathoracic course (on scalenus anterior, then between fibrous pericardium and mediastinal pleura anterior to the lung root) reflects the diaphragm's cervical origin and caudal migration.

Actions

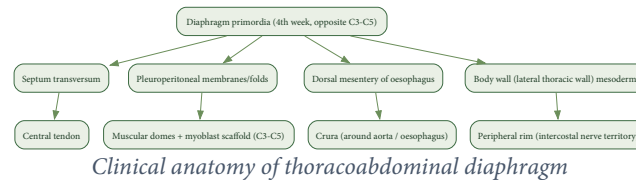
- ▶ **Principal muscle of inspiration** — contraction flattens the domes, increasing vertical thoracic diameter; excursion ~1.5 cm quiet, up to 6–10 cm deep.
- ▶ **Physiological sphincter at the gastro-oesophageal junction** — right crural fibres pinch-cock the oesophageal opening, reinforced by the phreno-oesophageal ligament, constricting on inspiration to resist reflux.
- ▶ **Aids venous return** — caval-opening dilatation plus falling intrathoracic/rising intra-abdominal pressure forces blood up into the right atrium.
- ▶ **Muscle of expulsive straining** — with abdominal wall muscles, raises intra-abdominal pressure for coughing, sneezing, vomiting, micturition, defaecation, parturition.
- ▶ **Muscle of weight-lifting** — raised intra-abdominal pressure splints the vertebral column.

Resting level reflects a balance of lung elastic recoil (pulls up), posture-dependent visceral pressure, and abdominal wall tone.

Development

The diaphragm develops opposite the C3–C5 somites in the fourth week from **four** sources, whose myogenic component is supplied by migrating C3–C5 myotomal myoblasts:

Embryonic source	Adult derivative
Septum transversum	Central tendon (pleuroperitoneal folds expand over and contribute connective tissue to it)
Pleuroperitoneal membranes/folds	Muscular domes; scaffold guiding C3–C5 myoblasts to form the bulk of the diaphragmatic musculature
Dorsal mesentery of the oesophagus	Crura around the aorta and oesophagus
Body wall (lateral thoracic wall) mesoderm	Peripheral rim, invaded by myoblasts from neighbouring somites; supplied by lower thoracic (intercostal) nerves



As the head and vertebral column grow faster than the ventral body wall, the diaphragm is carried caudally from the neck to the thoracoabdominal junction by the 8th week, dragging the phrenic nerve down with it — the embryological basis of its long course.

Applied / Clinical anatomy

► Congenital diaphragmatic hernia (CDH):

- **Posterolateral (Bochdalek) hernia** — the **commonest** congenital variety (~80% of CDH), through the pleuroperitoneal hiatus; more common on the **left** (larger, later-closing canal). Free pleuroperitoneal communication may cause acute neonatal respiratory distress from pulmonary hypoplasia — a surgical emergency.
- **Retrosternal (Morgagni) hernia** — through the space of Larrey/foramen of Morgagni, more common on the right, between pericardium and pleura; usually asymptomatic.
- **Posterior hernia** — a crus fails to develop; aorta/oesophagus lie in the gap but there is no true sac.
- **Central hernia** — rare, left-sided, from rupture of the fetal membranous dome.

- **Acquired hernia: Traumatic** (penetrating injury or sudden rise in intra-abdominal pressure); **Hiatal — sliding (Type I)**, the commonest of all internal hernias, with the gastro-oesophageal junction sliding up through a weak phreno-oesophageal ligament causing reflux/heartburn (linked to obesity); **para-oesophageal/rolling (Type II)** — fundus rolls up beside a normally-positioned junction.
- **Eventration** — congenital muscular thinning (typically left anteromedial segment); the intact but attenuated dome shows diminished/paradoxical movement on fluoroscopic sniff testing.
- **Diaphragmatic paralysis** — a phrenic lesion anywhere in its course causes **paradoxical movement** of the hemidiaphragm, seen on fluoroscopy/ultrasound sniff testing; bilateral paralysis risks respiratory failure.
- **Hiccup** — spasmodic contraction with glottic closure; **peripheral** (local diaphragmatic/phrenic irritation) or **central** (medullary hiccup centre, e.g. uraemia).
- **Referred shoulder-tip pain** — diaphragmatic pleural/peritoneal irritation (basal pneumonia, subphrenic abscess, splenic/hepatic injury) refers to the shoulder via the shared C3–C5 root value with the supraclavicular nerve.
- **Median arcuate ligament (Dunbar) syndrome** — a low ligament compresses the coeliac trunk, causing postprandial pain, weight loss and mesenteric angina.
- **Surgical anatomy** — the three phrenic rami (anterior, anterolateral, posterior/crural) mean circumferential peripheral or central-tendon incisions spare the nerve, whereas radial incisions from costal margin to hiatus risk denervation.

Recent advances in anatomical and diagnostic sciences

- ▶ **Molecular embryology of CDH** — pleuroperitoneal folds, not the septum transversum alone, are now seen as the principal morphogenetic driver, contributing the central-tendon scaffold and guiding C3–C5 myoblast migration. Over **150 genes** are implicated in CDH; **GATA4** (expressed in the folds) and co-factor **FOG2** are the strongest associations, and **8p23.1** deletions (containing GATA4) are found in patients — refining the classical four-source model into a fold-centred one.
- ▶ **Antenatal ultrasound** — detects CDH by loss of the normal diaphragmatic contour with herniated viscera in the thorax; colour Doppler distinguishes it from other fetal thoracic masses (e.g. absent systemic feeding vessel excludes bronchopulmonary sequestration).
- ▶ **Diaphragm ultrasonography in critical care** — imaged as a hypoechoic line between hyperechoic pleura and peritoneum; **M-mode excursion** and **B-mode thickening fraction** on inspiration now diagnose diaphragmatic dysfunction/atrophy and predict ventilator-weaning success.
- ▶ **Electrophysiological assessment** — electrical/magnetic phrenic nerve stimulation with compound muscle action potential and transdiaphragmatic pressure recording is the gold-standard objective test of the phrenic–diaphragm unit.
- ▶ **Phrenic nerve pacing** — implanted electrodes restore ventilatory rhythm in high cervical cord lesions and central alveolar hypoventilation ("Ondine's curse"), reducing ventilator dependence.
- ▶ **Cross-sectional trauma imaging** — spiral/multidetector CT with multiplanar reformation is now primary for suspected diaphragmatic rupture, MRI for equivocal cases, thoracoscopy for penetrating injury.
- ▶ **Minimally invasive surgical anatomy** — knowledge of phrenic nerve branching and phrenic-ganglion location (near the crura) guides laparoscopic/robotic hiatal repair, with crural sutures placed superior to the ganglia to avoid autonomic injury.

High-yield exam pointers

- ▶ **Sole motor nerve** of the diaphragm = phrenic nerve (C3, C4, C5) — "C3, 4, 5 keep the diaphragm alive."
- ▶ **Right crus** is longer/stronger (arises from upper 3 lumbar vertebrae) than the **left** (upper 2) — it pulls down against the liver and encircles the oesophagus as a sphincter.
- ▶ Mnemonic for openings: "**I 8 eggs 10 AT 12**" — IVC at T8, oesophagus at T10, Aorta at T12.
- ▶ Only the **vena caval opening dilates** on contraction (venous return); the **oesophageal opening constricts** (sphincter); the **aortic opening is unaffected** (lies posterior to the muscle).
- ▶ **Commonest congenital diaphragmatic hernia** = posterolateral (Bochdalek), through the pleuroperitoneal hiatus, left-sided.
- ▶ **Commonest of all internal hernias** = sliding (acquired) hiatal hernia.
- ▶ Diaphragm develops opposite **C3–C5** in the neck and descends to the thoracoabdominal junction — explains the long phrenic nerve course.
- ▶ **Referred shoulder-tip pain** shares the C3–C5 root value with the supraclavicular nerve.
- ▶ Diaphragm provides about **two-thirds of quiet tidal breathing**; excursion is 1.5 cm quiet, up to 10 cm deep.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 1 and Vol 2, 8e; Vishram Singh's Textbook of Anatomy Vol 1, 4e; Langman's Medical Embryology (Sadler) 14e; Larsen's Human Embryology 6e.



Clinical examination of Vagus nerve

Asked in: Paper IV 04-Aug-2021 — RGUHS MD/MS Anatomy

Definition / Introduction. The vagus (tenth cranial) nerve is the longest and most widely distributed cranial nerve, carrying special visceral efferent fibres to the palate, pharynx and larynx, general visceral efferent (parasympathetic) fibres to thoracic and abdominal viscera, and visceral/somatic afferent fibres from the same regions plus the external ear. Because bedside cranial-nerve examination cannot directly test the thoracoabdominal autonomic outflow, the "clinical examination of the vagus" in practice means testing its **branchiomotor function to the soft palate, pharynx and larynx**, and its two reflex arcs (pharyngeal/gag and cough). The nerve shares the nucleus ambiguus and the jugular foramen with the glossopharyngeal and accessory nerves, so it is conventionally examined together with cranial nerves IX and XI, and a vagal lesion is often accompanied by signs referable to these neighbours.

1. Functional anatomy relevant to bedside testing

The vagus has three nuclei in the medulla and two extracranial sensory ganglia; the table below links each component to what is actually tested at the bedside.

Functional component	Nucleus/ganglion	Structures/reflex tested clinically
Special visceral efferent (SVE)	Nucleus ambiguus	Muscles of soft palate (except tensor veli palatini), pharyngeal constrictors, and all intrinsic laryngeal muscles except cricothyroid — tested by palatal movement, gag reflex (efferent limb) and voice/cough
General visceral efferent (GVE)	Dorsal nucleus of the vagus	Parasympathetic supply to heart, lungs, gut to splenic flexure — not tested at the bedside as part of routine CN examination, but relevant to the carotid sinus/oculocardiac-type reflex arcs
General visceral afferent (GVA)	Lower part of nucleus of tractus solitarius ; cell bodies in inferior (nodose) ganglion	Sensation from pharynx, larynx (above and below the vocal folds via internal laryngeal and recurrent laryngeal nerves), trachea, oesophagus — afferent limb of the cough reflex

Functional component	Nucleus/ganglion	Structures/reflex tested clinically
Special visceral afferent (SVA)	Upper part of nucleus of tractus solitarius ; cell bodies in inferior ganglion	Taste from the epiglottis and valleculae (not routinely tested)
General somatic afferent (GSA)	Spinal nucleus of the trigeminal nerve ; cell bodies in superior (jugular) ganglion	Cutaneous sensation of the concha/root of the auricle, posterior meatal wall and outer tympanic membrane (auricular/Arnold's branch)

- **Superior (jugular) ganglion** — rounded, lies within the jugular foramen; carries GSA cell bodies; gives meningeal and auricular branches.
- **Inferior (nodose) ganglion** — cylindrical, about 2.5 cm long, lies just below the foramen; carries GVA/SVA cell bodies; gives off the pharyngeal, carotid and superior laryngeal branches and is where the cranial root of the accessory nerve joins the vagus proper.
- The **pharyngeal branch** (largely accessory-nerve fibres travelling with the vagus) forms the pharyngeal plexus with glossopharyngeal and sympathetic contributions and supplies the constrictors and the palatal muscles — this is the branch actually being tested when the palate and gag reflex are examined.
- The **superior laryngeal nerve** divides into an external laryngeal branch (motor to cricothyroid, the only tensor of the vocal fold) and an internal laryngeal branch (sensory to the larynx above the vocal folds, the afferent limb of the cough reflex).
- The **recurrent laryngeal nerve** supplies all remaining intrinsic laryngeal muscles (abductor — posterior cricoarytenoid; adductors — lateral cricoarytenoid, transverse/oblique arytenoids, thyroarytenoid/vocalis) and carries sensation from below the vocal folds; the right nerve hooks under the subclavian artery, the left under the arch of the aorta/ligamentum arteriosum, making the left nerve more often involved by mediastinal disease.

□ Fig 11.18 — Vagus nerve nuclei and their central connections. (Snell — Clinical Neuroanatomy — 7e, p.373)

2. Step-by-step method of examination

- **History** — ask specifically about nasal regurgitation of liquids, change in voice (hoarseness, nasal/bovine quality), difficulty swallowing, choking spells and persistent cough; these point to palatal, laryngeal or pharyngeal involvement respectively.
- **Listen to the resting voice** — a hoarse or breathy voice suggests vocal-cord palsy (recurrent laryngeal); a nasal, "twangy" voice suggests palatal palsy; a weak voice that tires easily suggests an isolated superior laryngeal nerve lesion (cricothyroid weakness).
- **Inspect the soft palate and uvula** — ask the patient to open the mouth wide and say "Ah". Normally both sides of the palate rise symmetrically and the uvula stays in the midline. In a unilateral lesion the paralysed side fails to arch, the palatal arch flattens on that side, and the uvula is pulled towards the normal side (the posterior pharyngeal wall is likewise drawn towards the healthy side — often described as the "curtain sign").
- **Elicit the pharyngeal (gag) reflex** — touch the posterior/lateral pharyngeal wall on each side in turn with an orange stick or spatula. The afferent limb runs in the glossopharyngeal nerve; the

efferent limb (contraction of the pharyngeal constrictors and elevation of the palate) runs in the vagus (with the glossopharyngeal supplying stylopharyngeus). A diminished or absent gag on one side, with preserved sensation reported by the patient, localises the efferent (vagal) defect to that side.

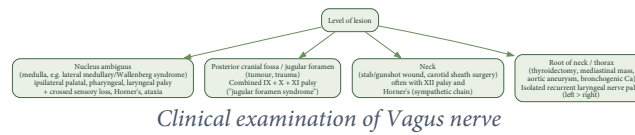
- ▶ **Assess cough** — ask the patient to cough voluntarily. A weak, non-explosive "bovine" cough (lacking the initial sharp glottic closure) indicates vocal-cord paralysis, because the cords cannot appose to build up sub-glottic pressure before expulsion.
- ▶ **Bedside swallowing assessment** — give a few sips of water and observe for nasal regurgitation, coughing, or a wet/gurgling voice afterwards, which suggest palatal or laryngeal incompetence and aspiration risk.
- ▶ **Indirect/fibre-optic laryngoscopy** — the definitive way to see vocal-cord position and mobility: a paramedian, immobile cord suggests an isolated recurrent laryngeal nerve lesion (the intact cricothyroid, via the external laryngeal nerve, still tenses and adducts the cord towards the midline), whereas a cord fixed midway between abduction and adduction (the "cadaveric position") indicates a complete (high) vagal lesion with loss of both superior and recurrent laryngeal function.
- ▶ **Examine the accompanying nerves in the same sitting** — because the vagus shares the nucleus ambiguus and jugular foramen with the glossopharyngeal and accessory nerves, always test the gag reflex (IX), shoulder shrug and head rotation against resistance (XI, spinal root) and tongue protrusion (XII, since it exits close by through the hypoglossal canal) to characterise the full extent of a posterior-fossa or skull-base lesion.

□ Fig 14.12 — Uvula deviated to right side in paralysis of left vagus nerve (BD Chaurasia — Human Anatomy Vol 3-4 — 8e, p.276)

3. Interpreting the findings

Sign	Normal	Unilateral vagal palsy	Bilateral vagal palsy
Palatal arch on phonation	Rises symmetrically	Flattened on the affected side	No elevation on either side
Uvula position	Midline	Deviated to the normal side	Remains midline (both sides equally weak)
Gag reflex	Brisk, symmetrical	Diminished/absent on the lesioned side	Absent bilaterally
Voice	Normal	Hoarse, nasal twang	Severe hoarseness or aphonia
Swallowing	Normal	Nasal regurgitation of liquids, mild dysphagia	Marked dysphagia, aspiration risk
Vocal cord (on laryngoscopy)	Full abduction/adduction	Paramedian (isolated RLN) or cadaveric (complete vagal) on the affected side	Bilateral paramedian cords → inspiratory stridor; bilateral cadaveric cords → aphonia

4. Localising the level of a vagal lesion



- ▶ **Nuclear/brainstem lesions** (e.g. lateral medullary/Wallerberg syndrome from a posterior inferior cerebellar artery infarct) damage the nucleus ambiguus and produce ipsilateral palatal, pharyngeal and laryngeal palsy together with other brainstem signs (crossed sensory loss, ipsilateral Horner's syndrome, cerebellar ataxia) — a purely lower-motor-neurone pattern because both cerebral hemispheres supply the nucleus ambiguus bilaterally, so unilateral cortical (supranuclear) lesions rarely produce a clinically obvious isolated vagal deficit.
- ▶ **Posterior cranial fossa/jugular foramen lesions** classically affect the glossopharyngeal, vagus and accessory nerves together, since all three traverse the jugular foramen in close proximity ("jugular foramen syndrome").
- ▶ **Neck lesions** (stab and gunshot wounds, carotid sheath surgery) can add hypoglossal nerve involvement and a Horner's syndrome from injury to the adjacent cervical sympathetic chain.
- ▶ **Thoracic lesions** selectively affect the recurrent laryngeal nerve, most often the left because of its longer intrathoracic course looping below the aortic arch/ligamentum arteriosum — seen with thyroid surgery (also right side at risk here), mediastinal lymphadenopathy, bronchogenic carcinoma or an aortic arch aneurysm.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled schematic of the vagus nerve's central connections and the peripheral branches actually used in bedside testing, showing:

- ▶ **Nucleus ambiguus, dorsal (motor) nucleus of the vagus, nucleus of the tractus solitarius,** and the **spinal nucleus of the trigeminal nerve**, in the medulla
- ▶ Nerve rootlets emerging between the olive and inferior cerebellar peduncle, passing to the **jugular foramen**
- ▶ **Superior (jugular) ganglion** (within the foramen) and **inferior (nodose) ganglion** (just below it), with the cranial root of the accessory nerve joining at this level
- ▶ **Pharyngeal branch** → pharyngeal plexus → soft palate and pharyngeal constrictors (the gag-reflex efferent pathway)
- ▶ **Superior laryngeal nerve** dividing into **external laryngeal** (to cricothyroid) and **internal laryngeal** (sensory, above the vocal folds)
- ▶ **Recurrent laryngeal nerve** (right looping under the subclavian artery; left looping under the aortic arch) supplying the remaining intrinsic laryngeal muscles and sensation below the vocal folds

Applied / Clinical anatomy

- ▶ **Jugular foramen syndrome** — a mass lesion (glomus jugulare tumour, meningioma, metastasis) or trauma at the jugular foramen produces combined loss of IX, X and XI function: absent gag reflex, palatal/pharyngeal/laryngeal palsy, and weakness of sternocleidomastoid and trapezius.

- ▶ **Recurrent laryngeal nerve palsy in thyroid surgery** — the nerve's close relation to the inferior thyroid artery in the tracheo-oesophageal groove puts it at risk during thyroidectomy; unilateral injury gives a paramedian, immobile cord with hoarseness, while bilateral injury causes both cords to lie close to the midline, producing severe inspiratory stridor and airway obstruction requiring emergency tracheostomy.
- ▶ **"Cadaveric" versus "paramedian" cord position** — an isolated recurrent laryngeal nerve lesion leaves the cricothyroid (external laryngeal nerve) intact, which tenses and adducts the cord to a paramedian position; a complete (high) vagal lesion abolishes both superior and recurrent laryngeal function and the cord lies midway between abduction and adduction — the cadaveric position.
- ▶ **Auriculo-vagal (ear-cough) reflex** — irritation of the auricular branch of the vagus in the external acoustic meatus (wax, syringing, a foreign body) can reflexly trigger persistent cough, vomiting, or rarely bradycardia/cardiac inhibition through vagal connections; conversely stimulation may reflexly increase appetite.
- ▶ **Carotid sinus reflex** — baroreceptor afferents from the carotid sinus travel in the glossopharyngeal nerve to the nucleus solitarius, which activates the dorsal nucleus of the vagus and slows the heart; an oversensitive reflex (carotid sinus hypersensitivity) can cause syncope on neck pressure or head turning.
- ▶ **Vagotomy** — surgical division of the vagal trunks (or selective/highly selective vagotomy sparing the hepatic and coeliac branches and the "crow's foot" innervating the pylorus) was historically used to reduce acid secretion in refractory peptic ulcer disease.
- ▶ **Herpes zoster and communicating fibres** — sensory fibres that join the vagus from the facial nerve's geniculate ganglion reach the auricle via the auricular branch, so herpes zoster oticus can produce vesicles here alongside facial and vagal symptoms.
- ▶ **Choking/laryngeal obstruction** — acute foreign-body obstruction of the airway (relevant to vagal/laryngeal sensory-motor failure) is relieved by the Heimlich manoeuvre (subdiaphragmatic abdominal thrusts).

Recent advances

- ▶ **Gag reflex has poor screening value for dysphagia** — a 2024 network meta-analysis of 21 bedside screening studies (3,314 patients, 6 tools) found that structured instruments such as the Gugging Swallowing Screen (GUSS) substantially outperform the isolated pharyngeal/gag reflex for detecting post-stroke dysphagia, supporting a shift away from gag reflex testing alone as a swallow-safety screen (Jiang et al., *Frontiers in Neurology* 2024) [PMID: 39165268].
- ▶ **Cervical vagus nerve anatomical variation on ultrasound** — a 2025 cross-sectional study of 347 patients using high-frequency neck ultrasonography found anatomical variation in the course of the cervical vagus nerve relative to the carotid artery/internal jugular vein in 38% of subjects (significantly more common on the left), with the nerve lying within 2 mm of the thyroid gland in a fifth of cases — relevant to avoiding iatrogenic vagal injury during thyroidectomy, carotid surgery and vagus-nerve-stimulator implantation (Randhawa et al., *Journal of Ultrasonography* 2025) [PMID: 41098505].

- ▶ **Transcutaneous auricular vagus nerve stimulation (taVNS)** — a 2025 narrative review of safety, stimulation parameters and efficacy in healthy subjects, stroke and Parkinson's disease summarises how the cutaneous (auricular branch) distribution of the vagus in the concha/tragus is now being exploited as a non-invasive route to modulate central vagal-solitary tract circuits, an application that builds directly on the classical auricular branch anatomy described above (Matsuoka et al., *Frontiers in Physiology* 2025).

High-yield exam pointers

- ▶ Vagus examination = testing the branches to **palate, pharynx and larynx**; thoracoabdominal autonomic function is not part of the bedside cranial-nerve exam.
- ▶ "Say Ah" test: normal = symmetrical palatal elevation, midline uvula; unilateral lesion = flattened arch and uvula pulled to the **normal** side.
- ▶ Gag reflex: afferent = **glossopharyngeal (IX)**; efferent = **vagus (X)** to pharyngeal constrictors (+ IX to stylopharyngeus).
- ▶ Cricothyroid (tensor of the vocal fold) is supplied by the **external laryngeal nerve**; all other intrinsic laryngeal muscles by the **recurrent laryngeal nerve**.
- ▶ Isolated recurrent laryngeal nerve palsy → cord **paramedian**; complete (high) vagal palsy → cord **cadaveric** position.
- ▶ Vagus shares the **nucleus ambiguus** and **jugular foramen** with IX and the cranial root of XI — always examine IX, XI (and XII) alongside X.
- ▶ Left recurrent laryngeal nerve is longer and more often injured (loops below the aortic arch/ligamentum arteriosum) than the right (loops below the subclavian artery).
- ▶ Bilateral recurrent laryngeal nerve palsy is a surgical emergency — cords lie close to the midline causing inspiratory stridor and airway obstruction.
- ▶ Bovine (non-explosive) cough on voluntary coughing points to vocal-cord palsy from a recurrent laryngeal nerve lesion.

SOURCE & COVERAGE

Snell's Clinical Neuroanatomy 7e; BD Chaurasia's Human Anatomy Vol 3-4 8e; Vishram Singh's Clinical Neuroanatomy 4e; Moore's Clinically Oriented Anatomy 9e; Gray's Anatomy (Standring) 41e.



Clinical importance of vascular segments of liver

Asked in: Paper IV 03-Oct-2025 — RGUHS MD/MS Anatomy

Definition / Introduction The liver is functionally divided, independent of its external (falciform-ligament-based) anatomical lobes, into **eight self-contained vascular segments (I–VIII)** first described by Claude Couinaud (1957). Each segment receives its own tertiary branch of the **portal triad** (portal vein + hepatic artery + bile duct, running together as a "Glissonian pedicle") and is drained by intervening **hepatic veins**. Because each segment can be resected, imaged, ablated, or transplanted as an independent vascular-biliary unit, Couinaud's segmentation is the single most important anatomical concept underlying modern hepatobiliary surgery, interventional radiology and liver transplantation.

Functional (physiological) division of the liver — Cantlie's line and portal sectors

- ▶ The liver's **true functional right and left hemi-livers** are separated by the **main portal fissure (Cantlie's line)** — a plane from the midpoint of the **gallbladder fossa** to the midpoint of the **inferior vena cava (IVC)** — which contains the **middle hepatic vein**. This functional division does **not** coincide with the anatomical right/left lobes demarcated by the falciform ligament; the anatomical right lobe actually contributes part of its bulk to the functional left liver (the quadrate and caudate territories).
- ▶ Each hemi-liver is supplied by its own primary branch of the portal vein and hepatic artery and drained by its own hepatic duct, and is further divided into **portal sectors** by three intersectoral (portal) fissures, each carrying a major hepatic vein:
 - **Right posterior/lateral sector** (segments VI, VII) and **right anterior/medial sector** (segments V, VIII), separated by the **right portal fissure** (right hepatic vein) — the most variable of the three fissures and the plane most often transected in resections through the thick right-lobe parenchyma.
 - **Left lateral sector** (segment II) and **left medial sector** (segments III, IV, and part of I), separated by the **left portal fissure** (left hepatic vein).
- ▶ Three **minor fissures** — the **umbilical fissure** (separates III from IV; contains the umbilical portion of the left portal vein), the **fissure for the ligamentum venosum**, and the **fissure of Gans (Rouvière's sulcus)**, which marks the variable division of the right posterior portal pedicle — are visible clefts on the liver surface and are important surgical landmarks.
- ▶ *Note on nomenclature:* many standard gross-anatomy texts (BD Chaurasia, AK Datta) teach the simpler clinical grouping — **left lateral sector = II + III** and **left medial sector = IV** (with I as an independent posterior segment) — rather than Couinaud's original strict scheme above. Both groupings are used in practice; the Brisbane 2000 (IHPBA) nomenclature calls these "sections" instead of "sectors" to reduce this exact confusion.

Couinaud's eight vascular segments

□ Fig 8.8 — ■ *Eight segments of the liver.* (Vishram Singh — *Textbook of Anatomy Vol 2 — 4e, p.366*)

Segment	Old lobar correlate / location	Portal–arterial supply (Glissonian sheath)	Venous drainage
I	Caudate lobe; posterior, between porta hepatis and IVC	Uniquely receives branches from both right and left portal/arterial pedicles	Multiple short veins draining directly into the IVC (not via a named hepatic vein)
II	Left lateral (superior); only segment of the left lateral sector	Single Glissonian sheath from left portal vein	Left hepatic vein
III	Left lateral/medial (inferior), between umbilical and left portal fissures	1–3 sheaths via the umbilical fissure	Left hepatic vein ($\pm$ vein of falciform ligament)
IV (sub-divided IVa/IVb)	Quadrangle lobe region, anterior to segment I	3–5 sheaths, mostly from the umbilical fissure	Middle hepatic vein ($\pm$ left hepatic vein)
V	Right anterior sector, inferior	Right anterior sheath	Right and/or middle hepatic vein
VI	Right posterior sector, inferior	2–3 branches of right posterior sheath	Right hepatic vein (occasionally a direct inferior right hepatic vein into the IVC)
VII	Right posterior sector, superior	Usually a single right posterior sheath	Right hepatic vein
VIII	Right anterior sector, superior	Terminal right anterior sheath (after giving branches to V)	Right and/or middle hepatic vein

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the liver's antero-superior and inferior surfaces side by side and label:

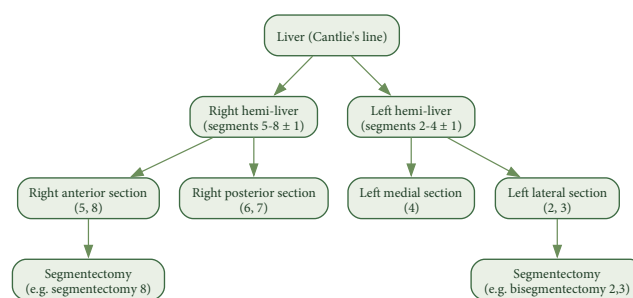
- ▶ **True (physiological) lobes:** Right lobe / Left lobe, divided by **Cantlie's line**.
- ▶ **Eight segments**, numbered I–VIII clockwise starting from the caudate lobe (viewed from below): I (caudate, posterior) → II (left lateral superior) → III (left lateral inferior) → IV (IVa/IVb, left medial) → V (right anterior inferior) → VI (right posterior inferior) → VII (right posterior superior) → VIII (right anterior superior).
- ▶ The **three hepatic veins** as intersegmental boundaries: **right hepatic vein** (between VI/VII and V/VIII), **middle hepatic vein** (Cantlie's line, between IV/V/VIII), **left hepatic vein** (between II and III/IV).
- ▶ **Portal vein bifurcation** at the porta hepatis (running centrally within each segment) and the IVC groove behind segment I.

The Glissonian pedicle and hepatic-vein watershed — the vascular basis of resection

- ▶ Within each segment, the **portal vein, hepatic artery and bile duct run together centrally** (an "intra-segmental" or centrilobar course), while the three **hepatic veins run in the intervening fissures**, i.e. "intersegmentally," collecting blood from the peripheries of adjacent segments.
- ▶ This out-of-phase arrangement — vascular-biliary pedicles at the centre of a segment, veins at its margins — means a segment (or a group of contiguous segments) can be devascularized and removed along the intersegmental venous planes **without disturbing the blood supply or biliary drainage of the remaining liver**. This is the anatomical justification for "anatomical" **segment-oriented hepatectomy**, as opposed to non-anatomical ("wedge") resection.
- ▶ The **segmental (Glissonian) arteries are functional end-arteries**, with only fine collateral channels between segments — hence occlusion or division of a segment's pedicle reliably devascularizes only that segment.

Nomenclature of segment-oriented liver resections (Brisbane 2000, IHPBA)

Because "lobe," "lobectomy," "segment" and "segmentectomy" were used inconsistently worldwide, the International Hepato-Pancreato-Biliary Association standardised resection terminology directly on Couinaud's segments:



Clinical importance of vascular segments of liver

Resection	Segments removed
Right hepatectomy (right hemihepatectomy)	5, 6, 7, 8 (± 1)
Left hepatectomy (left hemihepatectomy)	2, 3, 4 (± 1)
Right/left trisectionectomy (extended right/left hepatectomy)	4–8, or 2–8 minus 6,7
Sectionectomy (e.g. left lateral sectionectomy)	2 contiguous segments of one section
Segmentectomy / bisegmentectomy	any 1 or 2 contiguous Couinaud segments

Segment IV's division into IVa (superior)/IVb (inferior) is exploited in **central (transverse) hepatectomy**, where segments IVb, V and VI are removed along a transverse portal plane to excise centrally placed tumours while preserving both hemi-livers.

Recent advances — imaging- and technology-guided segmental liver surgery

- ▶ **Preoperative CT/MRI volumetry and "virtual hepatectomy" planning software** now routinely map individual segment volumes and vascular variants before major resection, allowing calculation of the **future liver remnant (FLR)** and surgical simulation along segmental planes.
- ▶ **Portal vein embolization (PVE)**, and its two-stage extension **ALPPS (Associating Liver Partition and Portal vein ligation for Staged hepatectomy)**, selectively occlude the portal supply of segments destined for resection, inducing compensatory hypertrophy of the segments that will remain — a direct clinical exploitation of the segment-independent portal vascular territories.
- ▶ **Indocyanine-green (ICG) fluorescence navigation**, given systemically or by selective portal-pedicle injection, allows real-time intraoperative delineation of Couinaud segment boundaries during laparoscopic and robotic **anatomical segmentectomy**.
- ▶ **Intraoperative and contrast-enhanced ultrasound** are used to confirm segmental vascular anatomy and localise tumours relative to hepatic-vein and portal-vein landmarks during resection.
- ▶ **CT/MRI volumetric assessment of donor hepatic arterial and venous variants** (e.g., replaced right hepatic artery, accessory hepatic veins) is now mandatory before **living-donor and split-liver transplantation**, since an unrecognised variant supplying segment IV or draining segments V/VIII can compromise the graft or the donor remnant.

Applied / Clinical anatomy

- ▶ **Living-donor and split-liver transplantation:** graft selection (right lobe, left lobe, or left lateral section for a paediatric recipient) is planned strictly along Couinaud's segmental and hepatic-vein territories. The **segment IV hepatic artery** most commonly arises from the left hepatic artery but arises from the right hepatic artery/hepatic artery proper in up to 30% of individuals; failure to recognise this can devascularise segment IV after right lobe donor hepatectomy. A **replaced or accessory right hepatic artery from the superior mesenteric artery (10–15%)** and a **replaced/accessory left hepatic artery from the left gastric artery (10–20%)** must similarly be identified to avoid vascular injury and to plan reconstruction.

- ▶ **Radiological tumour localisation and resectability planning:** hepatocellular carcinoma and metastatic deposits are described and staged by **Couinaud segment number** on CT/MRI, using the hepatic veins (at the level of their confluence with the IVC) and the right/left portal vein bifurcation as internal landmarks — enabling the surgeon to plan a segment- or section-based resection that spares adequate functioning liver.
- ▶ **Portal hypertension/TIPS:** the transjugular intrahepatic portosystemic shunt exploits the close intrahepatic proximity of a large portal vein branch and hepatic vein branch within adjoining segments to create a decompressive channel for severe portal hypertension.
- ▶ **Liver regeneration:** because of the liver's unique regenerative capacity, resection of one or more segments (segmentectomy/hepatectomy) is followed by compensatory hypertrophy of the remaining segments, restoring near-original liver volume within weeks to a few months — this is what makes major segmental resection and living-donor hepatectomy feasible.
- ▶ **Image-guided percutaneous intervention:** liver biopsy, radiofrequency/microwave ablation of tumours, and percutaneous transhepatic biliary drainage are all planned with reference to the segment in which the target lesion or duct lies, to choose the safest needle/catheter trajectory relative to segmental vessels.
- ▶ **Trauma:** the segmental distribution of the hepatic veins (particularly the right hepatic vein) and their fixation to the IVC make the venous confluence a major source of exsanguinating haemorrhage in blunt liver trauma; segment-preserving debridement (rather than formal lobectomy) is now preferred wherever the injury is confined to one or two segments.

High-yield exam pointers

- ▶ Couinaud (1957): liver divided into **8 functional vascular segments (I–VIII)**, each an independent portal-arterial-biliary (Glissonian) unit.
- ▶ **Cantlie's line (main portal fissure)** — gallbladder fossa to IVC, contains the **middle hepatic vein** — is the true right/left hemi-liver boundary, distinct from the falciform-ligament-based anatomical lobes.
- ▶ **Segment I (caudate)** is unique: dual (bilateral) portal/arterial supply and independent direct venous drainage into the IVC; must be removed en bloc in hilar cholangiocarcinoma surgery.
- ▶ Portal pedicles run **intrasegmentally** (centrally); the three hepatic veins run **intersegmentally** — the anatomical basis of "anatomical" segment-oriented resection.
- ▶ **Segment IV** is sub-divided into **IVa/IVb**, relevant to central (transverse) hepatectomy.
- ▶ **Brisbane 2000 (IHPBA)** standardised terms: hepatectomy/hemihepatectomy, sectionectomy, segmentectomy, trisectionectomy.
- ▶ Segmental vascular/hepatic-vein anatomy is the basis of planning for **living-donor and split-liver transplantation**.
- ▶ **PVE and ALPPS** exploit segment-selective portal occlusion to hypertrophy the future liver remnant before extended hepatectomy; **TIPS** exploits intrahepatic portal–hepatic vein proximity.
- ▶ Hepatic arterial **variants** (replaced right hepatic artery from SMA, replaced left from left gastric, variable segment IV artery origin) must be mapped before hilar/transplant surgery to avoid vascular injury.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; AK Datta's Human Anatomy Vol 1 (Thorax & Abdomen); BD Chaurasia's Human Anatomy Vol 2 8e; Moore's Clinically Oriented Anatomy 9e; Vishram Singh's Textbook of Anatomy Vol 2 4e (figure).



Describe the anatomical basis of neurological conditions associated with urinary bladder

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — Normal micturition is a somatic-autonomic reflex act, continuously modulated by the brain, in which the **detrusor muscle** and the **internal and external urethral sphincters** act reciprocally to first store and then void urine. Control operates through four hierarchical neural levels — cortical, pontine, spinal and peripheral (autonomic + somatic) — connected by a long ascending sensory limb and a descending motor limb. **Neurogenic bladder** is any disturbance of bladder storage/emptying that results from a lesion anywhere along this neuroaxis rather than from disease of the bladder wall itself; the *type* of dysfunction produced is determined almost entirely by the **anatomical level** of the lesion. This anatomical basis — the innervation of the bladder, the reflex arc, and the effect of interrupting it at each level — is described below.

1. The neural hierarchy controlling micturition

Level	Structure	Location / segments	Role
Cortical	Micturition (facilitatory/inhibitory) centre — paracentral lobule, medial frontal cortex	Superomedial surface of frontal lobe, both sides	Voluntary initiation/inhibition of voiding; perceives urge
Pontine	Pontine micturition centre (Barrington's nucleus) — pontine (paramedian) reticular formation	Dorsolateral pontine tegmentum, bilateral	Coordinates detrusor contraction with reciprocal sphincter relaxation — the "switching" centre for the storage↔voiding reflex
Spinal	Spinal micturition centre	Sacral segments S2–S4 (conus medullaris, ~L1–L2 vertebral level in adults)	Integrates the local reflex arc; site of parasympathetic outflow
Peripheral	Autonomic (parasympathetic + sympathetic) and somatic (pudendal) nerves	Pelvic plexuses / pudendal nerve	Effector limb to detrusor and sphincters; carries sensation of filling and pain

2. Peripheral innervation of the bladder and urethra

- ▶ **Parasympathetic (nervi erigentes)** — preganglionic fibres from S2, S3, S4 (spinal micturition centre) run in the **pelvic splanchnic nerves** through the **inferior hypogastric plexus** to postganglionic neurons in the **vesical plexus**; postganglionic fibres are **motor to the detrusor** and **inhibitory to the internal urethral sphincter (sphincter vesicae)**.
- ▶ **Sympathetic (thoraco-lumbar outflow)** — preganglionic fibres from T11, T12, L1, L2 (T10–L2 in some accounts) pass via the sympathetic chain, presacral (superior hypogastric) and inferior hypogastric plexuses to the vesical plexus; postganglionic fibres are **inhibitory to the detrusor** and **motor to the sphincter vesicae**, promoting bladder filling; in the male, sympathetic contraction of the sphincter vesicae during ejaculation prevents retrograde seminal flow.
- ▶ **Somatic (pudendal nerve, S2–S4)** — supplies the **external urethral sphincter** (striated, voluntarily controlled) and pelvic floor.
- ▶ **Sensory fibres** run with both autonomic pathways but ascend by *different* spinal tracts: fibres carrying **bladder distension/fullness** travel in the **posterior (dorsal) white columns**, while fibres carrying **bladder pain** travel in the **anterolateral white columns**. This anatomical separation explains why bilateral **anterolateral cordotomy** (done for intractable pelvic/visceral pain) relieves bladder pain without abolishing the sensation of bladder filling.

□ Fig 16.9 — Innervation of the urinary bladder (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.696)

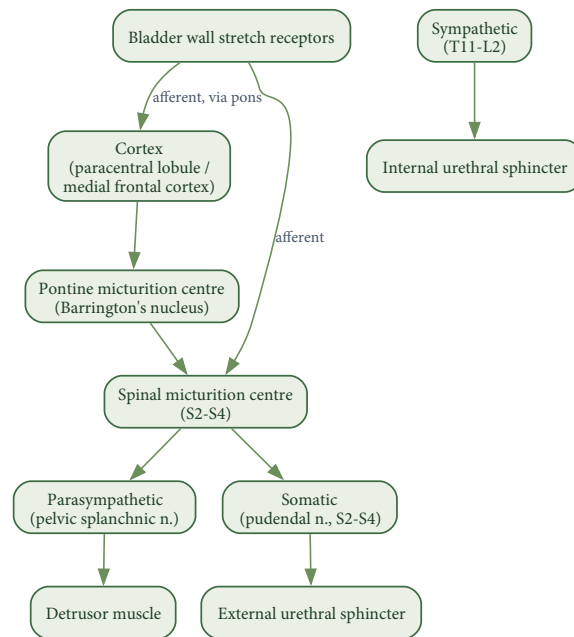
DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce the innervation scheme by hand, labelling:

- ▶ Spinal cord with segments T11–L2 (sympathetic outflow) and S2–S4 (parasympathetic + somatic outflow)
- ▶ Sympathetic chain, hypogastric nerve/plexus (blue), pelvic splanchnic nerves (red), pudendal nerve (black)
- ▶ Inferior hypogastric (pelvic) plexus and vesical plexus
- ▶ Urinary bladder with **detrusor muscle**, **internal urethral sphincter (sphincter vesicae)**, **external urethral sphincter**
- ▶ Arrows showing afferent fibres for distension (posterior column) vs pain (anterolateral column) ascending the cord

3. The micturition reflex — storage and voiding

During filling, stretch receptors in the bladder wall are progressively activated once volume crosses ~150–220 mL; afferents ascend in the posterior columns and pelvic splanchnic nerves to the spinal micturition centre and, via the spinothalamic/spinoreticular pathways, to the **pontine micturition centre** and cortex. Voluntary continence is maintained by cortical inhibition of the pontine centre and by guarding contraction of the external sphincter. When voiding is willed, cortical inhibition is released, the pontine centre drives a coordinated spinal reflex — **detrusor contraction with simultaneous relaxation of both sphincters** — and the bladder empties completely. This coordinated switch is precisely what is lost when the pathway is interrupted, producing the different clinical types of neurogenic bladder described next.



Describe the anatomical basis of neurological conditions associated with urinary bladder

4. Anatomical (lesion-level) classification of neurogenic bladder

Lesion level	Type of neurogenic bladder	Anatomical mechanism	Typical causes
Suprapontine (bilateral medial frontal cortex/paracentral lobule)	Uninhibited bladder	Cortical inhibitory control on the intact pontine–spinal reflex is lost; detrusor contracts reflexly and appropriately but <i>without</i> voluntary restraint	Superior sagittal sinus thrombosis, falx cerebri meningioma, occlusion of the (unpaired) anterior cerebral artery, bilateral frontal stroke/tumour
Suprasacral spinal cord (above S2–S4), after recovery from spinal shock	Automatic (reflex) bladder	Descending corticospinal/pontine fibres are cut, but the S2–S4 reflex arc itself is intact; detrusor fills and empties reflexly every 1–4 hours with no voluntary initiation or inhibition	Traumatic spinal cord transection/paraplegia, transverse myelitis, demyelinating (multiple sclerosis) plaques above the sacral cord
Acute spinal cord injury (immediately post-injury)	Atonic bladder of spinal shock	Detrusor is flaccid/areflexic, internal sphincter is tonically contracted (loss of higher inhibition), external sphincter relaxed → progressive painless distension with overflow	Early phase after any severe cord injury, before spinal reflexes return

Lesion level	Type of neurogenic bladder	Anatomical mechanism	Typical causes
Sacral/infrasacral — destruction of S2–S4 segments or their roots (conus medullaris/cauda equina)	Autonomous bladder	Both the reflex arc (efferent + afferent limb at S2–S4) and descending voluntary control are abolished; detrusor becomes flaccid, bladder capacity increases greatly, and it fills to capacity and overflows (continuous dribbling); may be emptied only by manual (Credé) compression or abdominal straining	Cauda equina compression (prolapsed lumbar disc, spinal stenosis, tumour), sacral spina bifida, pelvic trauma/fracture
Afferent (sensory) limb only	Atonic (sensory) neurogenic bladder with residual urine	Interruption of the sensory side of the reflex leaves the motor/efferent pathway intact, but loss of the sensation of fullness abolishes the reflex trigger; large volumes accumulate painlessly	Tabes dorsalis (neurosyphilis affecting posterior columns/dorsal roots); an analogous mechanism underlies diabetic (autonomic/sensory) cystopathy

Key correlating point — in lesions that lie **above S2 but below T4–T6**, the sympathetic outflow (which enters the cord above this level) remains intact, so the patient continues to have some autonomic awareness of a full bladder; lesions **above T6** additionally place the patient at risk of **autonomic dysreflexia** during bladder distension, because massive unopposed sympathetic discharge below the lesion cannot be buffered by descending inhibitory pathways.

Applied / Clinical anatomy

- **Spinal cord injury** passes through an early **atonic (spinal shock)** phase, then — if the lesion is suprasacral — evolves into an **automatic reflex bladder**; if the sacral cord/cauda equina itself is destroyed, an **autonomous bladder** results instead. Distinguishing the level clinically (bulbocavernosus reflex, anal tone, sensory level) determines whether reflex emptying can ever be expected.
- **Detrusor–sphincter dyssynergia**: because the coordinating pontine centre no longer communicates with the isolated spinal reflex in suprasacral cord lesions, the detrusor and external sphincter can contract *simultaneously* rather than reciprocally, generating dangerously high intravesical pressures that predispose to vesico-ureteric reflux and upper-tract (renal) damage — the anatomical rationale for urodynamic surveillance in all suprasacral cord lesions.
- **Cauda equina/conus medullaris syndrome** (e.g. massive lumbar disc prolapse) classically combines an autonomous bladder with **saddle anaesthesia**, loss of bowel control, and flaccid (lower motor neuron) weakness of the legs — reflecting simultaneous involvement of S2–S4

sensory roots, autonomic roots and the somatic sciatic/pudendal roots that all traverse the same narrow canal.

- ▶ **Tabes dorsalis** (neurosyphilis) selectively degenerates the posterior columns/dorsal roots, producing a painless, atonic, sensory neurogenic bladder — a classical example of pure afferent-limb disease.
- ▶ **Bilateral anterolateral cordotomy**, used to relieve intractable pelvic malignant pain, spares bladder-filling sensation because that modality ascends in the posterior columns, not the anterolateral columns that carry pain.
- ▶ **Suprapontine lesions** (bifrontal vascular disease, normal-pressure hydrocephalus, dementia) classically produce an **uninhibited bladder** with urgency, frequency and urge incontinence but *coordinated* (non-dyssynergic) sphincter behaviour, since the pontine switching mechanism is undisturbed.
- ▶ Clinical assessment of all these levels is by **video-urodynamics**, which directly demonstrates detrusor activity, sphincter coordination and pressures, and management is level-specific: clean intermittent catheterisation for autonomous/atonic bladders, anticholinergics/intraderusor botulinum toxin-A for detrusor overactivity in suprasacral and suprapontine lesions, and suprapubic catheterisation where long-term drainage is unavoidable.

Recent advances in neuro-urology

- ▶ The **2024 update of the EAU Guidelines on Neuro-urology** (Sartori AM, Kessler TM, Castro-Díaz DM, et al. *Eur Urol* 2024; [DOI: 10.1016/j.eururo.2024.03.026](https://doi.org/10.1016/j.eururo.2024.03.026)) reaffirms a risk-stratified, lesion-level approach to diagnosis, surveillance and treatment of neurogenic lower urinary tract dysfunction.
- ▶ The **AUA/SUFU Guideline on Adult Neurogenic Lower Urinary Tract Dysfunction** (Ginsberg DA, Boone TB, Cameron AP, et al. *J Urol* 2021;206(5):1097–1105, PMID: 34495687, DOI: 10.1097/JU.0000000000002235) formally replaced the older term "neurogenic bladder" with **NLUTD (neurogenic lower urinary tract dysfunction)**, emphasising that bladder, bladder neck and sphincter can each be independently affected, and introduced a **risk-stratification model** (low/moderate/high/unknown) for guiding surveillance intensity based on the anatomical level and completeness of the neurological lesion.
- ▶ The **NEUROGED Guidelines** — European Academy of Neurology/European Federation of Autonomic Societies/International Neuro-Urology Society joint guideline for practising neurologists (Panicker JN, Fanciulli A, Habek M, et al. *Eur J Neurol* 2025;32(4):e70119, DOI: 10.1111/ene.70119) — give neurologists a structured, lesion-level pathway (suprapontine/spinal/peripheral) for assessing and treating neurogenic urinary and sexual symptoms.
- ▶ A **non-invasive 7-Tesla fMRI study mapping the human brainstem during continence and micturition** (ClinicalTrials.gov NCT04846387, completed 2023) has begun to directly visualise activity in the pontine micturition centre (Barrington's nucleus) and periaqueductal grey in real time in humans, providing the first high-resolution *in-vivo* functional confirmation of the classical anatomical pontine-switch model described above.

(According to PubMed/EAU/AUA/EAN literature search; corpus textbooks describe the classical anatomical substrate, which these guidelines/studies update at the level of terminology, risk-stratification and functional imaging rather than gross anatomy.)

High-yield exam pointers

- ▶ Four control levels: **cortex** (paracentral lobule) → **pons** (Barrington's nucleus) → **spinal cord** (S2–S4) → **peripheral nerves** (parasympathetic, sympathetic, somatic).
- ▶ Parasympathetic S2–S4 (nervi erigentes) → motor to detrusor, inhibits internal sphincter; Sympathetic T11–L2 → inhibits detrusor, motor to internal sphincter; Somatic **puddendal** (S2–S4) → external sphincter.
- ▶ Distension sensation ascends in **posterior columns**; pain ascends in **anterolateral columns** — basis of cordotomy sparing bladder-fullness sensation.
- ▶ **Uninhibited bladder** = suprapontine (bifrontal) lesion; **automatic (reflex) bladder** = suprasacral cord lesion after spinal shock; **atonic bladder** = acute spinal shock phase; **autonomous bladder** = destruction of S2–S4 (conus/cauda equina); **atonic sensory neurogenic bladder** = afferent-limb lesion (tabes dorsalis).
- ▶ Detrusor–sphincter dyssynergia occurs only when the pontine coordinating centre is disconnected from an otherwise intact spinal reflex (suprasacral lesions) — risk to upper urinary tract.
- ▶ Lesions above T6 risk autonomic dysreflexia on bladder distension.
- ▶ Conus medullaris/cauda equina syndrome = autonomous bladder + saddle anaesthesia + bowel dysfunction + LMN leg weakness.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Textbook of Anatomy Vol 2 (4e); Vishram Singh's Clinical Neuroanatomy (4e); IB Singh's Textbook of Human Neuroanatomy; Snell's Clinical Neuroanatomy (7e).



Describe the applied anatomy associated with various deformities of the foot

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction — The normal foot is a triradiate, weight-bearing platform held in shape by two longitudinal and two transverse **arches**, maintained dynamically by tarsal bone shape, intersegmental ligaments (tie-beams) and the tone of long/short muscles (slings). Every deformity of the foot reflects a breakdown of one of these elements — arch collapse (pes planus), arch exaggeration (pes cavus/claw foot), fixed malposition at the ankle-subtalar-midtarsal complex (talipes/club foot), forefoot/toe malalignment (hallux valgus, hammer toe, rocker-bottom foot), or paralytic muscle imbalance from a specific nerve lesion (foot drop). The bony, ligamentous, muscular and neural anatomy that normally stabilises the foot thus directly explains the mechanism, clinical picture and correction of each deformity.

1. Applied anatomy of the arches — the anatomical basis of every arch deformity

The foot has two longitudinal arches (medial and lateral) and two transverse arches (anterior and posterior). Their bony, ligamentous ("tie-beam") and muscular ("sling") supports are the anatomical basis of pes planus and pes cavus:

Feature	Medial longitudinal arch	Lateral longitudinal arch
Anterior pillar	Talus, navicular, 3 cuneiforms, 1st–3rd metatarsals	Cuboid, 4th–5th metatarsals
Posterior pillar	Medial half of calcaneus	Lateral half of calcaneus
Key bone (summit)	Head/superior surface of talus	Cuboid
Main joint	Talocalcaneonavicular joint	Calcaneocuboid joint
Intersegmental tie	Spring (plantar calcaneonavicular) ligament	Long and short plantar ligaments
Tie-beam	Plantar aponeurosis (medial part), abductor hallucis, flexor digitorum brevis	Plantar aponeurosis (lateral part), abductor digiti minimi
Sling (long tendons)	Tibialis posterior, tibialis anterior, flexor hallucis longus	Peroneus longus, peroneus brevis
Character	Higher, mobile, resilient — acts as a spring/shock absorber	Lower, rigid — mainly transmits weight

- The **posterior transverse arch** (3 cuneiforms + cuboid) and **anterior transverse arch** (heads of 5 metatarsals) are supported by the tendon of peroneus longus (sling across the sole) and by intermetatarsal ligaments and the transverse head of adductor hallucis.
- **Functions of the arches:** (i) resilience/spring action during walking and running; (ii) shock absorption on stepping and jumping; (iii) even distribution of body weight over the heel and the metatarsal heads while sparing the concave sole; (iv) protection of the plantar nerves and vessels lodged in the concavity of the sole.

- ▶ Loss of arch integrity (pes planus) or its exaggeration (pes cavus) both disturb this weight-transmission mechanism and are the commonest arch-related deformities.

2. Pes planus (flat foot) — collapse of the medial longitudinal arch

- ▶ **Mechanism:** prolonged standing or increased body weight over-stretches the plantar aponeurosis and the spring ligament; the head of the talus then loses its sling support (normally provided by tibialis posterior) and sinks downward and medially between the calcaneus and the navicular, flattening the medial longitudinal arch.
- ▶ **Physiological vs pathological** (Gray's Anatomy): physiological pes planus (pre-school children, 2–6 years) is flexible — calcaneus swings into varus on tiptoeing; pathological pes planus is rigid — this correction fails. Causes of the pathological form: tarsal coalition, tibialis posterior tendon dysfunction/rupture, spring ligament rupture, tarsometatarsal or subtalar arthritis.
- ▶ **Effects:** clumsy shuffling gait (loss of spring); increased trauma/osteoarthritis (loss of shock absorption); compression of the medial-lateral plantar nerve communication causing forefoot neuralgia (**metatarsalgia**) and vascular disturbance of the toes (loss of sole concavity).
- ▶ **Clinical test:** wet-footprint test (whole sole imprinted, concavity obliterated) — the classical basis for rejecting flat-footed candidates from services requiring fast, prolonged running.

3. Pes cavus and claw foot — exaggeration of the arch, usually neurogenic

- ▶ **Pes cavus** (high-arched foot) results from a plantar-flexion contracture at the transverse tarsal joint, so that the anterior part of the foot drops below the level of the posterior part; the toes are dorsiflexed at the metatarsophalangeal (MTP) joints and plantar-flexed at the interphalangeal (IP) joints when the patient bears weight on the highly arched foot. Gray's Anatomy classifies pes cavus by the anatomical site of the deformity into **hindfoot, midfoot or forefoot cavus**; when all three segments are involved it is termed "**global**" cavus.
- ▶ **Aetiology:** mostly neurogenic — **Charcot–Marie–Tooth disease** (hereditary motor-sensory neuropathy), poliomyelitis, tethered cord and **spina bifida** are classical associations. In Charcot–Marie–Tooth disease, an overactive/unopposed fibularis longus plantar-flexes the first metatarsal; the hindfoot compensates into varus to keep the forefoot tripod grounded, giving the characteristic cavovarus posture.
- ▶ **Claw foot:** when the additional deformity of clawing of the toes is superimposed on pes cavus — dorsiflexion at the MTP joints together with plantar flexion at the IP joints, due to wasting/paralysis of the intrinsic muscles (lumbricals and interossei) with unopposed action of the long flexors and extensors — the condition is called **claw foot**. Its common causes, like pes cavus, are spina bifida and poliomyelitis.

□ Fig 13.9 — Clawfoot/pes cavus (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.223)

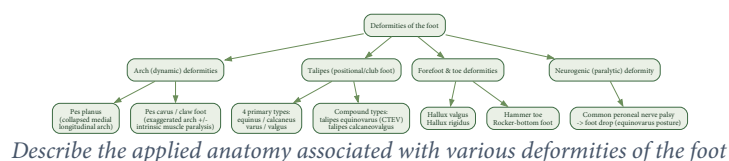
4. Talipes (club foot) — classification and congenital talipes equinovarus (CTEV)

Talipes (Latin *talus* + *pes*) denotes a fixed positional deformity of the foot. Four primary types are described, based on the position fixed at the ankle/subtalar joints:

Type	Position fixed	Clinical gait
Talipes equinus	Foot plantar-flexed at the ankle	Walks on the toes (heel raised), horse-like ("equinus")
Talipes calcaneus	Foot dorsiflexed at the ankle	Walks on the heel, forefoot raised
Talipes varus	Foot inverted and adducted (subtalar/talocalcaneonavicular joints)	Walks on the outer (lateral) border of the foot
Talipes valgus	Foot everted and abducted	Walks on the inner (medial) border of the foot

- Combinations occur — **talipes calcaneovalgus** (foot dorsiflexed at the ankle, everted at the midtarsal joints) and, most importantly, **talipes equinovarus** (CTEV), in which the foot is plantar-flexed, inverted and adducted. CTEV is the **commonest congenital deformity of the foot**, occurring in approximately **1 per 1000 live births**, with **males affected about twice as often as females** (Gray's Anatomy).
- **Pathoanatomy** (Gray's Anatomy): both bone and soft tissue are affected. The **talus** is decreased in size by up to 25%, has a foreshortened neck and a decreased body/neck angle, with the subtalar facets medially rotated; the **navicular** is small and medially deviated relative to the talus; the **calcaneus** is small, shows varus displacement and an equinus tilt, with its anterior facets corresponding to those of the talus. The entire affected foot and calf are smaller than normal; the foot is inverted and supinated, and the forefoot is adducted.
- **Aetiology** is multifactorial: a primary developmental defect of the talus (from which other deformities arise secondarily), abnormal tendon/ligament attachments and delayed muscle maturation are proposed; a genetic predisposition exists, so CTEV is not purely positional (intrauterine crowding/oligohydramnios). Congenital talipes is occasionally associated with **spina bifida**.
- Correction targets this exact talus-navicular-calcaneus malalignment — serial manipulation/casting of the adducted forefoot and inverted hindfoot, with tenotomy of tendo calcaneus for residual equinus.

□ Fig 20.25 — Newborn Infant With Bilateral Talipes Equinovarus Deformity (Larsen — Human Embryology — 6e, p.1238)



Describe the applied anatomy associated with various deformities of the foot

5. Forefoot and toe deformities

- **Hallux valgus**: lateral deviation of the great toe at the MTP joint with **metatarsus primus varus** (adducted first metatarsal); mainly genetic predisposition, aggravated by pointed/high-heeled footwear (greater incidence in females). A more spheroidal first metatarsal head is more unstable; adductor hallucis is a deforming force. Repeated footwear pressure over the prominent metatarsal head produces a protective adventitious bursa — the **bunion**.
- **Hallux rigidus**: pain and restricted movement at the first MTP joint.

- ▶ **Hammer toe:** MTP and distal interphalangeal (DIP) joints hyperextended, proximal interphalangeal (PIP) joint acutely flexed, typically the 2nd–3rd toes; follows plantar-plate rupture at the MTP joint or paralysis/wasting of the interossei (and sometimes lumbricals).
- ▶ **Rocker-bottom foot:** plantar concavity replaced by convexity; associated with congenital chromosomal syndromes, notably **trisomy 18 (Edward syndrome)**, with an equinus hindfoot and vertical, plantar-palpable talus; most such infants have associated neurological abnormalities.

6. Neurogenic (paralytic) deformity — common peroneal nerve palsy and foot drop

- ▶ **Anatomical basis:** the common peroneal (lateral popliteal) nerve — terminal branch of the sciatic nerve, root value **L4, L5, S1, S2** — winds subcutaneously around the neck of the fibula, where it can be rolled against bone, making it the most commonly injured lower-limb nerve (fibular neck fracture, tight plaster casts, prolonged squatting, leprosy/peripheral neuritis).
- ▶ **Effect:** paralysis of the anterior (extensor) and lateral (peroneal) compartments. With dorsiflexors and evertors paralysed, the unopposed plantar flexors and unopposed invertor tibialis posterior hold the ankle plantar-flexed and the foot inverted — **foot drop**.
- ▶ **Clinical picture:** high-stepping ("steppage") gait to clear the drooping forefoot; sensory loss confined to the first interdigital cleft (deep peroneal territory) and the dorsum of the foot (superficial peroneal territory).
- ▶ Since the posterior (tibial) compartment and plantar intrinsics are spared, early common peroneal palsy is a dynamic, correctable foot drop rather than fixed bony talipes — though a long-standing, unsupported palsy may progress to fixed equinovarus contracture.

Applied / Clinical anatomy

- ▶ **Army/recruitment screening:** flat foot is a classical disqualifying finding for services requiring sustained running (loss of the medial arch's spring action → early fatigue, shuffling gait).
- ▶ **Flexible vs rigid pes planus:** on tiptoe-standing, a flexible (physiological) flat foot shows the calcaneus swinging into varus; in pathological/rigid pes planus this correction fails.
- ▶ **Surgical relevance of CTEV pathoanatomy:** since the primary bony lesion lies in the talus-navicular-calcaneus complex, correction targets these three bones and their attachments rather than the forefoot alone.
- ▶ **Common peroneal nerve injury** is clinically important at the neck of the fibula (fracture-fixation, plaster casts, prolonged squatting) — an ankle-foot orthosis holds the ankle in neutral dorsiflexion to prevent tripping and secondary fixed equinus.
- ▶ **Claw foot/pes cavus of neurological origin** demands a full neurological examination of the limb and spine, since it is often the presenting sign of an underlying neuromuscular disorder (Charcot–Marie–Tooth disease, spina bifida, poliomyelitis).

High-yield exam pointers

- ▶ Two longitudinal arches (medial: talus is the keystone; lateral: cuboid is the keystone) + two transverse arches maintain the tripod of weight-bearing; supported by bone shape, ligamentous ties (spring ligament) and muscular slings (tibialis posterior/anterior, peronei).

- ▶ **Pes planus** = collapse of medial longitudinal arch (talar head loses tibialis-posterior/spring-ligament support); **pes cavus** = exaggeration from plantar-flexion contracture at the transverse tarsal joint, classified as hindfoot/midfoot/forefoot/global cavus.
- ▶ **Claw foot** = pes cavus + clawing of toes (MTP dorsiflexion + IP flexion) from intrinsic muscle (lumbrical/interossei) paralysis; common neurological causes of pes cavus/claw foot = Charcot–Marie–Tooth disease, poliomyelitis, spina bifida/tethered cord.
- ▶ Four primary talipes types: **equinus** (plantar-flexed, walks on toes), **calcaneus** (dorsiflexed, walks on heel), **varus** (inverted/adducted, walks on lateral border), **valgus** (everted/abducted, walks on medial border).
- ▶ **CTEV (talipes equinovarus)** = commonest congenital foot deformity, ~1:1000 live births, males : females ≈ 2:1; pathoanatomy = small, foreshortened, medially-rotated talus + medially-deviated navicular + varus/equinus-tilted calcaneus + adducted forefoot; may associate with spina bifida.
- ▶ **Hallux valgus** = lateral deviation of great toe + metatarsus primus varus + bunion; **hammer toe** = MTP/DIP hyperextension with PIP flexion (2nd–3rd toes); **rocker-bottom foot** = vertical talus, associated with trisomy 18.
- ▶ **Common peroneal nerve** (L4–S2) winds round the neck of fibula (subcutaneous, vulnerable) → paralysis of anterior + lateral compartments → **foot drop** (unopposed plantar flexion + inversion), steppage gait, sensory loss over first web space and dorsum of foot.
- ▶ Wet-footprint test and the tiptoe (calcaneal-varus) test clinically differentiate flat-foot types; flat foot is a classical cause for rejection at army medical recruitment.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2 (8e); AK Datta — Human Anatomy Vol 3 (Upper & Lower Limb); Vishram Singh — Textbook of Anatomy Vol 2 (4e); IB Singh — Textbook of Anatomy Vol 1 (6e); Larsen — Human Embryology (6e). Coverage note: the dedicated neuroanatomy texts (Snell, Vishram Singh Clinical Neuroanatomy, IB Singh Human Neuroanatomy) carry no section on foot deformities; the detail above is grounded in the gross-anatomy/embryology texts, with the neurological correlation drawn from Gray's Anatomy and their clinical-correlation sections.



Describe the boundaries and contents of the inguinal canal. Add a note on inguinal hernias

Asked in: Paper IV Oct 2006 — RGUHS MD/MS Anatomy

Definition / Introduction The inguinal canal is an oblique, musculo-aponeurotic intermuscular passage in the lower part of the anterior abdominal wall, above and parallel to the medial half of the inguinal ligament. It extends from the **deep (internal) inguinal ring** laterally to the **superficial (external) inguinal ring** medially, and transmits the spermatic cord in the male, the round ligament of the uterus in the female, and the ilioinguinal nerve in both sexes. It represents a deliberate gap in an otherwise continuous three-layered muscular wall, created to allow the gonad to descend into the scrotum/labium majus in development; this makes it the commonest site of weakness of the anterior abdominal wall, and per Gray's Anatomy (41e), hernia repair here is "the single most common operation performed by general surgeons."

Location and Extent

- Lies in the groin, above the medial half of the inguinal ligament, running obliquely **downwards, forwards and medially**.
- **Length:** about **4 cm** in the adult (Gray's 41e gives a range of **3–6 cm** depending on age); it is very short (~1 cm) in the newborn and infant because the deep and superficial rings lie almost superimposed, and it lengthens as the pelvis widens with growth.
- **Sex difference:** larger in the male (transmits the bulkier spermatic cord); narrower in the female, which is one reason indirect inguinal hernia is less common in women.
- Extends from the deep inguinal ring (an opening in the fascia transversalis) to the superficial inguinal ring (a gap in the external oblique aponeurosis).

Boundaries (Four Walls)

Wall	Composition
Anterior wall	Whole length: skin, superficial fascia, aponeurosis of external oblique. Lateral one-third: reinforced by the fleshy fibres of internal oblique arising from the lateral part of the inguinal ligament.
Posterior wall	Whole length: fascia transversalis, extraperitoneal tissue, parietal peritoneum. Medial two-thirds: reinforced by the conjoint tendon and, at its very medial end, the reflected part of the inguinal ligament.
Roof	Arched fibres of internal oblique and transversus abdominis , which fuse medially to form the conjoint tendon.
Floor	Grooved upper surface of the inguinal ligament ; reinforced medially by the lacunar ligament .

- The **conjoint tendon** (fusion of the lowest fibres of internal oblique and transversus abdominis, inserting into the pubic crest and pecten pubis) strengthens the posterior wall exactly where the

canal is otherwise weakest — behind the superficial ring — since the two rings do not lie opposite each other (obliquity; basis of the flap-valve mechanism below).

□ Fig 4.5 — Boundaries of the inguinal canal: (A) anterior (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.202)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

An oblique section through the right inguinal canal, labelled with:

- ▶ Skin → superficial fascia → external oblique aponeurosis — anterior wall; internal oblique fibres reinforcing it laterally
- ▶ Transversus abdominis + internal oblique (arched fibres) — roof, continuing medially as conjoint tendon
- ▶ Fascia transversalis → extraperitoneal tissue → parietal peritoneum — posterior wall; conjoint tendon + reflected inguinal ligament reinforcing it medially
- ▶ Inguinal ligament (grooved) + lacunar ligament — floor
- ▶ Deep inguinal ring with inferior epigastric vessels at its medial margin
- ▶ Superficial inguinal ring with lateral/medial crura and intercrural fibres
- ▶ Spermatic cord traversing deep to superficial ring

Inguinal Rings

Ring	Description
Deep (internal) inguinal ring	An oval opening in the fascia transversalis, situated about 1.2–1.25 cm above the mid-inguinal point (the midpoint between the anterior superior iliac spine and the pubic symphysis), immediately lateral to the stem of the inferior epigastric vessels, which run along its medial border. It is the site of origin of the internal spermatic fascia.
Superficial (external) inguinal ring	A triangular gap in the external oblique aponeurosis, just above and lateral to the pubic crest; base = pubic crest, apex points laterally towards the anterior superior iliac spine. Sides are the lateral crus (stronger; attached to the pubic tubercle) and medial crus (weaker; attached to the pubic symphysis); the two crura are united at and beyond the apex by intercrural fibres. About 2.5 cm long and 1.2 cm broad at the base; smaller in the female.

Contents of the Inguinal Canal

- ▶ Spermatic cord (male) or round ligament of the uterus (female) — enters at the deep ring and leaves at the superficial ring; this constitutes the entire content of the canal apart from the nerve below.
- ▶ Ilioinguinal nerve (in both sexes) — does *not* enter through the deep ring; it pierces internal oblique and enters the canal through the interval between the external and internal oblique muscles, running outside (external to) the spermatic cord, and leaves through the superficial

inguinal ring to supply the skin of the upper medial thigh, root of the penis/mons pubis and anterior scrotum/labium majus. It is the one canal content not carried within the coverings of the spermatic cord.

Constituents of the spermatic cord (mnemonic "3 arteries – 3 nerves – 3 others"):

Group	Structures
3 arteries	Testicular artery, artery to the ductus (vas) deferens, cremasteric artery
3 nerves/nerve-related	Genital branch of the genitofemoral nerve, sympathetic plexus around the artery to the vas (+ visceral afferents)
3 others	Ductus (vas) deferens, pampiniform plexus of veins, lymphatics from the testis; remnant of the processus vaginalis

Coverings of the spermatic cord (from within outwards) — derived from the three layers of the anterior abdominal wall it traverses:

- ▶ **Internal spermatic fascia** — from the fascia transversalis; covers the cord throughout its length.
- ▶ **Cremasteric fascia (with the cremaster muscle)** — from internal oblique and transversus abdominis; covers the cord below the level of these muscles.
- ▶ **External spermatic fascia** — from the external oblique aponeurosis; covers the cord below the superficial inguinal ring.

Mechanisms Preventing Herniation Through the Canal

Despite being a natural gap, the canal resists herniation through complementary mechanisms:

- ▶ **Flap-valve (obliquity):** the rings do not lie opposite each other; raised intra-abdominal pressure approximates the anterior and posterior walls, obliterating the passage.
- ▶ **Shutter mechanism:** internal oblique (anterior wall, roof, and posterior wall as conjoint tendon) contracts with arching transversus fibres, approximating roof to floor.
- ▶ **Deep ring** guarded anteriorly by fleshy internal oblique fibres; **superficial ring** guarded posteriorly by the conjoint tendon and reflected inguinal ligament.
- ▶ **Ball-valve mechanism:** cremaster contraction helps the spermatic cord plug the superficial ring.
- ▶ **Slit-valve mechanism:** external oblique contraction approximates the two crura, reinforced by intercrural fibres.

NOTE — FOR REFERENCE, NOT TO BE WRITTEN IN THE EXAM

An **inguinal hernia** is the protrusion of intra-abdominal contents (commonly a loop of small intestine or omentum) through the inguinal canal or its posterior wall. It is the commonest external abdominal hernia and, unlike in other mammals, occurs almost exclusively in humans — attributed to the erect posture (forward growth of the iliac crest into external oblique, reducing the sphincteric action of internal oblique/transversus on the canal, and widening of the crural passage). Two varieties are recognised — **indirect (oblique)** and **direct**:

Feature	Indirect (oblique) inguinal hernia	Direct inguinal hernia
Cause	Congenital — persistence (patency) of the processus vaginalis, giving a preformed sac	Acquired — weakness of the posterior wall of the canal / conjoint tendon
Path	Enters through the deep inguinal ring , traverses the whole canal, exits the superficial ring; may descend into the scrotum/labium majus	Enters directly through the inguinal (Hesselbach's) triangle in the posterior wall — does not traverse the whole canal
Neck relative to inferior epigastric artery	Lateral to the artery	Medial to the artery
Direction	Downwards, forwards and medially, following the oblique canal	Straight forwards
Age / predisposition	Young subjects, infants and children; usually unilateral	Older men (precipitated by chronic cough/bronchitis, prostatic enlargement — anything raising intra-abdominal pressure chronically)
Neck of sac	Narrow — more prone to obstruction/strangulation	Wide — obstruction/strangulation uncommon
Coverings	Receives all coverings of the spermatic cord — peritoneal sac, extraperitoneal tissue, internal spermatic fascia, cremasteric fascia, external spermatic fascia	Peritoneal sac, extraperitoneal tissue, fascia transversalis, ± conjoint tendon (if medial to obliterated umbilical artery), cremasteric fascia, external spermatic fascia — no internal spermatic fascia , since it never traverses the deep ring

Hesselbach's (inguinal) triangle — the peritoneal triangle in the posterior wall through which a direct hernia protrudes; bounded **laterally** by the inferior epigastric vessels, **medially** by the lateral border of rectus abdominis, and at its **base (inferiorly)** by the inguinal ligament. The obliterated umbilical artery crosses and subdivides it into a medial part (**supravesical fossa**) and a lateral part (**medial inguinal fossa**).

□ Fig 16.34 — Hesselbach's triangle (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.283)

Applied / Clinical anatomy

- ▶ **Surgical importance:** per Gray's Anatomy (41e), hernia repair is the single commonest operation done by general surgeons; open and laparoscopic repairs both rely on precise identification of the deep ring, conjoint tendon and inferior epigastric vessels.
- ▶ **Internal ring occlusion test:** reducing the hernia and occluding the deep ring is said to prevent reappearance of an indirect hernia on straining while a direct hernia still bulges medially; however, Gray's 41e cautions that clinical differentiation of indirect from direct hernia by examination alone is **not reliable** and is usually confirmed only at surgery.
- ▶ **Surface landmarks:** the deep ring lies at the mid-inguinal point (midway between the ASIS and the pubic symphysis), ~1.2 cm above the inguinal ligament — distinct from the "midpoint of the inguinal ligament" used to locate the femoral artery, a classic exam confusion. The superficial ring lies just above and lateral to the pubic crest/tubercle.
- ▶ **Complications**, as of any external hernia: **irreducibility, obstruction, and strangulation** (vascular compromise at the neck) — strangulation is commoner in indirect hernias because of their narrower neck.
- ▶ **Differentiation from femoral hernia:** inguinal hernia lies **above and medial** to the pubic tubercle; femoral hernia lies **below and lateral** to it and is never congenital.
- ▶ **Ilioinguinal nerve**, running external to the spermatic cord, is at risk during herniorrhaphy (groin/scrotal numbness, post-herniorrhaphy neuralgia).
- ▶ **Processus vaginalis anomalies:** fully patent → indirect hernia; patent at the deep end only → **congenital hydrocele**; isolated unobliterated segment → **encysted hydrocele of the cord**.

High-yield exam pointers

- ▶ Inguinal canal: oblique passage above the medial half of the inguinal ligament, ~4 cm long (3–6 cm, age-dependent), from deep to superficial ring.
- ▶ Four walls — **anterior:** external oblique aponeurosis (+ internal oblique laterally); **posterior:** fascia transversalis (+ conjoint tendon medially); **roof:** arched internal oblique + transversus abdominis; **floor:** inguinal ligament (+ lacunar ligament medially).
- ▶ Deep ring in fascia transversalis, ~1.2 cm above mid-inguinal point, lateral to inferior epigastric vessels; superficial ring is a triangular gap in external oblique aponeurosis above the pubic crest.
- ▶ Contents: spermatic cord (male)/round ligament of uterus (female) + ilioinguinal nerve (outside the cord).
- ▶ Spermatic cord — 3 arteries, 3 nerve-related structures, 3 others (mnemonic "3-3-3"); 3 coverings from within out — internal spermatic fascia, cremasteric fascia, external spermatic fascia.
- ▶ Canal remains competent via flap-valve (obliquity), shutter (internal oblique/transversus), ball-valve (cremaster) and slit-valve (external oblique crura) mechanisms.
- ▶ Indirect hernia = congenital, preformed sac (patent processus vaginalis), through deep ring, lateral to inferior epigastric artery, narrow neck (prone to strangulation).
- ▶ Direct hernia = acquired, through Hesselbach's triangle (posterior wall), medial to inferior epigastric artery, wide neck (rarely strangulates), older men.

- Hesselbach's triangle: inferior epigastric vessels (lateral), lateral border of rectus abdominis (medial), inguinal ligament (base/inferior).

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; BD Chaurasia — Human Anatomy Vol 2, 8e; AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen); Vishram Singh — Textbook of Anatomy Vol 2, 4e.



Describe the nerve supply to urinary bladder and discuss the neurological disorders

Asked in: Paper IV Sep 2007 — RGUHS MD/MS Anatomy

Definition / Introduction

The urinary bladder is a musculo-membranous reservoir whose two functions — low-pressure **storage** of urine and its **voluntary voiding** — depend entirely on its nerve supply. Innervation is triple: an **autonomic** supply (parasympathetic, motor to the detrusor; sympathetic, to the bladder neck and preprostatic sphincter) reaching the bladder through the vesical (pelvic) plexus, and a **somatic** supply (pudendal nerve) to the striated external urethral sphincter. All three limbs are integrated by a sacral spinal micturition reflex (S2–S4), which is itself switched on and off by a **pontine micturition centre** under voluntary control from the cerebral cortex. Interruption of any link in this chain — cerebral cortex, spinal cord, cauda equina or peripheral autonomic pathway — produces a distinct, recognisable pattern of bladder dysfunction, collectively termed **neurogenic bladder**.

1. Autonomic nerve supply of the bladder

Component	Spinal origin	Pathway	Ganglia	Action
Parasympathetic (nervi erigentes)	Intermediolateral grey column, S2, S3, S4	Pelvic splanchnic nerves → inferior hypogastric (pelvic) plexus → vesical plexus	Postganglionic neurones in the vesical plexus and within the bladder wall itself	Motor to the detrusor (releases acetylcholine, acts on muscarinic receptors); inhibitory to the smooth (internal) sphincter/bladder neck. Destruction of these fibres abolishes normal micturition

Component	Spinal origin	Pathway	Ganglia	Action
Sympathetic	Intermediolateral grey column, T11, T12, L1, L2 (lower three thoracic + upper two lumbar segments)	Lumbar sympathetic chain → superior hypogastric plexus → hypogastric nerves → inferior hypogastric plexus → vesical plexus	Ganglia in the sympathetic chain/hypogastric plexus	Inhibitory to the detrusor (via β -receptors, maintains bladder compliance during filling) and motor to the preprostatic sphincter/bladder neck (α -receptors) — prevents retrograde ejaculation; does not supply the true detrusor to a functionally significant degree

The pelvic (hypogastric) plexus — a mesh of autonomic nerves and ganglia on the lateral aspects of the rectum, internal genitalia and bladder base — carries both components; its anterior part, applied to the bladder, is specifically called the **vesical plexus**. Small intramural ganglia (up to ~20 neurones each) lie throughout the detrusor, so that a dense terminal plexus of acetylcholinesterase-rich fibres ramifies among the muscle bundles themselves.

2. Somatic (voluntary) nerve supply

- ▶ The **striated external urethral sphincter (rhabdosphincter)** — the muscle responsible for voluntary continence — is supplied by **somatic motor fibres from S2, S3, S4**, running principally in the **puddendal nerve**.
- ▶ Their cell bodies lie in a specialised column of anterior horn grey matter unique to the sacral cord, **Onuf's nucleus** (S2–S4), which is under direct descending control from the pontine storage centre.
- ▶ These slow-twitch fibres sustain tonic sphincteric contraction for long periods and are actively **relaxed** just before voluntary voiding begins.

3. Sensory (afferent) innervation

- ▶ **Afferents from stretch receptors** in the detrusor and trigonal mucosa signal the degree of bladder filling; they travel predominantly in the **parasympathetic (pelvic splanchnic)** pathway to S2–S4, and also relay via spinoreticulothalamic fibres to the thalamus (ventral posterior nucleus) and cortex.
- ▶ **Pain fibres** (from distension, spasm due to a calculus, inflammation, or malignant infiltration) travel in **both** sympathetic and parasympathetic nerves, though predominantly the latter; pain is referred to the cutaneous dermatomes **T10–L2 and S2–S4** — the lower anterior abdominal wall, perineum and penis/clitoris.
- ▶ Within the cord, the two sensations take **different ascending routes**: awareness of bladder **fullness** travels in the **posterior columns** (fasciculus gracilis), while **pain** travels in the **anterior and lateral white columns**. Consequently, bilateral **anterolateral cordotomy** relieves intractable vesical pain (e.g. from carcinoma) without abolishing the sensation of a full bladder — division

of the sympathetic pathways (presacral neurectomy) does not relieve vesical pain, since pain fibres run mainly with the parasympathetic supply.

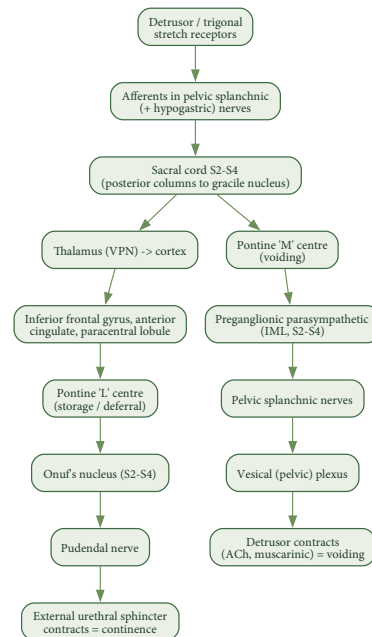
DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 16.9 — *Innervation of the urinary bladder* (Vishram Singh — *Textbook of Anatomy Vol 2 — 4e, p.696*)

Reproduce a schematic of the bladder with its nerve supply and label: **spinal cord segments T11–L2 (sympathetic) and S2–S4 (parasympathetic + somatic)**, **sympathetic chain** → **superior hypogastric plexus** → **hypogastric nerve**, **pelvic splanchnic nerves**, **inferior hypogastric (pelvic) plexus**, **vesical plexus**, **detrusor muscle**, **internal urethral sphincter (lissosphincter)**, **external urethral sphincter (rhabdosphincter)**, and **pudendal nerve**.

4. Central control of micturition — storage and voiding phases

Phase	Central events
Storage	Vesical afferents signal increasing volume; a spinal/pontine gating mechanism reflexively inhibits preganglionic parasympathetic outflow, and sympathetic activity increases detrusor compliance while keeping the bladder neck closed. The pontine storage ('L') centre simultaneously drives Onuf's nucleus to increase external sphincter tone. Voluntary deferral is imposed by the inferior frontal gyrus , which inhibits the right anterior cingulate gyrus, preoptic area and periaqueductal grey matter
Voiding	Once filling nears capacity (mean adult bladder capacity ≈ 400 mL; pain begins around 500 mL), threshold afferent activity triggers the micturition ('M') centre in the rostral pons (paramedian pontine reticular formation), which activates preganglionic parasympathetic neurones (S2–S4) via descending spinal pathways. These drive detrusor contraction through the pelvic splanchnic nerves and vesical plexus, while Onuf's nucleus and the external sphincter are reflexly inhibited. Voluntary initiation is exerted through the prefrontal cortex , which drives the perineal area of the motor cortex to relax the pelvic floor; the vesical/anal sphincter motor representation itself lies in the paracentral lobule on the medial cerebral surface



Describe the nerve supply to urinary bladder and discuss the neurological disorders

5. Neurological disorders of the bladder (neurogenic bladder)

Any lesion along cortex → spinal cord → cauda equina → peripheral autonomic/somatic pathway produces a characteristic clinical picture:

Type	Site / cause of lesion	Mechanism	Clinical features
Uninhibited bladder	Bilateral medial frontal cortex (parasagittal meningioma of the falx, superior sagittal sinus thrombosis, occlusion of an unpaired/azygos anterior cerebral artery)	Loss of cortical inhibition of the pontine micturition centre; the sacral reflex arc itself is intact	Triad of hesitancy , urgency and precipitancy — initiation is delayed but, once begun, micturition cannot be voluntarily stopped
Atonic bladder	Acute spinal cord transection at any level above the sacral segments, during the phase of spinal shock	Total but temporary loss of all reflex activity; sphincter vesicae remains tightly contracted (loss of higher inhibition) while sphincter urethrae is relaxed	Bladder distends progressively and finally overflows ; may last days to weeks before reflex activity returns
Automatic reflex bladder	Chronic suprasacral cord lesion (transection/severe injury above S2–S4) once spinal shock has resolved	Sacral reflex arc and pontine reticulospinal connections to it are disconnected from voluntary/cortical control, but the arc itself remains intact — the pattern normally seen in infancy	Detrusor fills and empties reflexly every 1–4 hours ; no voluntary initiation or inhibition

Type	Site / cause of lesion	Mechanism	Clinical features
Autonomous bladder	Destruction of the sacral segments (S2–S4) of the cord, or a cauda equina/conus lesion	Both afferent and efferent limbs of the sacral reflex are lost; bladder wall becomes flaccid	Capacity is greatly increased; bladder fills to capacity and dribbles continuously (overflow incontinence) ; may be partly emptied by manual suprapubic compression or straining
Sensory neurogenic (atonic) bladder	Lesion of the afferent/sensory limb only, e.g. tabes dorsalis (neurosyphilis), diabetic autonomic neuropathy, subacute combined degeneration	Efferent motor pathway is intact, but loss of stretch-afferent input abolishes the desire to void	Large, painless, atonic bladder with residual urine and eventual overflow; the patient is unaware the bladder is full

Applied / Clinical anatomy

- **Detrusor–sphincter dyssynergia (DSD)**: in chronic suprasacral spinal cord injury, the pontine coordinating influence over detrusor contraction and external sphincter relaxation is lost, so the two contract simultaneously — this generates dangerously high intravesical voiding pressures with large post-void residuals and, over time, vesico-ureteric reflux and renal damage; it is the single most important cause of upper-tract deterioration in neurogenic bladder.
- **Iatrogenic pelvic-plexus injury**: the vesical (pelvic) plexus lies close to the lateral pelvic wall and cervix/vagina and can be damaged during radical hysterectomy or abdomino-perineal resection of the rectum, producing a temporary atonic/autonomous-type bladder — the anatomical rationale for "nerve-sparing" radical pelvic surgery.
- **Vesical pain relief**: because pain fibres run chiefly with the parasympathetic supply and travel in the anterolateral spinal white columns, bilateral anterolateral cordotomy (not presacral/sympathetic neurectomy) is the surgical option for intractable vesical pain, and it spares the posterior-column-mediated awareness of bladder fullness.
- **Bladder outflow obstruction** (benign prostatic hyperplasia, urethral stricture, posterior urethral valves) causes detrusor hypertrophy, a coarsely **trabeculated bladder** with mucosal diverticula, incomplete emptying and risk of infection and back-pressure renal damage — a mechanical, non-neurogenic mimic that must be distinguished from true neurogenic bladder on urodynamic study.
- **Intermittent catheterisation and cystometry**: clean intermittent self-catheterisation is the mainstay of managing an autonomous/areflexic bladder to prevent overdistension and infection; urodynamic (cystometric) assessment is essential to characterise detrusor overactivity/compliance in any suprasacral cord lesion.

Recent advances

- A structured review of **detrusor–sphincter dyssynergia** clarifies its basis in loss of the spinobulbospinal (pontine) coordinating pathway after suprasacral spinal cord lesions, and

discusses videocystometrography-guided treatment escalation from pharmacotherapy through intradetrusor **botulinum toxin** to **sacral neuromodulation** (Furrer, Kessler, Panicker, *Urologic Clinics of North America*, 2024) [DOI: 10.1016/j.ucl.2024.01.001].

- ▶ A comparative urodynamic review of pharmacotherapy for neurogenic detrusor overactivity after spinal cord injury found **anticholinergics** and **β 3-agonists (particularly vibegron)** produce meaningful improvement in overactive-bladder parameters, with **onabotulinumtoxinA** remaining highly effective when oral agents fail (Findlay, Anderson, *European Urology Focus*, 2026) [DOI: 10.1016/j.euf.2026.03.011].
- ▶ The German interdisciplinary **clinical practice guideline (update 3.0)** on intermittent catheterisation in neurogenic lower urinary tract dysfunction standardises technique and complication management (urinary infection, autonomic dysreflexia) for patients with sacral-reflex-arc bladder dysfunction (Kurze, Geng, Wenig, König, Böthig, *International Urology and Nephrology*, 2026) [DOI: 10.1007/s11255-026-05236-8].
- ▶ A large real-world veteran cohort study of **supra-sacral spinal cord injury** patients found only 29–31% received guideline-recommended urological review and cystometrography, underscoring a persistent gap between neuroanatomical risk (upper-tract damage from unmonitored detrusor overactivity) and actual surveillance practice (Hornberger, Lavelle, *Neurourology and Urodynamics*, 2026) [DOI: 10.1002/nau.70259].
- ▶ (According to PubMed/journal literature; see DOIs above.)

High-yield exam pointers

- ▶ Parasympathetic: **S2–S4**, pelvic splanchnic nerves → vesical plexus → **motor to detrusor**, inhibitory to internal sphincter.
- ▶ Sympathetic: **T11–L2**, hypogastric plexus/nerve → vesical plexus → **inhibitory to detrusor**, motor to bladder neck/preprostatic sphincter (prevents retrograde ejaculation).
- ▶ Somatic: **pudendal nerve (S2–S4)**, cell bodies in **Onuf's nucleus** → external urethral sphincter (voluntary continence).
- ▶ Sensory: fullness travels in **posterior columns**; pain travels in **anterolateral columns** with parasympathetic fibres — basis of anterolateral cordotomy for vesical pain.
- ▶ Central control: pontine '**M**' (**voiding**) and '**L**' (**storage**) centres in the rostral pons; voluntary control from the **inferior frontal gyrus** and **paracentral lobule** (vesical/anal sphincter motor cortex).
- ▶ Five classic neurogenic bladder patterns: **uninhibited** (bilateral medial frontal lesion), **atonic** (spinal shock), **automatic reflex** (chronic suprasacral UMN lesion), **autonomous** (sacral S2–S4/cauda equina LMN lesion), **sensory neurogenic** (afferent lesion, e.g. tabes dorsalis).
- ▶ **Detrusor–sphincter dyssynergia** = hallmark of chronic suprasacral cord lesions; drives upper-tract damage via high voiding pressures.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; BD Chaurasia's Human Anatomy Vol 2 8e; Vishram Singh's Textbook of Anatomy Vol 2 4e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy. Recent-advances section per PubMed/journal literature (see DOIs above).



Describe the surgical anatomy of portal vein

Asked in: Paper IV May 2018 — RGUHS MD/MS Anatomy

Definition / Introduction The **hepatic portal vein** is the short, wide, valveless venous trunk draining the abdominal alimentary tract (except the lower anal canal), gallbladder, pancreas and spleen — carrying this blood not to the heart but to a second capillary bed, the hepatic sinusoids, before it reaches the IVC via the hepatic veins. It is the classic **portal venous system** (capillaries → vein → capillaries). Though only a vein, it supplies **75–80% of hepatic blood flow** (hepatic artery ~20–25%), and its formation, hepatoduodenal-ligament relations and portosystemic anastomoses form the anatomical basis of hepatobiliary surgery, transplantation and portal-hypertension management — hence its "surgical anatomy."

Formation, course and the three surgical parts

- ▶ **Formation:** formed by the union of the **superior mesenteric vein** and the **splenic vein** behind the **neck of the pancreas**, at the **transpyloric plane**, opposite the **L1–L2 vertebral level** (Gray's places it between the lower border of L1 and upper border of L2; BD Chaurasia/Vishram Singh place it at L2). The **inferior mesenteric vein** usually joins the splenic vein just before this confluence (in about a third of individuals it joins the SMV–splenic vein angle itself).
- ▶ **Length:** about **7–8 cm** ($\approx$ 3 inches).
- ▶ **Course:** runs upward and slightly to the right — first behind the neck of the pancreas, then behind the first part of the duodenum, and finally in the **right free margin of the lesser omentum (hepatoduodenal ligament)** — to reach the **porta hepatis**, where it terminates by dividing into **right and left branches**.
- ▶ For description, surgeons/anatomists divide it into **three parts**:

Part	Extent	Anterior relation(s)	Posterior relation
Infraduodenal	Below the 1st part of duodenum	Neck of pancreas	Inferior vena cava
Retroduodenal	Behind the 1st part of duodenum	1st part of duodenum, bile duct, gastroduodenal artery	Inferior vena cava
Supraduodenal	In the free margin of the lesser omentum	Hepatic artery (left) and bile duct (right)	Inferior vena cava (separated by the epiploic foramen)

□ Fig 21.13 — Formation of portal vein (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.359)

- **Developmental basis** (why the vein has these three named parts): the portal vein develops from the **vitelline (omphalomesenteric) veins** — the *infraduodenal part* from the left vitelline vein distal to the dorsal anastomosis, the *retroduodenal part* from the dorsal anastomosis between the two vitelline veins, and the *supraduodenal part* from the cranial part of the right vitelline vein.

Relations at the porta hepatis — the hepatoduodenal ligament and the "portal triad"

- Within the free edge of the lesser omentum, three structures run together, enclosed in a common fibrous (Glissonian) sheath — the **portal triad**: the **bile duct** (anteriorly, to the right), the **hepatic artery proper** (anteriorly, to the left), and the **portal vein** (posterior to both). A useful mnemonic order from front-to-back, right-to-left is "**D-A-V**" (Duct–Artery anterior, Vein posterior).
- This ligament forms the **anterior boundary of the epiploic (omental) foramen of Winslow** — a vertical slit about 3 cm high — whose posterior boundary is the IVC, superior boundary the caudate process of the liver, and inferior boundary the first part of the duodenum.
- **Surgical significance of this arrangement**: because all three inflow/outflow structures of the liver run together in one accessible fold, **compression of the free edge of the lesser omentum between finger and thumb (through the epiploic foramen) — the "Pringle manoeuvre"** — occludes both the hepatic artery and portal vein simultaneously, giving rapid, temporary control of hepatic inflow bleeding during liver trauma or resection.
- Within the sheath, the portal vein is surrounded by loose areolar tissue (making it easy to dissect free), whereas the tissue around the bile duct and hepatic artery is tougher — a fact exploited during hilar dissection.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Cross-section through the free edge of the lesser omentum (as at laparotomy, viewed from the patient's right); label:

- **Bile duct** — anterior, right; **hepatic artery proper** — anterior, left; **portal vein** — posterior to both (largest).
- The **epiploic foramen** immediately behind, with the IVC as its posterior wall and the **caudate process** as its roof.
- Finger-and-thumb icon showing the **Pringle manoeuvre** compressing the ligament through the foramen.

Termination — right and left branches, and the segmental (Couinaud) correlation

- At the right end of the porta hepatis the portal vein divides into a **right branch** (short, 2–3 cm, wider) and a **left branch** (longer, 4–5 cm, narrower, more horizontal).
- **Right branch**: after receiving the **cystic vein**, it divides into a **right medial (anterior) sectoral branch** (segments V, VIII) and a **right lateral (posterior) sectoral branch** (segments VI, VII).
- **Left branch**: crosses to the left, giving branches to the **caudate and quadrate lobes**, then turns anteriorly in the **umbilical fissure** supplying segments II, III and (mainly) IV; it receives the

obliterated **left umbilical vein (ligamentum teres)** and connects to the IVC via the **ligamentum venosum** (obliterated ductus venosus) — the fetal route by which oxygenated umbilical blood largely bypassed the liver.

- **Surgical variation:** in 10–15% of individuals the right branch is absent and the portal vein **trifurcates** into the left, right-medial-sectoral and right-lateral-sectoral branches — important to identify before **living-donor/split-liver transplantation**.
- The **caudate lobe (segment I)** uniquely receives twigs from **both** branches and drains independently direct into the IVC, so it is often spared in vascular occlusion and hypertrophies in Budd–Chiari syndrome.

Tributaries

Tributary	Drains into	Note
Splenic vein	Forms the portal vein (with SMV)	Larger formative tributary; receives short gastric, left gastro-epiploic, pancreatic veins and (usually) the inferior mesenteric vein
Superior mesenteric vein (SMV)	Forms the portal vein	Smaller formative tributary; drains jejunum, ileum, caecum, ascending and transverse colon
Left gastric (coronary) vein	Directly into the portal vein, near its origin	Receives lower oesophageal veins — the key portosystemic link
Right gastric vein	Directly into the portal vein	Receives the pre-pyloric vein (of Mayo) — a surgical landmark for the pylorus
Superior pancreaticoduodenal vein	Behind the 1st part of duodenum	—
Cystic vein	Right branch of portal vein	Drains gall bladder
Para-umbilical veins	Left branch of portal vein	Run in the falciform ligament along the ligamentum teres; the key channel in caput medusae

Portosystemic (portocaval) anastomoses — the surgical/clinical core of the topic

Because the portal vein and its tributaries are **valveless**, any obstruction to portal flow (commonest cause: **cirrhosis**; also **portal vein thrombosis**, Banti's disease) is transmitted retrogradely, dilating pre-existing communications between the portal and systemic (caval) venous systems into visible collateral channels.

Site	Portal tributary	Systemic tributary	Clinical result
Lower end of oesophagus	Left gastric vein	Oesophageal veins → azygos/hemiazygos → SVC	Oesophageal varices → haematemesis

Site	Portal tributary	Systemic tributary	Clinical result
Umbilicus	Para-umbilical veins (left branch of PV)	Superior/inferior epigastric veins	Caput medusae
Anal canal	Superior rectal vein (→ IMV)	Middle/inferior rectal veins → internal iliac	Haemorrhoids
Bare area of liver	Portal radicles	Phrenic and intercostal veins	Usually silent; at risk during liver mobilisation
Retroperitoneum (duodenum, ascending/descending colon)	Colic/duodenal veins	Renal, lumbar, phrenic veins ("veins of Retzius")	Dilated retroperitoneal veins at risk during surgery

□ Fig 21.17 — Sites of portosystemic anastomoses (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.362)

- ▶ **Normal portal pressure** is about 5–15 mmHg (measured classically by splenic puncture/intrasplenic pressure); **portal hypertension** is a sustained rise, conventionally quoted as pressure **above 40 mmHg**. Effects: congestive splenomegaly, ascites, and the collateral circulation above.
- ▶ Streamlined flow means SMV blood (small-intestinal, often bacterially contaminated) preferentially enters the right lobe, while splenic/IMV blood preferentially enters the left — the classical explanation for the right-lobe predilection of amoebic liver abscess.

Recent advances — imaging- and intervention-based exploitation of portal vein anatomy

- ▶ **CT/MR portovenography and 3-D "virtual hepatectomy" planning** are now routine before major hepatectomy and living-donor transplantation, precisely mapping the portal bifurcation pattern (including the 10–15% trifurcation variant) so segmental portal supply is preserved.
- ▶ **Portal vein embolization (PVE)** and its two-stage extension **ALPPS** deliberately occlude the portal branch to segments planned for resection, exploiting segment-specific portal territory to hypertrophy the future liver remnant before extended hepatectomy.
- ▶ **TIPS** has largely replaced open portocaval/splenorenal shunt surgery for refractory portal hypertension and as a bridge to transplantation: a stent is passed via the right internal jugular → hepatic vein → hepatic parenchyma → portal vein branch, exploiting the close intrahepatic proximity of a portal and a hepatic-vein radicle.
- ▶ **Doppler ultrasound and CT/MR venous-phase imaging** remain the mainstay for diagnosing **portal vein thrombosis** and **cavernous transformation (portal cavernoma)** — periportal collaterals recanalising flow around an occluded segment, seen especially in paediatric extrahepatic portal venous obstruction (EHPVO).
- ▶ **EUS-guided portosystemic pressure gradient measurement and elastography** are emerging non-invasive alternatives to HVPG catheterisation for grading portal hypertension, and **laparoscopic/robotic donor hepatectomy** now depends on precise preoperative portal-branching maps.

Applied / Clinical anatomy

- ▶ **Pringle manoeuvre:** temporary compression of the hepatoduodenal ligament (portal vein + hepatic artery) controls haemorrhage during hepatic trauma/resection.
- ▶ **Portosystemic shunt surgery:** classical treatment of portal hypertension — a **portocaval shunt** (portal vein/SMV anastomosed to the IVC, where the vessels lie close together) or a **splenorenal (lienorenal) shunt** (splenic vein anastomosed to the left renal vein, after splenectomy) — now largely superseded by TIPS and transplantation.
- ▶ **Liver transplantation:** the recipient portal vein provides the essential venous inflow anastomosis for the graft; pre-existing portal vein thrombosis must be assessed and, where needed, thrombectomy or a jump graft performed.
- ▶ **EHPVO/portal cavernoma:** thrombosis of the extrahepatic portal vein (idiopathic or post-umbilical-sepsis in children) produces tortuous periportal collaterals bypassing the block — a key cause of paediatric non-cirrhotic portal hypertension.
- ▶ **Streamlined flow and infection spread:** SMV blood (small-intestinal) preferentially enters the right lobe, explaining the right-lobe predilection of amoebic abscess and of pyogenic portal pyaemia from appendicitis (appendicular → ileocolic → SMV → portal vein).
- ▶ **Landmark for arterial variants:** a relatively superficial portal vein at the porta hepatis suggests a replaced hepatic artery from the SMA running behind it — important before Whipple's pancreaticoduodenectomy or hilar dissection.

High-yield exam pointers

- ▶ Formed behind the **neck of the pancreas**, at the **transpyloric plane (L1–L2 level)**, by union of **superior mesenteric + splenic veins**; length ~8 cm.
- ▶ Three parts: **infraduodenal, retroduodenal, supraduodenal** — each with IVC posteriorly; developmentally derived from the **vitelline veins**.
- ▶ In the hepatoduodenal ligament, order is **bile duct (right) and hepatic artery (left) anterior; portal vein posterior** — basis of the **Pringle manoeuvre**.
- ▶ Divides at the porta hepatis into **right branch (short, 2–3 cm) and left branch (long, 4–5 cm)**; **trifurcation in 10–15%** when the right branch is absent.
- ▶ Formative tributaries: **splenic vein + SMV**; direct tributaries: **left/right gastric, superior pancreaticoduodenal, cystic (right branch), para-umbilical (left branch)**.
- ▶ **Four classic sites of portosystemic anastomosis:** lower oesophagus (varices), umbilicus (caput medusae), anal canal (haemorrhoids), bare area/retroperitoneum (silent, at surgical risk).
- ▶ Normal portal pressure **5–15 mmHg**; portal hypertension quoted as **>40 mmHg**; commonest cause **cirrhosis**.
- ▶ Supplies ~75–80% of hepatic blood flow (hepatic artery ~20–25%); is **valveless**, permitting reversed (collateral) flow in obstruction.
- ▶ Modern surgical exploitation: **Pringle manoeuvre, portocaval/splenorenal shunt, TIPS, portal vein embolization/ALPPS**, and portal-branch mapping for liver transplantation.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2 8e; Vishram Singh's Textbook of Anatomy Vol 2 4e; IB Singh's Textbook of Anatomy Vol 2 6e; Moore's Clinically Oriented Anatomy 9e.



Describe the surgical anatomy of the retropharyngeal space

Asked in: Paper IV 20-Jul-2020 — RGUHS MD/MS Anatomy

Definition / Introduction The retropharyngeal space is the largest and most clinically important interfascial (potential) space of the neck, lying in the midline directly behind the pharynx and cervical oesophagus. It is bounded anteriorly by the buccopharyngeal fascia (the visceral part of the middle layer of deep cervical fascia investing the pharynx) and posteriorly by the prevertebral fascia (the deep layer of deep cervical fascia), and is closed on each side by the carotid sheath. Filled only with loose areolar tissue and a chain of retropharyngeal lymph nodes, it permits the pharynx, larynx, trachea and oesophagus to glide freely over the prevertebral musculature during swallowing and neck movement. Because it forms an unobstructed tissue plane connecting the skull base to the mediastinum, its surgical anatomy is dominated by two themes — it is the principal corridor for downward spread of deep neck infection into the thorax, and it is the avascular surgical plane exploited for anterior access to the cervical viscera and vertebral column.

Extent and Boundaries

Boundary	Structure
Anterior	Buccopharyngeal fascia covering the pharyngeal constrictors (continues below as the fascia around the cervical oesophagus)
Posterior	Prevertebral fascia covering longus colli and longus capitis, and the cervical vertebral column
Lateral	Carotid sheath on each side; continuous with the parapharyngeal space around the sides of the pharynx
Superior	Base of skull (basiocciput) — the space is closed here
Inferior	Continues as the retrovisceral space and opens into the superior mediastinum; the alar fascia fuses with the visceral (buccopharyngeal) fascia at a variable level between C6 and T4, marking the true lower limit of the retropharyngeal space proper — the danger space behind it continues further

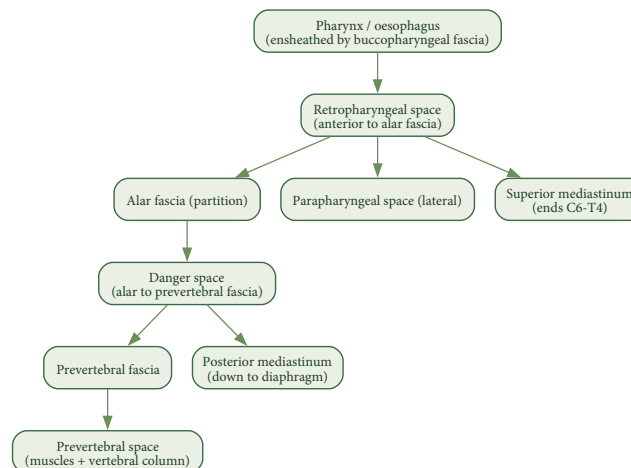
- The retropharyngeal space forms the posterior part of the **peripharyngeal space**, whose anterior part is formed by the submental/submandibular spaces and whose lateral part is formed by the paired parapharyngeal spaces.

- A midline fibrous median raphe divides it into two lateral compartments, the **spaces of Gillette**, each containing a chain of retropharyngeal lymph nodes — this is why acute suppuration here typically bulges to one side of the midline rather than centrally.

Fascial Layers and Subdivisions — Alar Fascia, Danger Space and Prevertebral Space

From front to back, the lamination behind the pharynx is: buccopharyngeal fascia → **retropharyngeal space** → **alar fascia** → **danger space** → **prevertebral fascia** → **prevertebral space** → vertebral column.

- **Alar fascia** — a thin, coronally-oriented sheet attached in the midline to the buccopharyngeal fascia, extending laterally to blend with the carotid sheath. It subdivides the interval behind the pharynx into two clinically distinct compartments.
- **Retropharyngeal space proper** — anterior to the alar fascia; ends inferiorly where the alar fascia fuses with the visceral fascia (variably between C6 and T4).
- **Danger space** — between the alar fascia in front and the prevertebral fascia behind; closed above (skull base) and at the sides, but continues downward, unobstructed, all the way to the posterior mediastinum and diaphragm. This is the classic route for rapid, life-threatening downward spread of infection.
- **Prevertebral space** — a separate potential space lying deep to the prevertebral fascia itself, between the fascia and the vertebral bodies; it encloses the prevertebral muscles (longus colli, longus capitis) and extends from the skull base to the coccyx. Pathology here is typically vertebral in origin (classically a tuberculous "cold" Pott's abscess of the cervical spine), and may secondarily perforate forward into the danger space and retropharyngeal space.



Describe the surgical anatomy of the retropharyngeal space

Contents, Lymphatics and Communications

- **Contents:** loose areolar connective tissue only — a true potential space, seen at surgery or on imaging only when distended by pus, blood or oedema — plus the retropharyngeal lymph nodes.
- **Retropharyngeal lymph nodes:** a median group and two lateral groups, the lateral group lying anterior to the lateral masses of the atlas along the medial border of longus capitis. They receive afferents from the nasopharynx, the pharyngotympanic (auditory) tube, and the atlanto-occipital and atlanto-axial joints, and drain into the upper deep cervical nodes.

- **Relations:** anteriorly the pharyngeal wall and, lower down, the cervical oesophagus; posteriorly the prevertebral fascia, longus colli/capitis and cervical vertebral bodies; laterally the carotid sheath (common/internal carotid artery, internal jugular vein, vagus, sympathetic trunk, deep cervical nodes) and, beyond it, the parapharyngeal space with its prestyloid (parotid, fat, nodes) and retrostyloid (internal carotid artery, internal jugular vein, cranial nerves IX–XII, sympathetic chain) compartments; superiorly the skull base; inferiorly the superior and posterior mediastinum.
- **Communications,** which underlie its clinical importance: laterally with the paired parapharyngeal spaces around the pharynx; anterolaterally with the peritonsillar space and, via the parapharyngeal space, with the parotid space; inferiorly with the retrovisceral space and superior mediastinum (retropharyngeal space proper) and, independently and further, with the posterior mediastinum down to the diaphragm (danger space).

Surgical Significance — the Retropharyngeal Space as an Anatomical Plane

Because it is an avascular, loosely areolar plane sandwiched between the visceral (pharyngo-oesophageal) and musculoskeletal (vertebral) compartments of the neck, this space is deliberately developed and used by surgeons as a natural corridor:

- **Anterior (retropharyngeal/retrovisceral) approach to the cervical spine** — used for anterior cervical discectomy and fusion, odontoidectomy, or drainage of a prevertebral (Pott's) abscess; the plane is opened by retracting the carotid sheath laterally and the pharynx/larynx/trachea/oesophagus medially, staying anterior to the prevertebral fascia to protect the sympathetic trunk and the prevertebral muscles.
- **Anterior neck and visceral surgery** (thyroidectomy, parathyroidectomy, oesophageal mobilisation) exploits the same loose areolar plane to free the pharyngo-oesophagus off the prevertebral fascia with minimal bleeding.
- **Surgical drainage of a retropharyngeal abscess:** a localised collection confined above the hyoid, bulging medially, is classically drained by a transoral (intraoral) incision; a collection extending laterally, inferiorly, or into the danger space/mediastinum requires an external transcervical approach (anterior to sternocleidomastoid) for adequate drainage and airway control.
- **The carotid sheath forms the lateral wall** of the space — any surgical dissection or spreading infection in this plane directly threatens the carotid vessels, internal jugular vein and the lower cranial nerves (IX–XII) coursing in the retrostyloid parapharyngeal compartment, and these must be identified and protected.
- Because the danger space communicates unimpeded with the posterior mediastinum, any instrumentation that perforates the posterior pharyngeal or oesophageal wall (rigid oesophagoscopy, nasogastric tube insertion, foreign-body extraction) can seed this plane and precipitate descending necrotising mediastinitis — the reason head and neck surgeons regard it as the "space of danger."

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

embed: ![Fig 4.13 — ■ Retropharyngeal space. (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.269)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/83e23fffe2b6c03.jpg)

Reproduce a mid-sagittal/paramedian section of the neck by hand with these exact labels:

- ▶ Base of skull (superior limit)
- ▶ Pharynx (naso-/oro-/laryngopharynx) invested by buccopharyngeal fascia
- ▶ Retropharyngeal space (shown widened as a potential space)
- ▶ Alar fascia (thin midline partition)
- ▶ Danger space
- ▶ Prevertebral fascia
- ▶ Prevertebral muscles (longus colli, longus capitis) and cervical vertebral bodies
- ▶ Carotid sheath (lateral wall, shown in a cross-section inset)
- ▶ Level of hyoid bone / C6 vertebra
- ▶ Continuation of the retropharyngeal space into the superior mediastinum and of the danger space into the posterior mediastinum

Applied / Clinical anatomy

- ▶ **Acute retropharyngeal abscess** — typically seen in infants and young children (retropharyngeal lymph nodes are prominent up to early childhood and involute thereafter); follows suppuration of the lateral retropharyngeal nodes secondary to nasopharyngitis, tonsillitis, adenoiditis or otitis media. Because the median raphe fixes the buccopharyngeal fascia to the prevertebral fascia in the midline, the abscess characteristically bulges to one side of the midline (paramedian bulge).
- ▶ **Chronic (cold) retropharyngeal abscess** — seen in adults, results from tuberculous caries of the cervical vertebral bodies (Pott's disease) tracking forward from the prevertebral space; being centred over the vertebral bodies, it produces a midline posterior pharyngeal wall bulge, and the pus may also track laterally into the posterior triangle deep to the prevertebral fascial floor and along the axillary sheath into the axilla or arm.
- ▶ **Clinical features** common to both: odynophagia, dysphagia, drooling, a muffled voice, neck stiffness/torticollis and fever; stridor if the airway is compromised. Examination shows a smooth bulge of the posterior pharyngeal wall.
- ▶ **Spread of infection:** perforation of the alar fascia lets infection track through the loose areolar danger space, unobstructed, down to the diaphragm, producing acute descending mediastinitis — a surgical emergency.
- ▶ **Imaging:** a lateral soft-tissue neck radiograph classically shows widening and straightening (loss of normal cervical lordosis) of the prevertebral soft-tissue shadow; contrast-enhanced CT of the neck, extended to include the mediastinum, is the investigation of choice to confirm a rim-enhancing collection, delineate its cranio-caudal extent, and plan surgical drainage.

- ▶ **Atlanto-axial subluxation:** chronic pharyngeal/retropharyngeal inflammation adjacent to the atlas can decalcify the atlas vertebra and loosen the attachment of its transverse ligament; if the ligament yields, sudden dislocation of the dens can follow, a recognised cause of sudden death, particularly in children.
- ▶ **Foreign bodies and instrumentation:** a sharp swallowed foreign body (e.g., fish bone) or instrumental perforation of the posterior pharyngeal/oesophageal wall is the commonest traumatic/iatrogenic route of entry of organisms into this space.

High-yield exam pointers

- ▶ Retropharyngeal space = largest, most important interfascial space of the neck; buccopharyngeal fascia in front, prevertebral fascia behind, closed laterally by the carotid sheath.
- ▶ Alar fascia subdivides it into the true retropharyngeal space (ends C6–T4) and the danger space (extends unobstructed to the diaphragm).
- ▶ Prevertebral space is a distinct, deeper compartment behind the prevertebral fascia containing the prevertebral muscles — the classic site of a tuberculous (Pott's) cold abscess.
- ▶ Median raphe → spaces of Gillette → two lateral compartments, each with retropharyngeal lymph nodes → basis for a unilateral bulge in acute (childhood) abscess versus a midline bulge in chronic (tuberculous) abscess.
- ▶ Retropharyngeal lymph nodes drain the nasopharynx, auditory tube and atlanto-occipital/atlando-axial joints into the upper deep cervical nodes, and normally atrophy after early childhood.
- ▶ Communicates laterally with the parapharyngeal space, anterolaterally with the peritonsillar and parotid spaces, and inferiorly with the superior and posterior mediastinum — the anatomical basis of descending mediastinitis.
- ▶ Surgically, it is the avascular anterior retropharyngeal plane used for approaches to the cervical spine and for mobilising the pharyngo-oesophagus; the carotid sheath forms its lateral wall and must always be protected.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 3-4 8e; AK Datta Human Anatomy Vol 2 (Head & Neck); Vishram Singh Textbook of Anatomy Vol 3 4e; IB Singh Textbook of Anatomy Vol 3 6e; Moore's Clinically Oriented Anatomy 9e.



Discuss in detail the surgical anatomy of anal canal

Asked in: Paper IV Apr 2008 — RGUHS MD/MS Anatomy

Definition / Introduction The anal canal is the terminal ~3–4 cm of the alimentary tract, extending from the anorectal junction — where the rectal ampulla narrows abruptly through the puborectalis sling of the pelvic diaphragm — to the anus, lying in the anal triangle of the perineum between the two ischioanal fossae. It is guarded by an inner involuntary (internal anal) sphincter and an outer voluntary (external anal) sphincter. The single fact that dominates its surgical anatomy is that the **pectinate (dentate) line** marks the junction of two embryologically, histologically, vascularly, lymphatically and neurologically distinct halves.

Extent, Situation and Relations

- ▶ Length ≈ 3.8 cm (BD Chaurasia; Moore cites 2.5–3.5 cm); directed downwards and backwards.
- ▶ Begins at the **anorectal junction** — 2–3 cm in front of and slightly below the tip of the coccyx, at the level of the prostatic apex in the male.
- ▶ Ends at the **anus**, in the natal cleft, about 4 cm below and in front of the coccygeal tip; surrounding skin is pigmented, radially folded and bears apocrine glands.
- ▶ Relations:

Direction	Male	Female
Anterior	Perineal body; membranous urethra; bulb of penis	Perineal body; lower end of vagina
Posterior	Anococcygeal ligament; tip of coccyx	Same
Lateral (each side)	Ischioanal fossa	Same

Interior of the Anal Canal

The **pectinate line** divides the interior into an upper mucosal part (~15 mm, endodermal, from the hindgut) and a lower part (15 mm transitional + 8 mm cutaneous = 23 mm, ectodermal, from the proctodeum).

□ Fig 33.10 — Interior of the anal canal (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.510)

- ▶ **Upper mucous part (15 mm):** 6–10 vertical mucosal folds, the **anal columns of Morgagni**, containing radicles of the superior rectal vein; joined below by crescentic **anal valves**; a depression above each valve, the **anal sinus**, receives the ducts of mucus-secreting **anal glands** (about a dozen, sited in the intersphincteric space — the source of most anal fistulae); occasional epithelial tags on the valves are **anal papillae**, vestiges of the embryonic anal membrane.
- ▶ **Middle part / pecten / transitional zone (15 mm):** stratified squamous epithelium, thin, pale and glossy, devoid of skin appendages; looks bluish owing to a dense submucosal venous plexus. Its lower limit is the **white line of Hilton** — the palpable groove between the subcutaneous part of external sphincter and the lower border of internal sphincter.
- ▶ **Lower cutaneous part (8 mm):** true perianal skin, with hair follicles, sebaceous and sweat glands.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ Anorectal junction; anal columns of Morgagni (6–10) with superior rectal vein radicles
- ▶ Anal valves; anal sinuses with anal-gland openings; anal papillae
- ▶ Pectinate (dentate) line
- ▶ Pecten/transitional zone — bluish venous plexus
- ▶ White line of Hilton
- ▶ Perianal skin — sebaceous/sweat glands, hair follicles
- ▶ Internal anal sphincter (upper three-fourths) and external anal sphincter labelled alongside

Musculature — Sphincters, Conjoint Coat and Anorectal Ring

- ▶ **Internal anal sphincter (IAS):** involuntary; a thickening of the circular smooth-muscle coat; surrounds the **upper three-fourths** (≈ 30 mm) of the canal, from its upper end to the white line of Hilton; tone maintained by sympathetic fibres (L1–L2), relaxed by parasympathetic fibres (S2–S4) and by the recto-anal inhibitory reflex on rectal distension.
- ▶ **External anal sphincter (EAS):** voluntary striated muscle surrounding the **whole length** of the canal; supplied by the inferior rectal nerve and the perineal branch of S4. Now regarded as a single functional/anatomic entity with subcutaneous, superficial and deep parts — uppermost fibres blend with puborectalis; middle fibres attach to the perineal body anteriorly and the anococcygeal ligament posteriorly, with some fibres decussating in the midline; lowest fibres lie free below the IAS, separated from the anal epithelium only by submucosa.
- ▶ **Conjoint longitudinal coat:** formed by fusion of puborectalis with the rectal longitudinal muscle at the anorectal junction; lies between IAS and EAS; breaks up at Hilton's line into fibroelastic septa — the most lateral forms the **perianal fascia**, the most medial the **anal intermuscular septum** (attached to the white line), and intervening septa fan out through the subcutaneous EAS to the perianal skin as the **corrugator cutis ani**.
- ▶ **Anorectal ring:** the palpable muscular ring at the anorectal junction, formed by **puborectalis + uppermost fibres of EAS + IAS** (less marked anteriorly, where puborectalis fibres are absent). It is the sole anatomical basis of **rectal continence** — its surgical division (e.g. an over-zealous fistulotomy) causes permanent incontinence, the single most important caution in anal surgery.

Blood Supply, Venous and Lymphatic Drainage

The pectinate line is also the vascular, lymphatic and nerve-supply watershed of the canal.

Feature	Above pectinate line	Below pectinate line
Development	Hindgut (endoderm)	Proctodeum (ectoderm)
Arterial supply	Superior rectal artery (continuation of inferior mesenteric); middle rectal artery contributes via anastomoses	Inferior rectal arteries (from internal pudendal)

Feature	Above pectinate line	Below pectinate line
Venous drainage	Internal rectal (haemorrhoidal) plexus → superior rectal vein → inferior mesenteric vein → portal system	External rectal plexus → inferior rectal vein → internal pudendal vein → systemic (caval) system
Lymphatic drainage	Internal iliac nodes	Medial group, superficial inguinal nodes
Nerve supply	Autonomic (visceral)	Somatic (inferior rectal, S2–4)
Sensitivity	Ischaemia, distension, spasm only (painless)	Pain, touch, temperature, pressure (exquisitely sensitive)

- ▶ The internal rectal venous plexus forms three constant dilated radicles in the anal columns at the 3, 7 and 11 o'clock positions (lithotomy view) — left lateral, right posterior and right anterior columns — the sites of **primary internal piles**; with the surrounding erectile-like tissue they constitute the **anal cushions**, which help seal the canal and contribute to continence.
- ▶ Free communication between the internal (portal) and external (systemic) rectal venous plexuses makes the anal canal a clinically important **portosystemic anastomotic site**.

Nerve Supply

- ▶ **Above the pectinate line:** sympathetic fibres (inferior hypogastric plexus, L1–2) maintain internal sphincter tone; parasympathetic fibres (pelvic splanchnic, S2–4) inhibit it and mediate reflex relaxation; visceral afferents run with the parasympathetic supply to S2–4 sensory ganglia — sensitive only to stretch, not pain.
- ▶ **Below the pectinate line:** somatic supply via the **inferior rectal nerve** (branch of the pudendal nerve, S2–4) to the external sphincter, mucosa and perianal skin — richly sensitive to pain, touch and temperature. This explains why injections/incisions above the line are painless while a fissure or thrombosed external pile below it is agonising.

Surgical Spaces around the Anal Canal

□ Fig 28.7 — Coronal section through the ischioanal fossa (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.441)

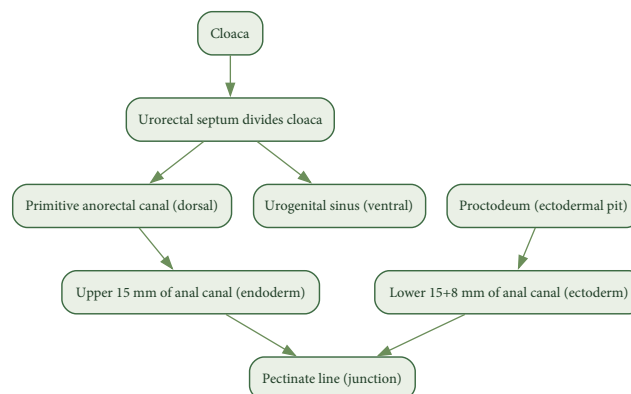
- ▶ **Ischioanal (ischiorectal) fossa** — wedge-shaped, fat-filled space on each side of the canal (base = perineal skin, apex = line where obturator fascia meets the levator-ani/anal fascia); dimensions ≈5 cm (AP) × 2.5 cm (width) × 5–6.2 cm (depth).
 - Lateral wall: obturator internus with its fascia, which carries the **pudendal canal (Alcock's canal)** — the pudendal nerve and internal pudendal vessels.
 - Medial wall: levator ani/anal fascia above, external anal sphincter below.
 - Recesses: anterior (up to the pubis), posterior (deep to sacrotuberous ligament), and the **horseshoe (deep post-anal) recess**, which connects the two fossae behind the anal canal.
 - Contents: ischioanal fat pad; inferior rectal vessels and nerve (crossing medially); pudendal canal; posterior scrotal/labial vessels and nerves; perineal branch of S4; perforating cutaneous branches of S2–3.
- ▶ **Perianal space:** shallow, subcutaneous, below Hilton's line; fat tightly loculated by complete septa, so infections here are intensely painful.

- **Submucous space:** above Hilton's line, between mucosa and internal sphincter; contains the internal rectal venous plexus and lymphatics.
- **Surgical relevance:** the loose ischioanal fat permits distension of the canal during defaecation but is a frequent site of **abscess**, which may spread through the horseshoe recess to become **bilateral** ("horseshoe") abscess.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- Obturator internus + obturator fascia (lateral wall)
- Levator ani + anal fascia (medial wall, upper) / external anal sphincter (medial wall, lower)
- Ischioanal fat pad; lunata fascia
- Pudendal (Alcock's) canal — pudendal nerve + internal pudendal vessels
- Inferior rectal vessels and nerve crossing the fossa
- Perianal space (below Hilton's line) vs deep ischioanal space
- Ischial tuberosity; sacrotuberous ligament; perineal membrane

Development — Basis of the Upper/Lower Divide



Discuss in detail the surgical anatomy of anal canal

- Failure of normal partitioning of the cloaca by the urorectal septum, or of canalisation/fusion of the two components, underlies **imperforate anus** and the spectrum of **anorectal malformations** — anal stenosis, anal or anorectal agenesis, with or without an associated fistula (recto-vaginal/vesical/urethral).

Applied / Clinical Anatomy

- **Per rectum (PR) examination:** the anorectal ring, coccyx/sacrum and the ischioanal fossae/ischial spines are palpable in both sexes; additionally the prostate, seminal vesicles and vasa in males, and cervix, perineal body and the presenting foetal part in females.
- **Internal haemorrhoids (piles):** prolapse of the anal cushions/internal rectal plexus above the pectinate line, classically at the 3, 7 and 11 o'clock columns; painless (autonomic innervation) but bleed bright red owing to rich arteriovenous anastomoses; favoured by poor connective-tissue support, absence of valves in the portal/superior rectal veins, and portal hypertension.
- **External piles:** thrombosis of the external rectal (subcutaneous) plexus below the line, covered by skin — painful (somatic innervation).

- ▶ **Anal fissure:** a tear of an anal valve/lining, classically in the **posterior midline**; intensely painful with reflex sphincter spasm because this zone is somatically innervated.
- ▶ **Fistula-in-ano:** almost always cryptoglandular — an infected intersphincteric anal gland opening into an anal sinus/crypt tracks medially into the lumen, laterally into the ischioanal fossa, or to the perianal skin; the internal opening usually lies at the floor of an anal crypt. Parks, Gordon and Hardcastle's classification (inter-, trans-, supra- and extra-sphincteric) is built on this anal-gland pathogenesis and the track's relation to the sphincter complex; the anorectal ring must be safeguarded during fistulotomy to avoid incontinence.
- ▶ **Ischioanal/perianal abscess:** may burst internally into the canal, laterally into the fossa, or externally onto the skin; a unilateral abscess can become bilateral through the horseshoe recess.
- ▶ **Anorectal incontinence:** follows division of the anorectal ring, or pudendal nerve stretch injury after difficult vaginal delivery; endoanal ultrasonography and MRI now directly image the internal sphincter, external sphincter and puborectalis, and guide sphincter-preserving repair.
- ▶ **Carcinoma of rectum/anal canal:** treated by abdominoperineal excision — anus, anal canal and rectum with fascial sheaths removed en bloc through the ischioanal fossa/levator ani plane, with a permanent left iliac colostomy.

High-yield exam pointers

- ▶ Length $\approx$ 3.8 cm; internal sphincter covers the upper three-fourths (30 mm); external sphincter the whole length.
- ▶ Pectinate line is the single most important landmark — embryological, histological, vascular, lymphatic and nerve-supply watershed.
- ▶ Primary piles occur at 3, 7, 11 o'clock (left lateral, right posterior, right anterior anal columns).
- ▶ Anorectal ring = puborectalis + upper EAS + IAS $\rightarrow$ sole basis of continence; never divide it surgically.
- ▶ White line of Hilton = intersphincteric groove; lower limit of the pecten.
- ▶ Above the line: endoderm, superior rectal vessels, portal drainage, internal iliac nodes, autonomic nerves — painless lesions.
- ▶ Below the line: ectoderm (proctodeum), inferior rectal vessels, systemic drainage, superficial inguinal nodes, somatic nerves — painful lesions.
- ▶ Ischioanal fossae communicate posteriorly via the horseshoe recess — basis of bilateral (horseshoe) abscess.
- ▶ Anal canal is a recognised portosystemic anastomotic site (internal $\leftrightarrow$ external rectal venous plexus).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2 8e; Vishram Singh — Textbook of Anatomy Vol 2 4e; Moore — Clinically Oriented Anatomy 9e.



Discuss the applied anatomy of ischiorectal fossa

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction. The **ischiorectal (ischioanal) fossa** is a wedge-shaped, fat-filled space situated one on each side of the anal canal, below the pelvic diaphragm, in the posterior (anal) triangle of the perineum. The two fossae communicate with each other behind the anal canal and permit distension of the anal canal and rectum during defaecation. Its clinical importance far exceeds its purely descriptive anatomy: the loosely arranged, poorly vascularised fat within it is the commonest site of perianal sepsis, the two fossae's posterior communication explains the "horseshoe" spread of abscess and fistula, and the fossa is used routinely as a surgical plane and as the landmark for pudendal nerve block. This answer covers its location, boundaries, recesses, fascial spaces, the pudendal canal, its contents, and its applied/clinical significance.

1. Location, shape and dimensions

- ▶ A paired, **wedge/pyramidal-shaped** space, one on either side of the anal canal, lying below the pelvic diaphragm (levator ani) and occupying most of the anal triangle.
- ▶ **Base** directed downward toward the perineal skin; **apex** directed upward and laterally.
- ▶ **Dimensions:** length (antero-posterior) ~5 cm; width (side-to-side) ~2.5 cm; depth (vertical) ~5–6 cm.
- ▶ Filled with loose adipose tissue (the **ischiorectal pad of fat**) traversed by vessels and nerves — hence, though called a "fossa," it is not an empty space.

2. Boundaries

Boundary	Formed by
Base (floor)	Skin of the perineum
Apex (roof)	Line of fusion of the obturator fascia with the inferior fascia of the pelvic diaphragm (anal fascia) — corresponds to the origin of levator ani from the lateral pelvic wall
Lateral wall (vertical)	Obturator internus muscle and its fascia; medial surface of the ischial tuberosity below the attachment of the obturator fascia
Medial wall (sloping medially and downward)	Levator ani with the anal fascia above; external anal sphincter with its covering fascia below
Anterior	Posterior border of the perineal membrane (except for the anterior recess)
Posterior	Lower border of gluteus maximus and the sacrotuberous ligament

The medial "arm" is triangular in cross-section because levator ani slopes medially from its lateral pelvic origin to the anorectal junction, so the anal canal and its sphincters occupy the centre of the horseshoe-shaped fossa.

3. Recesses of the fossa

- ▶ **Anterior recess:** extends forward above the perineal membrane (urogenital diaphragm) almost up to the posterior surface of the pubic body; lies closely related to the prostate (male) or vagina (female).
- ▶ **Posterior recess:** smaller; extends deep to the sacrotuberous ligament.
- ▶ **Horseshoe (posterior) recess:** the two ischiorectal fossae communicate with each other **behind the anal canal**, around the attachment of the external anal sphincter to the coccyx — the anatomical basis of horseshoe-shaped abscess/fistula.

4. Fascial spaces within the fossa

- ▶ The **perianal fascia** is a septum passing laterally from the lower end of the longitudinal muscle coat of the anal canal (at the white line of Hilton) to the pudendal canal, separating a shallow, subcutaneous **perianal space** from the large, deep **ischiorectal space**.
 - Perianal space: fat tightly packed in small loculi by complete septa → infection here is **very painful** (tension builds quickly).
 - Ischiorectal space: fat loosely arranged in large loculi by incomplete, delicate septa → infection here is **relatively painless** (swelling occurs with little tension).
- ▶ The **lunate fascia (fascia lunata)** arches over the ischiorectal fat, from the pudendal canal laterally to the fascia over the deep external anal sphincter medially, dividing the ischiorectal space further into a **supratsegmental space** (above the fascia lunata) and a **tegmental space** (below it).

5. Pudendal (Alcock's) canal

- ▶ A **fascial tunnel in the lateral wall** of the ischiorectal fossa, roughly **2.5 cm (1 inch) above the ischial tuberosity**.
- ▶ Formed either by a splitting of the obturator fascia or by separation between the fascia lunata and the obturator fascia.
- ▶ Extends from the **lesser sciatic foramen** to the **posterior limit of the deep perineal pouch**.
- ▶ **Contents:** the **pudendal nerve** (which divides within/near the canal into the inferior rectal nerve, the perineal nerve, and the dorsal nerve of the penis/clitoris) and the **internal pudendal vessels** (giving the inferior rectal, perineal, and terminal branches to the erectile tissues).

6. Contents of the ischiorectal fossa

- ▶ **Ischiorectal pad of fat** — fills the fossa; provides a compressible, cushion-like support that permits distension of the anal canal/rectum during defaecation.
- ▶ **Inferior rectal vessels and nerve** — cross the fossa from the pudendal canal (lateral) to the anal canal (medial), arching upward over the fat pad to supply the external anal sphincter, anal mucosa, and perianal skin.
- ▶ **Pudendal canal with its contents** — in the lateral wall.
- ▶ **Posterior scrotal (or posterior labial) vessels and nerves** — cross the anterolateral part of the fossa to enter the urogenital triangle.

- ▶ **Perineal branch of the 4th sacral (S4) nerve** — enters the posterior angle of the fossa and runs over levator ani to reach the external anal sphincter.
- ▶ **Perforating cutaneous branches of S2, S3** — appear at the lower border of gluteus maximus in the posterior part of the fossa.

□ Fig 15.18 — Boundaries of the ischiorectal fossa as seen in coronal section through the anal triangle (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.671)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

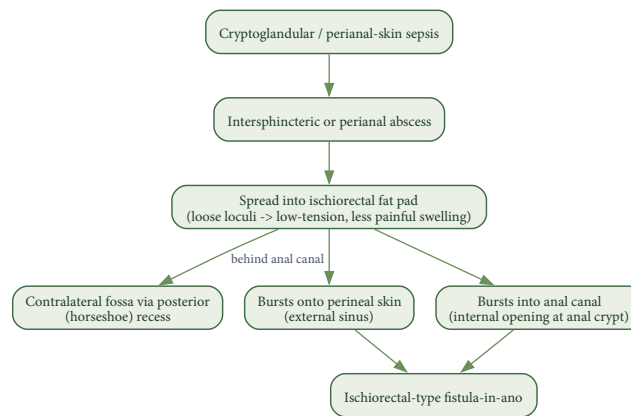
Reproduce a coronal section through the anal triangle at the level of the anal canal, labelling in sequence:

- ▶ **Anal canal** with the **external anal sphincter** in the centre, flanked on each side by the **ischiorectal fossa**
- ▶ **Apex** (fusion of obturator fascia with anal/pelvic diaphragmatic fascia — levator ani origin) and **base** (perineal skin)
- ▶ **Lateral wall**: obturator internus + obturator fascia + ischial tuberosity
- ▶ **Medial wall**: levator ani (upper) sloping to external anal sphincter (lower)
- ▶ The **ischiorectal fat pad**, with the **lunate fascia** arching over it dividing supra-tegmental (above) from tegmental (below) space
- ▶ The **pudendal (Alcock's) canal** in the lateral wall carrying the **internal pudendal vessels** and **pudendal nerve**
- ▶ **Inferior rectal vessels/nerve** crossing the fat pad from lateral to medial

Applied / Clinical anatomy

- ▶ **Ischiorectal abscess**: the fossa's loose, poorly vascularised fat is a common site of perianal sepsis, seeding from perianal skin lesions, infected anal (cryptoglandular) glands, or pelvic infection. Because the fat is loosely loculated, the abscess enlarges with comparatively **little pain/tension** (unlike the tightly loculated, very painful perianal space).
- ▶ **Horseshoe abscess/fistula**: sepsis readily spreads from one fossa to the other through the posterior (horseshoe) recess behind the anal canal, producing a bilateral, horseshoe-shaped collection.
- ▶ **Ischiorectal-type fistula-in-ano**: if the abscess is neglected, it may burst internally (usually into an anal crypt at the pectinate line) and/or externally onto the perineal skin, establishing a chronic track — the ischiorectal type of fistula-in-ano.
- ▶ Because the fossa contains **no vital named structure in its central fat**, it can be **incised fearlessly** for surgical drainage of an abscess.
- ▶ **Loss of the fat cushion** (e.g. in debilitating childhood diarrhoea) removes the supporting cushion for the rectum/anal canal and predisposes to **rectal prolapse**.
- ▶ **Hiatus of Schwalbe**: an occasional gap between the tendinous origin of levator ani and the obturator fascia at the apex of the fossa, through which pelvic viscera may rarely herniate — an **ischiorectal hernia**.

- **Pudendal nerve block:** the nerve is anaesthetised where it crosses the ischial spine (just before entering the pudendal canal), via a transvaginal or transperineal approach, to provide analgesia for episiotomy/instrumental delivery.
- **Surgical plane:** the fossa provides an easy, relatively bloodless plane of dissection during perineal excision of the anorectum, leading up to the inferior surface of levator ani.



Discuss the applied anatomy of ischioanal fossa

Recent advances

- A randomised controlled trial of a **trans-intersphincteric double seton (TRISDS)** technique — placed through the intersphincteric/ischioanal planes described above — showed a significantly higher cure rate than conventional incision-and-drainage for perianal abscess (78.2% vs 41.2%), while aiming to preserve sphincter integrity (Zhang et al., *Gastroenterology Report*, 2025) [DOI: 10.1093/gastro/goaf091].
- **3-D MRI reconstruction** of anorectal abscesses (perianal, intersphincteric, **ischioanal**, and supralelevator types) has been used to create patient-specific volumetric models of the abscess cavity together with the internal/external sphincters and levator ani, giving precise pre-operative visualisation of exactly how far sepsis has tracked through the fossa (*Scientific Reports*, 2024) [PMID: 39122753].
- The **ischioanal fat pad** itself is now harvested as a **vascularised adipose/gracilis flap** for perineal reconstruction after abdominoperineal resection, exploiting the same internal pudendal perforator supply described in the classical anatomy above (retrospective cohort, *Annals of Medicine and Surgery*, 2025) [PMC12889297].
- (According to PubMed/*Gastroenterology Report/Scientific Reports/Annals of Medicine and Surgery search*.)

High-yield exam pointers

- Paired, **wedge-shaped, fat-filled** space beside the anal canal, below the pelvic diaphragm; the two fossae **communicate behind the anal canal** (horseshoe recess).
- Dimensions: ~5 cm (AP) × 2.5 cm (width) × 5–6 cm (depth).
- Boundaries: **base** = perineal skin; **apex** = fusion of obturator + anal (pelvic diaphragmatic) fascia; **lateral wall** = obturator internus + fascia + ischial tuberosity; **medial wall** = levator ani above, external anal sphincter below; **anterior** = perineal membrane; **posterior** = sacrotuberous ligament + gluteus maximus.

- ▶ Recesses: **anterior** (above perineal membrane, near prostate/vagina), **posterior** (deep to sacrotuberous ligament), **horseshoe** (behind anal canal — key to bilateral spread).
- ▶ **Perianal space** (tightly loculated, painful) vs **ischiorectal space** (loosely loculated, less painful), separated by the **perianal fascia**; **lunate fascia** further divides supratagmental from tagmental space.
- ▶ **Pudendal (Alcock's) canal**, lateral wall, ~2.5 cm above ischial tuberosity, carries the **pudendal nerve** and **internal pudendal vessels**.
- ▶ Contents: fat pad, inferior rectal vessels/nerve, pudendal canal, posterior scrotal/labial vessels/nerve, perineal branch of S4, perforating cutaneous nerves S2–S3.
- ▶ Clinical triad: **ischiorectal abscess** → **horseshoe abscess** → **ischiorectal-type fistula-in-ano**; also **hiatus of Schwalbe** → **ischiorectal hernia**, and **fat loss** → **rectal prolapse**.
- ▶ Used as a **bloodless surgical plane** and as the landmark region for **pudendal nerve block** (at the ischial spine).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2 8e; Vishram Singh's Textbook of Anatomy Vol 2 4e; IB Singh's Textbook of Anatomy Vol 2 6e. Recent-advances section per Gastroenterology Report, Scientific Reports and Annals of Medicine and Surgery (DOIs/PMID above).



Erb's paralysis

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction Erb's paralysis (Erb–Duchenne palsy) is a traction lesion of the **upper trunk of the brachial plexus (C5, C6 roots)** at **Erb's point**, produced by forcible widening of the angle between the head/neck and the shoulder. It is the commonest brachial plexus injury, occurring classically as an **obstetric (birth) palsy** during difficult delivery or as an **adult traction injury** (fall on the shoulder, motorcycle accidents, traction under anaesthesia). Paralysis of the C5,C6-innervated shoulder and elbow muscles produces the pathognomonic "**waiter's tip**" (**policeman's/porter's tip**) **deformity** — the arm adducted and medially rotated, the elbow extended and the forearm pronated. It is discussed here in full, together with its differentiation from Klumpke's paralysis and the pre-/postganglionic distinction that governs prognosis and treatment.

Erb's point — anatomical basis

- ▶ **Erb's point** is the region, ~2–3 cm above the clavicle in the lower part of the posterior triangle of the neck, where the **ventral rami of C5 and C6 unite to form the upper trunk** of the brachial plexus, which immediately gives off two supraclavicular branches and then splits into its anterior and posterior divisions.
- ▶ **Six structures meet here:** the **C5 root**, the **C6 root**, the **suprascapular nerve**, the **nerve to subclavius**, and the **anterior and posterior divisions of the upper trunk**.

- ▶ The upper trunk lies superficially, deep only to the investing layer of cervical fascia and platysma, and is palpable in the supraclavicular fossa — this superficial, relatively fixed position (roots anchored at the intervertebral foramina and by their attachment to the transverse processes/scalene muscles) against a highly mobile shoulder girdle is precisely why traction on the limb concentrates shear stress at this point.
- ▶ **Surgical/clinical relevance:** Erb's point is also the standard site for the **interscalene brachial plexus block**.

□ Fig 4.15 — Erb's point (BD Chaurasia — Human Anatomy Vol 1 — 8e, p.85)

Aetiology and mechanism of injury

Setting	Mechanism
Birth injury (obstetric brachial plexus palsy)	Excessive lateral traction/flexion of the head and neck away from the shoulder during a difficult vertex delivery complicated by shoulder dystocia, or traction on the extended arm during delivery of the aftercoming head in a breech presentation
Adult traction injury	Fall from a height landing on the point of the shoulder (classically "fall from a horse"); forceful separation of the head from the shoulder in high-speed (motor-cyclist) road accidents; traction on an abducted arm positioned overhead during prolonged anaesthesia

- ▶ In every mechanism the common element is a **sudden, violent increase in the angle between the head/neck and the shoulder**, stretching the upper trunk region between its relatively fixed proximal roots and the mobile shoulder.
- ▶ Risk factors specifically for the obstetric form include **fetal macrosomia (birthweight ≥ 4000 g), shoulder dystocia, maternal diabetes, and instrumental (vacuum/forceps) delivery**.
- ▶ Severity is a spectrum — from **neurapraxia** (transient conduction block, best prognosis) through **axonotmesis** to frank **root rupture/avulsion** (see pre-/postganglionic distinction below), depending on the force and duration of traction.

Nerve roots and muscles paralysed

Root value	Muscles paralysed
C5 (mainly) and C6 (partly)	Deltoid, biceps brachii, brachialis, brachioradialis, coracobrachialis, subclavius — and, partly, supraspinatus, infraspinatus, teres minor and supinator

- ▶ The nerves carrying these roots — axillary, musculocutaneous, suprascapular, nerve to subclavius, and part of the radial nerve — are all derived from the **upper trunk and its divisions**, explaining why a single lesion at Erb's point paralyses muscles supplied by several peripheral nerves simultaneously.

The "waiter's tip" deformity — muscle-by-muscle basis

This is the key "explain the anatomical basis" component of the question — each element of the deformity follows directly from loss of a specific C5/C6 muscle and the resulting unopposed action of its antagonist:

Component of deformity	Paralysed muscle (action lost)	Unopposed antagonist producing the posture
Arm adducted, hanging by the side	Deltoid, supraspinatus (abductors)	Pectoralis major, latissimus dorsi, teres major
Arm medially rotated	Infraspinatus, teres minor (lateral rotators)	Subscapularis, pectoralis major, latissimus dorsi
Elbow extended	Biceps brachii, brachialis (flexors)	Triceps brachii
Forearm pronated	Biceps brachii (a supinator), supinator muscle	Pronator teres

- The resulting posture — arm adducted and medially rotated, elbow extended, forearm pronated so that the palm faces backwards/outwards — gives the limb the fond nickname of the **waiter's tip / policeman's tip / porter's tip position**, as though the patient were holding out a hand for a gratuity.

□ Fig 4.16 — Erb's paralysis of right arm (BD Chaurasia — Human Anatomy Vol 1 — 8e, p.86)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Reproduce two linked sketches by hand:

- **Erb's point** — C5 and C6 roots converging into the upper trunk; label the **suprascapular nerve** and **nerve to subclavius** arising from the trunk, and its division into an **anterior** and a **posterior division**; ring the confluence and label it "Erb's point."
- **Waiter's tip posture** of the upper limb — arm hanging **adducted and medially rotated** at the shoulder, elbow **extended**, forearm **pronated** (palm facing backwards); annotate each posture element with the paralysed muscle responsible (deltoid/supraspinatus → adduction; infraspinatus/teres minor → medial rotation; biceps/brachialis → extension of elbow; biceps/supinator → pronation).

Clinical features (disability)

- **Movements lost:** abduction and lateral rotation of the arm at the shoulder joint; flexion and supination of the forearm at the elbow.
- **Reflexes lost:** biceps jerk and supinator jerk (both C5,C6-mediated).
- **Sensory loss:** a small area of diminished sensation over the **lower/lateral part of the deltoid** (C5,C6 dermatome), corresponding to the cutaneous distribution of the axillary and lateral cutaneous nerves of the arm/forearm.
- **Autonomic signs:** absent — unlike Klumpke's paralysis, T1 (and hence the sympathetic outflow) is not involved, so there is no Horner's syndrome.

Applied / Clinical anatomy

- **Erb's paralysis vs Klumpke's paralysis** — the two classical brachial plexus palsies are frequently compared in the same question:

Feature	Erb's paralysis	Klumpke's paralysis
Site of lesion	Upper trunk (Erb's point)	Lower trunk
Roots	C5 and C6	C8 and T1
Mechanism	Increased angle between head and shoulder (downward traction on shoulder/upward traction on head)	Hyperabduction of the arm (clutching at something while falling, or breech delivery)
Muscles paralysed	Deltoid, biceps, brachialis, brachioradialis, supraspinatus, infraspinatus, supinator	All intrinsic muscles of the hand (T1); ulnar flexors of wrist/fingers (C8)
Deformity	Waiter's/policeman's tip hand	Complete claw hand
Sensory loss	Outer aspect of arm	Medial border of forearm and hand
Autonomic signs	Absent	Horner's syndrome if T1 injured proximal to the white ramus communicans to the first thoracic sympathetic ganglion

- **Preganglionic vs postganglionic injury** — a supraclavicular traction lesion may **avulse** the roots proximal to the dorsal root ganglion (preganglionic, between the DRG and the spinal cord — the weakest link in the chain, and the most common site of rupture) or **rupture** the spinal nerve distal to the DRG (postganglionic). Preganglionic injury carries a poor prognosis because the root cannot be reimplanted into the cord by conventional grafting (only reattempted in highly selected cases); postganglionic rupture is repairable by nerve grafting. Clues to a preganglionic component include a strong **Tinel's sign** on percussion in the posterior triangle, sensory loss extending **above the clavicle**, and (for lesions extending to C4–C7) paralysis of serratus anterior or the ipsilateral hemidiaphragm.
- **Investigations:** plain radiographs may show an elevated hemidiaphragm (phrenic nerve involvement) or first-rib fracture; **CT myelography or MRI** is used to detect nerve-root avulsion and traumatic pseudomeningoceles, and to plan surgical exploration.
- **Management:** mild/neurapraxic birth palsies largely recover spontaneously over weeks to months with physiotherapy and splinting (to prevent shoulder adduction/medial-rotation and elbow-extension contractures); persistent palsy at 3–6 months is an indication for surgical **nerve grafting or nerve transfer** (e.g. spinal accessory-to-suprascapular, or an Oberlin ulnar-fascicle-to-biceps transfer) to restore shoulder abduction/external rotation and elbow flexion; long-standing residual deformity in older children/adults is corrected by secondary **tendon transfers** (e.g. latissimus dorsi transfer to the rotator cuff) and, if needed, derotation osteotomy of the humerus.

High-yield exam pointers

- ▶ Erb's point = union of C5, C6 into the **upper trunk**; six nerves meet — roots C5, C6; anterior and posterior divisions of the upper trunk; suprascapular nerve; nerve to subclavius.
- ▶ **Roots involved: C5 (mainly), C6 (partly)** — never confuse with Klumpke's (C8, T1).
- ▶ Deformity = **waiter's tip / policeman's tip / porter's tip** position: arm adducted + medially rotated, elbow extended, forearm pronated.
- ▶ Muscles paralysed: **deltoid, biceps brachii, brachialis, brachioradialis, coracobrachialis, ± supraspinatus, infraspinatus, teres minor, supinator.**
- ▶ Movements lost: abduction + lateral rotation at shoulder; flexion + supination of forearm. **Biceps and supinator jerks lost.**
- ▶ Sensory loss is minimal — small patch over the lower/outer deltoid; **no Horner's syndrome** (T1 spared).
- ▶ Causes: birth injury (shoulder dystocia/breech aftercoming head) and adult traction (fall on shoulder, motorcycle accidents, anaesthesia).
- ▶ **Preganglionic** (root avulsion, poor prognosis) vs **postganglionic** (rupture, graftable) — Tinel's sign and supraclavicular sensory loss point to a preganglionic component.

Recent advances

- ▶ A large Finnish case-control study identified independent risk factors for shoulder-dystocia-related brachial plexus injury — birthweight ≥ 4000 g (adjusted OR 15.3), maternal diabetes (aOR 4.0), vacuum extraction (aOR 3.7) and maternal height ≤ 160 cm (aOR 2.7) — and a predictive model combining them achieved a 92.9% negative predictive value, useful for anticipating high-risk deliveries (Heinonen et al., *Acta Obstetrica et Gynecologica Scandinavica*, 2026) [DOI: 10.1111/aogs.70116].
- ▶ A 2025 review of imaging in brachial plexopathies confirms that **ultrasound and MRI are complementary**: ultrasound best assesses superficial post-traumatic lesions in real time, while MRI (and MR myelography) remains the gold standard for deep root-level pathology, including distinguishing preganglionic root avulsion from postganglionic rupture (Pacella et al., *Journal of Clinical Medicine*, 2025) [DOI: 10.3390/jcm14176311].
- ▶ A 2025 meta-analysis of comparative studies in brachial plexus birth palsy found that **single tendon transfer (e.g. isolated latissimus dorsi transfer) achieves shoulder functional outcomes comparable to double tendon transfer**, with a possibly lower rate of loss of midline function — supporting a simpler surgical strategy for residual Erb's-pattern shoulder deficit (Sabry et al., *BMC Musculoskeletal Disorders*, 2025) [DOI: 10.1186/s12891-025-08803-9].
- ▶ (According to PubMed.)

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e (Commentary 6.1 — Injuries of the supraclavicular brachial plexus); BD Chaurasia — Human Anatomy Vol 1, 8e; Vishram Singh — Textbook of Anatomy Vol 1, 4e; IB Singh — Textbook of Anatomy Vol 1, 6e. Recent-advances section per PubMed search (DOIs above).



Fascial spaces in Palm and their surgical importance

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction The fascial (palmar) spaces of the hand are **potential spaces** lying deep to the flexor tendons and palmar aponeurosis, normally obliterated by loose areolar tissue and rendered visible only when distended by fluid or pus. They are demarcated by fibrous septa that run from the deep surface of the palmar aponeurosis to the metacarpal bones, and their precise boundaries and communications determine how infection of the hand spreads and how an abscess must be surgically drained. Knowledge of these spaces is therefore of direct operative importance to the hand surgeon.

1. Fascial architecture of the palm

- ▶ The palmar aponeurosis (a thickening of the deep fascia over the central palm) sends three fibrous septa deep to the metacarpals, dividing the palm into three fascial compartments — **thenar, central (intermediate), and hypothenar**.
- ▶ **Lateral palmar septum** — from the lateral border of the aponeurosis to the first metacarpal; separates the thenar compartment from the intermediate compartment.
- ▶ **Medial palmar septum** — from the medial border of the aponeurosis to the fifth metacarpal; separates the hypothenar compartment from the intermediate compartment.
- ▶ **Intermediate palmar septum** (also called the **oblique palmar septum**; clinicians term it the **lateral fibrous septum**) — passes obliquely from the deep surface of the aponeurosis to the front of the third metacarpal, subdividing the intermediate compartment into a lateral **thenar space** and a medial **midpalmar space**.
- ▶ These two potential spaces lie between the long flexor tendons (with their synovial sheaths) anteriorly and the fascia covering the interossei/adductor pollicis posteriorly.

2. Classification of the fascial spaces of the hand

A. Palmar spaces

- ▶ Pulp space of the digits
- ▶ Web spaces (of the interdigital clefts)
- ▶ Midpalmar space
- ▶ Thenar space
- ▶ Hypothenar space (rarely a true clinical space)

B. Dorsal spaces

- Dorsal subcutaneous space — deep to the loose skin of the dorsum
- Dorsal subaponeurotic space — between the metacarpals/extensor tendons and the overlying extensor aponeurosis

C. Forearm space of Parona — the distal continuation of the midpalmar space into the forearm.

3. Midpalmar space and thenar space — boundaries and communications

Feature	Midpalmar space	Thenar space
Shape & situation	Triangular; under the medial half of the hollow of the palm	Triangular; under the lateral half of the hollow of the palm
Proximal limit	Distal margin of the flexor retinaculum	Distal margin of the flexor retinaculum
Distal limit	Distal transverse palmar crease	Proximal transverse palmar crease
Anterior boundary	Palmar aponeurosis → superficial palmar arch → digital nerves/vessels of the medial 3½ fingers → ulnar bursa with flexor tendons of the medial three fingers → 2nd, 3rd, 4th lumbricals	Palmar aponeurosis (lateral part) → digital nerves/vessels of the lateral 1½ digits → radial bursa with flexor pollicis longus tendon → flexor tendons of the index finger → 1st lumbrical
Posterior boundary	Fascia covering the interossei and medial three metacarpals	Transverse head of adductor pollicis and its fascia
Lateral boundary	Intermediate (oblique) palmar septum	Intermediate (oblique) palmar septum
Medial boundary	Medial palmar septum	Lateral palmar septum
Contents	2nd, 3rd, 4th lumbrical tendons in their canals	1st lumbrical tendon in its canal
Proximal communication	Forearm space of Parona, through the carpal tunnel	Forearm space of Parona, through the carpal tunnel
Distal communication	Medial three lumbrical canals → 2nd, 3rd, 4th web spaces	1st lumbrical canal → 1st (thumb) web space
Drainage incision	Vertical incision in the 3rd or 4th web space	Vertical incision in the 1st web space (dorsal approach preferred)

The two spaces are normally sealed off proximally but communicate freely with each other in disease, so infection readily crosses from one to the other across the intermediate palmar septum.

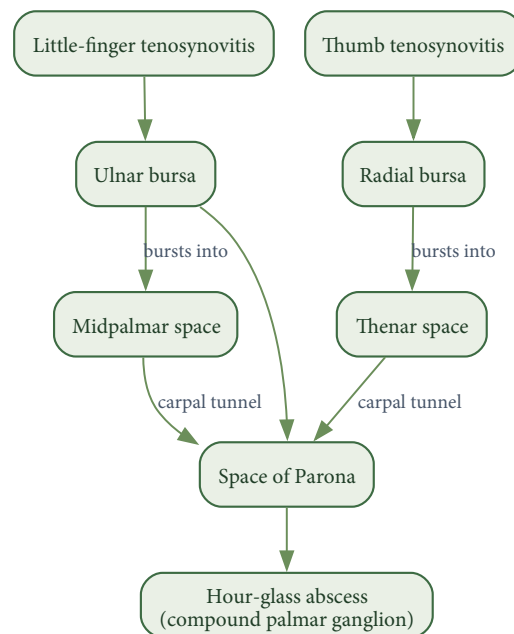
4. Hypothenar space, web spaces and the pulp space

- Hypothenar space — the compartment deep to the hypothenar muscles; true infection here is rare because it is tightly confined by the hypothenar fascia. When it does occur, it produces swelling of the ulnar border of the hand with flexion/adduction of the little finger, and is drained by an incision along the ulnar border of the space.

- ▶ **Web spaces** — subcutaneous spaces in each interdigital cleft, extending from the free margin of the web proximally to the level of the metacarpophalangeal joints/transverse metacarpal ligament; they contain the lumbrical and interosseous tendons and the digital vessels/nerves, and form the distal drainage outlets of the midpalmar and thenar spaces.
- ▶ **Pulp space of the digits** — a subcutaneous compartment on the palmar tip of each finger/thumb, bounded superficially by skin and deeply by the distal two-thirds of the terminal phalanx, crossed by numerous fibrous septa running from skin to periosteum that create multiple loculi. The digital artery supplying the phalangeal shaft (diaphysis) traverses this space, while the epiphysis is supplied proximal to it.
 - Infection here is the **pulp-space infection (felon/whitlow)**; rising tension causes severe throbbing pain, and if neglected, septal compression of the diaphyseal vessels can cause **avascular necrosis of the distal four-fifths of the terminal phalanx**, the epiphysis being spared.
 - Drainage is by a **lateral incision** opening all loculi while sparing the tactile pulp skin anteriorly.

5. Forearm space of Parona and the synovial bursae

- ▶ The **space of Parona** is a rectangular potential space in the distal forearm, lying in front of pronator quadratus and deep to the long flexor tendons; it extends from the oblique origin of flexor digitorum superficialis proximally to the flexor retinaculum distally, where it communicates with the midpalmar space through the carpal tunnel.
- ▶ The **ulnar bursa** (common flexor synovial sheath of the medial four digits) and the **radial bursa** (sheath of flexor pollicis longus) extend about 2 cm proximal to the flexor retinaculum into this space. The synovial sheaths of the index, middle and ring fingers are independent and end at the metacarpal-head level, but the little finger's sheath is continuous with the ulnar bursa and the thumb's with the radial bursa — so infection of the little finger or thumb can track proximally into the palm and forearm.
- ▶ An inflamed ulnar bursa may burst into the midpalmar space, and an inflamed radial bursa into the thenar space; conversely, infection of the space of Parona from a burst ulnar bursa produces an **hour-glass (dumb-bell) swelling** — one swelling in the palm and one in the forearm joined by a constriction at the flexor retinaculum — also called a **compound palmar ganglion**.
- ▶ The space of Parona is drained by vertical incisions along its lateral and medial margins in the distal forearm.



Fascial spaces in Palm and their surgical importance

□ Fig 11.21 — ■ Midpalmar and thenar spaces of the hand (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.511)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Transverse (cross-)section through the middle of the palm, labelling:

- ▶ Palmar aponeurosis (superficial)
- ▶ Lateral palmar septum, intermediate (oblique) palmar septum, medial palmar septum
- ▶ Thenar space (with 1st lumbrical, FPL tendon/radial bursa)
- ▶ Midpalmar space (with 2nd–4th lumbricals, flexor tendons/ulnar bursa, superficial palmar arch)
- ▶ Hypothenar space (over hypothenar muscles)
- ▶ Fascia over interossei/adductor pollicis (posterior wall)
- ▶ Metacarpals 1–5

Also sketch a palmar outline showing surface projections: thenar space over the outer half, midpalmar space over the inner half of the hollow of the palm, with drainage incision lines in the 1st web (thenar) and 3rd/4th web (midpalmar).

Applied / Clinical anatomy

- ▶ **Compartment syndrome of the hand:** there are 10 osteofascial compartments — four containing the dorsal interossei, three the palmar interossei, and three the thenar, hypothenar and adductor pollicis muscles. A rise in intracompartmental pressure from crush injury, burns or high-pressure injection can compromise perfusion, producing an intrinsic-minus (claw) posture; suspected compartment syndrome needs pressure measurement and prompt fasciotomy.
- ▶ **Safe surgical incisions:** incisions in the palm/hand should run parallel to the flexion creases and never cross a crease at a right angle, to avoid post-operative contracture. A **dorsal approach through the first web space**, perpendicular to the web and between the first and second

metacarpals, is preferred for draining the thenar space because a palmar incision risks the recurrent motor branch and palmar cutaneous branch of the median nerve; the midpalmar space is best approached by a transverse distal palmar incision with an oblique extension.

- ▶ **Route of clinical spread:** tenosynovitis of the little finger or thumb (via the ulnar/radial bursa) is the classical inlet of infection into the midpalmar/thenar spaces, with the lumbrical canals/web spaces acting as the distal outlets — this sequence explains why an apparently trivial finger infection can present as a spreading palmar or forearm abscess.
- ▶ **Surface projection:** because the thenar and midpalmar spaces project respectively to the lateral and medial halves of the palmar hollow between the distal wrist crease and the palmar creases, clinical localisation of a fluctuant swelling to one half of the palm predicts which space is involved and guides the drainage incision.

High-yield exam pointers

- ▶ Three fascial septa (lateral, intermediate/oblique, medial palmar septa) create the thenar, midpalmar and hypothenar compartments from the deep surface of the palmar aponeurosis.
- ▶ **Midpalmar space** = medial half of palm, floor = interosseous fascia + medial 3 metacarpals, contains 2nd–4th lumbricals; drained via 3rd/4th web space.
- ▶ **Thenar space** = lateral half of palm, floor = adductor pollicis, contains 1st lumbrical + FPL/radial bursa; drained via 1st web space (dorsal approach to protect median nerve).
- ▶ Both spaces communicate proximally with the **space of Parona** through the carpal tunnel, and are normally sealed but often communicate with each other once infected.
- ▶ **Pulp space (whitlow/felon):** septate compartment over the terminal phalanx; neglected infection → avascular necrosis of the distal four-fifths of the phalanx (epiphysis spared); drained by a lateral incision.
- ▶ **Ulnar bursa** (little finger + medial 3 sheaths) and **radial bursa** (thumb/FPL) link digital tenosynovitis to the midpalmar/thenar spaces and to the space of Parona.
- ▶ **Hour-glass swelling / compound palmar ganglion** = simultaneous palmar + forearm swelling joined by a waist at the flexor retinaculum, from a burst ulnar bursa.
- ▶ Hypothenar space infection is rare, confined by hypothenar fascia; drained along the ulnar border.
- ▶ Golden rule of hand incisions: parallel to skin creases, never crossing a crease at right angles.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 1, 8e; Vishram Singh — Textbook of Anatomy Vol 1, 4e; IB Singh — Textbook of Anatomy Vol 1, 6e; Moore's Clinically Oriented Anatomy, 9e.



Gastroscopy

Asked in: Paper IV Nov 2016 — RGUHS MD/MS Anatomy

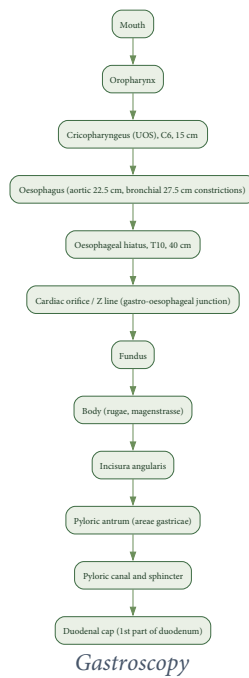
Definition / Introduction — Gastroscopy (oesophago-gastro-duodenoscopy, OGD; "upper GI endoscopy") is the direct, per-oral visual and instrumental examination of the oesophagus, stomach and proximal duodenum with a flexible fibre-optic/video endoscope (the **gastroscope**). It is fundamentally an *applied-anatomy* procedure — the instrument is guided along the natural curves and constrictions of the upper alimentary canal, and the images it produces are read against the named external and internal landmarks of the oesophagus and stomach described below.

1. Anatomical basis of the endoscope's transoral path

The gastroscope is passed through the mouth → oropharynx → **cricopharyngeus** (upper oesophageal sphincter) → **oesophagus**, which shows four constant sites of narrowing measured from the upper incisor teeth; these very distances are used clinically to judge how far the instrument has been advanced.

Constriction	Cause	Vertebral level	Distance from incisor teeth
1st — cervical (pharyngo-oesophageal)	Cricopharyngeus muscle	C6	15 cm (6 in)
2nd — aortic	Crossed by the arch of aorta	T4	22.5 cm (9 in)
3rd — bronchial	Crossed by the left principal bronchus	T6	27.5 cm (11 in)
4th — diaphragmatic	Oesophageal hiatus of diaphragm	T10	40 cm (16 in)

- ▶ The oesophagus is about 25 cm long (cervical part 4 cm, thoracic part 20 cm, abdominal part 1–2 cm) and is narrowest at its commencement, at the cricopharyngeal sphincter.
- ▶ These constrictions are the sites where swallowed foreign bodies lodge, corrosive strictures and carcinoma preferentially develop, and — of direct relevance here — **through which it may be difficult to pass an oesophagoscope/gastric tube**; the incisor-teeth distances are used clinically while introducing an endoscope.
- ▶ Along the thoracic part the endoscopist's tip lies successively related, anteriorly, to the trachea, arch of aorta, right pulmonary artery, left bronchus and left atrium, and posteriorly to the vertebral column, thoracic duct and azygos system — an important reason why oesophageal instrumentation must be gentle and image-guided.



□ Fig 23.7 — Anatomical sites of constrictions in the oesophagus, with distances from the upper incisor teeth (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.903)

2. The gastro-oesophageal junction and the Z line

- ▶ The **cardiac orifice** lies to the left of the midline behind the 7th costal cartilage at the level of T11, about 40 cm from the incisor teeth; its right border continues as the lesser curvature, its left border as the greater curvature (separated by the **cardiac notch**).
- ▶ Internally, the squamocolumnar transition — the pale-pink oesophageal squamous epithelium meeting the red columnar gastric epithelium — forms a circumferential "**zigzag**" or "**Z**" line, normally located at the proximal limit of the gastric mucosal folds; this is the first endoscopic landmark identified on gastroscopy.
- ▶ Proximal extension of columnar (intestinalized) epithelium above the Z line is pathological and is termed **Barrett's oesophagus**, visible endoscopically as a colour change and carrying an increased risk of oesophageal adenocarcinoma.
- ▶ Anti-reflux mechanisms constituting the physiological **lower oesophageal sphincter/high-pressure zone**: tonic "clasp" (circular) fibres of the lesser-curvature side reinforced by the right diaphragmatic crus, "sling"-like oblique gastric fibres on the greater-curvature side, the **angle of His** (acute cardio-oesophageal angle, a flap valve), the mucosal folds forming a "**mucosal rosette**," and the length of intra-abdominal oesophagus buttressed by peri-hiatal fat.
- ▶ **Hiatus hernia** — herniation of the stomach through a widened oesophageal hiatus; sliding type ($\geq 90\%$) versus para-oesophageal/mixed type (remainder) — is diagnosed on retroflexed gastroscopic view of the cardia together with barium studies.

3. External form and parts of the stomach — the endoscopic landmarks

The stomach (mean adult capacity 1000–1500 mL, versus 20–30 mL at birth) is divided by external lines into four descriptive parts, each with a distinct endoscopic appearance:

Part	Boundary	Endoscopic feature
Fundus	Dome above a horizontal line from the cardiac notch to the greater curvature; in contact with the left diaphragmatic dome	Usually gas-filled; best seen on retroflexion ("J-manooeuvre") of the gastroscope
Body	Fundus to the angular incisure	Longitudinal mucosal folds (rugae); a smoother strip along the lesser curvature forms the gastric canal (" magenstrasse ") that fast-tracks liquids to the pylorus
Pyloric antrum	Angular incisure to where the stomach narrows into the pyloric canal	Few folds; areae gastricae — subtle cobblestone mucosal undulations
Pylorus (canal + sphincter)	1–2 cm long, ends at the pyloric orifice	Smooth prepyloric mucosa culminating in a puckered orifice from sphincteric contraction; surface marked by the prepyloric vein (of Mayo)

- ▶ **Lesser curvature:** concave, shorter, right border; its most dependent point is the **angular incisure** (*incisura angularis*), a constant landmark marking the body–antrum junction.
- ▶ **Greater curvature:** convex, 2–3× longer than the lesser curvature; the apex of the fundus lies near the left 6th rib; the curvature ends at the pylorus in the transpyloric plane (lower border of L1).
- ▶ Shape varies with build and filling — "**J-shaped**" when empty/erect, a horizontal "**steer-horn**" shape in short, obese individuals (double-contrast barium correlate).

□ Fig 7.10 — Interior of the stomach showing the gastric canal (*magenstrasse*), rugae, gastric pits and pyloric sphincter (Vishram Singh — *Textbook of Anatomy Vol 2 — 4e, p.330*)

4. Internal appearances seen during the procedure

- ▶ With the stomach partly air-distended, the cardia and lowest oesophagus are normally closed by lower-oesophageal-sphincter tone; on **retroflexion of the gastroscope** from within the distended stomach, the cardiac orifice is seen medial to the fundus with a mucosal fold at the acute angle of the orifice — this retroflexed/"J" view is essential to inspect the fundus and cardia, areas not seen on the straight forward view.
- ▶ Rugae are most prominent on the antero-lateral, lateral and postero-lateral body wall toward the greater curvature; they flatten with full distension.
- ▶ The stomach's rich lymphatic drainage follows the named arteries and is continuous with oesophageal lymphatics above and duodenal/pancreatic lymphatics below — relevant when endoscopic biopsies are being mapped for staging.

5. Vascular and nerve supply relevant to endoscopic bleeding and biopsy

Curvature/region	Artery
Lesser curvature	Left gastric artery (coeliac trunk) + right gastric artery (proper hepatic artery)
Greater curvature	Left gastroepiploic artery (splenic artery) + right gastroepiploic artery (gastroduodenal artery)
Fundus	Short gastric arteries (splenic artery, 5–7 in number)

- ▶ Venous drainage mirrors the arteries into the **portal system**; when portal pressure is chronically raised (typically > 15 mmHg), the submucosal plexus of the distal oesophagus and gastric fundus dilates into **oesophageal and gastric varices** — readily seen at gastroscopy because they protrude superficially into the lumen, and a major cause of upper GI bleeding requiring endoscopic banding/sclerotherapy.
- ▶ **Vagal (parasympathetic) supply**: anterior and posterior vagal trunks lie on the corresponding oesophageal surfaces; the anterior trunk's main gastric branch (anterior/greater nerve of the lesser curvature) runs in the lesser omentum and typically terminates near the angular incisure in a "**crow's foot**" branching pattern — an intra-operative landmark during vagotomy that corresponds to the endoscopic angular incisure.
- ▶ **Sympathetic supply** (T5–T12 via splanchnic nerves/coeliac plexus) carries the nociceptive fibres, explaining epigastric referral of gastric pain.

6. Advances in gastrointestinal endoscopy

- ▶ **High-definition video-chip endoscopes** have replaced fibre-optic instruments, sharply improving resolution of the mucosal detail (rugae, areae gastricae, Z line) described above.
- ▶ **Chromoendoscopy and narrow-band imaging (NBI)** enhance mucosal/vascular-pattern contrast to delineate the Z line and detect early Barrett's/gastric dysplasia that is otherwise inconspicuous on white-light gastroscopy.
- ▶ **Magnification endoscopy/endocytoscopy** resolve individual areae gastricae and gastric pit patterns in vivo, approaching histological detail without biopsy.
- ▶ **Endoscopic ultrasound (EUS)**, using a gastroscope-mounted transducer through the gastric/duodenal wall, images the layered gastric wall itself and adjacent structures (coeliac/hepatoduodenal nodes, pancreas, distal common bile duct) and is used for locoregional staging of gastric, pancreatic and biliary tumours.
- ▶ **Endoscopic mucosal resection (EMR) and endoscopic submucosal dissection (ESD)** excise mucosal/submucosal dysplastic lesions and early cancers confined to those layers, sparing patients a formal gastrectomy when there is no deep submucosal invasion.
- ▶ **Per-oral endoscopic myotomy (POEM)** for achalasia cardia creates a submucosal tunnel down to, and divides, the circular muscle of the lower oesophageal sphincter — a direct endoscopic application of the muscularis-layer anatomy described in Section 2.

- ▶ **Capsule endoscopy**, though primarily a small-bowel tool, and **virtual (CT) gastroscopy** are complementary non-invasive alternatives when conventional gastroscopy is contraindicated or incomplete.
- ▶ **AI-assisted lesion-detection software** is increasingly integrated into endoscopy platforms to flag suspicious mucosal areas (e.g. early gastric cancer, Barrett's dysplasia) in real time.

Applied / Clinical anatomy

- ▶ **Peptic ulcer sites**: gastric ulcer occurs typically along the **lesser curvature** (site of maximal contact with swallowed irritants, along the "gastric canal"/magenstrasse); duodenal ulcer occurs most commonly in the **first part of the duodenum (duodenal cap)**, directly exposed to acidic chyme. A posteriorly-perforating duodenal ulcer may erode the **gastroduodenal artery** (major haemorrhage) or track into the lesser sac; an anteriorly-perforating ulcer opens into the greater sac, causing generalized peritonitis.
- ▶ **Gastric carcinoma** more often involves the **greater curvature**, with lymphatic spread following the named arteries — the anatomical basis for radical lymphadenectomy and for EUS-based nodal staging (Section 6).
- ▶ **Achalasia cardia**: failure of LOS relaxation due to loss of myenteric ganglion cells, producing dysphagia and proximal oesophageal dilation; treated by balloon dilation, Heller's cardiomyotomy, or POEM.
- ▶ **Gastric volvulus**: organoaxial (rotation about the cardio-pyloric axis, greater curvature flips above the lesser curvature) or mesenteroaxial (rotation about an axis across the body, near the incisura) — both alter the endoscopic orientation of landmarks.
- ▶ **Gastrostomy**: the antero-inferior surface of the body, related to the anterior abdominal wall, is the standard site for endoscopically-guided percutaneous gastrostomy tube placement, with care to avoid the interposed transverse colon.
- ▶ Oesophageal/gastric varices, hiatus hernia, Barrett's oesophagus and peptic ulcers together account for the great majority of indications for diagnostic and therapeutic gastroscopy.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A composite labelled schematic of the endoscope's path and the landmarks encountered, showing:

- ▶ Upper incisor teeth (0 cm reference point)
- ▶ Cricopharyngeus/pharyngo-oesophageal junction — C6, 15 cm
- ▶ Arch of aorta crossing — T4, 22.5 cm
- ▶ Left principal bronchus crossing — T6, 27.5 cm
- ▶ Oesophageal hiatus of diaphragm — T10, 40 cm
- ▶ Cardiac orifice / gastro-oesophageal junction with the Z line (squamocolumnar junction)
- ▶ Fundus, with cardiac notch and angle of His
- ▶ Body of stomach — longitudinal rugae and the gastric canal (magenstrasse) along the lesser curvature
- ▶ Angular incisure (incisura angularis) — body–antrum junction
- ▶ Pyloric antrum with areae gastricae
- ▶ Pyloric canal and pyloric sphincter
- ▶ Duodenal cap (first part of duodenum)

High-yield exam pointers

- ▶ Four oesophageal constrictions and their incisor-teeth distances (15 / 22.5 / 27.5 / 40 cm) are the key numbers governing safe endoscope passage.
- ▶ The **Z line** is the squamocolumnar mucosal junction at the cardia — the first landmark on gastroscopy; its proximal displacement = Barrett's oesophagus.
- ▶ Stomach parts: fundus → body → pyloric antrum → pylorus, separated by the cardiac notch and the angular incisure.
- ▶ **Magenstrasse** (gastric canal along the lesser curvature) and **areae gastricae** (antral mucosal cobblestoning) are classic endoscopic descriptive terms.
- ▶ Retroflexion ("J-manoevre") of the gastroscope is required to inspect the fundus and cardia from within the distended stomach.
- ▶ Arterial supply: left/right gastric (lesser curvature), left/right gastroepiploic (greater curvature), short gastric (fundus) — all coeliac-trunk territory.
- ▶ Gastric ulcer → lesser curvature; duodenal ulcer → duodenal cap; posterior duodenal ulcer perforation risks the gastroduodenal artery.
- ▶ Portal hypertension → oesophageal/gastric varices, seen bulging into the lumen at gastroscopy — a major bleeding source.
- ▶ EUS, EMR/ESD and POEM are direct clinical extensions of gastric-wall-layer and LOS-muscle anatomy.

SOURCE & COVERAGE

Gray's Anatomy (Standing) 41e; Vishram Singh Textbook of Anatomy Vol 1 4e and Vol 2 4e; BD Chaurasia Human Anatomy Vol 1 8e and Vol 2 8e; IB Singh Textbook of Anatomy Vol 2 6e; Moore's Clinically Oriented Anatomy 9e.

Coverage note: neither the spine text nor the specialty text carries a dedicated "gastroscopy" chapter; the answer is grounded in each book's standard descriptive/applied anatomy of the oesophagus and stomach (constrictions, gastro-oesophageal junction, gastric form, vasculature) together with Gray's own descriptions of the endoscopic appearances of these structures.



Give the surgical (Applied) anatomy of anal fissure

Asked in: Paper IV May 2010 — RGUHS MD/MS Anatomy

Definition / Introduction An anal fissure (fissure-in-ano) is a longitudinal tear/ulcer in the anoderm of the lower anal canal, most often produced by the passage of hard, constipated stool that ruptures an anal valve. Its surgical anatomy is best understood by combining (a) the epithelial/zonal architecture of the anal canal, (b) the pattern of arterial supply and its relative deficiency at the midline commissures, (c) the somatic pain innervation of the anoderm, and (d) the two-sphincter musculature whose spasm perpetuates the lesion. These four factors together explain why the fissure occurs where it does, why it is so painful, why it becomes chronic, and why surgery is deliberately placed away from the fissure itself.

Anal canal — zonal anatomy relevant to the fissure

- ▶ **Length ~38 mm (3–4 cm)**, extending from the anorectal junction (anorectal ring) to the anal verge.
- ▶ **Anatomical vs surgical anal canal:** the *anatomical* anal canal runs from the anal verge to the pectinate (dentate) line only (~2 cm); the *surgical* anal canal is the clinically-used span from the anal verge to the anorectal ring (~4 cm) — the extra proximal segment (upper mucous zone) is included because it behaves as part of the continent canal.
- ▶ **Three epithelial zones** (BD Chaurasia; Vishram Singh):
- ▶ **Upper mucous zone (~15 mm)** — endodermal (hindgut) origin; simple columnar epithelium; shows 6–10 **anal columns of Morgagni**, joined below by **anal valves**, each valve overhung by an **anal sinus** containing anal glands.
- ▶ **Middle zone / pecten (~15 mm)** — transitional stratified epithelium, bluish (dense submucosal venous plexus), bounded below by the **white line of Hilton**.
- ▶ **Lower cutaneous zone (~8 mm)** — true skin-like **anoderm**: stratified squamous, no hair/sweat/sebaceous glands, densely somatically innervated.
- ▶ **Pectinate (dentate) line** = fused anal valves; marks the ectoderm–endoderm (proctodeum–hindgut) junction and the single most important applied landmark of the canal — it divides arterial, venous, lymphatic and nerve supply (see table).
- ▶ The anal fissure classically lies **just below the anal valves, in the anoderm of the lower/middle zone** — precisely the segment that is somatic, richly sensitive, and only weakly vascularised.

Feature	Above pectinate line	Below pectinate line (fissure site)
Embryological origin	Hindgut (endoderm)	Proctodeum (ectoderm)
Epithelium	Columnar/transitional	Stratified squamous (anoderm)
Arterial supply	Superior rectal artery	Inferior rectal artery
Venous drainage	Portal (superior rectal vein)	Systemic (inferior rectal vein)
Lymphatic drainage	Internal iliac nodes	Superficial inguinal nodes
Nerve supply	Autonomic (sympathetic L1–2, parasympathetic S2–4)	Somatic — inferior rectal nerve (S2–4)
Sensation	Ischaemia, stretch only (painless)	Pain, touch, temperature (exquisitely sensitive)

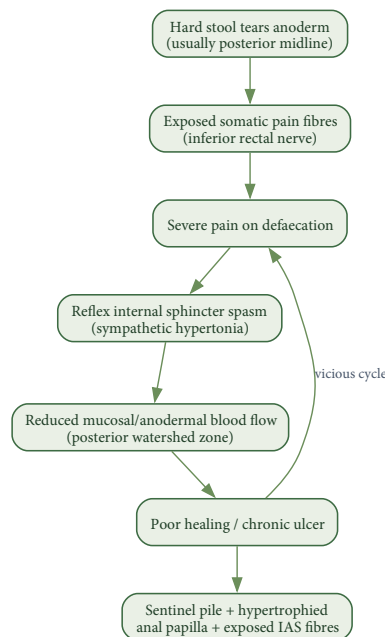
Musculature — internal and external anal sphincters

- ▶ **Internal anal sphincter (IAS)** — thickened continuation of the **circular smooth-muscle coat**; involuntary; extends over the upper three-fourths (~30 mm) of the canal down to the white line; tonically contracted at rest (~85% of resting anal tone), contracted further by **sympathetic** fibres and relaxed by **parasympathetic** fibres.
- ▶ **External anal sphincter (EAS)** — striated, voluntary; three parts (subcutaneous, superficial, deep) that form a single functional unit; supplied by the **inferior rectal nerve** and the **perineal branch of S4**; middle/deep fibres decussate anteriorly and posteriorly to form the anterior and posterior **commissures** — precisely the two poles where sphincteric support is weakest.
- ▶ **Anorectal ring** = puborectalis + deepest EAS fibres + IAS, palpable per rectum; surgical division of this ring causes permanent faecal incontinence and must never be transected during fissure or fistula surgery.
- ▶ **Conjoint longitudinal coat**, between IAS and EAS, breaks into fibroelastic septa (corrugator cutis ani) at the level of Hilton's white line.

Arterial supply and the vascular basis of fissure siting

- ▶ **Above the pectinate line** — superior rectal artery (terminal branch of inferior mesenteric artery), running in the anal columns.
- ▶ **Below the pectinate line** — paired **inferior rectal arteries**, branches of the internal pudendal artery given off within the pudendal (Alcock's) canal, piercing the ischioanal fat to reach the lower canal.
- ▶ **Applied point (the anatomical basis of fissure chronicity)**: angiographic/topographic studies of the inferior rectal artery (cited as classic further-reading in BD Chaurasia's Rectum & Anal Canal chapter) show that its terminal twigs anastomose poorly in the **posterior midline**, so the posterior commissure of the anoderm is a relatively **watershed, poorly-vascularised zone** compared to the antero-lateral canal. This relative ischaemia — worsened by reflex spasm of the internal sphincter after injury — explains both why most fissures occur posteriorly and why they fail to heal spontaneously (a "chronic primary anal fissure").

- Middle rectal artery (internal iliac) and median sacral artery contribute only minor anastomotic supply and do not compensate at the commissures.



Give the surgical (Applied) anatomy of anal fissure

Nerve supply and the pain-spasm cycle

- Below the pectinate line, the anoderm is supplied by the **somatic inferior rectal nerve (S2–4)** — carrying pain, touch and temperature — which is why even a shallow tear here is agonising, unlike a painless internal pile arising above the line.
- The pain reflexly drives **sympathetically-mediated hypertonia/spasm of the internal anal sphincter**. This spasm (a) perpetuates pain, (b) splints the fissure edges apart, and (c) further compromises the already-poor posterior-commissure blood flow — a self-sustaining cycle that converts an acute tear into a chronic non-healing ulcer.

Embedded real plate — arterial supply of the rectum and anal canal (superior/middle/inferior rectal vessels), the structural basis of the point above:

embed: ![Fig 33.6 — Blood supply of rectum and anal canal (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.507)](C:/Users/Harshad/Documents/anatomy-notes/answer-bank/rguhs-anatomy/answers/figures/plates/47316d7227932dfd.jpg)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Coronal section through the anal canal — label:

- ▶ Anal columns of Morgagni
- ▶ Anal valves and anal sinuses (with anal glands)
- ▶ Pectinate/dentate line
- ▶ Anal papilla
- ▶ Pecten (transitional zone) and white line of Hilton
- ▶ Anoderm (lower cutaneous zone)
- ▶ Internal anal sphincter (circular smooth muscle)
- ▶ External anal sphincter — subcutaneous, superficial, deep parts
- ▶ Conjoint longitudinal coat / corrugator cutis ani
- ▶ Anorectal ring
- ▶ Superior rectal artery (above pectinate line) and inferior rectal artery (below pectinate line), showing sparse posterior-commissure anastomoses
- ▶ Site of a typical fissure — posterior midline anoderm, just below the anal valve

Applied / Clinical anatomy

- ▶ **Site:** ~90% occur in the **posterior midline**; ~10% in the **anterior midline** (anterior fissures are relatively commoner in females, related to a thinner anterior EAS/perineal-body support after childbirth); a fissure away from the midline ("lateral" or atypical) should raise suspicion of Crohn's disease, tuberculosis, HIV, syphilis or anal carcinoma rather than a simple primary fissure.
- ▶ **Chronic fissure triad:** (1) a distal **sentinel skin tag** (the torn, oedematous remnant of the anal valve/papilla), (2) a **hypertrophied anal papilla** proximally, and (3) the **fissure bed itself, exposing the pale transverse fibres of the internal sphincter** at its base — all direct consequences of the zonal/muscular anatomy above.
- ▶ **Lateral internal sphincterotomy** (the definitive surgery for chronic fissure): the internal sphincter is divided deliberately at the **3 or 9 o'clock position, lateral to and away from the fissure**, up to the level of the dentate line/apex of the fissure — never through the fissure bed itself. This avoids (a) further devascularising the already-poor posterior watershed zone and (b) a "keyhole deformity" with permanent minor soiling that follows posterior sphincterotomy; the EAS and anorectal ring are deliberately spared to prevent incontinence.
- ▶ **Botulinum toxin injection** ("chemical sphincterotomy") is targeted into the IAS on either side of the fissure to relax spasm without a cut, exploiting the same sympathetic-tone anatomy.
- ▶ **Anal stretch (Lord's procedure)**, historically used to overcome sphincter spasm, is now largely abandoned because uncontrolled forcible dilatation disrupts both IAS and EAS fibres non-selectively, risking incontinence.
- ▶ **Fissurectomy/advancement anoplasty** for refractory fissures relies on the anoderm's vascular territory (inferior rectal artery branches) for flap viability.

- **Anorectal ring** must be positively identified and preserved in every anal-canal procedure (fissure, fistula, haemorrhoidectomy) — its division is the single anatomical cause of iatrogenic faecal incontinence.

High-yield exam pointers

- Fissure lies in the **anoderm**, the ectodermal/stratified-squamous lower zone below the pectinate line — hence painful (somatic inferior rectal nerve) unlike a painless internal pile above the line.
- **90% posterior midline**; posterior commissure is a relative arterial **watershed** (sparse inferior rectal artery anastomoses) — the anatomical reason for chronicity.
- **Pain → internal sphincter spasm → further ischaemia → non-healing** is the applied vicious cycle to state explicitly.
- Chronic fissure triad: **sentinel pile + hypertrophied anal papilla + exposed internal sphincter fibres** at the ulcer base.
- **Lateral internal sphincterotomy at 3/9 o'clock**, never posteriorly through the fissure — key applied-surgical point examiners look for.
- **Anorectal ring** (puborectalis + deep EAS + IAS) must never be divided — risk of permanent incontinence.
- Internal sphincter = involuntary smooth muscle, sympathetic-contracted; External sphincter = voluntary striated muscle, inferior rectal nerve + S4 perineal branch — know which one surgery targets and why.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2 8e (Rectum and Anal Canal, incl. cited angiographic study on inferior rectal artery topography and chronic anal fissure); Vishram Singh — Textbook of Anatomy Vol 2 4e; IB Singh — Textbook of Anatomy Vol 2 6e; Moore's Clinically Oriented Anatomy 9e; Netter's Atlas of Human Anatomy 8e. Coverage note: the corpus is rich on anal-canal gross/microscopic anatomy but does not elaborate operative steps of sphincterotomy in anatomical-textbook depth; the surgical-anatomy correlations above (siting of sphincterotomy, keyhole deformity, sentinel-pile triad) are standard, universally-taught applied points consistent with the cited BD Chaurasia clinical-anatomy passage and vascular reference.



Glial Cells

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction

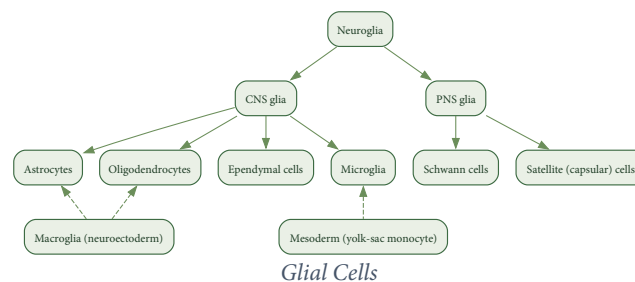
Neuroglia ("nerve glue") are the non-neuronal, supporting cells of nervous tissue. Unlike neurons, which are post-mitotic after maturity, glial cells retain the capacity to divide throughout life — the basis both of reactive **gliosis** after CNS injury and of **gliomas**, the commonest primary CNS neoplasms. Glia do not generate or conduct action potentials, but provide structural, trophic, immune, myelinating and barrier functions essential to neuronal survival and signalling. Six types are recognised — four confined

to the CNS (astrocytes, oligodendrocytes, ependymal cells, microglia) and two in the PNS (Schwann cells, satellite/capsular cells) — distinguished further by their **embryonic origin**.

1. Classification and embryonic origin

Glial cell	Location	Embryonic origin
Astrocytes	CNS (grey and white matter)	Neuroectoderm — neural-tube spongioblasts (macroglia)
Oligodendrocytes	CNS (mainly white matter/tracts)	Neuroectoderm — neural-tube spongioblasts (macroglia)
Ependymal cells	CNS — line ventricles & central canal	Neuroectoderm — matrix (ependymal) zone of neural tube
Microglia	CNS (grey and white matter)	Mesoderm — embryonic monocyte precursors of the yolk sac
Schwann cells	PNS — ensheath axons	Neural crest
Satellite (capsular) cells	PNS — encapsulate ganglion-cell bodies	Neural crest

- ▶ The neural-tube wall differentiates into a **matrix (ependymal) zone**, whose cells give rise to bipotential **neuroblasts** (→ neurons) and **spongioblasts** (→ astrocytes, oligodendrocytes, and the ependymal lining itself); astrocytes + oligodendrocytes together are termed **macroglia**.
- ▶ **Microglia are the sole glial line NOT of neuroectodermal origin** — they are mesodermal (monocyte/yolk-sac) in lineage, invade the brain early in development, and are functionally the resident macrophages of the CNS.
- ▶ **Schwann cells and satellite cells**, the two PNS glia, both arise from the **neural crest**.



2. Astrocytes

- ▶ **Star-shaped** cells with numerous long, branching processes; the most abundant and morphologically diverse glial cell. Marker: **glial fibrillary acidic protein (GFAP)**, an intermediate filament — not universally expressed.
- ▶ Two classic morphological types:
 - **Protoplasmic astrocytes** — grey matter; short, profusely branching processes; contact synapses at both pre- and postsynaptic membranes.
 - **Fibrous astrocytes** — white matter; long, straight processes running parallel to axons.

- ▶ Special forms: **Bergmann glia** (cerebellum, somata in Purkinje layer), **Müller cells** (retina, span its full thickness), **tanycytes** and **pituicytes** (infundibulum/neurohypophysis); **radial glial cells** of early development act as stem cells for neurons and glia and later transform into typical astrocytes.
- ▶ **Astrocytes are absent from the pineal gland and the posterior pituitary.**
- ▶ Functions:
 - Induce and maintain the **blood–brain barrier** — perivascular end-feet completely enwrap capillaries/arterioles and instruct endothelial tight-junction formation.
 - Buffer extracellular K^+ and take up synaptic **glutamate/GABA** via specific transporters, terminating neurotransmission.
 - Interconnected by **gap junctions** into a functional syncytium — exchange Ca^{2+} , ATP, glucose; the only CNS cells that store **glycogen**, converting it to lactate for neuronal use.
 - Form the **glia limitans** at the pial/subpial surface.
 - Guide neuronal migration during development (radial glia).
 - Proliferate after CNS injury to form the **astrocytic (glial) scar** — walls off damage but inhibits axonal regrowth.

3. Oligodendrocytes

- ▶ The CNS counterpart of the **Schwann cell**; myelinate CNS axons. Small cell with a condensed, rounded nucleus and scant, poorly-staining cytoplasm (H&E) due to abundant Golgi.
- ▶ A single oligodendrocyte sends multiple flattened processes, **each wrapping a segment of a different, nearby axon** — **up to ~50 axonal segments per cell** (contrast: one Schwann cell myelinates only **one segment of one axon**). Unlike Schwann cells, oligodendrocytes lay down **no basal lamina**.
- ▶ **Interfascicular oligodendrocytes** lie in rows within white-matter tracts, interspersed with astrocytes; **perineuronal (satellite) oligodendrocytes** lie close to neuronal somata and do not myelinate.
- ▶ Predominant glia of **white matter** (its pale colour reflects myelin lipid).
- ▶ Myelin proteins: **myelin basic protein (MBP)** — marker, present in both CNS/PNS myelin; **proteolipid protein (PLP)/DM20** — CNS-specific; **myelin-associated glycoprotein (MAG)** — common to both.
- ▶ Originate from the ventricular neuroectoderm/subependymal plate; **oligodendrocyte precursor cells (OPCs)** persist and continue to be generated postnatally.

4. Microglia

- ▶ Smallest glial cell — elongated nucleus, scant cytoplasm, several highly branched processes; nearly as numerous as neurons in some CNS regions, evenly distributed in grey and white matter.
- ▶ **Endogenous immune cells/resident macrophages of the CNS** — professional phagocytes that remove apoptotic cells, microbial invaders and debris, and act as antigen-presenting cells.
- ▶ Two functional states:

- **Ramified ("surveying") microglia** — normal brain; soma fixed, fast-moving processes continuously scan the surrounding territory and sense neuronal activity via neurotransmitter receptors.
- **Activated (amoeboid) microglia** — after any pathological insult; processes retract within hours, cells proliferate and phagocytose.
- ▶ Respond to "**on**" **signals** (new/upregulated, e.g. bacterial wall components) and loss of "**off**" **signals** (normally-present cytokines/neurotransmitters that decline in disease).
- ▶ Not interconnected by gap junctions (unlike macroglia); marker **Iba1**.

5. Ependymal cells

- ▶ A simple, single-layered epithelium (cuboidal to columnar) lining the **ventricles** and the **central canal of the spinal cord**; apical **cilia** (drive CSF flow) and **microvilli** (absorption); joined by gap junctions and desmosomes/junctional complexes but characteristically **lack a basal lamina**.
- ▶ Four regional types:
- ▶ **General ependyma over grey matter** — cuboidal, ciliated; underlain by a **subependymal (subventricular) zone** harbouring neural progenitor/stem cells (adult neurogenic niche; significance in humans debated).
- ▶ **General ependyma over white matter** — flatter, few cilia, interdigitating margins; no subependymal zone.
- ▶ **Specialized ependyma of the circumventricular organs** (median eminence, subcommissural/subfornical organs, vascular organ of the lamina terminalis; area postrema analogous) — rarely ciliated; **tanycytes (ependymal astrocytes)** contact **fenestrated capillaries** — **no blood–brain barrier** here, permitting neurohumoral exchange with CSF.
- ▶ **Choroidal epithelium** — highly modified ependyma of the choroid plexus; secretes CSF.

□ Fig 9.9 — Glial cells of the CNS and PNS. (*Junqueira's Basic Histology — Text & Atlas — 17e, p.432*)

6. Peripheral glia — Schwann cells and satellite cells

- ▶ **Schwann cells (neurolemmocytes)** — principal PNS glial cell, **neural-crest-derived**. Myelinate PNS axons; **one Schwann cell myelinates only one internode of a single axon** and deposits a **basal lamina** (both unlike the oligodendrocyte). Non-myelinating Schwann cells ensheath bundles of small unmyelinated axons (Remak bundles). Central to **Wallerian degeneration and peripheral nerve regeneration** — proliferate, clear debris and align into **bands of Büngner** guiding axonal regrowth — the basis of the PNS's superior regenerative capacity versus the CNS.
- ▶ **Satellite (capsular) cells** — small, neural-crest-derived cells capsulating each neuronal cell body in sensory and autonomic ganglia; continuous with the Schwann sheath of the emerging axon. Insulate, nourish and regulate the neuronal microenvironment; share several astrocyte-like properties (glutamine synthetase, gap-junction coupling, ATP receptors) but, unlike astrocytes, **completely surround** each individual neuronal soma in a continuous glial sheath.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw Figure 9.9-style schematic of "Glial cells of the CNS and PNS" and label: (CNS panel) a capillary with astrocyte end-feet, an astrocyte contacting both a synapse and a blood vessel, an oligodendrocyte with multiple processes each myelinating a separate axon segment (show the node of Ranvier), an ependymal cell with apical cilia lining a ventricle, and a microglial cell with fine ramified processes; (PNS panel) a Schwann cell wrapped around a single axon (with its basal lamina) forming one internode, and a satellite (capsular) cell layer encapsulating a ganglion neuron cell body. Annotate embryonic origin beside each cell: macroglia + ependyma = neuroectoderm; microglia = mesoderm; Schwann/satellite = neural crest.

Applied / Clinical anatomy

- ▶ **Gliomas** — because glial cells (unlike mature neurons) retain mitotic capacity, virtually all primary intra-axial CNS tumours are of glial origin: **astrocytoma/glioblastoma** (commonest, GFAP-positive, from fibrous astrocytes), **oligodendroglioma**, **ependymoma** (classically fourth ventricle in children; filum terminale/conus in adults), and rarer **microglioma**.
- ▶ **Gliosis** — reactive proliferation of glia is the CNS's substitute for fibrous scarring; a spontaneous gliosis signals an underlying degenerative process.
- ▶ **Astrocytic (glial) scar** after trauma or infarction seals the lesion but is a major biological barrier to CNS axonal regeneration — in sharp contrast to the PNS, where Schwann-cell-mediated bands of Büngner actively promote axonal regrowth after nerve injury; this asymmetry underlies the poor prognosis of spinal cord injury versus peripheral nerve injury.
- ▶ **Multiple sclerosis** — autoimmune, T-lymphocyte-mediated destruction of CNS myelin/oligodendrocytes; activated microglia phagocytose myelin debris; when oligodendrocyte remyelinating capacity is outstripped, permanent plaques result.
- ▶ **Blood-brain barrier** — formed by astrocytic end-feet plus endothelial tight junctions; physiologically absent at the **circumventricular organs** (e.g. area postrema — the chemoreceptor trigger zone for vomiting) where fenestrated capillaries and tanocytes allow free neurohumoral exchange — exploited/relevant in drug action (e.g. apomorphine, dopamine-antagonist antiemetics) and vulnerable to toxin/pathogen entry.
- ▶ **Alzheimer's disease** — microglial activation around amyloid plaques and reactive (GFAP-positive) astroglia accompany neurofibrillary degeneration.

Recent advances

- ▶ The long-taught **10:1 glia-to-neuron ratio** has been revised: using the isotropic-fractionator cell-counting method, Azevedo et al. (*J Comp Neurol*, 2009) showed the adult human brain contains roughly **equal numbers of neurons and glial cells (~86 billion each)** — the human brain is an isometrically scaled-up primate brain, not glia-dominant as classically taught.
- ▶ **WHO CNS5 (2021)** reclassified diffuse gliomas by integrating **molecular markers** (IDH-mutation status, 1p/19q co-deletion) with histology — astrocytoma and oligodendroglioma are now defined genetically rather than purely morphologically, directly updating the classical glial-cell-type-based tumour nomenclature taught in anatomy.

- ▶ **Oligodendrocyte precursor cells (NG2-glia)** are now recognised as a distinct, proliferative "fifth" CNS glial population persisting throughout adult life, generating new oligodendrocytes for adaptive myelination and **remyelination** — the Phase 2 CCMR-Two trial (2025) (metformin + clemastine) provided the first clinical evidence that pharmacologically driven remyelination is achievable in relapsing multiple sclerosis.
- ▶ The **glymphatic system** — perivascular polarisation of the water channel **aquaporin-4 (AQP4)** on astrocytic end-feet — has been shown to drive CSF–interstitial fluid exchange and clearance of metabolic waste (including amyloid- β), extending the classical "supportive" role of astrocytes into CNS waste clearance and implicating astrocyte dysfunction in neurodegeneration.
- ▶ A 2025 study (*Cell*) defined a precise **microglia–astrocyte "two-step" mechanism of synaptic pruning**: neuron-to-microglia fractalkine signalling triggers microglial Wnt-ligand release, which causes astrocytes to retract from synapses before microglia engulf them — refining the classical view of microglia as passive CNS "housekeeper" cells into active partners in synaptic remodelling.
- ▶ (*According to PubMed/journal search.*)

High-yield exam pointers

- ▶ **Six types of neuroglia**: CNS — astrocytes, oligodendrocytes, ependymal cells, microglia; PNS — Schwann cells, satellite (capsular) cells.
- ▶ **Origin**: macroglia (astrocytes, oligodendrocytes, ependyma) = **neuroectoderm** (spongioblasts); microglia = **mesoderm** (yolk-sac monocyte precursors); Schwann + satellite cells = **neural crest**.
- ▶ Astrocytes: **protoplasmic** (grey matter) vs **fibrous** (white matter); GFAP marker; form BBB, buffer K^+ /glutamate, absent from pineal gland and posterior pituitary; form the glial scar (astrogliosis).
- ▶ One **oligodendrocyte** myelinates up to **50 CNS axon segments**; one **Schwann cell** myelinates only **one PNS axon segment** and (unlike the oligodendrocyte) lays down a basal lamina.
- ▶ **Microglia** = CNS resident macrophage (mesodermal origin); ramified (surveying) $\leftrightarrow$ amoeboid (activated) states; activated in MS, Alzheimer's disease, stroke.
- ▶ **Ependymal cells**: 4 regional types; subependymal/subventricular zone = adult neurogenic niche; tanycytes of circumventricular organs sit on fenestrated capillaries with **no BBB**; choroidal epithelium secretes CSF.
- ▶ **Satellite cells** encapsulate ganglion neuronal somata; functionally resemble astrocytes but do not form a barrier.
- ▶ Glial cells (unlike neurons) remain mitotically active $\rightarrow$ **gliomas** are the commonest primary CNS tumours; gliosis is the CNS equivalent of scarring.
- ▶ **Astrocytic scar blocks CNS axon regeneration**; Schwann-cell bands of Büngner enable PNS axon regeneration — the key applied contrast.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Junqueira's Basic Histology (Text & Atlas) 17e; Snell's Clinical Neuroanatomy 7e; Vishram Singh's Clinical Neuroanatomy 4e; IB Singh's Textbook of Human Neuroanatomy; BD Chaurasia's Human Anatomy Vol 3-4 8e; Sontakke's Textbook of Human Histology 2e; Ross Histology — A Text and Atlas 7e. Recent-advances section per PubMed/journal search (see citations above).



Hepato renal pouch

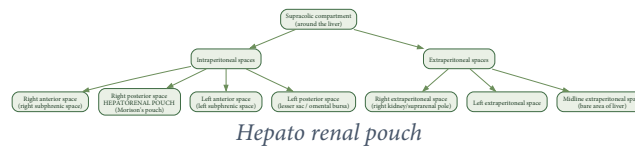
Asked in: Paper IV Apr 2008 — RGUHS MD/MS Anatomy

Definition / Introduction The hepatorenal pouch — also called the **right subhepatic space** or the **pouch (recess) of Morison** — is a peritoneal recess of the supracolic (perihepatic) compartment of the greater sac of the peritoneal cavity. It lies between the inferior (visceral) surface of the right lobe of the liver above and the anterior surface of the upper pole of the right kidney and right suprarenal gland below. Together with the pelvic pouch (rectouterine/rectovesical pouch), it is one of the two most dependent parts of the peritoneal cavity — the hepatorenal pouch being the most dependent point *above* the pelvic brim when the body is supine — which makes it the classical site for the gravitational pooling of blood, bile, pus or ascitic fluid in the upper abdomen. The eponym honours **James Rutherford Morison (1853–1939)**, Professor of Surgery at Durham, UK.

Peritoneal compartments and location

- ▶ The peritoneal cavity is divided by the **transverse colon and transverse mesocolon** into a **supracolic compartment** (liver, stomach, spleen) and an **infracolic compartment** (small and large intestine).
- ▶ The supracolic compartment around the liver is further subdivided into a set of **perihepatic (subphrenic) spaces** — two intraperitoneal spaces (anterior and posterior) and one extraperitoneal space on each side, plus a midline extraperitoneal space corresponding to the bare area of the liver:
 - **Right anterior (right subphrenic) space** — between the liver and the diaphragm, in front of the coronary and right triangular ligaments.
 - **Right posterior space — the hepatorenal pouch (Morison's pouch)** — the space under discussion.
 - **Left anterior (left subphrenic) space** — between the left lobe of the liver, stomach and diaphragm.
 - **Left posterior space** — this is simply the **lesser sac (omental bursa)**.
 - **Right and left extraperitoneal spaces** — around the upper poles of the right and left kidneys/suprarenal glands respectively.
 - **Midline extraperitoneal space** — corresponds to the **bare area of the liver**, between the two layers of the coronary ligament.

- The hepatorenal pouch is therefore the **right posterior intraperitoneal (perihepatic) space**, lying posterior to the liver and continuous below with the general peritoneal cavity.



- Peritoneal fluid tends to circulate in a predominantly **clockwise** direction around the supracolic and infracolic compartments; this movement explains why infected fluid, bile, blood or malignant cells arising anywhere in the abdomen or pelvis tend to be carried up the **right paracolic gutter** and collect in the hepatorenal pouch.

Boundaries

Boundary	Structure(s)
Roof / anterior	Inferior (visceral) surface of the right lobe of the liver; the gallbladder lies anterior to the pouch
Superior limit	Inferior (posterior) layer of the right coronary ligament
Floor / posterior	Peritoneum covering the anterior surface of the upper pole of the right kidney and the right suprarenal gland , continuing on to the diaphragm
Inferomedial	Hepatic (right colic) flexure of the colon, the transverse mesocolon , the second (descending) part of the duodenum , and part of the head of the pancreas
Right (lateral)	Right lateral abdominal wall, deep to the diaphragm
Left	Communicates through the epiploic foramen (of Winslow) with the lesser sac (omental bursa)
Inferior (open end)	Freely continuous with the general peritoneal cavity and the right paracolic gutter

□ Fig 18.28 — Hepatorenal pouch (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.313)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A sagittal section through the right upper abdomen showing the hepatorenal pouch, labelled with:

- ▶ **Liver** (inferior/visceral surface) — forming the roof
- ▶ **Gallbladder** — anterior relation
- ▶ **Right kidney (upper pole) and right suprarenal gland** — posterior/floor
- ▶ **Diaphragm** — posterosuperior
- ▶ **Inferior layer of the coronary ligament** — superior limit
- ▶ **Second part of the duodenum, hepatic flexure of colon, transverse mesocolon, head of pancreas** — inferomedial boundary
- ▶ **Epiploic foramen (of Winslow)** — communication to the lesser sac, on the left
- ▶ **Right paracolic gutter** — inferior communication to the general peritoneal cavity
- ▶ The recess itself labelled "**Hepatorenal pouch (Morison's pouch)**"

Communications

- ▶ **Left:** through the **epiploic foramen (of Winslow)**, the pouch communicates with the **lesser sac (omental bursa)**; a collection in the lesser sac (e.g. pancreatitis) can therefore track into the hepatorenal pouch.
- ▶ **Along the sharp inferior border of the liver:** the pouch communicates with the **right anterior intraperitoneal (subphrenic) space**; however, adhesions that commonly form between the transverse colon/greater omentum and the inferior border of the liver tend to wall off this communication, which is why an abscess forming in one perihepatic space often stays localised rather than spreading freely to the other.
- ▶ **Below:** it opens freely into the **right paracolic gutter** and thence into the general peritoneal cavity and pelvis — the **right paracolic gutter** is deeper than the left and lacks an obstructing fold (the left has the phrenicocolic ligament), so it conducts fluid from the pelvis and right iliac fossa upward into the hepatorenal pouch particularly efficiently.

Peritoneal fluid dynamics and clinical dependency

- ▶ In the **supine** position, the hepatorenal pouch is the most dependent part of the peritoneal cavity **above the pelvic brim** — more dependent even than the right paracolic gutter — because the liver "roofs" it against the posterior abdominal wall.
- ▶ In the **erect/sitting** position, gravity instead directs fluid down into the pelvic pouch (rectouterine pouch of Douglas in females; rectovesical pouch in males), which becomes the overall most dependent part of the peritoneal cavity.
- ▶ This dual dependency (hepatorenal pouch when supine; pelvic pouch when erect) is why patients nursed supine after abdominal surgery are prone to right subphrenic collections, while ambulant/sitting patients localise infection to the pelvis instead.

Applied / Clinical anatomy

- ▶ **Commonest site of subphrenic abscess:** because it is the most dependent recess of the upper abdomen in a supine patient, the hepatorenal pouch is the single commonest site for a subphrenic abscess to form.
- ▶ **Sources of infection/fluid:** perforated acute appendicitis (tracking up the right paracolic gutter), perforated duodenal or gastric ulcer, a ruptured or gangrenous gallbladder, bile leakage after cholecystectomy, a ruptured pyogenic liver abscess, and lesser-sac collections (e.g. from acute pancreatitis) reaching the pouch through the epiploic foramen.
- ▶ **Difficulty of diagnosis:** subphrenic abscess is notoriously silent, giving rise to the classical surgical aphorism — *"pus somewhere, pus nowhere, pus under the diaphragm."*
- ▶ **Compartmentalisation:** adhesions between the greater omentum/transverse colon and the sharp inferior liver border usually prevent an abscess in the hepatorenal pouch from spreading around the liver into the right anterior (subphrenic) space, keeping the collection localised and easier to drain surgically once located.
- ▶ **Imaging:** ultrasound and CT are the investigations of choice for a suspected right subphrenic/subhepatic collection; being the most dependent recess of the upper abdomen in the supine position, the hepatorenal pouch is also the classical site interrogated for free intraperitoneal fluid/haemoperitoneum on point-of-care abdominal ultrasound (e.g. the "FAST" trauma protocol) after blunt abdominal trauma.
- ▶ **Rupture into the pouch:** an inflamed, distended gallbladder or a perforated second part of the duodenum, both of which directly abut its anterior/inferomedial boundary, may rupture into the hepatorenal pouch.
- ▶ **Surgical relevance:** the pouch is inspected as a standard step during laparoscopic cholecystectomy and laparotomy for suspected right upper quadrant sepsis, since it is the natural collecting point for bile, blood or exudate in that region.

High-yield exam pointers

- ▶ Hepatorenal pouch = **right subhepatic space** = **pouch/recess of Morison**; named after **James Rutherford Morison** (Professor of Surgery, Durham, UK).
- ▶ It is the **right posterior intraperitoneal (perihepatic) space** of the supracolic compartment — contrast with the **left posterior space**, which is simply the **lesser sac**.
- ▶ **Boundaries:** roof — visceral surface of liver (+ gallbladder anteriorly); floor/posterior — upper pole of right kidney + suprarenal gland; superior limit — inferior layer of coronary ligament; inferomedial — hepatic flexure, transverse mesocolon, 2nd part of duodenum, head of pancreas; left — epiploic foramen to lesser sac; inferior — open to right paracolic gutter.
- ▶ **Most dependent part of the peritoneal cavity above the pelvic brim in the supine position** (the pelvic pouch is most dependent when erect).
- ▶ **Commonest site of subphrenic abscess** — aphorism: *"pus somewhere, pus nowhere, pus under the diaphragm."*
- ▶ Communicates with the lesser sac via the epiploic foramen (left) and with the right paracolic gutter (below); communication with the right anterior subphrenic space along the liver's inferior border is often blocked by adhesions.

- Clinically interrogated on ultrasound (including FAST scanning in trauma) as the classic site for free fluid/blood/pus collection in the right upper abdomen.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2, 8e; Vishram Singh — Textbook of Anatomy Vol 2, 4e; IB Singh — Textbook of Anatomy Vol 2, 6e; AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen).



Inferior constrictor muscle of pharynx

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction — The inferior constrictor is the lowest and thickest of the three constrictor muscles that form the muscular coat of the pharyngeal wall. It is described in **two functionally distinct parts** — the upper, propulsive **thyropharyngeus** and the lower, sphincteric **cricopharyngeus** — the latter forming the principal component of the upper oesophageal (pharyngo-oesophageal) sphincter. The pharynx becomes continuous with the oesophagus at the lower border of cricopharyngeus, at the level of the **sixth cervical vertebra** (lower border of the cricoid cartilage). Its two-nerve, two-function design is the anatomical basis of Killian's dehiscence and Zenker's (pharyngeal pulsion) diverticulum, making this a high-yield gross-and-applied anatomy topic.

1. Origin (attachments)

Part	Origin
Thyropharyngeus	Oblique line on the lamina of the thyroid cartilage (including the inferior tubercle), a strip of the lamina behind this line, and a small slip from the inferior cornu of the thyroid cartilage; additional fibres arise from a tendinous band/arch that loops over the cricothyroid muscle, attached above to the inferior (thyroid) tubercle
Cricopharyngeus	Side of the cricoid cartilage, between the origin of cricothyroid and the articular facet for the inferior thyroid cornu

- Cricopharyngeus is further described as having a superficial, upper **pars obliqua** (oblique fibres) and a deeper, lower **pars fundiformis** (transverse, circular fibres) — the interval between the two is **Killian's dehiscence/triangle** (see Applied anatomy).
- Together with the other constrictors, the inferior constrictor develops from **4th (and, via cricopharyngeus, overlapping 6th) pharyngeal arch mesoderm**.

2. Insertion

- **Thyropharyngeus** fibres pass obliquely upwards and backwards to insert into the **median pharyngeal raphe**; its upper fibres ascend to overlap the middle constrictor.

- **Cricopharyngeus** fibres run horizontally, encircle the upper end of the oesophagus, and are **continuous with the corresponding fibres of the opposite side without a median raphe** — merging with the circular muscle coat of the oesophagus at the narrowest part of the pharynx.
- General constrictor arrangement: **inferior overlaps middle, which overlaps superior**; the lower border of the inferior constrictor is continuous with the circular muscle of the oesophagus.

□ Fig 14.10 — Origin and insertion of constrictors of the pharynx (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.614)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A lateral schematic of the three constrictors (as above) — label: **superior constrictor** (pterygoid hamulus/pterygomandibular raphe origin), **middle constrictor**, **inferior constrictor** split into **thyropharyngeus** (upper, oblique) and **cricopharyngeus** (lower, transverse), **median pharyngeal raphe**, **oesophagus** continuing below, and the three nerves running down over the constrictors — **glossopharyngeal nerve** (between superior/middle), **internal laryngeal nerve** (between middle/inferior), **external laryngeal nerve** (crossing the surface of, then piercing, the inferior constrictor to reach cricothyroid), and **recurrent laryngeal nerve** (ascending deep to the lower border of the inferior constrictor).

3. Relations

Aspect	Structures
External	Buccopharyngeal fascia
Posterior	Prevertebral fascia and muscles (longus colli, longus capitis), separated from the pharynx by the retropharyngeal space
Lateral	Thyroid gland, common carotid artery, sternothyroid
Internal	Middle constrictor, stylopharyngeus, palatopharyngeus, pharyngobasilar fascia

- **Internal laryngeal nerve** and the **laryngeal branch of the superior thyroid artery** pierce the thyrohyoid membrane in the **gap between the middle and inferior constrictors**.
- **External laryngeal nerve** descends on the superficial (external) surface of the inferior constrictor, just behind its thyroid attachment, and **pierces its lower part** before curving round the inferior thyroid tubercle to supply cricothyroid.
- **Recurrent laryngeal nerve** and the **laryngeal branch of the inferior thyroid artery** ascend **deep to the lower border of the inferior constrictor**, in the tracheo-oesophageal groove, to enter the larynx behind the cricothyroid joint.
- Beneath the mucosa of the **piriform fossa** (lateral to the laryngeal inlet, bounded medially by the aryepiglottic fold and laterally by the thyroid cartilage/thyrohyoid membrane) lies the internal laryngeal nerve — instrumentation for an impacted foreign body here risks nerve injury.

4. Nerve supply

- ▶ **Motor:** both parts are supplied via the **pharyngeal plexus** (pharyngeal branch of the vagus, classically described as carrying fibres of the cranial root of the accessory nerve — though contemporary evidence increasingly attributes this motor supply directly to the vagus/nucleus ambiguus rather than a true accessory contribution).
- ▶ **Additional supply:** the inferior constrictor uniquely receives extra branches beyond the pharyngeal plexus —
 - **Thyropharyngeus** — an additional twig from the **external laryngeal nerve**.
 - **Cricopharyngeus** — an additional twig from the **recurrent laryngeal nerve** (and, per some descriptions, the external branch of the superior laryngeal nerve).
- ▶ This **dual/differential innervation of the two parts** (pharyngeal plexus-driven propulsive thyropharyngeus vs recurrent-laryngeal-driven sphincteric cricopharyngeus) is the physiological basis of neuromuscular incoordination and pulsion-diverticulum formation.
- ▶ **Sensory** supply to the pharynx overall is mainly via the glossopharyngeal nerve, with a vagal contribution.

5. Blood supply

- ▶ **Arterial:** pharyngeal branch of the **ascending pharyngeal artery** (external carotid branch) and muscular branches of the **inferior thyroid artery**.
- ▶ **Venous:** drains via the pharyngeal venous plexus on the posterolateral pharyngeal wall into the **internal jugular** and **facial veins**.
- ▶ **Lymphatic:** to the retropharyngeal and deep cervical lymph nodes.

6. Actions and physiological role in deglutition

- ▶ All three constrictors contract **reflexly and sequentially** (**superior** → **middle** → **inferior**) during swallowing, producing a peristaltic wave that drives the bolus caudally.
- ▶ **Thyropharyngeus is propulsive**, actively squeezing the bolus downward; **cricopharyngeus is sphincteric** — tonically contracted at rest and relaxing only during swallowing, thereby keeping the pharyngo-oesophageal junction closed between swallows (preventing air entry into the oesophagus and reflux of oesophageal contents into the pharynx).
- ▶ **Reciprocal action:** as thyropharyngeus contracts, cricopharyngeus relaxes, and vice versa. Failure of this coordination (cricopharyngeus failing to relax as thyropharyngeus contracts) raises intraluminal pressure at the weak zone between them and predisposes to a pulsion (Zenker's) diverticulum.
- ▶ Cricopharyngeus, together with thyropharyngeus and the proximal cervical oesophageal musculature, constitutes the **upper oesophageal sphincter (pharyngo-oesophageal high-pressure zone)** — manometrically a 2–4 cm zone of elevated pressure at the hypopharynx–cervical-oesophagus junction; cricopharyngeus itself always participates in closure, whereas the contribution of thyropharyngeus/proximal oesophagus varies with physiological state.

Applied / Clinical anatomy

- ▶ **Killian's dehiscence (Killian's triangle/"pharyngeal dimple")** — a potential gap in the posterior pharyngeal wall between the upper oblique fibres of the inferior constrictor (thyropharyngeus/pars obliqua of cricopharyngeus) and the lower transverse/circular fibres (pars fundiformis of cricopharyngeus). It is the **commonest site of a pharyngeal pouch**.
- ▶ **Pharyngeal pouch / Zenker's diverticulum** — a **pulsion diverticulum** of mucosa and submucosa herniating through Killian's dehiscence, attributed to neuromuscular incoordination between the differently-innervated thyropharyngeus (pharyngeal plexus) and cricopharyngeus (recurrent laryngeal nerve). It typically enlarges dorsal to, and usually to the **left of**, the oesophagus at the level of C6, and presents with **dysphagia**, regurgitation of old food, halitosis, and risk of aspiration pneumonia. Treatment involves excision/inversion of the pouch combined with division of the circular fibres of cricopharyngeus (cricopharyngeal myotomy) to relieve the high-pressure zone and prevent recurrence.
- ▶ **Laimer's triangle** — a second, less common site of weakness immediately *below* cricopharyngeus, where the longitudinal (outer) muscle fibres of the oesophagus diverge laterally to the cricoid cartilage, leaving only circular muscle in the wall; diverticula here are rarer and usually lateral rather than midline.
- ▶ **Surgical/instrumentation risk to nerves related to the inferior constrictor:**
 - **External laryngeal nerve**, applied to the surface of the muscle near the superior thyroid pedicle, is vulnerable during **thyroidectomy** ligation of the superior thyroid vessels — injury produces a weak, easily-fatigued voice (cricothyroid paralysis).
 - **Recurrent laryngeal nerve**, ascending deep to the lower border of the inferior constrictor close to the thyroid gland, is likewise at risk during thyroid/parathyroid surgery — injury causes vocal cord paralysis and hoarseness/aspiration.
 - **Internal laryngeal nerve**, deep to the piriform fossa mucosa, may be damaged during endoscopic removal of an impacted foreign body from the fossa, producing supraglottic laryngeal anaesthesia and predisposing to aspiration.
- ▶ **Radiological correlation:** a barium swallow outlines a Zenker's pouch as a posterior midline (or left-sided) outpouching at the C5–C6 level, often with barium pooling and delayed emptying; endoscopic per-oral or open surgical myotomy of cricopharyngeus is the definitive treatment principle.

□ Fig 14.11 — Killian's dehiscence (Vishram Singh — *Textbook of Anatomy Vol 3 — 4e*, p.616)

High-yield exam pointers

- ▶ Inferior constrictor = **thickest** constrictor; two parts — **thyropharyngeus** (from thyroid cartilage, propulsive) and **cricopharyngeus** (from cricoid cartilage, sphincteric/upper oesophageal sphincter).
- ▶ **Nerve supply:** pharyngeal plexus (vagus) for both parts; **additionally**, thyropharyngeus via **external laryngeal nerve**, cricopharyngeus via **recurrent laryngeal nerve**.
- ▶ **Killian's dehiscence** = gap between thyropharyngeus and cricopharyngeus (oblique vs transverse fibres) → site of **Zenker's/pharyngeal pulsion diverticulum**, usually to the left, at C6.

- ▶ **Laimer's triangle** = weak area below cricopharyngeus, between diverging longitudinal oesophageal fibres.
- ▶ Gaps and their contents: superior constrictor–skull base (sinus of Morgagni) = auditory tube, levator veli palatini, ascending palatine artery; superior–middle constrictor = stylopharyngeus, glossopharyngeal nerve; **middle–inferior constrictor = internal laryngeal nerve + superior laryngeal vessels**; below inferior constrictor = **recurrent laryngeal nerve + inferior laryngeal vessels**.
- ▶ Pharynx becomes oesophagus at the **lower border of cricopharyngeus, C6 level**.
- ▶ Lateral relations of the inferior constrictor: **thyroid gland and common carotid artery** — clinically important during thyroid surgery (external and recurrent laryngeal nerve injury).
- ▶ Reciprocal thyropharyngeus–cricopharyngeus action underlies both normal deglutition and the pathogenesis of pharyngeal diverticula.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3-4 8e; Vishram Singh's Textbook of Anatomy Vol 3 4e; AK Datta's Human Anatomy Vol 2 (Head & Neck); IB Singh's Textbook of Anatomy Vol 3 6e; Langman's Medical Embryology (Sadler) 14e (pharyngeal arch derivation).



Inguinal canal and its applied anatomy

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction The inguinal canal is an oblique intermuscular passage in the lower part of the anterior abdominal wall, lying above and parallel to the medial half of the inguinal ligament. It develops as the pathway of descent of the testis (and its coverings) from the posterior abdominal wall into the scrotum, guided by the gubernaculum and preceded by an evagination of peritoneum, the processus vaginalis. In the male it transmits the spermatic cord; in the female, the round ligament of the uterus. Because the canal traverses the full thickness of an otherwise strong abdominal wall, it is the single most important site of herniation in the body — inguinal hernias account for about 75% of all abdominal wall hernias — which makes its anatomy of major surgical importance.

1. Location, extent and surface marking

Feature	Description
Position	Above and parallel to the medial half of the inguinal ligament
Length	About 4 cm (adult range 3–6 cm, Gray's)
Direction	Downward, forward and medially
Extent	From the deep inguinal ring to the superficial inguinal ring

Feature	Description
Surface marking	Two parallel lines, 1 cm apart and 4 cm long, just above the medial half of the inguinal ligament
Deep ring marking	1.25 cm above the mid-inguinal point (mid-point between the anterior superior iliac spine and the pubic symphysis), at the lateral end of the two lines
Superficial ring marking	Just above and lateral to the pubic tubercle/crest, at the medial end of the two lines
Sex difference	Larger and more oblique in the male than the female

2. Inguinal rings — deep and superficial

	Deep inguinal ring	Superficial inguinal ring
Site	Oval opening in the fascia transversalis, 1.25 cm above the mid-inguinal point	Triangular gap in the aponeurosis of external oblique, above and lateral to the pubic crest
Relations	Inferior epigastric vessels lie immediately medial to it	Pubic crest forms the base; medial and lateral crura (external oblique fibres) united by intercrural fibres at the apex
Fascial prolongation	Fascia transversalis is carried onward as the internal spermatic fascia	External oblique fibres continue onto the cord as the external spermatic fascia
Size	—	About 2.5 cm long, 1.2 cm broad at the base
Structures through it	Spermatic cord (ductus deferens + vessels), or round ligament of uterus; genital branch of genitofemoral nerve; obliterated processus vaginalis	Spermatic cord/round ligament of uterus; ilioinguinal nerve (which pierces the wall of the canal and does not pass through the deep ring)

3. Boundaries of the inguinal canal

Wall	Formed by (superficial/deep to deep/superficial)
Anterior wall	Skin, superficial fascia and external oblique aponeurosis throughout; reinforced by internal oblique fibres in the lateral one-third
Posterior wall	Fascia transversalis throughout; reinforced by the conjoint tendon in the medial two-thirds and by the reflected part of the inguinal ligament medially
Roof	Arched lowest fibres of internal oblique and transversus abdominis

Wall	Formed by (superficial/deep to deep/superficial)
Floor	Grooved upper surface of the inguinal ligament throughout; the lacunar ligament reinforces the medial end

□ Fig 4.5 — Boundaries of the inguinal canal: (A) anterior and posterior walls in coronal section, (B) roof and floor in sagittal section (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.202)

4. Contents of the inguinal canal

- ▶ **Male:** spermatic cord and ilioinguinal nerve.
- ▶ **Female:** round ligament of the uterus and ilioinguinal nerve.
- ▶ The ilioinguinal nerve, although a content of the canal, enters through a slit between the internal and external oblique muscles (not through the deep ring); it runs in front of the cord and leaves through the superficial ring to supply the inguinal skin.

5. Spermatic cord — constituents and coverings

Group	Constituents
Ducts	Ductus (vas) deferens — lies in the posterior part of the cord
Arteries (3)	Testicular artery (from abdominal aorta); cremasteric artery (from inferior epigastric artery); artery to the ductus deferens (from inferior vesical artery)
Veins	Pampiniform venous plexus
Nerves (3)	Genital branch of the genitofemoral nerve; cremasteric nerve; sympathetic fibres accompanying the arteries
Others	Lymphatics (from testis to para-aortic nodes; from coverings to external iliac nodes); remnant of the processus vaginalis

Coverings, from within outward, mirror the layers of the canal wall through which the cord descends:

- ▶ **Internal spermatic fascia** — derived from the fascia transversalis (at the deep ring).
- ▶ **Cremasteric fascia** — loops of striated (cremaster) muscle in areolar tissue, derived from internal oblique.
- ▶ **External spermatic fascia** — derived from the external oblique aponeurosis (at the superficial ring).

6. Mechanisms maintaining the integrity of the inguinal canal

- ▶ **Flap-valve mechanism** — obliquity of the canal means the two rings do not lie opposite each other; raised intra-abdominal pressure approximates the anterior and posterior walls like a flap.
- ▶ **Guarding of the rings** — deep ring guarded anteriorly by internal oblique; superficial ring guarded posteriorly by the conjoint tendon and reflected part of the inguinal ligament.

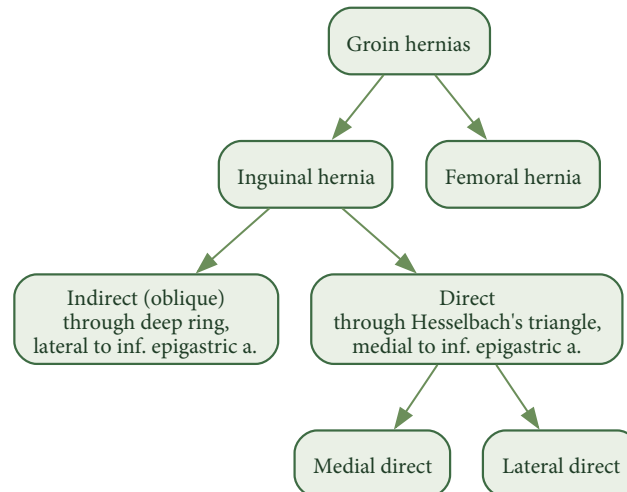
- **Shutter mechanism** — internal oblique arches over the canal (anterior wall, roof, posterior wall); its contraction pulls the roof down onto the floor like a shutter.
- **Slit-valve mechanism** — contraction of external oblique approximates the medial and lateral crura of the superficial ring, aided by the intercrural fibres.
- **Ball-valve mechanism** — cremaster contraction pulls the testis up and plugs the superficial ring with the cord.

The **interfoveolar ligament** (arching fibres of transversus abdominis to the superior pubic ramus) additionally strengthens the fascia transversalis at the medial edge of the deep ring.

7. Inguinal (Hesselbach's) triangle

Boundary	Structure
Medial	Lateral border of rectus abdominis (lower ~5 cm)
Lateral	Inferior epigastric artery
Base/inferior	Inguinal ligament
Floor	Peritoneum, extraperitoneal tissue and fascia transversalis

The obliterated umbilical artery (medial umbilical ligament) crosses the floor of the triangle, dividing it into medial and lateral parts; the medial part is reinforced by the conjoint tendon, while the lateral part is weak and is the usual site of a direct inguinal hernia.



Inguinal canal and its applied anatomy

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw an oblique canal above the medial half of the inguinal ligament with a coronal-section inset. Label: skin, superficial fascia, external oblique aponeurosis (anterior wall), internal oblique fibres (lateral 1/3 of anterior wall and roof), transversus abdominis (roof), fascia transversalis (posterior wall), conjoint tendon (medial 2/3 of posterior wall), reflected part of inguinal ligament (medial-most posterior wall), inguinal ligament and lacunar ligament (floor), deep inguinal ring with inferior epigastric vessels medial to it, superficial inguinal ring with medial and lateral crura, spermatic cord/round ligament of uterus. In a second small sketch, mark Hesselbach's triangle (rectus abdominis medially, inferior epigastric artery laterally, inguinal ligament as base) with the obliterated umbilical artery bisecting it.

Applied / Clinical anatomy

Inguinal hernia is protrusion of a peritoneal sac (containing bowel loop, omentum, or, rarely, a Meckel's diverticulum — *Littre's hernia*) through the inguinal canal.

Feature	Indirect (oblique) hernia	Direct hernia
Cause	Congenital defect (patent/partially patent processus vaginalis) or acquired	Acquired weakness of the posterior wall
Site of entry	Deep inguinal ring, lateral to inferior epigastric vessels	Hesselbach's triangle, medial to inferior epigastric vessels
Shape	Pear-shaped	Globular
Course	Oblique, may reach scrotum (complete/vaginal type) or stay confined to the canal (incomplete/bubonocoele)	Straight, rarely scrotal
Neck of sac	Narrow	Wide
Reducibility	Sometimes irreducible	Usually easily reducible
Age	Children and young adults	Older men
Internal ring occlusion test	Positive (hernia stays reduced)	Negative (hernia reappears)

Coverings of both types are essentially the same (extraperitoneal tissue, internal spermatic fascia/fascia transversalis, cremasteric fascia/conjoint tendon, external spermatic fascia, skin); in a direct hernia the internal spermatic fascia is replaced by fascia transversalis, and the cremasteric fascia by the conjoint tendon (medial direct) or is retained (lateral direct).

Inguinal vs femoral hernia: inguinal hernia is commoner overall and lies above and medial to the pubic tubercle; femoral hernia protrudes below and lateral to the pubic tubercle through the femoral canal, is commoner in females, and — because the femoral ring is rigid — is more prone to strangulation and is easily missed clinically, particularly in the obese.

Canal of Nuck — persistence of the processus vaginalis along the round ligament in the female, analogous to a congenital indirect hernial sac, and the basis of encysted hydrocele of the canal of Nuck.

Surgical/imaging correlates: on the posterior (laparoscopic) view, the iliopubic tract — not the inguinal ligament — is the visible landmark; Fruchaud's concept of a single myopectineal orifice (bounded by the rectus sheath medially, iliopsoas fascia laterally, and the inguinal ligament/iliopubic tract inferiorly) through which indirect, direct and femoral hernias all emerge underlies transabdominal preperitoneal (TAPP) and totally extraperitoneal (TEP) mesh repairs, which cover the whole orifice rather than a single defect. Clinical differentiation of direct from indirect hernia by examination alone has been shown to be unreliable, which is why the type is usually confirmed only at operation or on imaging.

High-yield exam pointers

- ▶ Inguinal canal: ~4 cm, oblique, deep ring (fascia transversalis) to superficial ring (external oblique aponeurosis).
- ▶ Deep ring is 1.25 cm above the mid-inguinal point, just lateral to the inferior epigastric artery.
- ▶ Anterior wall strongest laterally (external oblique + internal oblique); posterior wall strongest medially (conjoint tendon) — the two rings are never both weak at the same point.
- ▶ All contents of the canal lie within the spermatic cord **except** the ilioinguinal nerve.
- ▶ Coverings of the cord = coverings of an indirect hernia: internal spermatic fascia, cremasteric fascia, external spermatic fascia.
- ▶ Hesselbach's triangle: rectus abdominis (medial), inferior epigastric artery (lateral), inguinal ligament (base) — site of the direct hernia.
- ▶ Indirect hernia — lateral to inferior epigastric vessels, through the deep ring, pear-shaped, common in the young; Direct hernia — medial to the vessels, through Hesselbach's triangle, globular, common in the elderly.
- ▶ Five mechanisms guard the canal: flap-valve, ring-guarding, shutter, slit-valve and ball-valve.
- ▶ Femoral hernia lies below/lateral to the pubic tubercle and is commoner in women; inguinal hernia lies above/medial to it.

SOURCE & COVERAGE

Vishram Singh — Textbook of Anatomy Vol 2 (4e); BD Chaurasia — Human Anatomy Vol 2 (8e); AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen); Gray's Anatomy (Standing) 41e.



Inguinal hernia

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction. An **inguinal hernia** is the protrusion of abdominal viscera (commonly a loop of small intestine or omentum) through the **inguinal canal**, a 4 cm oblique intermuscular passage in the lower anterior abdominal wall that transmits the spermatic cord in the male and the round ligament of the uterus in the female. Because the canal is a natural site of weakness created by the descent of the testis in fetal life, it is the commonest site of herniation in the body and occurs exclusively in humans as a consequence of the erect posture. Inguinal hernias are of two anatomically distinct types — **indirect (oblique)** and **direct** — distinguished by their site of origin relative to the deep inguinal ring, the inferior epigastric vessels, and Hesselbach's triangle. A thorough grasp of the canal's boundaries, rings, coverings and the mechanisms that normally guard it is essential to understand hernia formation, clinical differentiation and surgical repair.

1. Inguinal canal — extent, direction and boundaries

- Lies above and parallel to the medial half of the **inguinal ligament**; extends from the **deep inguinal ring** (an oval opening in the fascia transversalis) to the **superficial inguinal ring** (a triangular gap in the external oblique aponeurosis); directed **downward, forward and medially**.
- About **4 cm long**; larger in the male.
- Surface marking: two parallel lines 1 cm apart and 4 cm long, just above the medial half of the inguinal ligament.

Wall	Formed by (superficial → deep, or as stated)
Anterior wall	Skin, superficial fascia (whole extent) + external oblique aponeurosis (whole extent) + internal oblique fibres (lateral one-third)
Posterior wall	Fascia transversalis (whole extent) + conjoint tendon (medial two-thirds) + reflected part of inguinal ligament (medial-most part)
Roof	Arched lower fibres of internal oblique and transversus abdominis
Floor	Grooved upper surface of the inguinal ligament (whole extent) + lacunar ligament (medial end)

- **Contents:** spermatic cord and ilioinguinal nerve (male); round ligament of the uterus and ilioinguinal nerve (female). *Note: the ilioinguinal nerve is a content of the canal but enters through a slit between external and internal oblique — not through the deep ring — and is therefore not enclosed within the fascial coverings of the cord itself.*

2. Inguinal rings and Hesselbach's (inguinal) triangle

- **Deep inguinal ring:** an oval opening in the fascia transversalis, about **1.25 cm above the mid-inguinal point** (the midpoint between the ASIS and pubic symphysis — not the midpoint of the inguinal ligament, a frequent exam confusion). The **inferior epigastric artery** lies just medial to it. Fascia transversalis is prolonged from its margins as the internal spermatic fascia.

- ▶ **Superficial inguinal ring:** a triangular gap in the external oblique aponeurosis above and lateral to the pubic crest; base = pubic crest; sides = medial and lateral **crura**, united laterally by **intercrural fibres**; about 2.5 cm long and 1.2 cm broad.
- ▶ **Hesselbach's (inguinal) triangle** — an important clinical landmark, best appreciated from within the abdomen:

Boundary	Structure
Medial	Lower 5 cm of the lateral border of rectus abdominis
Lateral	Inferior epigastric artery
Inferior (base)	Medial half of the inguinal ligament
Floor	Peritoneum, extraperitoneal tissue, fascia transversalis

- ▶ The **obliterated umbilical artery** (medial umbilical ligament) crosses the triangle, dividing it into medial and lateral parts; the medial part's floor is reinforced by the conjoint tendon, while the **lateral part is weak** — the usual site of a direct hernia.

3. Spermatic cord — contents and coverings

- ▶ **Contents (six groups — "3-3-3" mnemonic):** ductus deferens; three arteries (testicular, cremasteric, artery to ductus deferens); pampiniform venous plexus; three nerves (genital branch of genitofemoral, cremasteric nerve, sympathetic fibres accompanying the arteries); lymphatics (testis → pre-/para-aortic nodes); and remains of the processus vaginalis.
- ▶ **Coverings, from within outward:**

Layer	Derived from
Internal spermatic fascia	Fascia transversalis
Cremasteric fascia (+ cremaster muscle)	Internal oblique
External spermatic fascia	External oblique aponeurosis

- ▶ These same three layers form the coverings of the testis and dictate the coverings of an indirect inguinal hernia (see below).

4. Mechanisms maintaining the integrity of the inguinal canal

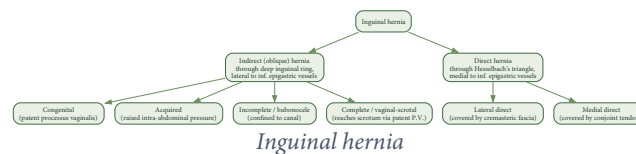
The canal is a potential site of weakness but herniation is normally prevented by five mechanisms:

- ▶ **Flap-valve mechanism** — obliquity of the canal means the deep and superficial rings do not lie opposite each other, so raised intra-abdominal pressure approximates the anterior and posterior walls like a flap.
- ▶ **Guarding of the rings** — deep ring guarded anteriorly by internal oblique; superficial ring guarded posteriorly by the conjoint tendon and reflected part of the inguinal ligament.
- ▶ **Shutter mechanism** — internal oblique forms an arch (anterior wall, roof, posterior wall); its contraction pulls the roof down onto the floor like a shutter.
- ▶ **Slit-valve mechanism** — contraction of external oblique approximates the two crura of the superficial ring, aided by the intercrural fibres.

- **Ball-valve mechanism** — cremaster contraction pulls the testis up, plugging the superficial ring with the cord itself.

The **interfoveolar ligament** (arched fibres from transversus abdominis to the superior pubic ramus) additionally strengthens the fascia transversalis at the medial edge of the deep ring. Failure of these mechanisms, combined with a preformed sac (processus vaginalis) or acquired weakness, underlies hernia formation.

5. Classification and anatomical basis of inguinal hernia



- **Indirect (oblique) hernia** — sac enters through the **deep ring**, **lateral to the inferior epigastric artery**, following the oblique canal; predisposed by a patent **processus vaginalis**. Commonest groin hernia; typical of children/young adults. Two forms: **incomplete/bubonocoele** (confined to canal) and **complete/vaginal** (reaches the scrotum, pear-shaped).
- **Direct hernia** — sac bulges straight forward through the **weak lateral part of Hesselbach's triangle**, medial to the inferior epigastric artery, pushing the posterior wall ahead of it; wide neck. Typical of the elderly with chronically raised intra-abdominal pressure (chronic bronchitis, straining, enlarged prostate). Division of the triangle by the obliterated umbilical artery gives **lateral direct** (cremasteric fascia covering) and **medial direct** (conjoint tendon covering) varieties.

□ Fig 4.14 — Coverings of the indirect inguinal hernia. (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.217)

Feature	Indirect inguinal hernia	Direct inguinal hernia
Cause	Preformed sac (patent processus vaginalis), present since birth	Acquired weakness of posterior wall, developed over time
Site of protrusion	Deep inguinal ring	Posterior wall of canal (Hesselbach's triangle)
Shape	Pear-shaped	Globular
Extent	Often reaches scrotum	Rarely scrotal
Direction	Oblique (down, forward, medial)	Straight (forward)
Neck of sac	Narrow; lateral to inferior epigastric vessels	Wide; medial to inferior epigastric vessels
Reducibility	Sometimes irreducible; obstruction common (narrow neck)	Usually easily and completely reducible
Age group	Children, young adults	Elderly
Internal-ring occlusion test	Positive (hernia controlled)	Negative (hernia still appears)

Feature	Indirect inguinal hernia	Direct inguinal hernia
Coverings	Extraperitoneal tissue, internal spermatic fascia, cremasteric fascia, external spermatic fascia, skin	Extraperitoneal tissue, fascia transversalis, conjoint tendon (medial) / cremasteric fascia (lateral), external spermatic fascia, skin

- **Coverings compared:** essentially identical — in the (medial) direct hernia, internal spermatic fascia is replaced by fascia transversalis, and cremaster is replaced by the conjoint tendon.
- If the content of the hernial sac is a **Meckel's diverticulum**, it is termed a **Littre's hernia**.

6. Inguinal hernia versus femoral hernia

Feature	Inguinal hernia	Femoral hernia
Sex	More common in males	More common in females
Site of protrusion	Into the inguinal canal	Into the femoral canal
Neck of sac (relation to pubic tubercle)	Above and medial to the pubic tubercle	Below and lateral to the pubic tubercle

- Despite the female predisposition to femoral hernia, **inguinal hernia is still the commoner groin hernia in women overall.**

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the posterior (intra-abdominal) view of the right inguinal region in coronal section, labelling in sequence:

- ▶ **Rectus abdominis** (lateral border) with the **inferior epigastric artery** ascending medial to the deep ring
- ▶ **Deep inguinal ring** — oval opening in fascia transversalis, 1.25 cm above the mid-inguinal point, lateral to the inferior epigastric vessels
- ▶ **Hesselbach's (inguinal) triangle** — medial border (rectus abdominis), lateral border (inferior epigastric artery), base (medial half of inguinal ligament) — crossed by the **obliterated umbilical artery**, dividing it into medial (conjoint-tendon-reinforced) and lateral (weak) parts
- ▶ **Conjoint tendon** reinforcing the medial two-thirds of the posterior wall/medial triangle floor
- ▶ **Superficial inguinal ring** — triangular defect in external oblique aponeurosis above the pubic crest, with medial and lateral **crura** and **intercrural fibres**
- ▶ Arrow tracing the **indirect hernia** path: deep ring → obliquely along the canal → superficial ring → scrotum
- ▶ Arrow tracing the **direct hernia** path: bulging straight forward through the lateral (or medial) part of Hesselbach's triangle
- ▶ **Pubic tubercle** marked as the landmark separating an inguinal hernia (above/medial) from a femoral hernia (below/lateral)

Applied / Clinical anatomy

- ▶ **Internal (deep) ring occlusion test:** after reducing the hernia, pressure is applied over the deep inguinal ring and the patient asked to cough — if the hernia stays reduced, it is **indirect**; if it reappears (medial to the occluding finger), it is **direct**, since the defect (Hesselbach's triangle) lies medial to the ring.
- ▶ **Precipitating factors for direct hernia:** chronic bronchitis, chronic constipation, benign prostatic enlargement — all causes of chronically raised intra-abdominal pressure acting on an already weak posterior wall.
- ▶ **Congenital vs acquired indirect hernia:** congenital form results from a patent processus vaginalis (failure of obliteration after testicular descent); acquired form follows sudden or repeated rises in intra-abdominal pressure (heavy lifting) acting on the deep ring.
- ▶ **Canal of Nuck:** the female equivalent persistence of the processus vaginalis, which may itself become the site of a hernia or hydrocele of the round ligament.
- ▶ **Surgical relevance:** repair (e.g., Bassini-type) reinforces the weakened posterior wall by approximating the conjoint tendon to the inguinal ligament/tract, directly restoring the same structure whose failure produces a direct hernia; mesh repairs restore the myopectineal orifice as a whole (see Recent advances).

- ▶ **Groin hernias** collectively comprise indirect inguinal, direct inguinal and femoral hernias — clinical differentiation on examination alone can be unreliable, hence the importance of imaging and the ring-occlusion test.
- ▶ Complications: **obstruction** is common in indirect hernia (narrow neck) and less common in direct hernia (wide neck); irreducibility and strangulation are surgical emergencies that follow directly from the sac's route through the fixed fascial/muscular planes described above.

Recent advances

- ▶ **The critical view of the myopectineal orifice (MPO) and the "inverted-Y, five-triangles" concept** now standardises the posterior (laparoscopic/robotic) view of the groin: the inferior epigastric vessels, vas deferens and gonadal vessels form an inverted "Y" with the iliopubic tract crossing it at the deep ring, generating five zones used to systematically identify the danger areas before mesh placement in TAPP/TEP/robotic repair (Claus C, Furtado M, Malcher F, Cavazzola LT, Felix E. "Ten golden rules for a safe MIS inguinal hernia repair using a new anatomical concept as a guide." *Surgical Endoscopy* 2020;34(4):1458–1464) [PMID: 32076858].
- ▶ **Cadaveric re-mapping of the "triangle of doom" (vas deferens, gonadal vessels, peritoneal fold — overlying the external iliac vessels) and the "triangle of pain" (iliopubic tract, gonadal vessels, peritoneal fold — overlying the lateral femoral cutaneous, femoral and genitofemoral nerves)** has produced precise surface measurements from the deep ring/ASIS for safer accessory trocar placement in laparoscopic hernia surgery (Gupta R, Gupta T, Kumari C, Aggarwal A, Sahni D. "Revisiting the surgical anatomy of the triangle of doom and the triangle of pain." *Clinical Anatomy* 2022;35(7):899–905) [PMID: 35426468].
- ▶ **Long-term outcomes of robotic TAPP (r-TAPP) repair**, which reconstructs the myopectineal orifice under three-dimensional magnified vision, show a very low recurrence rate (0.46% over 3–8 years in a 434-case series) supporting the anatomical adequacy of orifice-wide mesh coverage in this modern approach (Viera OJ, Florin JL, Morales KE. *Journal of Robotic Surgery* 2025;19(1):57) [PMID: 39885082].
- ▶ **AI-assisted intraoperative landmark recognition**: a deep-learning segmentation model that automatically highlights the vas deferens, gonadal vessels and inferior epigastric vessels during laparoscopic repair achieved ~90% concordance with expert identification, illustrating an emerging application of anatomical sciences to reduce nerve/vessel injury during hernia surgery (Sato K, Ishikawa Y. *Surgical Endoscopy* 2025;39(8):4985–4990) [PMID: 40588601].
- ▶ (According to *Surgical Endoscopy/Clinical Anatomy/Journal of Robotic Surgery* search.)

High-yield exam pointers

- ▶ **Deep ring**: oval, fascia transversalis, 1.25 cm above mid-inguinal point, **lateral** to inferior epigastric vessels. **Superficial ring**: triangular, external oblique aponeurosis, above pubic crest.
- ▶ **Hesselbach's triangle**: medial — rectus abdominis; lateral — inferior epigastric artery; base — medial half of inguinal ligament; divided by the obliterated umbilical artery.
- ▶ **Indirect hernia** = lateral to inferior epigastric vessels, through the deep ring, along a preformed sac (patent processus vaginalis); commonest groin hernia, more common in the young.

- ▶ **Direct hernia** = medial to inferior epigastric vessels, through the weak lateral part of Hesselbach's triangle, acquired weakness; commoner in the elderly.
- ▶ Coverings of both are essentially the same three fascial layers as the spermatic cord/testis; only the deepest layer differs (internal spermatic fascia/cremaster vs. fascia transversalis/conjoint tendon).
- ▶ **Internal ring occlusion test**: hernia controlled by pressure over deep ring = indirect; hernia still appears = direct.
- ▶ **Littre's hernia** = hernial sac containing a Meckel's diverticulum.
- ▶ Femoral hernia neck lies **below and lateral** to the pubic tubercle (vs. inguinal, above and medial); more common in females, but inguinal hernia remains the commonest groin hernia even in women.
- ▶ Five mechanisms guarding the canal: flap-valve, ring-guarding, shutter, slit-valve, ball-valve — their failure predisposes to hernia.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Vishram Singh's Textbook of Anatomy Vol 2 4e; BD Chaurasia's Human Anatomy Vol 2 8e. Recent-advances section per Surgical Endoscopy, Clinical Anatomy and Journal of Robotic Surgery (PMIDs cited above).



Injuries of brachial plexus

Asked in: Paper IV 14-Jul-2023 — RGUHS MD/MS Anatomy

Definition / Introduction The **brachial plexus** is formed by the ventral rami of C5–C8 and T1 and supplies almost the entire upper limb; because its long, mobile course runs from the neck, across the first rib, through the axilla and into the arm, it is exposed at every level to traction, compression and penetrating trauma. Injuries are classified by the **site** of the lesion (supraclavicular root/trunk vs infraclavicular cord/branch), by the **root level** involved (upper vs lower vs total plexus), and — for the closed traction lesions that dominate clinical practice — by whether the lesion is **pre-ganglionic** (root avulsion, no distal repair possible) or **post-ganglionic** (rupture of the nerve, graftable). The classic named syndromes, **Erb-Duchenne (upper) palsy** and **Klumpke's (lower) paralysis**, are the high-yield core of this topic.

1. Formation of the plexus — the anatomical basis of the classification

- ▶ **Roots** (supraclavicular): ventral rami of C5, C6, C7, C8, T1, lying between scalenus anterior and scalenus medius.
- ▶ **Trunks** (supraclavicular, in the posterior triangle of the neck): C5 + C6 → **upper trunk**; C7 alone → **middle trunk**; C8 + T1 → **lower trunk**.
- ▶ **Divisions** (retroclavicular, behind the clavicle): each of the three trunks splits into an **anterior** and a **posterior division**.

- ▶ **Cords** (infraclavicular, in the axilla, named from their relation to the second part of the axillary artery): **lateral cord** = anterior divisions of the upper and middle trunks; **medial cord** = anterior division of the lower trunk alone; **posterior cord** = posterior divisions of all three trunks.
- ▶ **Key branches at risk**: from the roots — **long thoracic nerve** (C5–C7, to serratus anterior) and dorsal scapular nerve; from the upper trunk — **suprascapular nerve**; from the cords — the terminal nerves (musculocutaneous and lateral root of median from the lateral cord; ulnar and medial root of median from the medial cord; axillary and radial from the posterior cord).

□ Fig 4.14 — The right brachial plexus (BD Chaurasia — Human Anatomy Vol 1 — 8e, p.83)

2. Classification of brachial plexus injuries

By site

- ▶ **Supraclavicular (root/trunk) injuries** — the great majority of closed traction injuries; subdivided by root level into upper, lower and total plexus lesions (below).
- ▶ **Infraclavicular (cord/branch) injuries** — less common; usually from anterior shoulder dislocation, fracture of the surgical neck of the humerus, or penetrating/missile wounds in the axilla; named for the cord damaged (lateral, medial or posterior cord), each reproducing a pattern resembling combined loss of that cord's terminal nerves.

By mechanism

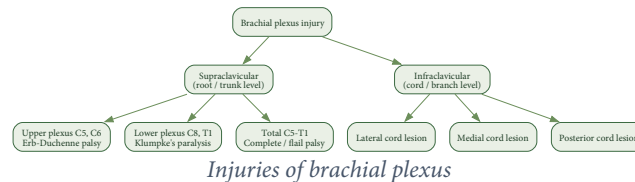
- ▶ **Traction/stretch** (commonest) — violent separation of the shoulder from the head/neck, as in high-speed motorcycle road traffic accidents, falls on the shoulder, or birth injury (shoulder dystocia, breech delivery); also traction during anaesthesia with the arm abducted and the head turned away.
- ▶ **Compression** — cervical rib/thoracic outlet compression of the lower trunk, crutch pressure in the axilla, prolonged abnormal posture.
- ▶ **Direct/penetrating trauma** — stab and gunshot wounds of the neck or axilla.
- ▶ **Iatrogenic** — misplaced interscalene/supraclavicular nerve blocks, faulty positioning during surgery, axillary lymph-node clearance (risk to the long thoracic, thoracodorsal and intercostobrachial nerves).
- ▶ **Neoplastic/other** — infiltration of the lower trunk by an apical (Pancoast) lung tumour; radiation-induced plexopathy.

By level of the lesion (Bonney classification, closed supraclavicular traction injuries)

Type	Site of lesion	Nature	Repair
Pre-ganglionic	Between the spinal cord and the dorsal root ganglion (intradural rootlets)	Avulsion (central, through CNS tissue) or rupture (peripheral to the dorsal root ganglion but still intradural) — avulsion is more central, rupture more peripheral	No proximal stump — cannot be repaired directly; needs extraplexal nerve transfer

Type	Site of lesion	Nature	Repair
Post-ganglionic	Distal to the dorsal root ganglion, in the mixed spinal nerve/ventral ramus	Rupture of the peripheral nerve trunk	Proximal stump present — amenable to nerve grafting

The dorsal root ganglion cell bodies remain viable even when avulsed from the cord, so peripheral conduction can persist despite complete central disconnection — this is the physiological basis for the clinical and electrodiagnostic tests below.



3. Erb-Duchenne (upper plexus) palsy

- **Site:** upper trunk, at Erb's point, where six elements converge — the C5 and C6 ventral rami, which unite here to form the upper trunk; the suprascapular nerve and the nerve to subclavius (both branches of the upper trunk); and the anterior and posterior divisions of the upper trunk. Injury here is therefore also called the "upper lesion of the brachial plexus."
- **Cause:** excessive widening of the angle between the head/neck and the shoulder — birth injury/difficult labour, a fall on the shoulder (e.g. from a height or off a horse), or traction of the arm during anaesthesia.
- **Root value:** mainly C5, partly C6.
- **Muscles paralysed:** deltoid, supraspinatus, infraspinatus, teres minor (partly), biceps brachii, brachialis, brachioradialis, supinator, and extensor carpi radialis longus.
- **Deformity — "policeman's tip"/"waiter's tip"/"porter's tip" position:** the arm hangs **adducted and medially rotated** (unopposed pectoralis major, latissimus dorsi and subscapularis, with deltoid/supraspinatus/infraspinatus/teres minor paralysed), the elbow is **extended** and the forearm **pronated** (biceps and supinator paralysed, unopposed triceps and pronator teres).
- **Disability:** loss of abduction and lateral rotation at the shoulder; loss of flexion and supination at the elbow/forearm; **biceps and supinator jerks are lost**.
- **Sensory loss:** a small patch over the lower part of the deltoid/outer aspect of the arm (C5, C6 territory) — often minimal.

4. Klumpke's (lower plexus) paralysis

- **Site:** lower trunk.
- **Cause:** sudden **hyperabduction** of the arm — clutching at something overhead during a fall from a height, the arm being pulled into machinery, or in a breech delivery with the arm extended above the head.
- **Root value:** mainly T1, partly C8 (occasionally C7 also involved).
- **Muscles paralysed:** all the **intrinsic muscles of the hand** (T1) and the **ulnar** (flexor carpi ulnaris/ulnar half of flexor digitorum profundus) **flexors of the wrist and fingers** (C8).

- **Deformity — claw hand (main en griffe):** hyperextension at the metacarpophalangeal joints with flexion at the interphalangeal joints, from unopposed long extensors and flexors once the intrinsics are lost.
- **Sensory loss:** along the medial (ulnar) border of the forearm and hand.
- **Horner's syndrome** (ptosis, miosis, anhydrosis, enophthalmos, loss of the ciliospinal reflex): occurs **only if T1 is injured proximal to its white ramus communicans** to the first thoracic (stellate) sympathetic ganglion — its presence is a strong pointer to a pre-ganglionic lesion.
- **Vasomotor/trophic changes** in long-standing cases: warm, dry skin from loss of sudomotor tone, later dry scaly skin, cracked nails and pulp atrophy.

5. Total (complete) brachial plexus palsy and the long thoracic nerve

- **Total/complete plexus injury (C5–T1)** follows the most violent traction injuries (typically high-speed motorcycle accidents) and produces a completely **flail, anaesthetic limb** — combining the features of both Erb's and Klumpke's palsy. Sensation is preserved only in the small strips supplied outside the plexus (supraclavicular nerves of the cervical plexus over the point of the shoulder, C4 above, and the intercostobrachial nerve, T2, on the inner aspect of the arm below). In large operated surgical series, complete lesions account for close to half of all supraclavicular injuries, and carry the worst prognosis and the highest likelihood of a combined pre- and post-ganglionic pattern.
- **Long thoracic nerve (nerve to serratus anterior, "nerve of Bell")** arises directly from the roots (C5–C7) and runs a long, superficial course over serratus anterior, making it vulnerable to a sudden blow on the shoulder, carrying heavy loads on the shoulder, or as a complication of axillary surgery (e.g. mastectomy/axillary clearance). Injury causes **winging of the scapula** — the medial border becomes abnormally prominent, especially on pushing against resistance — with loss of the pushing/punching action and weakened overhead abduction beyond 90° (trapezius, being intact, still initiates abduction).

6. Localising a pre-ganglionic from a post-ganglionic lesion (clinical evaluation)

Clinical/investigative feature	Significance
Linear abrasion/bruising at the tip of the shoulder; history of violent separation of the shoulder from the head (e.g. motorcyclist thrown from the machine)	Confirms the mechanism of violent traction
Severe, constant, burning/crushing pain in an otherwise anaesthetic limb	Strongly suggests root avulsion
Horner sign	Points to pre-ganglionic injury of C8/T1
Sensory loss extending above the clavicle	Indicates pre-ganglionic injury of the upper roots
Paralysis of serratus anterior and the ipsilateral hemidiaphragm (phrenic nerve)	Localises the lesion to the most proximal (root) segments, C4–C7 — pre-ganglionic

Clinical/investigative feature	Significance
Positive Tinel's sign on percussion in the posterior triangle, present from the day of injury	Localises a post-ganglionic rupture , and the level from which the radiating "pins and needles" is felt (e.g. into the thumb for C6, the little finger for the lower trunk)
Plain radiographs (elevated hemidiaphragm; cervical spine tilted away from the injured side; fracture/dislocation of the first rib); CT myelography/MRI (pseudomeningocele from a dural tear at an avulsed root); electrodiagnostic studies (nerve conduction, EMG)	Confirm the level and completeness of the lesion, and reveal associated bony/diaphragmatic injury

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the brachial plexus schema (roots → trunks → divisions → cords → terminal branches, as in the figure above) and mark the sites of injury directly on it:

- ▶ **C5, C6 roots / upper trunk** — ring this as **Erb's point**; label "**Erb-Duchenne palsy**" here.
- ▶ **C8, T1 roots / lower trunk** — ring this and label "**Klumpke's paralysis**".
- ▶ Shade the **entire plexus C5–T1** and label "**total/complete palsy**" for the whole-plexus pattern.
- ▶ Mark the **dorsal root ganglion** on each root, and indicate the **pre-ganglionic zone** (between cord and ganglion) versus the **post-ganglionic zone** (distal to the ganglion, along the mixed spinal nerve) with a dotted boundary line.
- ▶ Label the **long thoracic nerve** arising from C5–C7 roots and running down to serratus anterior.
- ▶ Alongside, sketch the two limb postures: **waiter's-tip position** (adducted, medially rotated arm; extended, pronated forearm) for Erb's, and **claw hand** for Klumpke's.

Applied / Clinical anatomy

- ▶ **Obstetric brachial plexus palsy**: the great majority of neonatal Erb's palsies recover spontaneously within weeks to a few months; absence of return of biceps activity by 3–6 months is the usual indication to proceed to surgical exploration.
- ▶ **Pre-ganglionic (root avulsion) injuries** have no proximal stump and cannot be repaired directly; they are treated by **extraplexal nerve transfer (neurotisation)** — e.g. spinal accessory nerve to suprascapular nerve, intercostal nerves to the musculocutaneous nerve, phrenic nerve transfer, contralateral C7 transfer, or an ulnar/median nerve fascicle to the biceps branch of the musculocutaneous nerve (Oberlin-type transfer) to restore elbow flexion.
- ▶ **Post-ganglionic ruptures** with a healthy proximal stump are treated by **direct nerve grafting** (commonly using sural nerve grafts) once the zone of injury is resected.
- ▶ **Palliation**: custom orthoses (to prevent contractures and support the flail limb), and **tendon transfers** once nerve recovery is deemed unlikely; free functioning muscle transfer and, in a subset of severe complete injuries that fail reconstruction, elective amputation with myoelectric prosthetic fitting are used for salvage.

- Injury to the subclavian artery, cervical spine, chest and other long bones commonly accompanies severe closed traction lesions, so a systemic trauma survey is mandatory before focusing on the plexus injury itself.

Recent advances

- **National shift towards nerve transfers:** analysis of a US national surgical database (2006–2022) showed steadily increasing adoption of nerve transfers in traumatic brachial plexus injury reconstruction, with significantly lower 30-day complication rates than traditional nerve grafting (2.5% vs 11%) despite being used in higher-risk patients — supporting continued adoption of the technique across specialties (Dhupati et al, *Ann Plast Surg* 2026) [PMID: 42384613].
- **Timing of reconstruction in incomplete injuries:** a cohort of 84 adults with incomplete supraclavicular (C5–C6/C5–C7/C5–C8) traction injuries found that distal fascicular nerve transfer gave comparable rates of useful elbow flexion (MRC ≥ 3) to early supraclavicular nerve grafting, but that grafting outcomes worsened by roughly 50% in odds per month of delay — reinforcing that root grafting, unlike distal transfer, is strongly time-sensitive (Groen et al, *Brain Spine* 2026) [PMID: 42292286].
- **Long-term shoulder outcomes after nerve transfer:** in 46 patients followed for a mean of 36 months after spinal accessory-to-suprascapular nerve transfer (with or without axillary nerve reconstruction), satisfactory shoulder abduction and external rotation were achieved in the majority, though scapular instability from lower trapezius weakness was noted as a transfer-related complication in five patients (Hems, *J Hand Surg Eur Vol* 2026) [PMID: 42206697].
- **Quality of life after distal nerve transfer:** a prospective cohort of 36 patients undergoing spinal accessory-to-suprascapular and/or radial-to-axillary nerve transfer for shoulder reanimation achieved satisfactory abduction in 91.9% and satisfactory external rotation in 78.4%, with a marked shift from poor/fair to good-to-excellent quality-of-life scores postoperatively; younger age and surgery within 6 months trended towards better recovery (Savić et al, *Brain Spine* 2026) [PMID: 42403573].
- **Amputation and myoelectric prosthesis as salvage:** for adults with complete traumatic brachial plexus injury who fail to regain functional grasp after nerve reconstruction, elective amputation combined with modern myoelectric prosthetic fitting is emerging as a reliable option for restoring function and quality of life, though neuropathic pain often persists and intensive multidisciplinary rehabilitation is required (Lee et al, *Hand Clin* 2026) [PMID: 42362321].

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High-yield exam pointers

- Supraclavicular (root/trunk) injuries are far commoner than infraclavicular (cord) injuries; classify by root level as **upper (Erb-Duchenne)**, **lower (Klumpke's)** or **total plexus palsy**.

- ▶ **Erb-Duchenne palsy:** C5, C6 (upper trunk/Erb's point) → **waiter's-tip/policeman's-tip deformity** (arm adducted, medially rotated; forearm extended, pronated); biceps and supinator jerks lost.
- ▶ **Klumpke's paralysis:** C8, T1 (lower trunk) → **claw hand**; sensory loss along the ulnar border of the limb; **Horner's syndrome** if **pre-ganglionic**.
- ▶ **Pre-ganglionic (root avulsion):** no proximal stump, needs nerve transfer; suggested by severe pain in an anaesthetic limb, Horner sign, sensory loss above the clavicle, and paralysed serratus anterior/hemidiaphragm. **Post-ganglionic (rupture):** has a repairable stump; localised by a positive **Tinel's sign**.
- ▶ **Long thoracic nerve** (C5–C7, "nerve of Bell") injury → **winging of the scapula**; vulnerable during axillary surgery and to direct pressure on the shoulder.
- ▶ Total plexus palsy (C5–T1) → completely flail, anaesthetic limb, with sensation spared only in the cervical-plexus/intercostobrachial (T2) strips outside the brachial plexus.
- ▶ Commonest mechanism overall: **closed traction** (motorcycle RTA, birth injury); infraclavicular (cord-level) injuries usually follow shoulder dislocation, humeral fracture or penetrating trauma.
- ▶ Management principle: **nerve transfer** for irreparable pre-ganglionic avulsions, **grafting** for post-ganglionic ruptures, and **tendon transfer/orthoses/amputation with prosthesis** for salvage once nerve recovery fails.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e (Commentary 6.1, Injuries of the supraclavicular brachial plexus); BD Chaurasia's Human Anatomy Vol 1 (8e); Vishram Singh — Textbook of Anatomy Vol 1 (4e); AK Datta — Human Anatomy Vol 3 (Upper & Lower Limb); IB Singh — Textbook of Anatomy Vol 1 (6e); Moore's Clinically Oriented Anatomy (9e).



Injuries of median nerve

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction

The **median nerve** (C5–T1) is formed by the union of a **lateral root** (C5, C6, C7 — from the lateral cord) and a **medial root** (C8, T1 — from the medial cord) of the brachial plexus, anterior to the third part of the axillary artery. Called the "**labourer's nerve**" (it supplies most long flexors that produce power grip) and the "**eye of the hand**" (it is sensory to the pulp of the thumb, index and middle fingers), it is the nerve most often injured in the upper limb. Because it gives off successive branches as it descends — at the elbow, in the forearm, and at the wrist — the level of a lesion produces a characteristic, examination-defining pattern of motor and sensory loss, which is the basis of this question.

Applied course and level-wise vulnerability

The nerve's relations explain why each level of injury has a distinct clinical picture.

Region	Course / relation	Structures lost distal to a cut at this level
Axilla	Lies on the lateral side of the third part of the axillary artery	Entire median distribution
Arm	Runs lateral to the brachial artery, crosses in front of it at mid-arm to lie medial to it in the cubital fossa; no branches in the arm	—
Cubital fossa	Medial to the brachial artery and biceps tendon, deep to the bicipital aponeurosis	Branches to pronator teres, flexor carpi radialis, palmaris longus, flexor digitorum superficialis
Upper forearm	Passes between the two heads of pronator teres, then deep to the tendinous arch of flexor digitorum superficialis	Anterior interosseous nerve — flexor pollicis longus, lateral half of flexor digitorum profundus, pronator quadratus
Lower forearm / wrist	Emerges lateral to the FDS tendons, lies deep to palmaris longus tendon; gives off the palmar cutaneous branch just above the flexor retinaculum, then enters the carpal tunnel	Palmar cutaneous branch (skin of thenar eminence and lateral palm)
Palm	Divides after the retinaculum into lateral and medial divisions	Thenar muscular branch, first and second lumbricals, digital branches to lateral 3½ digits

Sites, causes and classification of injury

Lesions are conventionally described at four levels.



Clinical features of a proximal (elbow) lesion — "high" median palsy

- ▶ Forearm kept **supine** — paralysis of pronator teres and pronator quadratus.
- ▶ Wrist flexion is weak and **adducted** — flexor carpi radialis and palmaris longus paralysed; unopposed flexor carpi ulnaris and ulnar half of flexor digitorum profundus.
- ▶ No flexion at the interphalangeal joints of the index and middle fingers — on attempted fist-making these two fingers remain extended while the ring and little fingers flex normally (ulnar-supplied profundus intact); this is the **benediction attitude** (a posture, not the fixed ulnar claw hand).
- ▶ Loss of flexion of the terminal phalanx of the thumb — flexor pollicis longus paralysed.
- ▶ **Ape-thumb (simian) deformity** — the thenar eminence is flattened and the thumb lies adducted in the plane of the palm, due to paralysis of the thenar muscles with an unopposed, normally-innervated adductor pollicis (ulnar nerve).

□ Fig 9.40 — Ape-/monkey-like thumb deformity (BD Chaurasia — Human Anatomy Vol 1 — 8e, p.162)

- ▶ Sensory loss over the lateral two-thirds of the palm and the palmar aspect of the lateral 3½ digits, extending onto the dorsal tips of the same digits.
- ▶ Vasomotor and trophic changes — the anaesthetic skin becomes warm and dry initially (arteriolar dilatation from loss of sympathetic tone), later dry, scaly, with cracked nails and pulp atrophy; a partial injury may progress to **causalgia** — severe burning pain with trophic change.

Clinical features of a mid-forearm lesion — anterior interosseous nerve (AIN) syndrome

- ▶ The AIN is a **pure motor** branch (no cutaneous fibres); it supplies flexor pollicis longus, the lateral (radial) half of flexor digitorum profundus, and pronator quadratus.
- ▶ An isolated AIN lesion is therefore distinguished from a high median lesion by the **complete absence of any sensory loss**.
- ▶ "**Pointing index**" sign — because the radial head of flexor digitorum superficialis (and the AIN-supplied profundus/FPL) fail, the index (and, less markedly, the middle) finger remains straight while the rest of the hand flexes on making a fist.
- ▶ Attempted pinch between the thumb and index fingertip becomes a flattened, "pinch"-type grip instead of a rounded "O", because both flexor pollicis longus and index flexor digitorum profundus are weak.
- ▶ Forearm pronation is weak only in its terminal range (pronator teres, supplied above this level, is spared).

Clinical features of a distal (wrist) lesion and carpal tunnel syndrome

- ▶ **At the wrist (distal forearm):** deep lacerated wounds — classically self-inflicted ("suicidal") cuts — sever the median trunk together with its palmar cutaneous branch just proximal to the flexor retinaculum. This produces the ape-thumb deformity as above, **plus** sensory loss extending onto the thenar eminence itself, because the palmar cutaneous branch is also cut.
- ▶ **Carpal tunnel syndrome (CTS):** compression of the median nerve within the osteofibrous carpal tunnel (concave carpus + flexor retinaculum), which is tightly packed with nine long flexor tendons and their synovial sheaths.
 - Burning pain / "pins and needles" in the median distribution (lateral 3½ digits), classically worse at night.
 - **No sensory loss over the thenar eminence** — the palmar cutaneous branch leaves the trunk proximal to, and runs superficial to, the flexor retinaculum, so it escapes compression. This is the key feature separating CTS from a wrist-laceration lesion.
 - Weakness and wasting of the thenar muscles; ape-thumb deformity if neglected.
 - Positive **Tinel's sign** (percussion over the flexor retinaculum reproduces the paraesthesiae) and **Phalen's test** (acute flexion of both wrists against each other for one minute reproduces symptoms).
 - Reduced motor/sensory conduction velocity across the wrist (< 30 m/s) is diagnostic.
 - Occurs between 25–70 years, more common in women and in those with repetitive wrist use; symptoms are dramatically relieved by surgical decompression (division of the flexor retinaculum).

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw a schematic of the volar forearm and hand with the median nerve's course, marking (numbered top to bottom):

- ▶ Brachial plexus roots C5–T1 with lateral root (C5–7) and medial root (C8, T1) uniting anterior to the axillary artery.
- ▶ Nerve crossing the cubital fossa medial to the brachial artery, deep to bicipital aponeurosis.
- ▶ **Site 1 — elbow:** nerve passing between the two heads of pronator teres (label "supracondylar fracture / pronator teres entrapment").
- ▶ Origin of the **anterior interosseous nerve** just below this — **Site 2 — mid-forearm**, running on the interosseous membrane to flexor pollicis longus, lateral half flexor digitorum profundus, pronator quadratus.
- ▶ **Site 3 — wrist:** palmar cutaneous branch arising just above the flexor retinaculum and running superficial to it; main trunk passing deep to the retinaculum through the carpal tunnel.
- ▶ **Site 4 — carpal tunnel**, shaded, with the nine flexor tendons alongside the nerve.
- ▶ Hand outline shaded to show the area of sensory loss — palmar aspect of lateral 3½ digits and lateral palm, with dorsal tips of the same digits, and the thenar-eminence patch labelled "spared in CTS, lost in wrist-laceration/high lesions."
- ▶ Small insets of the three deformities: benediction attitude (index + middle finger extended on fist-making), pointing index, and ape-thumb (flattened, adducted thumb).

Special clinical/diagnostic tests

Test	Technique	What it demonstrates
Tinel's sign	Percuss over the flexor retinaculum	Tingling in median distribution — used for CTS and nerve regeneration
Phalen's test	Both wrists held acutely flexed against each other for 1 minute	Reproduces CTS symptoms
Froment's sign / book test	Patient grasps a thin book between thumb and fingers of both hands	Tests adductor pollicis (ulnar); the thumb IP joint flexes (via flexor pollicis longus, median-supplied) on the paralysed side — useful to cross-check combined lesions
Pen (or bottle) test	Ask the patient to point the thumb vertically upward (palmar abduction) against resistance	Tests abductor pollicis brevis — weakness indicates median (thenar) palsy

Applied / Clinical anatomy

- ▶ **Localizing the level of injury** rests on which branches are lost: sensory loss is present in a high (elbow) lesion and in a wrist-laceration lesion, absent in isolated AIN palsy (pure motor), and absent only over the thenar eminence in CTS (palmar cutaneous branch spared).

- ▶ **Trick movements** may mask the loss of thumb opposition on casual bedside testing: extensor pollicis brevis (posterior interosseous nerve) and abductor pollicis longus (radial nerve) can simulate an ineffective opposition-like movement even after the median nerve is completely divided — the examiner must isolate true opposition (pad-to-pad contact with the thumb rotated into the plane of the palm) to avoid missing the lesion.
- ▶ **Complete (true) claw hand** results from combined median and ulnar nerve section at the elbow — hyperextension at the wrist and metacarpophalangeal joints with flexion at the interphalangeal joints of all four fingers, as all long flexors and all lumbricals/interossei are lost together.
- ▶ The **autonomous sensory area** of the median nerve (the pulp of the index finger, with no overlap from adjacent nerves) is used to assess true sensory recovery after nerve repair.
- ▶ **Management:** clean, sharp lacerations are treated by primary epineural nerve repair (ideally within 24–72 hours); nerve gaps require an interfascicular nerve graft (e.g. sural nerve). Neglected or irreparable high lesions are salvaged by tendon transfers to restore opposition (e.g. extensor indicis or ring-finger flexor digitorum superficialis routed to insert on the thumb — an "opponensplasty"). Carpal tunnel syndrome is treated by open or endoscopic release of the flexor retinaculum, which gives rapid relief once the nerve is decompressed.
- ▶ **Investigations** that supplement clinical localization include nerve conduction studies (motor and sensory latency/velocity across the site of compression — the classic < 30 m/s slowing at the wrist in CTS), electromyography of the thenar muscles, and high-resolution ultrasonography or MR neurography to image a compressive lesion, neuroma-in-continuity, or nerve discontinuity when clinical and electrophysiological findings are equivocal.

High-yield exam pointers

- ▶ Median nerve = C5–T1; lateral root (C5–7, lateral cord) + medial root (C8, T1, medial cord), uniting anterior to the third part of the axillary artery.
- ▶ Called the "**labourer's nerve**" (long flexors) and the "**eye of the hand**" (sensory to lateral 3½ digit pulps).
- ▶ The one small hand muscle **always** supplied by the median nerve, regardless of variation, is **abductor pollicis brevis**.
- ▶ **AIN syndrome** = **pure motor**, no sensory loss — the classic differentiator from a high (elbow) median lesion.
- ▶ **CTS is the commonest entrapment neuropathy** in the body; **flexor tenosynovitis** is its commonest cause; thenar skin sensation is spared because the palmar cutaneous branch runs superficial to the flexor retinaculum.
- ▶ Three classic deformities at three different levels: **benediction attitude** (elbow lesion, on attempted fist), **pointing index** (mid-forearm/AIN lesion), and **ape-thumb deformity** (any lesion affecting the thenar muscles).
- ▶ Combined median + ulnar nerve injury at the elbow produces the **complete/true claw hand**.
- ▶ Tinel's and Phalen's tests localize/confirm CTS; Froment's (book) test isolates adductor pollicis (ulnar) function; the pen test isolates abductor pollicis brevis (median) function.

- ▶ **Trick movements** (extensor pollicis brevis + abductor pollicis longus) can simulate thumb opposition and mask a complete median nerve division on casual examination.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 1 8e; Vishram Singh — Textbook of Anatomy Vol 1 4e; Snell — Clinical Neuroanatomy 7e.



List the clinical features and their anatomical basis of a) Complete transection of spinal cord caudal to the arm level b) Brown–Séquard syndrome

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction — A **complete transection** is a total division of the entire cross-section of the spinal cord at one level, interrupting every ascending and descending tract on both sides; a **hemisection** (**Brown–Séquard syndrome**) divides only one lateral half of the cord. Both lesions are best understood by asking, for each tract, (i) whether it is cut on one side or both, and (ii) whether it has already crossed the midline above the cord (corticospinal tract, dorsal columns — crossing occurs in the medulla) or crosses obliquely within the cord itself (spinothalamic tracts). "**Caudal to the arm level**" specifies that the transection lies **below the cervical enlargement** (the C4–T1 segments that supply the upper limb through the brachial plexus), so the neck, both upper limbs and the diaphragm are spared and the resulting picture is a **paraplegia**, not a quadriplegia. Brown–Séquard syndrome, being a hemisection, additionally produces the classical **dissociated** pattern — ipsilateral motor/proprioceptive loss with contralateral pain/temperature loss.

1. Complete transection caudal to the arm level — general anatomical basis

- ▶ **Level:** the lesion lies below the cervical enlargement (C4–T1 spinal segments, maximum cord diameter ~38 mm at C6), so all fibres to and from the upper limb are intact; a fracture-dislocation at or below the **L2–3 vertebral level** damages only the cauda equina, not the cord itself, since the adult cord ends at the lower border of L1 vertebra.
- ▶ **Bilaterality:** because the *entire* cross-section is divided, every long tract — corticospinal, dorsal column, spinothalamic — is destroyed on **both** sides, so the deficit below the lesion is symmetrical and total, unlike the asymmetric picture of a hemisection.
- ▶ **Two temporal phases:**
- ▶ **Spinal shock** (immediately after injury; lasts hours to 1–4 weeks): all segmental reflexes below the lesion are depressed by sudden withdrawal of facilitatory influences normally carried in the corticospinal, reticulospinal, vestibulospinal and tectospinal tracts, giving a **flaccid, areflexic** paralysis with an **atonic bladder and bowel**; a high lesion may also cause profound **hypotension** from loss of descending sympathetic vasomotor tone.

- **Established phase** (after shock resolves): the segmental reflex arcs below the lesion, now released from descending control, become hyperactive — **spasticity, exaggerated tendon reflexes and an extensor plantar response** appear.

2. Clinical features of complete transection (caudal to arm level) and their anatomical basis

Site relative to lesion	Clinical feature	Anatomical basis
At the level of the lesion	Bilateral lower motor neurone (LMN) paralysis and wasting of the myotome of that segment	Destruction of anterior grey column cells and/or the emerging ventral (motor) roots on both sides
At the level	Bilateral segmental band of anaesthesia	Destruction of both posterior (dorsal) roots at their point of entry
Below the level	Bilateral spastic (UMN) paraplegia — increased tone, brisk reflexes, bilateral extensor plantar (Babinski) response, loss of superficial abdominal and cremasteric reflexes	Bilateral interruption of the lateral corticospinal tracts and other descending motor tracts
Below the level	Bilateral loss of tactile discrimination, vibration and proprioception	Bilateral destruction of the posterior (dorsal) white columns
Below the level	Bilateral loss of pain, temperature and light touch, appearing 2–3 segments below the anatomical level distally	Bilateral destruction of the lateral and anterior spinothalamic tracts, which cross obliquely a segment or two above their point of entry
Below the level	Loss of voluntary control of bladder and bowel; initially atonic, later an automatic (reflex) bladder once shock resolves	Interruption of the descending autonomic pathways controlling the sacral micturition/defaecation centres
Below the level	Paraplegia in flexion (a pure flexor withdrawal response to noxious stimuli)	Complete section removes <i>all</i> descending tracts, including the extensor-facilitating vestibulospinal and medial reticulospinal tracts, leaving only the flexor-withdrawal spinal reflex unopposed
Above the level, including both upper limbs, neck and diaphragm	Fully normal — no weakness, no sensory loss, normal respiration	The cervical enlargement (C4–T1) and the phrenic supply to the diaphragm lie rostral to a lesion caudal to the arm level and are therefore untouched

- If the transection is only **incomplete**, some fibres of the vestibulospinal/medial reticulospinal tracts may survive, giving **paraplegia in extension** instead of flexion — the two are distinguished clinically by the direction of the reflex limb response to a noxious stimulus.

3. Brown–Séquard syndrome — anatomical basis of hemisection

The clinical picture follows directly from *where* each tract decussates relative to the lesion.

Tract / column	Modality	Level of decussation	Effect of hemisection
Lateral corticospinal tract	Voluntary motor (UMN)	Pyramidal decussation in the lower medulla — above the cord	Ipsilateral spastic paralysis below the lesion
Posterior (dorsal) white column	Proprioception, vibration, fine/discriminative touch	Ascends uncrossed in the cord; crosses as internal arcuate fibres in the medulla — again above the cord	Ipsilateral loss of proprioception, vibration and discriminative touch below the lesion
Lateral spinothalamic tract	Pain and temperature	Crosses obliquely in the anterior white commissure, 1–2 segments above its level of entry — within the cord	Contralateral loss of pain and temperature, beginning 2–3 segments below the lesion
Anterior spinothalamic tract	Crude/light touch	Also crosses in the anterior white commissure	Contralateral but incomplete loss of touch — never fully abolished
Anterior horn cells / ventral root (segmental)	LMN outflow	No crossing	Ipsilateral LMN paralysis and wasting at the level of the lesion
Posterior root (segmental)	All sensory modalities of that dermatome	No crossing	Ipsilateral band of cutaneous anaesthesia at the level of the lesion

4. Clinical features of Brown–Séquard syndrome and their anatomical basis

At the level of the lesion:

- ▶ Ipsilateral LMN paralysis and muscular atrophy — damage to anterior horn cells and/or the ventral root of that segment.
- ▶ Ipsilateral band of cutaneous anaesthesia — destruction of the posterior root at its point of entry.
- ▶ A narrow zone of ipsilateral hyperaesthesia at the upper margin of this band — irritation of intact dorsal rootlets adjoining the lesion.

Below the level of the lesion:

- ▶ Ipsilateral UMN (spastic) paralysis — increased tone, brisk reflexes, extensor plantar response, loss of ipsilateral superficial abdominal/cremasteric reflexes (lateral corticospinal tract).
- ▶ Ipsilateral loss of proprioception, vibration and discriminative touch (posterior white column).
- ▶ Contralateral loss of pain and temperature, typically 2–3 segments below the lesion (lateral spinothalamic tract).

- **Contralateral, incomplete loss of crude touch** — never total, since discriminative touch ascending in the intact contralateral posterior column is preserved (anterior spinothalamic tract).

Above the level of the lesion: function is entirely normal.

5. Comparative summary — complete transection vs Brown–Séquard syndrome

Feature	Complete transection	Brown–Séquard syndrome
Extent of section	Entire cross-section	One lateral half only
Motor loss below lesion	Bilateral spastic paraplegia	Ipsilateral spastic paralysis only
Pain/temperature loss below lesion	Bilateral , total	Contralateral only
Proprioception/vibration below lesion	Bilateral loss	Ipsilateral loss only
Bladder/bowel/sexual function	Lost (both descending autonomic pathways cut)	Relatively preserved (only one half of cord damaged)
Segmental (at-level) signs	Bilateral LMN paralysis + bilateral anaesthetic band	Ipsilateral LMN paralysis + ipsilateral anaesthetic band + hyperaesthesia above

□ Fig 7.24 — Brown–Séquard syndrome due to hemisection of spinal cord (Vishram Singh — *Clinical Neuroanatomy* — 4e, p.230)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw two transverse (cross) sections of the spinal cord at a mid-thoracic level, side by side, and label on each:

- ▶ **Anterior median fissure, posterior median sulcus, central canal, anterior and posterior grey horns**
- ▶ **Section 1 — Complete transection:** shade the *entire* cross-section; label the **lateral corticospinal tracts** (both sides — *bilateral spastic paraplegia below*), **posterior white columns** (both sides — *bilateral loss of proprioception/vibration*), and **lateral + anterior spinothalamic tracts** (both sides — *bilateral loss of pain, temperature and touch, 2–3 segments below*)
- ▶ **Section 2 — Hemisection (Brown–Séquard):** shade only the *right half*; label the **lateral corticospinal tract** and **posterior white column** on the shaded (right) side (*ipsilateral spastic paralysis + loss of proprioception below*), and the **lateral spinothalamic tract** with an arrow showing fibres crossing to the left in the anterior white commissure a segment or two below entry (*contralateral loss of pain/temperature below*)
- ▶ A small paired body-outline beneath each section, shaded to show the distribution of motor and sensory loss (bilateral for transection; ipsilateral-motor/contralateral-sensory for hemisection)

Applied / Clinical anatomy

- ▶ **Localising the level:** the segmental signs (band of LMN paralysis and cutaneous anaesthesia) indicate the exact spinal segment damaged; since the cord is shorter than the vertebral column, a **spinal segment lies at a higher vertebral level** than the corresponding vertebral spine (e.g. the T9–T12 segments lie opposite the T7–T9 vertebrae).
- ▶ A fracture-dislocation **below L2–3 vertebral level** spares the cord (which ends at the lower border of L1 in the adult) but produces a **cauda equina syndrome** — a predominantly LMN, saddle-distribution picture distinct from a true cord transection.
- ▶ **MRI of the spine** localises the level/side of a lesion and its cause — fracture-dislocation, penetrating trauma, extradural/intramedullary tumour, disc prolapse, or inflammatory/demyelinating myelitis.
- ▶ Common causes: **fracture-dislocation** (typically closed/blunt trauma → complete transection), **penetrating injury** (stab/gunshot — the classic cause of a clean hemisection), an **expanding tumour**, or **myelitis/multiple sclerosis** evolving over days.
- ▶ **Anterolateral cordotomy** — division of the antero-lateral column anterior to the denticulate ligament, sparing the pyramidal tract behind it — treats intractable unilateral pain by deliberately reproducing a controlled "iatrogenic hemisection."
- ▶ Nursing priorities in complete transection: prevent **pressure sores** over anaesthetic pressure points (sacrum, heels, ischial tuberosities), since sensory loss removes the normal warning of tissue damage; the **anal reflex** is used to test whether spinal shock has resolved.

High-yield exam pointers

- ▶ "Caudal to the arm level" = below the cervical enlargement (C4–T1) → upper limbs, neck and diaphragm spared → the picture is **paraplegia**, not quadriplegia.
- ▶ Complete transection = **bilateral** loss of all motor and sensory modalities below the lesion (both sides cut); Brown–Séquard = **dissociated** loss (ipsilateral motor/proprioceptive, contralateral pain/temperature) because only one half is cut.
- ▶ Two phases of complete transection: **spinal shock** (flaccid, areflexic, atonic bladder) → **established phase** (spastic, hyperreflexic, automatic bladder).
- ▶ **Paraplegia in flexion** follows a truly complete section (all descending tracts lost, pure flexor reflex); **paraplegia in extension** follows an incomplete section (vestibulospinal/reticulospinal fibres partly spared).
- ▶ Segmental ("at-level") signs are always **LMN** (anterior horn cell/ventral root) with a band of anaesthesia (posterior root); signs **below** the level are always **UMN/tract-type**.
- ▶ Mechanistic key to Brown–Séquard: corticospinal tract and dorsal columns cross **above** the cord (medulla) → ipsilateral deficit; spinothalamic tracts cross **within** the cord → contralateral deficit, appearing 2–3 segments lower.
- ▶ **Bladder, bowel and sexual function are lost in complete transection but relatively preserved in Brown–Séquard** — a key distinguishing and prognostic point.
- ▶ A fracture below L2–3 vertebral level spares the cord (which ends at L1) and produces cauda equina syndrome, not a cord transection syndrome.
- ▶ Touch is **never completely abolished** on either side in Brown–Séquard, since it travels via both the crossed anterior spinothalamic tract and the uncrossed posterior column.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell Clinical Neuroanatomy 7e; Vishram Singh Clinical Neuroanatomy 4e; BD Chaurasia Human Anatomy Vol 3–4 8e; IB Singh Textbook of Human Neuroanatomy.



Mastoid antrum

Asked in: Paper IV Sep 2007 — RGUHS MD/MS Anatomy

Definition / Introduction The mastoid (tympanic) antrum is a small, air-containing cavity situated in the petrous part of the temporal bone, immediately posterior to the epitympanic recess of the middle ear, with which it communicates through the **aditus ad antrum**. Although it lies within the mastoid process region developmentally and functionally, it is topographically housed in the petrous, not the mastoid, part of the bone. It develops as a backward (dorsal) expansion of the tympanic cavity and is already almost adult size at birth, unlike every other air sinus of the skull, which develop chiefly after birth. Its walls have considerable surgical importance because they separate the antrum from the middle cranial fossa, the sigmoid sinus and the labyrinth, and because infection reaching it from the middle ear (mastoiditis) can spread to any of these neighbouring structures.

1. Situation, size and general features

- Lies in the petrous part of the temporal bone, posterior to the epitympanic recess; also called the **tympanic antrum**.
- Small and roughly circular/oval; about the **size of a small pea** in the child, reaching about **1 cm** in diameter and a capacity of about **1 mL** in the adult.
- Present and almost adult in size **at birth** — the mastoid process itself is not yet formed and is not palpable/perceptible until late in the second year of life.
- Communicates anteriorly with the epitympanic recess of the tympanic cavity through the aditus ad antrum, and inferiorly with the mastoid air cells.

2. Boundaries of the mastoid antrum

Wall	Relation
Roof (superior)	Tegmen tympani (its posterior continuation, sometimes termed <i>tegmen antri</i>) — a thin plate of the petrous temporal bone separating the antrum from the middle cranial fossa and the temporal lobe of the cerebral hemisphere
Floor (inferior)	Continuous with, and perforated by, several openings leading into the mastoid air cells
Anterior	The aditus ad antrum , opening into the epitympanic recess; medial to the aditus is the ampulla of the lateral (horizontal) semicircular canal ; anteroinferior/below the aditus lies the descending (mastoid) part of the facial nerve canal
Posterior	Separated by a thin plate of bone (thickness variable with the degree of pneumatization) from the sigmoid sinus ; beyond the sinus lies the cerebellum in the posterior cranial fossa
Medial	Petrous temporal bone; behind the aditus, the medial wall is related to the posterior semicircular canal

Wall	Relation
Lateral	Formed by the squamous part of the temporal bone (the postmeatal process); on the outer skull surface this corresponds to the suprameatal triangle — the surgical approach to the antrum

□ Fig 18.7 — ■ Section through long axis of the petromastoid bone showing pharyngot (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.787)

3. Suprameatal (Macewen's) triangle — the surgical landmark

- ▶ The lateral bony wall of the antrum corresponds, on the outer surface of the skull, to the **suprameatal triangle (Macewen's triangle)**, bounded:
 - **Superiorly** by the **supramastoid crest** (level with the floor of the middle cranial fossa);
 - **Anteroinferiorly** by the **posterosuperior margin of the bony external acoustic meatus** (this side roughly indicates the position of the descending facial nerve canal);
 - **Posteriorly** by a vertical line tangential to the posterior margin of the meatus (anterior to the sigmoid sinus).
- ▶ Thickness of bone over the antrum at this site: only about **2 mm at birth**, increasing at an average rate of **~1 mm per year** to a final adult thickness of about **12–15 mm**, attained by puberty. In the young child, therefore, the antrum lies very superficially and can be entered through only a thin scale of bone.
- ▶ Surgically, this triangle is the site of the classical **cortical (simple) mastoidectomy** approach used to drain a mastoid abscess or to open the antrum; the facial nerve, running anteroinferior to the aditus, must be safeguarded during this approach.

□ Fig 12.13 — Boundaries of the suprameatal triangle (IB Singh — Textbook of Anatomy Vol 3 — 6e, p.233)

4. Mastoid air cells and patterns of pneumatization

- ▶ The mastoid air cells are intercommunicating spaces of variable number, size and extent within the mastoid process, opening into the floor of the antrum; they are lined by mucosa continuous with that of the antrum and tympanic cavity (non-ciliated squamous-type epithelium).
- ▶ They may be confined to the upper mastoid process, extend through it, or even extend beyond it into the squamous or petrous parts of the temporal bone; some cells lie close to the sigmoid sinus, the roof of the external acoustic meatus, or the jugular bulb.
- ▶ Absent at birth (only minute antral diverticula are present); they extend into the mastoid from the second year, are well formed by the fourth year, and undergo their greatest growth at **puberty**.

Type of mastoid process	Description	Surgical significance
Pneumatic (cellular)	Air cells well developed, septa thin, cells may extend well beyond the mastoid process	Antrum well formed and readily accessible; commonest pattern
Diploic (mixed)	Narrow marrow-containing spaces with only a few air cells	Intermediate pattern

Type of mastoid process	Description	Surgical significance
Sclerotic (acellular)	No air cells or spaces; dense compact bone	Antrum small, and the sigmoid sinus lies close to/interposed near the surface — greater risk of venous sinus injury at mastoidectomy

5. Development

- ▶ The tympanic cavity (and hence the antrum) develops from the **tubotympanic recess**, an endodermal derivative of the first pharyngeal pouch.
- ▶ The mastoid antrum itself arises as a **dorsal (backward) expansion of the tympanic cavity** during the **late fetal period**, and is already almost adult in size at birth.
- ▶ The **mastoid air cells**, by contrast, are not present at birth; they begin developing from the antrum during the second year, are well formed by four years, and reach maximal development at puberty as the mastoid process itself enlarges.
- ▶ The **mastoid process** is a postnatal structure — it is not perceptible until late in the second year of life; it grows downward and forward as the squamous and petrous parts expand, carrying the stylomastoid foramen and the emerging facial nerve progressively deeper (in infants, before the process forms, the facial nerve is very superficial as it leaves the stylomastoid foramen, making it vulnerable in neonatal surgery).

6. Vessels, lymphatics and nerve supply

- ▶ **Artery**: posterior tympanic branch, derived from the stylomastoid branch of the posterior auricular artery.
- ▶ **Veins**: drain to the mastoid emissary vein, the posterior auricular vein, and the sigmoid sinus.
- ▶ **Lymphatics**: postauricular (mastoid) nodes and the upper deep cervical group.
- ▶ **Nerves**: the tympanic plexus (formed chiefly by the glossopharyngeal nerve) and the meningeal branch of the mandibular nerve.

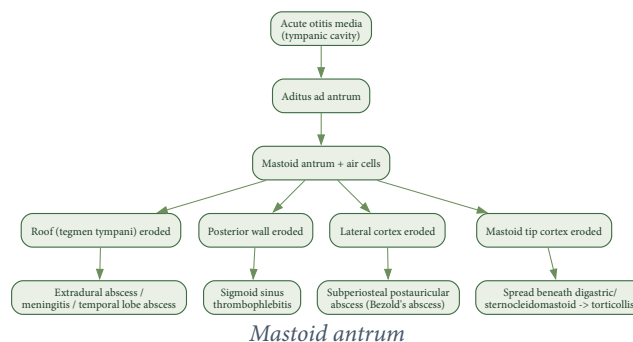
DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled sagittal/coronal schematic through the petromastoid region, showing:

- ▶ Epitympanic recess (attic) of the tympanic cavity, with the aditus ad antrum leading back from it
- ▶ **Mastoid antrum**, labelled with its approximate size (~1 cm) and capacity (~1 mL)
- ▶ Roof — tegmen tympani/tegmen antri — with the middle cranial fossa and temporal lobe above it
- ▶ Floor, opening into the mastoid air cells within the mastoid process
- ▶ Posterior wall with the sigmoid sinus (thin bony plate) and the cerebellum beyond
- ▶ Medial wall relations: ampulla of the lateral semicircular canal (medial to the aditus) and the posterior semicircular canal (medial to the antrum proper)
- ▶ Facial nerve canal, descending anteroinferior to the aditus
- ▶ Lateral wall = squamous temporal bone, with the **suprameatal (Macewen's) triangle** drawn on the external skull surface (supramastoid crest above, posterosuperior meatal margin anteroinferiorly, tangent line posteriorly) and its thickness noted (2 mm at birth → 12–15 mm in the adult)

Applied / Clinical anatomy

- ▶ **Mastoiditis**: a potentially life-threatening spread of bacterial infection from the tympanic cavity, via the aditus, into the antrum and mastoid air cells — almost always secondary to acute otitis media in which pus fails to drain adequately through the pharyngotympanic tube or a perforated tympanic membrane.
- ▶ **Routes of spread from the antrum/mastoid** (each wall is a potential route of complication):



- ▶ **Fracture of the middle cranial fossa** may breach the tegmen tympani/antri, tearing the tympanic membrane and causing bleeding with CSF otorrhoea.
- ▶ **Petrosquamous fissure**: in the neonate this may remain open directly into the antrum; it usually closes within the first year but can rarely persist to age 19, providing a route by which middle-ear infection reaches the meninges.
- ▶ **Cortical (simple) mastoidectomy**, performed through the suprameatal (Macewen's) triangle, is the classical surgical access to drain a mastoid abscess or chronically diseased antrum/air cells; the facial nerve (anteroinferior to the aditus) and the sigmoid sinus/dural plate (posteriorly) are the structures most at risk.

- **Imaging (radiological anatomy):** high-resolution CT (HRCT) of the temporal bone is the investigation of choice before mastoid surgery, delineating pneumatisation pattern, the position of the sigmoid sinus and tegmen, facial-canal dehiscence, and antral/aditus anatomy — the information needed to plan a safe cortical mastoidectomy or an endoscope-assisted/image-guided approach in modern otological practice.

High-yield exam pointers

- Mastoid antrum = tympanic antrum; lies in the **petrous** (not mastoid) part of the temporal bone; ~1 cm diameter, ~1 mL capacity; present and near-adult size **at birth**.
- Communicates anteriorly via the **aditus ad antrum** with the epitympanic recess, and inferiorly with the mastoid air cells.
- Six boundaries: roof = tegmen tympani (→ middle cranial fossa/temporal lobe); floor = mastoid air cells; anterior = aditus (medial to it, lateral SCC ampulla; below it, facial nerve canal); posterior = sigmoid sinus; medial = posterior SCC (behind aditus); lateral = squamous bone = suprameatal (Macewen's) triangle.
- Suprameatal triangle boundaries: supramastoid crest (above), posterosuperior meatal margin (anteroinferior), tangent to posterior meatal margin (posterior) — the surgical route to the antrum.
- Lateral wall thickness: 2 mm at birth → ~1 mm/year → 12–15 mm in the adult (full thickness by puberty).
- Mastoid air cells are absent at birth, develop from the second year, well formed by the fourth year, maximal growth at puberty; three pneumatisation patterns — pneumatic, diploic (mixed), sclerotic.
- Develops as a dorsal expansion of the tympanic cavity (itself from the tubotympanic recess, first pharyngeal pouch) in late fetal life; the mastoid process is a purely postnatal structure, not perceptible till late in the second year.
- Mastoiditis spreads via the aditus from otitis media; complications include extradural abscess/meningitis/temporal lobe abscess (through the roof), sigmoid sinus thrombophlebitis (posteriorly), Bezold's abscess (through the lateral mastoid cortex), and torticollis (spread to the digastric/sternocleidomastoid attachment at the mastoid tip).
- Cortical mastoidectomy is performed through the suprameatal triangle; the facial nerve and sigmoid sinus are the structures at greatest surgical risk.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 3-4, 8e; Vishram Singh — Textbook of Anatomy Vol 3, 4e; IB Singh — Textbook of Anatomy Vol 3, 6e; Moore — The Developing Human, 9e.



Perforating veins

Asked in: Paper IV Oct 2006 — RGUHS MD/MS Anatomy

Definition / Introduction Perforating veins (perforators) are short, valved venous channels of the lower limb that pierce the deep fascia to connect the **superficial venous system** (great and small saphenous veins and their tributaries) with the **deep venous system** (venae comitantes of the leg arteries, popliteal and femoral veins). Their number and principal sites are fairly constant, and every perforator is guarded by valves oriented to permit blood flow **only from superficial to deep veins**. They form the structural basis of the musculo-venous ("calf") pump that returns blood against gravity, and incompetence of their valves is the commonest anatomical basis of varicose veins and venous ulcers — which is why the topic is repeatedly examined.

Classification of perforating veins

- ▶ **Direct perforators** — connect a superficial vein straight to a deep vein without any intervening muscular channel. The **great and small saphenous veins themselves function as large direct perforators** at their terminations into the femoral and popliteal veins respectively; in addition, several small, constant direct perforators (adductor canal, knee, ankle) connect saphenous tributaries directly to named deep veins.
- ▶ **Indirect perforators** — connect the superficial veins to the deep veins indirectly, through intervening **muscular veins/venous plexuses** (e.g., the venous plexus of soleus and gastrocnemius) before the blood reaches a named deep vein.

Course and valvular mechanism

- ▶ Each perforator pierces the deep fascia **obliquely**, close to its point of origin from a superficial tributary.
- ▶ Valves are present at both ends of the perforator (and often an intermediate valve as well) and are oriented so that blood can flow **only from the low-pressure superficial compartment into the high-pressure deep compartment**, never in reverse.
- ▶ The oblique passage through the deep fascia is functionally important: when the calf muscles contract, intrafascial pressure rises and **compresses the obliquely-running perforator**, adding a mechanical "flap-valve" effect that reinforces closure of the true venous valves and prevents deep-to-superficial reflux.
- ▶ Because of this arrangement, in the leg and thigh blood is continuously shunted **superficial → deep**; only in the foot does normal flow run the other way, from the deep plantar veins to the superficial dorsal venous arch.

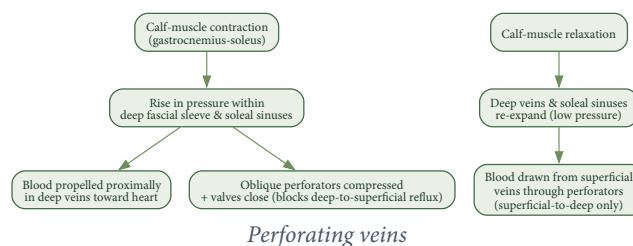
Named and constant perforating veins

A small number of direct perforators occupy fixed, clinically important sites and are given eponymous names:

Perforator	Alternative name(s)	Connects	Site
Adductor canal perforator	Hunterian perforator / Dodd's perforator	Great saphenous vein ↔ femoral vein	Lower part of the adductor (Hunter's) canal
Knee perforator	Boyd's perforator / tubercle perforator	Great saphenous vein (or posterior arch vein) ↔ posterior tibial vein	Just below the knee, close to the medial border of the tibia
Lateral ankle perforator	—	Small saphenous vein (or a tributary) ↔ peroneal (fibular) vein	Junction of the middle and lower thirds of the leg
Upper medial ankle perforator	one of Cockett's perforators	Posterior arch vein ↔ posterior tibial vein	Junction of the middle and lower thirds of the leg
Middle medial ankle perforator	one of Cockett's perforators	Posterior arch vein ↔ posterior tibial vein	≈4 cm above the medial malleolus
Lower medial ankle perforator	one of Cockett's perforators	Posterior arch vein ↔ posterior tibial vein	Posteroinferior to the medial malleolus

- The three medial ankle perforators are collectively the **perforators of Cockett**; they are joined to one another by a series of **venous arcades**, which together constitute the **posterior arch vein** — also called the "**vein of Leonardo (da Vinci)**", as it was first illustrated by him.
- More than three medial ankle perforators, or one above mid-calf, is uncommon.
- Numerous smaller, unnamed perforators exist along the entire course of both saphenous systems, in addition to these constant, surgically important ones.

Physiological role — the musculo-venous (calf) pump



- On standing, the calf muscles (chiefly gastrocnemius–soleus) act as a **peripheral heart**: contraction squeezes blood out of the valveless **soleal venous sinuses** into the deep veins, propelling it proximally; relaxation lets the sinuses refill from the superficial veins via the perforators.
- Unidirectional, superficial-to-deep shunting through the perforators keeps the diameter of the saphenous veins remarkably uniform despite the many tributaries they continuously receive along their length.
- Additional aids to venous return: numerous valves in both superficial and deep veins (more numerous in the deep system), the negative intrathoracic pressure of inspiration, and pulsatile compression of the venae comitantes by their companion arteries.

- ▶ Because the soleal sinuses have sluggish flow at rest, they are a common site of **thrombosis**, and phlebitis here can damage perforator valves — the anatomical link between prolonged immobility, deep vein thrombosis and pulmonary embolism.

□ Fig 11.4 — Small direct perforating veins of the lower limb (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.180)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A medial-view outline of the lower limb (thigh to foot) labelled with, from above downward:

- ▶ Femoral vein and long (great) saphenous vein — upper thigh
- ▶ Adductor canal (Hunterian) perforator — lower thigh
- ▶ Popliteal vein and short (small) saphenous vein — knee/popliteal fossa
- ▶ Below-knee (Boyd's) perforator — just below the knee
- ▶ Lateral perforator — junction of middle/lower third of leg
- ▶ Upper, middle and lower medial ankle (Cockett's) perforators — descending toward the medial malleolus, joined by arcades forming the posterior arch vein

Applied / Clinical anatomy

- ▶ Pathogenesis of varicose veins — two anatomical mechanisms, often coexisting:
- ▶ Incompetence of perforator valves: the defective perforator becomes a "high-pressure leak," transmitting the high pressure generated in the deep veins during muscular contraction into the low-pressure superficial system, producing dilated, tortuous superficial veins.
- ▶ Incompetence at the termination of a superficial vein, e.g., the saphenofemoral valve — varicosity then begins at the saphenofemoral junction and extends progressively downward. (In roughly 80% of individuals a competent valve in the terminal external iliac vein additionally protects the saphenofemoral junction from very high central venous pressure.)
- ▶ Varicose (venous) ulcers: chronic incompetence, especially of the medial ankle (Cockett's) perforators, produces sustained venous hypertension over the "gaiter" area — pigmentation, induration and ulceration classically just above the medial malleolus.
- ▶ Trendelenburg's test: the limb is emptied by elevation and stroking, pressure is applied at the saphenofemoral junction, and the patient stands. Releasing the pressure and observing rapid filling tests the superficial (saphenofemoral) valve; maintaining the pressure for about a minute and observing gradual filling tests the perforator valves.
- ▶ Perthes' (tourniquet) test: a tourniquet occludes the superficial veins in the thigh while the patient exercises (walks); shrinkage of the varicosities confirms patent, competent deep veins and perforators, whereas worsening distension indicates deep venous obstruction — an essential check before any perforator ligation is attempted.
- ▶ Surgical management: saphenofemoral flush ligation with stripping of the great saphenous vein (Trendelenburg's operation) for saphenofemoral incompetence; subfascial ligation of the individually localised incompetent perforators (at the constant Hunterian, Boyd's, lateral and Cockett's sites) for perforator incompetence.

- ▶ **Venesection (cut-down)**: performed on the great saphenous vein anterior to the medial malleolus for emergency fluid/blood access; the saphenous nerve, lying close by, must be identified and preserved.
- ▶ **Vascular graft**: the great saphenous vein is harvested and reversed (to negate its valves) for coronary artery bypass grafting and peripheral arterial bypass — a direct surgical application of its perforator-rich, easily accessible course.
- ▶ **Deep vein thrombosis / pulmonary embolism**: stasis in the valveless soleal sinuses during prolonged bed rest predisposes to DVT; after recanalisation the perforators may lack valves, permitting persistent deep-to-superficial reflux and secondary varicosity even without primary valve incompetence.

High-yield exam pointers

- ▶ Perforators pierce the **deep fascia** to connect superficial ↔ deep veins; valved for **superficial-to-deep flow only**.
- ▶ Classified as **direct** (saphenous veins and their small direct connections) and **indirect** (via muscular veins/sinuses).
- ▶ Named sites: **Hunterian/Dodd's** (adductor canal, GSV ↔ femoral vein); **Boyd's/tubercle** (below knee, GSV/posterior arch vein ↔ posterior tibial vein); **lateral ankle** (SSV ↔ peroneal vein); **three medial ankle perforators of Cockett** (posterior arch vein ↔ posterior tibial vein).
- ▶ The three Cockett perforators are linked by arcades forming the **posterior arch vein** ("vein of Leonardo").
- ▶ Oblique course through deep fascia → muscle contraction compresses the perforator, reinforcing valve closure (anatomical basis of the **musculo-venous/calf pump**; soleus = "peripheral heart").
- ▶ Incompetent perforator valves = "**high-pressure leaks**" → varicose veins and venous ulcers, classically at the medial ankle.
- ▶ **Trendelenburg's test** localises superficial vs perforator incompetence; **Perthes' test** excludes deep venous block before perforator surgery.
- ▶ Great saphenous vein: harvested (reversed) as an arterial graft, and used for ankle venesection anterior to the medial malleolus.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2, 8e; Vishram Singh's Textbook of Anatomy Vol 2, 4e; AK Datta's Human Anatomy Vol 3 (Upper & Lower Limb); IB Singh's Textbook of Anatomy Vol 1, 6e; Moore's Clinically Oriented Anatomy, 9e.



Persistent vitello – intestinal duct

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction The vitello-intestinal duct (VID) — also called the omphalomesenteric/omphaloenteric duct or yolk stalk — is the narrow endodermal channel that connects the midgut of the embryo to the yolk sac, and which normally obliterates completely within the first two months of intrauterine life. Failure of this obliteration, wholly or in part, leaves behind a spectrum of congenital anomalies — Meckel's diverticulum, vitelline (umbilical) fistula, vitelline sinus, vitelline cyst (enterocystoma) and fibrous vitelline ligaments — collectively grouped as "persistent vitello-intestinal duct." Meckel's diverticulum, the commonest of these, is also the commonest congenital anomaly of the gastrointestinal tract, seen in 2–4% of the population.

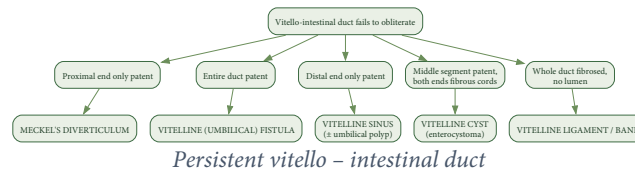
1. Normal embryology of the vitello-intestinal duct

- ▶ In the early embryo (3rd week), the midgut is in **wide, open communication** with the yolk sac.
- ▶ As lateral and cephalocaudal folding proceeds, this broad connection is progressively **narrowed**: by Carnegie stage 12–13 (~4th week) it is reduced to a slender **yolk stalk containing the vitelline (vitello-intestinal) duct**.
- ▶ By the **5th week**, the opening has narrowed into a definite tubular vitelline-intestinal duct running within the connecting stalk/umbilical cord.
- ▶ The duct normally **loses its connection with the gut tube and disappears during the 6th week** of intrauterine life, along with the yolk sac and the paired vitelline arteries/veins that accompanied it.
- ▶ The related but distinct **umbilical (extraembryonic) coelom**, which houses the physiological umbilical herniation of the midgut loop, persists longer and is only obliterated by about the **10th week**, when the herniated midgut returns to the abdominal cavity — this later event should not be confused with duct obliteration itself.
- ▶ **Failure of obliteration**, complete or partial, produces the anomaly spectrum described below.

2. Classification / spectrum of persistent vitello-intestinal duct

Pattern of persistence	Resulting anomaly	Basis
Proximal (ileal) end patent; rest of duct obliterates	Meckel's diverticulum — a blind pouch on the antimesenteric border of the ileum	Commonest pattern
Entire duct remains patent, end to end	Vitelline (umbilical) fistula — direct communication between ileal lumen and umbilicus	Least common, most dramatic
Distal (umbilical) end patent, proximal part obliterates	Vitelline sinus — blind pit at the umbilicus; may show a mucosal/umbilical polyp	Mucous, non-faeculent discharge
Both ends obliterate to fibrous cords, middle segment remains patent and dilates	Vitelline cyst (enterocystoma) — a cyst tethered to ileum and umbilicus by fibrous vitelline ligaments	Risk of volvulus around the cords

Pattern of persistence	Resulting anomaly	Basis
Entire duct obliterates to a solid fibrous cord	Vitelline ligament/band — fibrous cord from ileum (or Meckel's diverticulum) to the umbilicus, patent lumen absent	Asymptomatic unless it entraps bowel



3. Meckel's diverticulum — gross anatomical features

- ▶ A **true diverticulum**: its wall contains all four coats of the gut — serous, muscular, submucous and mucous — because it is a genuine embryological remnant, unlike acquired pulsion diverticula.
- ▶ Arises from the **antimesenteric border** of the ileum; lumen has the **same calibre as the ileum**.
- ▶ Mucosa is usually of **ileal type**, but heterotopic **gastric (body-type)**, **pancreatic**, **colonic** or **jejunal** tissue is frequently present in its wall.
- ▶ Blood supply: a persisting **vitellointestinal artery**, the remnant of the embryonic vitelline artery, running from the termination of the **superior mesenteric artery** through a short fatty "mesentery" to the base of the diverticulum.
- ▶ Its apex may be **free** or attached by a fibrous cord (the obliterated distal duct) to the umbilicus, mesentery, or another abdominal viscus.

"Rule of 2's" (classic teaching mnemonic):

Feature	Value
Incidence	2% of the population
Length	about 2 inches (5 cm)
Distance from ileocaecal valve	about 2 feet (60 cm), on the antimesenteric border
Sex	2 times more common in men
Ectopic tissue	2 types commonly present (gastric, pancreatic)

(Note: exact figures vary slightly between textbooks — length is usually cited as 2–5 cm, and the distance from the ileocaecal junction is variously given as ~40–60 cm, ~50–100 cm, or ~50 cm in adults [30–60 cm in infants] by different authors — but the "Rule of 2's" above is the standard recalled teaching point.)

4. Vitelline cyst (enterocystoma) and umbilical (mucosal) polyp

- ▶ Formed when **both ends** of the vitello-intestinal duct convert to solid fibrous cords (vitelline ligaments) while a **middle segment** remains patent and distends into a cystic swelling — the **enterocystoma**.
- ▶ The cyst lies free in the peritoneal cavity, tethered to the ileum and to the umbilicus by the fibrous vitelline ligaments; it may bulge visibly at the umbilicus.

- ▶ Because the fibrous cords traverse the peritoneal cavity, loops of small bowel can twist around them, causing **volvulus and strangulation** — the major clinical hazard of this variant.
- ▶ When only the **distal (umbilical) stump** of the duct persists as a mucus-secreting sinus, chronically everted intestinal mucosa at the umbilicus can present clinically as a small, moist, red umbilical growth — described classically as a "**raspberry**" or "**cherry-red**" **umbilical tumour** (mucosal/umbilical polyp).

5. Vitelline (umbilical) fistula and vitelline sinus

- ▶ **Vitelline/umbilical fistula:** the entire duct remains patent, giving a direct communication between the lumen of the ileum and the umbilicus — **faecal matter (and gas) discharge from the umbilicus**, evident soon after birth.
- ▶ **Vitelline sinus:** only the distal (umbilical) end remains patent while the proximal duct obliterates; this presents as a blind-ending sinus opening at the umbilicus, discharging mucus rather than faeces, and may be associated with an umbilical polyp as above.
- ▶ Both patterns are far less common than Meckel's diverticulum.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 14.10 — Remnants of the vitellointestinal (vitelline) duct: (A) Meckel's diverticulum; (B) Vitelline cyst; (C) Vitelline fistula (Sontakke — *Textbook of Human Embryology*, p.142)

Reproduce a three-panel diagram of the ileum, mesentery and umbilicus, labelling in each panel:

- ▶ Terminal ileum with its mesentery, and the antimesenteric border.
- ▶ Ileocaecal junction (as the fixed distance reference point).
- ▶ **Panel A** — Meckel's diverticulum: blind pouch on the antimesenteric border, its apex connected to the umbilicus by a fibrous vitelline ligament.
- ▶ **Panel B** — Vitelline cyst (enterocystoma): a mid-duct cyst suspended between ileum and umbilicus by two fibrous vitelline ligaments.
- ▶ **Panel C** — Vitelline fistula: the fully patent duct forming an open tube from ileal lumen to umbilicus, with faecal discharge indicated at the umbilical opening.
- ▶ Umbilicus in all three panels, as the common distal landmark.

6. Histological structure

- ▶ All layers of the normal small-bowel wall are represented: **mucosa** (villi and crypts, usually ileal type), **submucosa**, **muscularis externa** (inner circular, outer longitudinal), and **serosa**.
- ▶ Heterotopic epithelium, when present, most often is **gastric body-type mucosa** (acid- and pepsin-secreting) or **pancreatic acinar/ductal tissue**; less commonly colonic or duodenal-type mucosa.
- ▶ This heterotopic gastric mucosa is functionally active and secretes acid unopposed by the surrounding alkaline ileal environment — the histological basis for peptic ulceration in the adjacent normal ileal mucosa (see Applied anatomy).

7. Recent advances in diagnosis and management

- ▶ **^{99m}Tc -pertechnetate scintigraphy ("Meckel's scan"):** the pertechnetate ion is preferentially taken up by acid-secreting gastric mucosa, so a Meckel's diverticulum containing heterotopic gastric mucosa shows as a focal area of tracer uptake; this remains the investigation of choice for a child presenting with painless lower gastrointestinal bleeding of suspected Meckel's origin, and its sensitivity can be improved by H₂-blocker or pentagastrin premedication.
- ▶ **Cross-sectional small-bowel imaging (CT/MR enterography):** increasingly used to characterise the small bowel and its diverticula and to detect complications such as diverticulitis, intussusception or obstruction.
- ▶ **Video capsule endoscopy:** used to localise an obscure mid- or distal-ileal bleeding source to the region of a Meckel's diverticulum when scintigraphy is negative or equivocal.
- ▶ **Laparoscopic (or laparoscopy-assisted) diverticulectomy/segmental ileal resection:** now the preferred surgical approach for a symptomatic diverticulum, largely replacing open surgery; whether an incidentally discovered, asymptomatic diverticulum found during laparotomy/laparoscopy for another indication should be resected prophylactically remains debated.

Coverage note: the anatomy corpus grounds the developmental/gross-anatomical facts above in detail; the specific radiology/surgery points in this section reflect standard, widely-taught clinical practice rather than a dedicated passage in these anatomy texts.

Applied / Clinical anatomy

- ▶ **Peptic ulceration and bleeding:** unopposed acid secretion from heterotopic gastric mucosa in a Meckel's diverticulum erodes the adjacent normal ileal mucosa, producing painless lower GI bleeding — a classic presentation in children.
- ▶ **Diverticulitis mimicking appendicitis:** inflammation of a Meckel's diverticulum can closely mimic acute appendicitis; because both the appendix and Meckel's diverticulum are midgut derivatives, pain from either is referred to the **periumbilical region** (T10 dermatome) before localising.
- ▶ **Intestinal obstruction, intussusception and volvulus:** the diverticulum (or, more often, its fibrous band/vitelline ligament) can act as a lead point for ileo-ileal **intussusception**, or cause obstruction/**volvulus** by fibrous bands twisting around loops of bowel — a particular risk with the fibrous cords of a vitelline cyst.
- ▶ **Perforation, enterolith formation and rare tumours:** chronic inflammation may perforate the diverticulum or lead to calculus (enterolith) formation within it; carcinoid and other tumours are rare but recognised complications, arising from neuroendocrine cells in its wall, analogous to the vermiform appendix.
- ▶ **Littre's hernia:** when a Meckel's diverticulum enters a hernial sac (classically inguinal, occasionally femoral or umbilical), the condition is termed Littre's hernia.
- ▶ **Umbilical anomalies:** a patent vitello-intestinal duct produces a faecal umbilical fistula; a persistent distal stump produces a vitelline sinus with mucous discharge and, often, a raspberry/cherry-red umbilical (mucosal) polyp — these must be distinguished clinically from a patent urachus (urinary discharge) and an umbilical granuloma of purely inflammatory origin.

- ▶ **Surgical landmark:** the antimesenteric location and fixed distance from the ileocaecal valve make identification of a Meckel's diverticulum a routine step whenever the terminal ileum is examined at laparotomy for unexplained abdominal pain, bleeding or obstruction.

High-yield exam pointers

- ▶ Vitello-intestinal duct (omphalomesenteric/omphaloenteric duct, yolk stalk) connects midgut to yolk sac; normally obliterates by the **6th week** of intrauterine life.
- ▶ Failure of obliteration → **Meckel's diverticulum** (proximal end patent — commonest), **vitelline fistula** (entire duct patent), **vitelline sinus** (distal end patent), **vitelline cyst/enterocystoma** (middle segment patent), or a solid **vitelline ligament/band**.
- ▶ Meckel's diverticulum = **commonest congenital anomaly of the GIT**; a **true diverticulum** (all four gut-wall coats present).
- ▶ "**Rule of 2's**": 2% incidence, 2 inches long, 2 feet from ileocaecal valve, 2× more common in males, 2 types of ectopic tissue (gastric, pancreatic).
- ▶ Lies on the **antimesenteric border** of the ileum; supplied by the **vitellointestinal artery** (remnant of the vitelline artery, from the terminal SMA).
- ▶ Key complications: **peptic ulceration/bleeding** (heterotopic gastric mucosa), **diverticulitis** (mimics appendicitis, periumbilical referred pain), **intussusception/volvulus/obstruction, perforation, Littre's hernia**.
- ▶ Vitelline cyst risk = **volvulus around persisting fibrous vitelline ligaments**; vitelline fistula = **umbilical faecal discharge**; vitelline sinus/polyp = **mucous discharge ± raspberry-red umbilical polyp**.
- ▶ Modern work-up of a symptomatic case: ^{99m}Tc-pertechnetate ("Meckel's") scan for ectopic gastric mucosa; management is now usually **laparoscopic diverticulectomy/segmental resection**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Langman's Medical Embryology (Sadler) 14e; Larsen — Human Embryology 6e; Moore's Clinically Oriented Anatomy 9e; BD Chaurasia — Human Anatomy Vol 2 8e; AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen); Sontakke — Textbook of Human Embryology; Vishram Singh — Textbook of Clinical Embryology.



Phrenic nerve

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction — The **phrenic nerve** is a **mixed (motor and sensory)** nerve arising chiefly from the **fourth cervical ventral ramus**, with contributions from the **third and fifth cervical ventral rami** (root value C3, C4, C5). It is the **sole motor nerve supply of its own hemidiaphragm** and also carries sensory fibres from the diaphragm, mediastinal pleura, fibrous pericardium and parts of the peritoneum. Formed high in the neck but travelling all the way to the thoraco-abdominal junction, its unusually long course and cervical root value are both explained by the embryological origin of the diaphragm opposite the cervical somites. It is of major clinical importance because of its vulnerability along this course (neck surgery, cardiothoracic surgery), the referred pain pattern it produces, and its role in hiccups and diaphragmatic paralysis.

1. Origin and formation

- ▶ **Root value:** chiefly the **fourth cervical (C4) ventral ramus**, with variable contributions from C3 and C5.
- ▶ **Site of formation:** at the **upper part of the lateral border of scalenus anterior**, opposite the middle of the **sternocleidomastoid**, at the level of the **upper border of the thyroid cartilage**.
- ▶ **Accessory phrenic nerve:** C5 fibres may reach the diaphragm indirectly via the **nerve to subclavius** instead of joining the phrenic nerve directly. This separate bundle lies **lateral to the phrenic nerve**, descends posterior (occasionally anterior) to the subclavian vein, and usually **joins the main nerve near the first rib** (occasionally not until near the pulmonary hilum). Its clinical importance: crushing/blocking only the main trunk in the neck may fail to produce complete diaphragmatic paralysis if a substantial accessory phrenic nerve is present.

2. Course and relations in the neck

- ▶ Formed at the lateral border of scalenus anterior, the nerve runs **vertically downward on the anterior surface of scalenus anterior**, deep to the **prevertebral fascia**; because the muscle runs obliquely, the nerve appears to cross it obliquely from its lateral to its medial border.
- ▶ **Anterior relations** in this part of its course: prevertebral fascia, the **inferior belly of omohyoid**, the **transverse cervical** and **suprascapular arteries**, the **internal jugular vein**, **sternocleidomastoid**, and — on the **left side only** — the **thoracic duct**.
- ▶ At the root of the neck it passes **anterior to the second part of the subclavian artery** (separated from it by scalenus anterior) and **posterior to the subclavian vein** — a key front-to-back relation (vein in front, nerve behind, artery deep to scalenus anterior) exploited surgically and in regional anaesthesia.
- ▶ **Right vs left in the neck:** the two nerves are often symmetrical, but the **left phrenic nerve** commonly leaves the **medial edge of scalenus anterior** and crosses **anterior to the first part of the left subclavian artery**, whereas the right nerve typically stays lateral to scalenus anterior until it reaches the thoracic inlet.
- ▶ The nerve enters the thorax by crossing **medial to the internal thoracic artery**, behind the first costal cartilage.

3. Course and relations in the thorax

Once inside the thorax, the right and left phrenic nerves diverge in their relations because of the asymmetry of the mediastinum.

Feature	Right phrenic nerve	Left phrenic nerve
Length/direction	Shorter, more vertical	Longer, more oblique course
Great vessel relation	Descends lateral to the right brachiocephalic vein and the superior vena cava	Passes anterior to the first part of the left subclavian artery , posterior to the thoracic duct , then crosses anterior to the left internal thoracic artery
Relation to aortic arch/pulmonary hilum	Passes over the fibrous pericardium covering the right atrium and IVC	Crosses the medial aspect of the apex of the left lung , then superficial to the aortic arch and the left superior intercostal vein , anterior to the left pulmonary hilum
Pericardial relation	Divides just superior to, or at, the diaphragm	Lies between the fibrous pericardium (over the left ventricle) and the mediastinal pleura

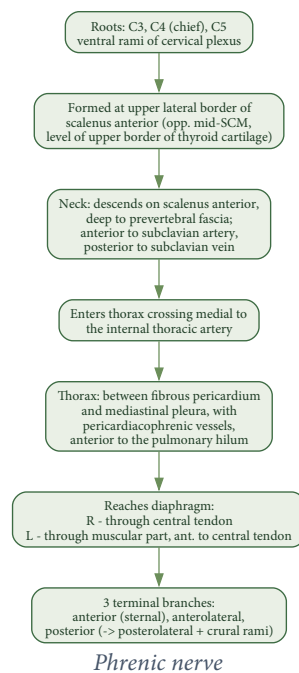
- In both cases the nerve descends **between the fibrous pericardium and the mediastinal pleura, anterior to the pulmonary hilum** (the vagus nerve and pulmonary plexus lie posterior to the hilum), accompanied throughout by the **pericardiophrenic vessels**.
- **Thoracic sensory branches:** each nerve supplies the **mediastinal pleura**, the **fibrous pericardium**, and the **parietal serous pericardium**.

□ Fig 12.12 — Phrenic nerve: A. Formation, course and distribution of phrenic nerve proper, B. Accessory phrenic nerve (Vishram Singh — Textbook of Anatomy Vol 3 — 4e, p.533)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the right and left phrenic nerves descending through the neck and mediastinum to the diaphragm, and label:

- ▶ **Roots of formation:** C3, C4, C5 ventral rami (converging just above scalenus anterior), on both sides
- ▶ **Right lung and left lung**, each with the nerve running along its mediastinal surface
- ▶ **Mediastinal pleura** (nerve related anteriorly)
- ▶ **Pericardium** (fibrous pericardium, over which the nerve descends)
- ▶ **Diaphragmatic pleura**
- ▶ **Diaphragm**, with the nerve piercing/terminating in it
- ▶ **Subdiaphragmatic peritoneum**, receiving terminal sensory twigs
- ▶ A separate inset showing the **accessory phrenic nerve**: nerve to subclavius (C5, C6), subclavius muscle, subclavian vein, and the accessory phrenic nerve joining the main phrenic nerve trunk



4. Termination, diaphragmatic branches and phrenic ganglia

- ▶ **Diaphragmatic entry point** differs on the two sides: the **right phrenic nerve** passes through the **central tendon** (through the caval hiatus or just lateral to it); the **left phrenic nerve** passes through the **muscular part of the diaphragm anterior to the central tendon**, just lateral to the left cardiac surface — and is therefore **more anterior** than the right nerve at this level.
- ▶ At, or just superior to, the diaphragm each nerve gives fine branches to the **parietal pleura** above and the **parietal peritoneum** below the central diaphragm, then divides into **three main branches**:

- ▶ An **anterior (sternal) branch**, running anteromedially toward the sternum and anastomosing with its fellow of the opposite side.
- ▶ An **anterolateral branch**, running to the lateral leaf of the central tendon.
- ▶ A short **posterior branch**, which itself divides into a **posterolateral ramus** (passing posterior to the lateral leaf) and a **posterior (crural) ramus** supplying the crural fibres.
- ▶ These branches carry **motor fibres to the diaphragmatic muscle**, **sensory fibres to the pleura and peritoneum related to the central diaphragm**, and **proprioceptive fibres** from the diaphragmatic musculature.
- ▶ **Crural supply is bilateral for the right crus**: the **right phrenic nerve** supplies the part of the **right crus** lying to the **right of the oesophagus**, while the **left phrenic nerve** supplies the **left crus** and the part of the **right crus** lying to the **left of the oesophagus**.
- ▶ **Phrenic ganglia**: the right phrenic nerve continuing below the diaphragm frequently connects to a **right phrenic ganglion** (with plexiform communications to the **coeliac** and **aorticorenal ganglia** and the **right suprarenal gland**); a left phrenic ganglion is less common. Through these communications the phrenic nerve also contributes sensory fibres to the **falciform and coronary ligaments of the liver**, the **inferior vena cava**, the **suprarenal glands**, and the **gallbladder** — the anatomical basis of diaphragmatic/hepatobiliary referred pain. Surgeons repairing a hiatus hernia must place crural sutures **superior to these ganglia** to avoid injuring the autonomic supply of the diaphragm and abdomen.

5. Functional distribution — motor and sensory summary

Component	Distribution
Motor	Sole motor supply to the ipsilateral hemidiaphragm (costal and crural parts)
Sensory — thorax	Mediastinal pleura, fibrous pericardium, parietal serous pericardium
Sensory — diaphragm/abdomen	Central diaphragmatic (parietal) pleura and peritoneum; falciform/coronary ligaments of liver (via coeliac plexus communications)
Proprioceptive	Diaphragmatic musculature
Peripheral (non-phrenic) diaphragmatic pleura/peritoneum	Supplied instead by the lower 6–7 intercostal nerves — clinically important, as it explains the two different patterns of referred pain from the diaphragm

6. Embryological basis of its course and root value

- ▶ The diaphragm begins development **opposite the cervical somites (C3–C5)** in the **fourth week**, from the **septum transversum**, **pleuroperitoneal membranes**, the **dorsal oesophageal mesentery**, and myoblasts migrating in from these cervical somites.
- ▶ Because muscle and nerve fibres for the diaphragm originate at cervical level, the phrenic nerve is derived from the **C3, C4 and C5 ventral rami** — summarised in the teaching mnemonic "**C3, 4, 5 keep the diaphragm alive.**"

- ▶ From the **sixth week** onward, faster growth of the dorsal part of the embryo (brain and vertebral column) relative to the ventral part carries the diaphragm **caudally and ventrally** to its adult thoraco-abdominal position, dragging the phrenic nerve along with it — which is why the nerve must traverse the entire length of the neck and thorax to reach a structure that lies at the T8–T10 level in the adult.
- ▶ The **common cardinal veins and phrenic nerves** become incorporated into the **pleuropericardial folds/membranes**, explaining the constant relation of the adult phrenic nerve to the fibrous pericardium.

Applied / Clinical anatomy

- ▶ **Referred pain:** irritation of the **central diaphragmatic pleura or peritoneum** (phrenic territory) is referred to the **C3–C4 dermatome** — the **shoulder tip**, via the supraclavicular nerves, which share the same root value as the phrenic nerve. Classic causes: **subphrenic abscess**, **gallbladder disease** (right shoulder tip pain), **splenic rupture** (left shoulder tip pain — Kehr's sign), and haemoperitoneum from a ruptured ectopic pregnancy. Irritation of the **peripheral diaphragm** (intercostal nerve territory) instead produces localised pain over the costal margin.
- ▶ **Hiccups (singultus):** involuntary, spasmodic contraction of the diaphragm from irritation of the phrenic nerve, its central connections, or the diaphragm itself — causes include indigestion, subphrenic abscess, alcoholism, and central/peripheral lesions disturbing the phrenic pathway.
- ▶ **Diaphragmatic (hemidiaphragm) paralysis:** section, crush, stretching or compression of a phrenic nerve anywhere along its course causes complete paralysis (and eventual atrophy) of the corresponding hemidiaphragm, unless a substantial accessory phrenic nerve is spared. Radiologically it shows a **permanently elevated dome** and **paradoxical movement** on fluoroscopic "**sniff testing**" (the paralysed dome rises, rather than descends, on sniffing, as it is pushed up by the abdominal viscera compressed by the active contralateral dome).
 - **Unilateral causes:** bronchogenic carcinoma/Pancoast tumour, mediastinal lymphadenopathy, cervical or thoracic trauma, and iatrogenic injury during cardiothoracic surgery (CABG, cold cardioplegia, pericardiectomy), thymectomy, neck dissection, or an interscalene brachial plexus/cervical plexus block.
 - **Bilateral causes:** high cervical spinal cord transection **above the C3–C5 segmental origin** of the phrenic nerves is rapidly fatal (loss of both diaphragmatic and intercostal function); Guillain–Barré syndrome may progress to involve the phrenic and intercostal nerves, producing respiratory failure.
 - **Eventration of the diaphragm** — a congenital focal thinning and bulging of the muscular diaphragm, typically on the left — can mimic paralysis radiologically but is distinguished on sniff testing by normal movement of the posterior part of the same dome.
- ▶ **Iatrogenic phrenic nerve block/crush:** a **phrenic nerve block** (anaesthetic infiltration where the nerve lies on the anterior surface of the middle third of scalenus anterior) produces short-lived unilateral diaphragmatic paralysis (historically used before lung surgery); a **surgical phrenic nerve crush** gives longer paralysis (used after diaphragmatic hernia repair); an accessory phrenic nerve must also be crushed/blocked to achieve complete paralysis.

- **Surgical/interventional relevance:** at risk during interscalene/cervical plexus blocks (routinely paralyses the ipsilateral hemidiaphragm — avoided in patients with poor pulmonary reserve), central line placement, cardiac surgery (internal thoracic artery harvest, cold cardioplegia), pericardiectomy, mediastinal node dissection, and lung transplantation. During diaphragmatic surgery, **radial incisions** (costal margin to oesophageal hiatus) risk cutting the main branches and are avoided in favour of **circumferential thoraco-abdominal incisions**.
- **Management of established paralysis:** partial dysfunction — conservative (non-invasive ventilation, physiotherapy); persistent symptomatic complete paralysis (especially infants after cardiac surgery) — **diaphragmatic plication**; select traumatic/iatrogenic or cervical-cord-injury cases — **phrenic nerve reconstruction/grafting** or **diaphragmatic pacing** (phrenic nerve stimulation), the latter requiring pre-implantation **nerve conduction studies** to confirm integrity.

Recent advances

According to PubMed, several recent studies extend classical phrenic nerve anatomy into contemporary diagnostic and therapeutic practice:

- **Point-of-care diaphragm and phrenic nerve ultrasound** has become a validated bedside technique to assess diaphragmatic excursion and thickening fraction, diagnose diaphragm dysfunction, and monitor recovery — a role that expanded markedly during the COVID-19 pandemic for ventilated patients with suspected phrenic/diaphragmatic involvement (Patel et al, *J Ultrasound Med* 2021) [PMID: 33772850].
- A state-of-the-art review confirms that **phrenic nerve injury causing diaphragm dysfunction is a recognised complication of cardiac surgery**, particularly after coronary artery bypass grafting, and that diaphragm ultrasound is now central to its bedside diagnosis and to predicting weaning from mechanical ventilation (Faysoil et al, *Medicines* 2022) [PMID: 35049938].
- A large single-centre series of 2,280 paediatric cardiac operations found **phrenic-nerve-injury-related diaphragm paralysis in 4.7% of cases** (partial 2.9%, complete 1.8%), more often on the left, with male sex and an open sternum as independent predictors of complete paralysis — reinforcing the nerve's vulnerability during mediastinal dissection near the great vessels (Shahzad et al, *J Saudi Heart Assoc* 2026) [PMID: 42094873].
- A multicentre randomised trial (STIMIT ACTIVATOR 1) is evaluating **non-invasive magnetic phrenic nerve stimulation** to preserve diaphragm thickness and prevent ventilator-induced diaphragmatic dysfunction in critically ill mechanically ventilated patients, reflecting growing interest in phrenic-nerve-based neuromodulation for diaphragm preservation (Schreiber et al, *Trials* 2025) [PMID: 40500715].
- A retrospective series of **phrenic nerve reconstruction in nine paediatric patients** with symptomatic diaphragm paralysis (from birth trauma, cervical cord injury, mediastinal tumour and other causes) showed improvement in nearly all unilateral cases on sniff testing, pulmonary function and electrodiagnostic testing, supporting nerve reconstruction as a treatment option distinct from plication (Kaufman et al, *Eur J Pediatr Surg* 2025) [PMID: 39933731].
- A cadaveric case report describes an **aberrant suprascapular artery coexisting with an atypically formed phrenic nerve and an unusual phrenic–long thoracic nerve interconnection**,

underscoring the continued clinical relevance of documenting phrenic nerve anatomical variants for surgeons and interventionists working in the supra- and infraclavicular regions (Tsakotos et al, *Cureus* 2023) [PMID: 37790061].

(According to PubMed; DOIs: [10.1002/jum.15706](https://doi.org/10.1002/jum.15706), [10.3390/medicines9010005](https://doi.org/10.3390/medicines9010005), [10.37616/2212-5043.1486](https://doi.org/10.37616/2212-5043.1486), [10.1186/s13063-025-08838-2](https://doi.org/10.1186/s13063-025-08838-2), [10.1055/a-2536-4405](https://doi.org/10.1055/a-2536-4405), [10.7759/cureus.44571](https://doi.org/10.7759/cureus.44571).)

High-yield exam pointers

- ▶ Root value C3, C4, C5 (C4 chief contributor); **mixed nerve** — sole motor supply to the hemidiaphragm, plus sensory/proprioceptive fibres.
- ▶ Formed at the **upper lateral border of scalenus anterior**, opposite mid-sternocleidomastoid, at the level of the **upper border of the thyroid cartilage**.
- ▶ In the root of the neck: **anterior to the subclavian artery, posterior to the subclavian vein** (vein in front, nerve behind, artery deepest).
- ▶ **Right nerve**: shorter, more vertical, passes through the **central tendon**. **Left nerve**: longer, crosses the aortic arch, passes through the **muscular diaphragm anterior to the central tendon** — more anterior than the right at diaphragmatic level.
- ▶ **Three diaphragmatic branches**: anterior (sternal), anterolateral, and posterior (→ posterolateral + crural rami).
- ▶ **Right phrenic** → **right crus (right of oesophagus)**; **left phrenic** → **left crus + part of right crus (left of oesophagus)**.
- ▶ **Referred pain to the shoulder tip** (C3, C4 dermatome via supraclavicular nerve) from central diaphragmatic pleura/peritoneum irritation — subphrenic abscess, biliary disease, splenic rupture (Kehr's sign).
- ▶ **Accessory phrenic nerve** (from C5 via nerve to subclavius) must also be interrupted to produce complete diaphragmatic paralysis.
- ▶ Diaphragmatic paralysis shows **elevated hemidiaphragm with paradoxical movement** on fluoroscopic **sniff testing**; differentiate from congenital **eventration**.
- ▶ Embryological basis: diaphragm develops opposite C3–C5 **somites**, then descends, dragging the phrenic nerve with it — **"C3, 4, 5 keep the diaphragm alive."**

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia Human Anatomy Vol 2 8e and Vol 3-4 8e; Vishram Singh Textbook of Anatomy Vol 3 4e; Vishram Singh Clinical Neuroanatomy 4e; Moore's Clinically Oriented Anatomy 9e; Snell Clinical Neuroanatomy 7e; Langman's Medical Embryology (Sadler) 14e.



Porto– systemic anastomosis and clinical importance

Asked in: Paper IV May 2009 — RGUHS MD/MS Anatomy

Definition / Introduction The hepatic portal vein drains venous blood from the abdominal part of the gut tube (lower third of oesophagus to upper anal canal), spleen, pancreas and gallbladder into the liver, where it is filtered through the hepatic sinusoids before reaching the systemic (caval) circulation. At several constant sites, radicles of this valveless portal system communicate directly with tributaries of the systemic venous system — these communications are called **porto-systemic (porto-caval) anastomoses**. Normally the flow through them is negligible, but whenever portal venous pressure rises (portal hypertension), these channels dilate, the direction of flow within them reverses, and they become important collateral pathways diverting portal blood into the systemic circulation. Their surgical, radiological and clinical importance — oesophageal varices, caput medusae, haemorrhoids, and the shunt operations used to decompress them — makes this a core applied-anatomy topic.

Portal Venous System — Formation, Course and Tributaries

- ▶ The **portal vein** is about **8 cm long**; it is formed behind the **neck of the pancreas**, at the level of the **second lumbar vertebra**, by the union of the **superior mesenteric vein** and the **splenic vein**; the **inferior mesenteric vein** usually drains into the splenic vein.
- ▶ It ascends behind the first part of the duodenum and then in the right free margin of the lesser omentum to reach the porta hepatis, where it divides into a **shorter, wider right branch** and a **longer, narrower left branch**.
- ▶ At the porta hepatis, from before backwards, lie the **bile duct**, the **hepatic artery**, and the **portal vein** (vein is the most posterior structure).
- ▶ Tributaries: left and right gastric veins, splenic vein (receiving short gastric, pancreatic and inferior mesenteric tributaries), superior mesenteric vein, superior pancreaticoduodenal vein, cystic vein (into the right branch), and paraumbilical veins (into the left branch, running in the ligamentum teres).
- ▶ **Streamline flow**: superior mesenteric venous blood preferentially perfuses the right lobe, while splenic/inferior-mesenteric blood perfuses the left lobe — clinically, toxin/infection-laden blood from the gut (e.g. amoebic infection) tends to produce right-lobe abscesses, while nutrient-poor blood favours left-lobe fibrosis.
- ▶ The portal vein contributes about **80% of total hepatic blood flow**, the hepatic artery the remaining **20%**.
- ▶ Normal portal venous pressure is **5–15 mmHg** (measured by splenic puncture/intrasplenic pressure); sustained portal hypertension is caused chiefly by **cirrhosis of the liver**, **Banti's disease** (splenomegaly with hypersplenism from portal venous obstruction) and **portal vein thrombosis**.

Sites of Porto-systemic Anastomoses

Because the portal system has no valves, blood can reverse direction at any point where it communicates with the systemic system. The classical sites are:

Site	Portal tributary	Systemic tributary	Chief clinical result
Lower end of oesophagus	Left gastric vein (and short gastric veins via splenic vein)	Oesophageal veins → azygos & hemiazygos veins → superior vena cava	Oesophageal (and gastric) varices → haematemesis
Lower end of rectum / anal canal	Superior rectal vein → inferior mesenteric vein	Middle and inferior rectal veins → internal iliac / internal pudendal veins → inferior vena cava	Internal haemorrhoids (rectal varices), bleeding per rectum
Umbilicus (anterior abdominal wall)	Paraumbilical veins running in the ligamentum teres, joining the left branch of the portal vein	Above: superior epigastric & lateral thoracic veins. Below: superficial & inferior epigastric veins. Sides: posterior intercostal & lumbar veins	Caput medusae
Bare area of the liver	Portal radicles (hepatic venules)	Diaphragmatic (phrenic) veins	Minor; surgically relevant retroperitoneal anastomoses
Posterior abdominal wall (retroperitoneal, near hepatic & splenic flexures) — veins of Retzius	Colic veins of ascending/descending colon; splenic tributaries	Renal, lumbar, phrenic, azygos and hemiazygos veins	Retroperitoneal varices; hazard during colonic/renal surgery
Falciform ligament	Paraumbilical vein — accessory portal system of Sappey	Diaphragmatic veins	Minor collateral channel
Fissure for the ligamentum venosum	Left branch of portal vein (remnant of the fetal ductus venosus)	Inferior vena cava	Patent ductus venosus — a rare congenital porto-caval shunt

The **three most clinically important sites** are the lower oesophagus, the anal canal and the umbilicus — these alone account for the classical triad of oesophageal varices, haemorrhoids and caput medusae seen in portal hypertension.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

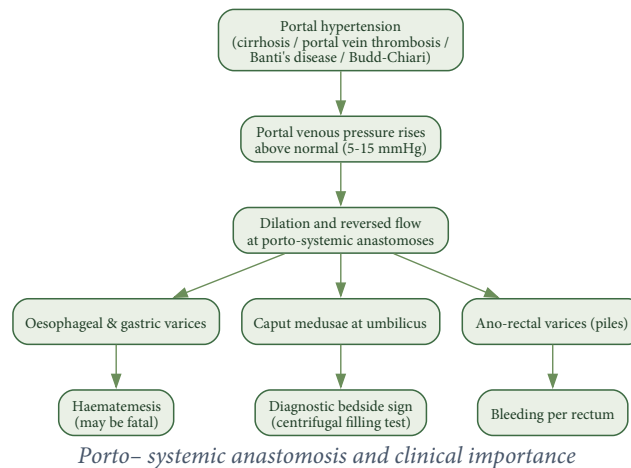
□ Fig 21.17 — Sites of portosystemic anastomoses (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.362)

Reproduce a simple outline of the trunk (diaphragm to pelvis) and label, at their correct level:

- ▶ Bare area of liver (upper pole, against the diaphragm)
- ▶ Lower end of oesophagus (piercing the diaphragm)
- ▶ Umbilicus (mid-anterior abdominal wall)
- ▶ Anterior aspect of kidney / posterior abdominal wall (retroperitoneal, mid-level)
- ▶ Anal canal (lowest point, at the pelvic floor)

Draw a short double-headed arrow at each labelled point to indicate the meeting of a portal and a systemic radicle.

Portal Hypertension — Mechanism and Consequences



- ▶ **Congestive splenomegaly** and **ascites** are the other two cardinal effects of portal hypertension besides the collateral triad above.
- ▶ **Oesophageal varices** are the most dangerous manifestation — the veins lie in loose submucosa with minimal surrounding support, so rupture produces sudden, often fatal, haematemesis; this is the single most common cause of death in decompensated cirrhosis.
- ▶ **Caput medusae** — dilated, tortuous paraumbilical veins radiating from the umbilicus "like the spokes of a wheel." On emptying a segment by digital pressure and releasing it, refilling occurs in a **centrifugal direction** (away from the umbilicus), confirming a portal (rather than a caval-obstruction) origin.
- ▶ **Internal haemorrhoids** develop from dilated radicles of the superior rectal vein above the pectinate line — visceral innervation, hence painless unlike external (systemic-vein) piles.

Surgical and Radiological Porto-systemic Shunts

- ▶ **Portacaval shunt ("Eck's fistula" operation)**: the splenic vein (or the main portal trunk) is anastomosed with the left renal vein or the inferior vena cava, with or without splenectomy, to divert portal blood directly into the systemic circulation and lower portal pressure.

- ▶ **Spleno-renal anastomosis:** a more selective decompression achieved by anastomosing the splenic vein to the left renal vein.
- ▶ **Transjugular Intrahepatic Porto-systemic Shunt (TIPS):** a catheter is passed via the internal jugular vein through the superior vena cava, right atrium and inferior vena cava into a hepatic vein; under radiological guidance a needle/balloon punctures across a strip of liver parenchyma to reach a dilated portal vein branch, and a stent is deployed to create a direct intrahepatic tract linking the hepatic vein to the portal vein — a minimally invasive alternative to open shunt surgery for refractory variceal bleeding or ascites.
- ▶ Sound knowledge of the porta hepatis, hepatic vein/segment anatomy and the relations of the portal vein is essential for safely performing and interpreting these procedures.

Applied / Clinical anatomy

- ▶ **Oesophageal varices:** bleeding is managed endoscopically (banding/sclerotherapy) precisely because the veins are confined to the submucosa of the lower oesophagus, a site with no protective serosal covering.
- ▶ **Caput medusae:** an important bedside sign of portal hypertension; the direction-of-flow (centrifugal-filling) test differentiates it from the caudo-cranial flow of inferior-vena-caval obstruction.
- ▶ **Haemorrhoids:** internal piles (above the pectinate line, portal/visceral) are distinguished clinically from external piles (below the line, systemic/somatic) partly on the basis of these anastomotic sites.
- ▶ **Retroperitoneal (veins of Retzius) and bare-area anastomoses** are of largely surgical significance — they may bleed troublesomely during mobilisation of the colon, kidney or liver in patients with unsuspected portal hypertension.
- ▶ **Banti's disease / extrahepatic portal venous obstruction** is an important paediatric cause of variceal bleeding with a normal liver, relevant to the differential diagnosis of portal hypertension in children.
- ▶ Awareness of these anastomotic sites underlies the choice of **surgical or TIPS decompression** described above, and explains the **streamline-flow** correlation between superior mesenteric venous drainage and right-lobe amoebic liver abscess.

High-yield exam pointers

- ▶ Portal vein = union of **superior mesenteric + splenic vein**, behind the **neck of pancreas**, at L2, ~8 cm long; divides into right/left branches at the porta hepatis.
- ▶ The portal system is **valveless** — this is why flow can reverse at anastomotic sites when portal pressure rises.
- ▶ **Three classical sites:** lower oesophagus, anal canal, umbilicus — giving the triad of **oesophageal varices, haemorrhoids and caput medusae**.
- ▶ Additional sites: bare area of liver, posterior abdominal wall (veins of Retzius), falciform ligament (portal system of Sappey), and the fissure for the ligamentum venosum.
- ▶ **Caput medusae** shows **centrifugal** filling on the emptying test — confirms portal origin.
- ▶ **Oesophageal varices** → **haematemesis** is the most lethal consequence of portal hypertension.

- Decompression: surgical — **portacaval / spleno-renal shunt (Eck's fistula)**; radiological — **TIPS**.
- Portal vein supplies ~80% of hepatic blood flow; hepatic artery supplies the remaining ~20%.
- Streamline flow: superior mesenteric blood → right lobe (amoebic abscess); splenic/inferior mesenteric blood → left lobe (fibrosis).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2, 8e; AK Datta — Human Anatomy Vol 1 (Thorax & Abdomen); Vishram Singh — Textbook of Anatomy Vol 2, 4e; IB Singh — Textbook of Anatomy Vol 2, 6e.



Surgical anatomy of inguinal canal

Asked in: Paper IV Nov 2018 — RGUHS MD/MS Anatomy

Definition / Introduction The inguinal canal is an obliquely placed intermuscular passage, about 4 cm long, in the lower part of the anterolateral abdominal wall, just above the medial half of the inguinal ligament. It extends from the deep (internal) inguinal ring laterally to the superficial (external) inguinal ring medially and transmits the spermatic cord in the male (round ligament of the uterus in the female) together with the ilioinguinal nerve. It is the persisting track of the gubernaculum and processus vaginalis along which the gonad descended, and it forms a mechanically reinforced but nonetheless inherent zone of weakness. Surgically, the canal and the femoral sheath below it together form one continuous gap in the musculo-aponeurotic wall — the **myopectineal orifice of Fruchaud** — through which every variety of groin hernia (indirect, direct and femoral) protrudes, so its walls, rings and posterior-wall reinforcements are the anatomical basis of open and laparoscopic hernia repair.

Location, extent and boundaries

Feature	Description
Location	Lower part of the anterolateral abdominal wall, just above the medial half of the inguinal ligament
Extent	Deep inguinal ring (lateral) to superficial inguinal ring (medial)
Length	~4 cm (1.5 in) in the adult; Gray's gives a range of 3–6 cm, and the canal is only ~1 cm long in an infant undergoing hernia repair
Direction	Downwards, forwards and medially
Sex difference	Larger in the male (transmits the bulkier spermatic cord)

Wall	Composition
Anterior wall	Skin, superficial fascia and the aponeurosis of external oblique throughout its whole extent; reinforced in the lateral one-third by the fleshy fibres of internal oblique
Posterior wall	Fascia transversalis, extraperitoneal tissue and parietal peritoneum throughout; reinforced in the medial two-thirds by the conjoint tendon, and at the extreme medial end by the reflected part of the inguinal ligament
Roof	Arched fibres of internal oblique and transversus abdominis, fusing medially to form the conjoint tendon
Floor	Grooved, gutter-like upper surface of the inguinal ligament; reinforced medially by the lacunar ligament

Because each wall is strongest exactly where the opposite wall is weakest, the canal is not a simple straight tube but an obliquely overlapping "shutter" — a key surgical fact, since a hernia repair must recreate this overlap rather than merely closing a hole.

Inguinal rings

- **Deep (internal) inguinal ring** — oval opening (~1–2 cm wide) in the fascia transversalis, ~1–1.2 cm above the mid-inguinal point (midpoint of ASIS–pubic symphysis line), immediately lateral to the inferior epigastric vessels. Related medially to the **interfoveolar ligament**, guarded anteriorly by internal oblique, gives origin to the internal spermatic fascia. (Not to be confused with the midpoint of the inguinal ligament — ASIS to pubic tubercle — which marks the femoral artery.)
- **Superficial (external) inguinal ring** — triangular hiatus in the external oblique aponeurosis above the pubic crest, ~2.5 cm × 1.2 cm at the base (pubic crest). Lateral crus → pubic tubercle, medial crus → pubic symphysis/crest, held together at the apex by **intercrural fibres**; gives origin to the external spermatic fascia.

Contents of the canal and the spermatic cord

- **Spermatic cord (male) or round ligament of the uterus (female)** — enters through the deep ring, leaves through the superficial ring.
- **Ilioinguinal nerve** — enters the canal through the interval between external and internal oblique (not through the deep ring), lies on the outer aspect of the cord, and leaves through the superficial ring; it is the only content that does not lie within the substance of the cord proper.

Constituents of the spermatic cord ("3-3")	Structures
3 arteries	Testicular artery, artery to the ductus (vas) deferens, cremasteric artery

Constituents of the spermatic cord ("3-3")	Structures
3 nerves	Genital branch of the genitofemoral nerve, sympathetic plexus around the artery to the vas, visceral afferents
3 others	Ductus deferens, pampiniform plexus of veins, remnant of the processus vaginalis

Coverings of the cord (within out)	Derived from
Internal spermatic fascia	Fascia transversalis — covers the cord throughout its length
Cremasteric fascia (+ cremaster muscle)	Internal oblique and transversus abdominis — covers the cord below the level of these muscles
External spermatic fascia	External oblique aponeurosis — covers the cord below the superficial ring

The cremaster is supplied by the genital branch of the genitofemoral nerve (L1); stroking the medial thigh skin elicits the **cremasteric reflex**, lost in upper motor neuron lesions above L1 — a bedside test of L1 integrity that is also relevant when planning inguinal incisions.

Mechanisms preventing herniation

- ▶ **Obliquity / flap-valve mechanism** — the deep and superficial rings do not lie directly opposite each other, so a rise in intra-abdominal pressure approximates the anterior and posterior walls, obliterating the canal.
- ▶ **Guarding of the superficial ring** from behind by the conjoint tendon and reflected part of the inguinal ligament; **guarding of the deep ring** from the front by the fleshy fibres of internal oblique.
- ▶ **Shutter mechanism of internal oblique** — forming the anterior wall (laterally), the roof and part of the posterior wall, its contraction approximates roof to floor, assisted by transversus abdominis; the conjoint tendon is, in fact, tonically active during standing, increasing further with any rise in intra-abdominal pressure.
- ▶ **Ball-valve action of the cremaster** plugs the superficial ring on contraction; **slit-valve action of external oblique** approximates the two crura, reinforced by the intercrural fibres.
- ▶ Hormonal tone of the inguinal musculature is also believed to contribute.

Failure of these mechanisms — congenital (persistent processus vaginalis) or acquired (posterior-wall weakening) — is the anatomical basis of inguinal hernia.

Hesselbach's triangle and inguinal hernia

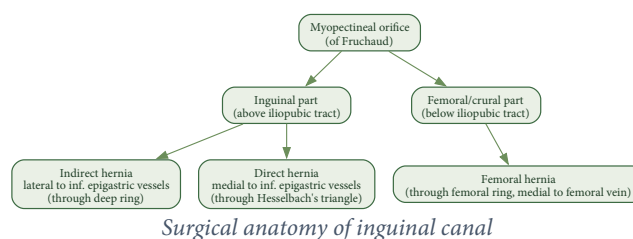
Hesselbach's (inguinal) triangle, the surgical landmark for direct herniation, is bounded:

- ▶ laterally by the **inferior epigastric vessels**,
- ▶ medially by the **lateral border of rectus abdominis**, and
- ▶ inferiorly by the **medial part of the inguinal ligament**.

The obliterated umbilical artery running along its floor further subdivides it into medial and lateral compartments.

Feature	Indirect (oblique) hernia	Direct hernia
Aetiology	Preformed sac — persistent processus vaginalis	Acquired weakness of the posterior wall (Hesselbach's triangle)
Relation to inferior epigastric vessels	Lateral	Medial
Path	Through deep ring → canal → superficial ring; may descend into scrotum	Bulges directly forward through/near Hesselbach's triangle
Age group	Infants, children, young adults	Older men (precipitated by chronic cough/bronchitis, prostatic enlargement)
Neck of sac	Narrow	Wide
Obstruction/strangulation	Common (narrow neck)	Uncommon (wide neck)
On standing	Reappears from lateral to medial	Bulges straight forward
Internal (deep) ring occlusion test	Controlled by digital pressure on the deep ring	Not controlled — swelling persists
Coverings	Same layers as the cord — extraperitoneal tissue, internal spermatic fascia, cremasteric fascia, external spermatic fascia, skin	Extraperitoneal tissue, fascia transversalis (+ conjoint tendon medially), external spermatic fascia, skin

Clinically, the two can still closely resemble each other, and imaging or laparoscopic inspection is often needed in doubtful cases.



□ Fig 16.34 — Hesselbach's triangle (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.283)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Label a right inguinal region schematic (front view, with an inset viewed from within the abdomen):

- ▶ ASIS and pubic tubercle; mid-inguinal point marked
- ▶ Inguinal ligament (grooved floor) and deep inguinal ring, lateral to the inferior epigastric vessels
- ▶ Superficial inguinal ring — medial/lateral crura + intercrural fibres
- ▶ Conjoint tendon and arching internal oblique/transversus fibres (roof)
- ▶ Hesselbach's triangle — inferior epigastric vessels, lateral border of rectus abdominis, inguinal ligament
- ▶ Spermatic cord/round ligament in the canal, with the ilioinguinal nerve outside it
- ▶ Iliopubic tract, deep and parallel to the inguinal ligament
- ▶ Femoral sheath/ring below the tract, showing continuity with the myopectineal orifice

Surgical/operative anatomy

- ▶ **Myopectineal orifice of Fruchaud** — a single quadrilateral musculo-aponeurotic gap bounded medially by rectus abdominis/conjoint tendon, laterally by iliopsoas, above by the arching internal oblique/transversus fibres, and below by the pecten pubis (Cooper's ligament); the inguinal ligament and iliopubic tract span it centrally, dividing it into an upper (inguinal) part carrying the spermatic cord and a lower (femoral) part carrying the femoral vessels. Being one continuous orifice, tension-free mesh repairs (open preperitoneal, laparoscopic TAPP/TEP) are designed to cover it in its entirety.
- ▶ **Iliopubic tract** ("deep crural arch") — a thickening of the transversalis fascia parallel to, and deep to, the inguinal ligament, fanning laterally to the iliopsoas fascia and passing medially behind the conjoint tendon to the pubis. As the inguinal ligament itself is not seen from the peritoneal aspect, the iliopubic tract is the actual operative landmark identified in open and laparoscopic repair.
- ▶ **Space of Bogros** — the potential extraperitoneal space between transversalis fascia and parietal peritoneum, opened to place prosthetic mesh in preperitoneal, TAPP and TEP repairs.
- ▶ **Conjoint tendon and posterior-wall reconstruction** — Bassini held that a "radical cure of inguinal hernia" requires restoring the normal anatomical relationships of the hernial orifice; classical repairs approximate the conjoint tendon to the inguinal ligament/iliopubic tract behind the cord, reconstituting the structures whose weakness produced the direct hernia.
- ▶ **Inferior epigastric vessels** are the key intraoperative landmark separating direct (medial) from indirect (lateral) hernia, and must be protected during dissection around the deep ring, along with the ilioinguinal nerve and genital branch of the genitofemoral nerve.

Applied / Clinical anatomy

- ▶ **Processus vaginalis anomalies**: complete persistence → congenital indirect hernia; persistence limited to the canal → **encysted hydrocele of the cord**; narrow persistent communication →

congenital/infantile hydrocele. Undescended testis may arrest anywhere along the canal; **varicocele** is a palpable dilatation of the pampiniform plexus.

- ▶ **Femoral vs inguinal hernia:** pubic tubercle is the key landmark — inguinal hernia lies above-medial to it, femoral below-lateral. Femoral hernias are far commoner in women (~20% of groin hernias vs <1% in men) due to a wider pelvis/femoral ring, and strangulate more readily.
- ▶ **Surface marking/anaesthetic block:** iliohypogastric and ilioinguinal nerves are blocked by a needle above the anterior superior iliac spine along the spino-umbilical line; the deep ring lies ~1–1.2 cm above the mid-inguinal point, the superficial ring just above-lateral to the pubic tubercle.

High-yield exam pointers

- ▶ Canal ≈ 4 cm, deep ring → superficial ring, downwards-forwards-medially, above the medial half of the inguinal ligament.
- ▶ Anterior wall = EO aponeurosis (+ IO laterally); posterior wall = fascia transversalis (+ conjoint tendon medially); roof = arching IO + transversus; floor = grooved inguinal ligament (+ lacunar ligament medially).
- ▶ Deep ring: oval, fascia transversalis, ~1–1.2 cm above mid-inguinal point, lateral to inferior epigastric vessels.
- ▶ Hesselbach's triangle = inferior epigastric vessels + lateral border of rectus abdominis + inguinal ligament — site of direct hernia.
- ▶ Direct hernia is medial to the inferior epigastric vessels (acquired, wide neck, elderly); indirect is lateral (patent processus vaginalis, narrow neck, young).
- ▶ Coverings of cord/indirect sac: internal spermatic fascia → cremasteric fascia → external spermatic fascia (from fascia transversalis, IO+transversus, EO aponeurosis respectively).
- ▶ Myopectineal orifice of Fruchaud (spanned by inguinal ligament/iliopubic tract) is the anatomical basis of all groin hernias and the template for mesh repair; mesh is placed in the space of Bogros.
- ▶ Protective mechanisms: obliquity/flap valve, shutter of internal oblique, ball-valve of cremaster, slit-valve of intercrural fibres.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2 8e; Moore's Clinically Oriented Anatomy 9e; Vishram Singh — Textbook of Anatomy Vol 2 4e; IB Singh — Textbook of Anatomy Vol 2 6e.



Surgical anatomy of Palatine Tonsil

Asked in: Paper IV May 2019 — RGUHS MD/MS Anatomy

Definition / Introduction

The **palatine tonsils** are a paired, almond-shaped mass of subepithelial lymphoid tissue lodged in the **tonsillar fossa (sinus)** of the lateral wall of the oropharynx, between the palatoglossal and

palatopharyngeal arches. They form the largest and most conspicuous component of the circumpharyngeal **Waldeyer's ring** of mucosa-associated lymphoid tissue guarding the oropharyngeal isthmus. Their close relationship to the superior constrictor, the facial and internal carotid arteries, and the glossopharyngeal nerve makes the "bed of the tonsil" one of the most frequently tested and clinically hazardous planes in head and neck surgery, since **tonsillectomy** is among the commonest operations performed in otolaryngology.

Location, gross features and the tonsillar fossa

- ▶ The **tonsillar fossa (sinus)** is a triangular recess on each side of the oropharynx between the diverging **palatoglossal arch** (anterior pillar, containing palatoglossus) and **palatopharyngeal arch** (posterior pillar, containing palatopharyngeus); it lodges the tonsil and can be inspected directly through the open mouth.
- ▶ Each tonsil is **almond-shaped**, with two surfaces (medial, lateral), two borders (anterior, posterior) and two poles (upper, lower); its long axis runs downwards and backwards.
- ▶ **Anterior border** — palatoglossal arch/muscle; **posterior border** — palatopharyngeal arch/muscle; **upper pole** — soft palate; **lower pole** — tongue.
- ▶ **Medial (free) surface**: non-keratinized stratified squamous epithelium continuous with the oral mucosa; pitted by **10–20 crypts**, the largest being the **intratonsillar cleft** (recessus palatinus) in the upper part — often wrongly called the "supratonsillar fossa" though it lies *within*, not above, the tonsil; a remnant of the second pharyngeal pouch and the classical site of onset of a **peritonsillar abscess (quinsy)**. Two inconstant folds may overlie it: the **plica triangularis** (anteroinferior) and **plica semilunaris** (upper part of the sinus).
- ▶ **Lateral (deep) surface**: covered by a fibrous **hemicapsule** (extension of the pharyngobasilar fascia), loosely attached to the muscular pharyngeal wall except **anteroinferiorly**, where it is firmly bound to the tongue just in front of the palatoglossus–palatopharyngeus junction (the "**suspensory ligament**" of the tonsil) — this anchors the tonsil during swallowing and is where the tonsillar artery pierces the superior constrictor to enter the gland.
- ▶ **Size/age changes**: tonsils enlarge rapidly in early childhood, reach a maximum at puberty (**20–25 mm vertical × 10–15 mm transverse**), then undergo progressive **involution from puberty/age 14 onward**.

The tonsillar bed — deep relations (surgically vital)

The muscular/fascial "bed" of the tonsil, traversed layer by layer during dissection, is built up **from within outward** as follows:

Layer (deep to superficial)	Structure
1	Pharyngobasilar fascia (deep to the hemicapsule)
2	Superior constrictor of the pharynx, with palatopharyngeus
3	Buccopharyngeal fascia
4	Styloglossus (at the lower part of the fossa)

Layer (deep to superficial)	Structure
5 (most lateral)	Glossopharyngeal nerve

- Beyond the glossopharyngeal nerve lie the **facial artery** and its **tonsillar and ascending palatine branches**; the tortuous facial artery itself occasionally lies close to the pharyngeal wall at the lower tonsillar level.
- The **glossopharyngeal nerve** runs immediately lateral to the muscular wall of the fossa — at risk if the wall is breached, and commonly (temporarily) affected by postoperative oedema after tonsillectomy.
- The **internal carotid artery** lies approximately **2.5 cm (25 mm) posterolateral** to the tonsil; an elongated styloid process may occasionally deviate toward the tonsillar bed, and an **aberrant, medially looped internal carotid artery** can bring the vessel dangerously close to the fossa (see Recent advances).

□ Fig 34.6 — The tonsillar bed, sagittal section. (Gray's Anatomy — Standring — 41e, p.797)

Arterial supply

The tonsil is supplied by **five branches** of the external carotid artery, all entering its deep surface, branching within connective-tissue septa, and giving capillary loops to the follicles:

Artery	Parent vessel	Site of entry
Tonsillar artery (chief/largest)	Facial artery (occasionally ascending palatine)	Pierces superior constrictor at upper border of styloglossus; lower pole
Ascending palatine artery	Facial artery	Lower pole (posteriorly)
Dorsal lingual branches	Lingual artery	Lower pole (anteriorly)
Ascending pharyngeal artery	External carotid artery	Upper pole (posteriorly)
Greater and lesser palatine arteries	Descending palatine artery (from maxillary artery)	Upper pole

□ Fig 34.7 — The arterial supply to the palatine tonsil. (Gray's Anatomy — Standring — 41e, p.798)

Venous drainage, lymphatic drainage and nerve supply

- **Venous drainage:** one or more veins leave the deep surface of the tonsil, pierce the superior constrictor, and join the palatine, pharyngeal or facial veins. A large **paratonsillar (external palatine) vein** descends from the soft palate in loose areolar tissue lateral to the hemicapsule and crosses the tonsil before piercing the pharyngeal wall — an important surgical landmark, since haemorrhage from this vessel at the upper angle of the tonsillar fossa is a recognized complication of tonsillectomy; the tonsillar artery and its venae comitantes often lie within the palatoglossal fold and may bleed if the fold is damaged.
- **Lymphatic drainage:** unlike ordinary lymph nodes, the palatine tonsil has **no afferent lymphatics**. Fine lymphatic plexuses surround each follicle and form efferents that pierce the superior constrictor to drain **directly to the jugulodigastric (tonsillar) node**, or indirectly via the retropharyngeal nodes, into the upper deep cervical chain. The jugulodigastric node is characteristically enlarged and palpable in tonsillitis, projecting beyond the anterior border of

sternocleidomastoid 1–2 cm below the angle of the mandible — the commonest palpable neck swelling.

- **Nerve supply:** tonsillar branches of the **glossopharyngeal nerve** and of the **lesser palatine nerve** (maxillary nerve, via the pterygopalatine ganglion, without synapsing) intermingle around the tonsil to form the **circulus tonsillaris**, also supplying the soft palate and oropharyngeal isthmus. Because the tympanic branch of the glossopharyngeal nerve (Jacobson's nerve) supplies the middle-ear mucosa, tonsillitis, malignancy or post-tonsillectomy inflammation is classically accompanied by **referred otalgia**.

Microstructure and development

- The oropharyngeal (medial) aspect is lined by **non-keratinized stratified squamous epithelium** invaginating to form 10–20 branching crypts; patches of thinner **reticulated epithelium** (functionally akin to gut M-cells) permit direct antigen transport to underlying lymphocytes — total reticulated surface area is estimated at **~295 cm²** per tonsil.
- The parenchyma is supported by a fine reticulin (collagen type III) meshwork condensed into septa merging with the deep hemicapsule; **four lymphoid compartments** are recognized — follicles with germinal centres (B-cell proliferation; mantle zone of small lymphocytes facing the mucosa), extrafollicular T-cell areas with high endothelial venules, and the subepithelial capillary-rich zone. Unlike a lymph node, the tonsil shows **no cortico-medullary differentiation**.
- **Development:** the palatine tonsil develops from the **endoderm of the ventral part of the second pharyngeal pouch**; epithelial buds grow into the mesenchyme and are excavated to form the fossa and crypts. Lymphoid infiltration (mesodermal in origin) begins around the **fifth month**, organizing into follicles with T- and B-cell zones; the intratonsillar cleft is a possible epithelial remnant of the pouch.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Sagittal section through the tonsillar bed (label from medial to lateral): **Palatine tonsil** → **Tonsillar fascia (hemicapsule)** → **Superior constrictor of the pharynx** → **Palatoglossus and Palatopharyngeus (arches)** → **Glossopharyngeal nerve** → **Tonsillar branches of the facial/ascending palatine/ascending pharyngeal arteries** → **Tonsillar branch of the lesser palatine nerve** → **Pharyngeal fascia**. Alongside, draw the arterial supply diagram labelling: **External carotid artery** → **Facial artery** → **Tonsillar branch (chief) and Ascending palatine artery**; **Lingual artery** → **Dorsal lingual branches**; **External carotid artery** → **Ascending pharyngeal artery**; **Maxillary artery** → **Descending palatine artery** → **Lesser/greater palatine arteries**, all converging on the lower and upper poles of the tonsil.

Applied / Clinical anatomy

- **Peritonsillar space and quinsy:** the peritonsillar space lies between the superior constrictor and the tonsillar hemicapsule, around the tonsil between the pillars of the fauces; suppuration here is a **peritonsillar abscess (quinsy)**, classically beginning in the intratonsillar cleft, causing trismus, dysphagia, and uvular deviation to the opposite side. It is drained by incision at the most bulging

point, staying medial and superficial to avoid the internal carotid artery lying ~2.5 cm posterolateral.

- ▶ **Tonsillectomy:** indicated for recurrent/chronic tonsillitis, obstructive hypertrophy/sleep apnoea, recurrent peritonsillar abscess, or suspected neoplasm. Dissection proceeds in the plane of the fibrous hemicapsule; because the nerve supply is diffuse, it can be performed under local infiltration rather than nerve blocks. Structures at risk include the **paratonsillar vein** (upper-pole haemorrhage), the **glossopharyngeal nerve** (postoperative oedema/dysphagia), and — rarely but catastrophically — an **aberrant, medially displaced internal carotid artery** within the tonsillar bed.
- ▶ **Haemostasis:** post-tonsillectomy bleeding from the raw tonsillar bed is controlled by **removal of the clot** (re-exposing and ligating/cauterizing the bleeding point) rather than by encouraging clot formation — the tonsillar bed and the post-partum uterus are the two sites in the body where haemorrhage is classically checked this way.
- ▶ The palatine tonsil is the **commonest subsite of HPV-related oropharyngeal squamous cell carcinoma**; because efferent lymphatics drain directly to the jugulodigastric node, this node is the classical first echelon for metastasis and the anatomical basis of neck dissection in oncological management.
- ▶ **Waldeyer's ring** — the circumpharyngeal lymphoid ring comprising, anteroinferiorly, the **lingual tonsil**; laterally, the **palatine and tubal tonsils**; and posterosuperiorly, the **pharyngeal tonsil (adenoid)** (mnemonic: "PPLT — people have tonsils": Pharyngeal, Palatine, Lingual, Tubal).

Recent advances in the surgical anatomy of the palatine tonsil

- ▶ A 2023 meta-analysis (17 studies; 1,996 intracapsular vs 4,565 total-tonsillectomy patients) found **intracapsular (subcapsular) tonsillectomy** — preserving the fibrous hemicapsule instead of dissecting the extracapsular plane against the superior constrictor — significantly cut post-tonsillectomy haemorrhage (RR 0.36, 95% CI 0.16–0.81) versus conventional total tonsillectomy, directly exploiting the hemicapsule plane described above (Sedgwick et al., *OTO Open*, 2023, PMID 36998549).
- ▶ A 2025 paediatric cohort of >11,000 patients (2019–2024) confirmed lower post-operative bleeding-related ED visits/readmissions after intracapsular versus extracapsular tonsillectomy, reinforcing the clinical value of this hemicapsule-preserving plane (Kulich et al., *The Laryngoscope*, 2025).
- ▶ A 2024 CT-angiography study found tortuosity, kinking or coiling of the extracranial internal carotid artery in roughly two-thirds of vessels examined, confirming that a **medially looped/aberrant internal carotid artery** can lie unexpectedly close to the tonsillar fossa — a recognised, occasionally fatal hazard in tonsillectomy, adenoidectomy and quinsy drainage, prompting proposed pre-operative clinicoradiologic grading of at-risk vessels (*Surgical and Radiologic Anatomy*, 2024, PMID 38926226).
- ▶ A 2025 study of **unilateral versus bilateral transoral robotic surgery (TORS)** for HPV-positive tonsillar carcinoma found omitting elective contralateral tonsillectomy oncologically safe, with fewer bleeding complications — a shift grounded in the tonsil's direct lymphatic drainage to the

jugulodigastric node (Parhar et al., *JAMA Otolaryngology–Head & Neck Surgery*, 2025, PMID 40638110).

(According to PubMed.)

High-yield exam pointers

- ▶ Tonsillar fossa boundaries: palatoglossal arch (anterior) and palatopharyngeal arch (posterior); lodges the almond-shaped tonsil with two surfaces, two borders, two poles.
- ▶ Bed of the tonsil (deep to superficial): pharyngobasilar fascia → superior constrictor + palatopharyngeus → buccopharyngeal fascia → styloglossus (lower part) → glossopharyngeal nerve.
- ▶ Internal carotid artery lies ~2.5 cm (25 mm) posterolateral to the tonsil — the single most important "danger" relation in tonsillectomy/quinsy drainage.
- ▶ Arterial supply — five vessels, all from the external carotid system: tonsillar (chief, from facial), ascending palatine, dorsal lingual, ascending pharyngeal, and greater/lesser palatine (from maxillary via descending palatine).
- ▶ **No afferent lymphatics**; efferents drain directly (or via retropharyngeal nodes) to the **jugulodigastric node** — the commonest palpable neck node in tonsillitis.
- ▶ Nerve supply: glossopharyngeal + lesser palatine nerves (circulus tonsillaris); explains referred otalgia via the tympanic (Jacobson's) branch of IX.
- ▶ Intratonsillar cleft = largest crypt, second-pouch remnant, classical site of quinsy onset.
- ▶ Development: endoderm of the ventral part of the **second pharyngeal pouch**; lymphocytes are mesodermal, infiltrating from the 5th month.
- ▶ Waldeyer's ring mnemonic "PPLT": Pharyngeal, Palatine, Lingual, Tubal tonsils.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 3–4 (8e).



Surgical anatomy of peritoneum

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction

The **peritoneum** is the largest serous membrane of the body — a continuous sheet of mesothelium and submesothelial connective tissue lining the abdominopelvic walls (**parietal peritoneum**) and reflected over the contained viscera (**visceral peritoneum**), the two layers being separated by a potential space, the **peritoneal cavity**, containing a thin film of lubricating fluid. In males the sac is closed; in females it communicates with the exterior through the uterine tubes. Surgically the peritoneum matters for three reasons: its reflections (mesenteries, omenta, ligaments) carry the neurovascular supply of the gut and are the surgeon's roadmap for mobilising organs; its recesses, gutters and dependent pouches dictate the **spread of infection, ascites and malignant cells**; and the membrane itself is exploited clinically for dialysis, drug delivery and diagnostic access (paracentesis, laparoscopy). This answer covers its

structure, folds, ligaments, mesenteries, the greater/lesser sac, and the applied surgical anatomy that follows from each.

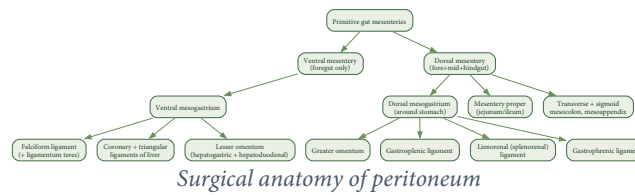
1. Structure and general properties

- ▶ **Parietal peritoneum** — lines abdominal/pelvic walls and inferior diaphragm; loosely attached by extraperitoneal connective tissue (firmly adherent only over the diaphragm and linea alba) and therefore easily stripped surgically; derived from **somatopleuric** lateral plate mesoderm; supplied by the same somatic nerves as the overlying wall (T7–T12, L1 for the abdomen; **obturator nerve** for the pelvis) — hence it is **pain-sensitive, well localised**, and evokes reflex guarding/rigidity when inflamed.
- ▶ **Visceral peritoneum** — firmly adherent to, and clinically regarded as part of, the underlying viscus (relevant to cancer staging: parietal deposits can be stripped without organ resection, visceral deposits usually need partial organ resection); derived from **splanchnopleuric** mesoderm; autonomically innervated, so pain is dull, poorly localised, and evoked only by stretch, traction or ischaemia — referred according to embryological origin (foregut → epigastrium, midgut → umbilicus, hindgut → suprapubic region).
- ▶ **Histology**: outer fibrous layer + inner monolayer of **mesothelium** on a basement membrane; microscopic **peritoneal stomata** (mesothelial pores, mainly under the diaphragm and anterior wall) open directly onto a submesothelial lymphatic plexus; **milky spots** (macrophage/lymphocyte aggregates) in the omenta and pelvic peritoneum absorb fluid, particulate matter and trap bacteria/malignant cells.
- ▶ **Peritoneal fluid**: normally < 5 ml in men/postmenopausal women (up to 25 ml in young women, cycle-dependent); < 30 g/L protein; flows in a predominantly **clockwise** direction driven by diaphragmatic movement, negative intrathoracic pressure and peristalsis.
- ▶ **Surface area** $\approx 1.4 \text{ m}^2$ in the adult (visceral peritoneum contributing ~80%) — the basis of its large absorptive/dialysing capacity.
- ▶ **Intraperitoneal pressure**: normally 2–10 mmHg; sustained pressure above ~25 mmHg (post-traumatic haemoperitoneum/oedema) can jeopardise organ blood flow, producing **abdominal compartment syndrome**.
- ▶ **Relation of viscera to peritoneum** — a key operative classification: **intraperitoneal** (stomach, jejunum, ileum, caecum, appendix, transverse and sigmoid colon), **retroperitoneal** (duodenum [except first 2 cm], pancreas, kidney, ureter, suprarenal), and **subperitoneal/pelvic** (bladder, prostate, seminal vesicle, cervix, vagina).

2. Classification and development of peritoneal folds

- ▶ **Mesentery/mesocolon** — a two-layered fold suspending gut from the posterior wall (named by prefix *mes-/meso-* + organ, e.g. mesentery of small intestine, transverse mesocolon).
- ▶ **Omentum** — a fold attached to the stomach (greater, lesser omentum).
- ▶ **Ligament** — a fold connecting two viscera, or a viscus to the wall, named after the structures joined (gastrosplenic) or its shape (triangular ligament).
- ▶ **Development**: the primitive gut tube is suspended by a **ventral mesentery** (foregut only, derived from the septum transversum) and a **dorsal mesentery** (foregut, midgut, hindgut). Rotation and

differential growth convert these into the adult folds; segments that fuse to the posterior wall become "retroperitoneal" (most duodenum, ascending and descending colon, rectum).



3. Named ligaments and their surgical significance

Ligament	Connects	Chief contents	Surgical relevance
Falciform ligament	Anterior abdominal wall (supra-umbilical)/diaphragm ↔ liver	Ligamentum teres (obliterated left umbilical vein) in free border	Landmark dividing liver into anatomical right/left parts; must be divided to mobilise the liver
Lesser omentum (hepatogastric + hepatoduodenal parts)	Lesser curvature of stomach + first 2 cm duodenum ↔ liver (porta hepatis)	Free right margin = portal vein, hepatic artery proper, bile duct (portal triad)	Free margin compressed in the Pringle manoeuvre to control hepatic haemorrhage
Gastrosplenic ligament	Greater curvature of stomach ↔ splenic hilum	Short gastric and left gastroepiploic vessels	Divided (vessels ligated) during splenectomy/gastric mobilisation
Lienorenal (splenorenal) ligament	Splenic hilum ↔ left kidney	Splenic vessels, tail of pancreas	Key plane for splenic mobilisation; tail of pancreas at risk during splenectomy
Gastrophrenic ligament	Fundus of stomach ↔ diaphragm	Avascular	Fixes stomach at cardio-oesophageal end
Phrenicocolic ligament	Splenic flexure of colon ↔ diaphragm	—	Forms a "sling" supporting the spleen; divided to mobilise splenic flexure
Coronary + right/left triangular ligaments	Liver ↔ diaphragm	Enclose the extraperitoneal bare area of the liver	Must be divided for hepatic mobilisation/transplantation; bare-area sepsis can track retroperitoneally without causing generalised peritonitis

□ Fig 27.10 — Liver, stomach and greater omentum (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.435)

4. Greater omentum

- ▶ A four-layered, fat-laden fold hanging from the greater curvature, folding on itself and fusing to the anterior surface of the transverse colon/mesocolon; contains the right and left **gastro-epiploic vessels** anastomosing between its first two layers.
- ▶ **Functions:** fat storage; cushions viscera and insulates against heat loss; prevents parietal-visceral adhesion; rich in macrophage-laden **milky spots** — traps bacteria and malignant cells and moves toward a site of inflammation, hence the epithet "**policeman of the abdomen.**"
- ▶ **Surgical uses:** omental patch (Graham's patch) repair of a perforated peptic ulcer; omentoplasty to buttress bowel anastomoses, fill dead space (e.g. post-pelvic exenteration), or seal a bronchopleural fistula; pedicled omental flaps in reconstructive surgery.

5. Mesentery of small intestine, transverse and sigmoid mesocolon

Fold	Root/attachment	Length	Contents	Surgical note
Mesentery proper	Obliquely from duodenojejunal flexure (L2, left) to right sacro-iliac joint; crosses 3rd part duodenum, aorta, IVC, right ureter, right psoas major	Root 15 cm; intestinal border 6 m	Jejunal/ileal branches of SMA + veins, autonomic plexuses, lacteals, 100–200 lymph nodes , fat	A short/malfixed root predisposes to midgut volvulus ; root is the operative guide to the SMA
Transverse mesocolon	Anterior surface of pancreatic head and body	—	Middle colic vessels	Divides supracolic from infracolic compartments; entry route to lesser sac in pancreatic surgery
Sigmoid mesocolon	Inverted "V"; apex over left ureter at bifurcation of left common iliac artery	—	Sigmoid vessels (left limb), superior rectal vessels (right limb)	Apex is the classic landmark to identify and protect the left ureter in sigmoid colectomy
Mesoappendix	From posterior surface of lower mesentery to appendix	Triangular	Appendicular vessels (an end-artery)	End-artery occlusion in appendicitis predisposes to gangrene/perforation

6. Greater sac, lesser sac and epiploic foramen

- ▶ The peritoneal cavity is divided into the main **greater sac** and the **lesser sac (omental bursa)**, a diverticulum behind the stomach, lesser omentum and caudate lobe, communicating with the greater sac only through the **epiploic foramen (of Winslow)**, at the level of T12.

- ▶ **Boundaries of the epiploic foramen:** anterior — free right margin of lesser omentum (portal vein, hepatic artery, bile duct); posterior — inferior vena cava; superior — caudate process of liver; inferior — first part of duodenum.
- ▶ A gastropancreatic fold raised by the common hepatic and left gastric arteries subdivides the lesser sac into a **superior recess** (behind lesser omentum/caudate lobe), an **inferior recess** (within the greater omentum, behind the stomach), and a **splenic recess** (between gastrosplenic and lienorenal ligaments).
- ▶ **Surgical relevance:** because none of its boundaries can safely be incised, a strangulated internal hernia through the epiploic foramen must be approached via the greater omentum; the lesser sac is entered surgically through the **gastrocolic ligament** for direct access to the pancreas (distal pancreatectomy, cyst-gastrostomy for a pancreatic pseudocyst).

□ Fig 5.27 — Subdivisions of peritoneal cavity. A. Median section of abdominopelvic (Moore — Clinically Oriented Anatomy — 9e, p.766)

7. Subdivisions of the peritoneal cavity — spaces, gutters and pouches

- ▶ The transverse colon/mesocolon divides the greater sac into **supracolic** and **infracolic** compartments; the infracolic compartment is further divided unequally by the root of the mesentery into right and left infracolic spaces, each continuous with a **paracolic gutter** lateral to the ascending/descending colon.
- ▶ **Subphrenic spaces:** right and left anterior, right and left posterior (the right posterior space = **hepatorenal pouch of Morison**, the most dependent part of the peritoneal cavity in the supine position and the commonest site of a subphrenic abscess); plus extraperitoneal perinephric spaces and the bare-area space of the liver.
- ▶ **Pelvic pouches:** male — a single **rectovesical pouch**; female — **rectouterine pouch (of Douglas)** and a shallower **vesicouterine pouch**; erect/sitting, the pelvic pouches become the most dependent part of the *entire* peritoneal cavity (Douglas' pouch floor $\approx$ 5.5 cm from the anal verge; rectovesical pouch $\approx$ 7.5 cm).
- ▶ (Duodenal, caecal and intersigmoid recesses — sites of internal herniation — are covered under "Clinical anatomy of peritoneal recesses.")

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- ▶ **Sagittal (median) section through the male abdomen** tracing the peritoneal reflection — label: anterior abdominal wall, falciform ligament, liver, lesser omentum, stomach, greater omentum (layers 1–4), transverse colon + transverse mesocolon, coils of small intestine + mesentery, rectum, rectovesical pouch, urinary bladder, caudate lobe, inferior vena cava, epiploic foramen.
- ▶ **Transverse section at the level of T12 through the epiploic foramen** — label: inferior vena cava, portal vein, hepatic artery proper, bile duct, caudate process of liver, first part of duodenum, right suprarenal gland, lesser sac, hepatorenal pouch.
- ▶ **Schematic of the peritoneal ligaments** around stomach/spleen/liver — label: falciform ligament + ligamentum teres, coronary ligament, right and left triangular ligaments, hepatogastric and hepatoduodenal ligament (lesser omentum), gastrosplenic ligament, lienorenal ligament, gastrophrenic ligament, phrenicocolic ligament.

Applied / Clinical anatomy

- ▶ **Peritonitis**: localised (parietal peritoneum over an inflamed organ → severe pain, rebound tenderness, board-like rigidity) or generalised (perforated appendix, peptic or typhoid ulcer, ruptured viscus) — a surgical emergency; patients characteristically lie with knees flexed and breathe shallowly to reduce intra-abdominal pain.
- ▶ **Ascites**: pathological accumulation of peritoneal fluid from cirrhosis/portal hypertension, tuberculous or malignant peritonitis, congestive cardiac failure, or hypoproteinaemia; **paracentesis** (surgical puncture for aspiration/analysis) is performed through the linea alba above an emptied bladder, or just above the anterior superior iliac spine avoiding the inferior epigastric vessels.
- ▶ **Peritoneal dialysis**: exploits the large, capillary-rich mesothelial surface (especially subdiaphragmatic) as a semipermeable dialysing membrane in renal failure — a temporary alternative to haemodialysis.
- ▶ **Adhesions**: fibrinous exudate from inflammation or surgery organises into fibrous bands between visceral-visceral or visceral-parietal peritoneum; may cause chronic pain or intestinal obstruction/volvulus, treated by **adhesiolysis**.
- ▶ **Pringle manoeuvre**: temporary control of hepatic/cystic-artery haemorrhage by compressing the hepatic artery within the hepatoduodenal ligament (index finger in the epiploic foramen, thumb on the ligament anteriorly).
- ▶ **Spread of infection and malignancy**: the clockwise flow of peritoneal fluid and the deeper **right paracolic gutter** preferentially carry fluid/pus toward the right subphrenic/subhepatic (Morison's) space in the supine position — hence its prominence as a subphrenic-abscess site after appendicitis, cholecystitis or a perforated ulcer; sitting the patient up directs exudate toward the pelvic pouches, which are easier and safer to drain. Malignant cells are trapped in **milky spots** and dependent recesses, producing an "**omental cake**" and pouch-of-Douglas deposits (palpable per rectum/vaginam) — the rationale for examining these sites during staging laparoscopy/laparotomy.

- ▶ **Cytoreductive surgery/HIPEC:** because parietal peritoneal tumour deposits can be stripped without resecting the underlying wall, whereas visceral deposits usually require partial organ resection, peritonectomy for peritoneal surface malignancy (e.g. pseudomyxoma peritonei) is planned around this parietal/visceral distinction; the large peritoneal surface area is exploited for intraperitoneal chemotherapy delivery.
- ▶ **Laparoscopy and pneumoperitoneum:** CO₂ insufflation (Veress needle, typically at the umbilicus, the thinnest fused parieto-peritoneal point) raises intra-abdominal pressure to ~12–15 mmHg for working space; awareness of the falciform ligament/ligamentum teres and inferior epigastric vessels is essential during port placement to avoid injury.
- ▶ **Subphrenic abscess:** today managed chiefly by image-guided (ultrasound/CT) percutaneous drainage rather than open surgical drainage, reflecting the predictable, imaging-defined anatomy of the subphrenic/subhepatic/pelvic spaces.
- ▶ **Internal hernia through the epiploic foramen and posterior gastric ulcer perforation into the lesser sac** (leaking via the epiploic foramen into the hepatorenal pouch, or forming a pancreatic pseudocyst) are classic, if uncommon, complications that follow directly from lesser-sac anatomy.

High-yield exam pointers

- ▶ Peritoneum = parietal (somatic pain, T7–T12/L1 + obturator) + visceral (autonomic, dull/referred pain); mesothelial surface area $\approx 1.4 \text{ m}^2$.
- ▶ Fold nomenclature: mesentery/mesocolon (gut), omentum (stomach), ligament (viscus–viscus or viscus–wall); derived from **ventral mesentery** (foregut only) and **dorsal mesentery** (fore-, mid-, hindgut).
- ▶ **Lesser omentum's free margin = portal triad;** compressed in the **Pringle manoeuvre**; **epiploic foramen** (T12) bounded by IVC (post.), caudate process (sup.), 1st part duodenum (inf.).
- ▶ **Greater omentum** = "abdominal policeman" — four layers, milky spots, seals perforations, used surgically as an omental patch/flap.
- ▶ **Root of mesentery** (15 cm, DJ flexure → right SI joint) crosses duodenum, aorta, IVC, right ureter, right psoas.
- ▶ **Sigmoid mesocolon apex** overlies the **left ureter** — critical landmark in sigmoid colectomy.
- ▶ **Morison's (hepatorenal) pouch** = deepest recess supine → commonest subphrenic abscess site; **rectouterine pouch of Douglas** = deepest recess erect/sitting.
- ▶ Peritoneal fluid flows **clockwise**; right paracolic gutter (deeper) carries infection/malignant cells to the right subphrenic space; malignancy also seeds omental milky spots ("omental cake") and the pouch of Douglas.
- ▶ Surgical exploitation: paracentesis, peritoneal dialysis, Pringle manoeuvre, omentoplasty, lesser-sac access via gastrocolic ligament, peritonectomy/HIPEC, laparoscopic pneumoperitoneum.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2 8e; Moore's Clinically Oriented Anatomy 9e; Vishram Singh — Textbook of Anatomy Vol 2 4e; Langman's Medical Embryology (Sadler) 14e.



Surgical anatomy of rectus sheath

Asked in: Paper IV 18-Nov-2019 — RGUHS MD/MS Anatomy

Definition / Introduction

The rectus sheath is a strong, midline aponeurotic envelope that encloses the paired **rectus abdominis** (and, when present, **pyramidalis**) muscles of the anterior abdominal wall, formed by the splitting and interlacing of the aponeuroses of the three flat muscles — external oblique, internal oblique and transversus abdominis. It runs from the costal margin and xiphoid process above to the pubic crest and symphysis below, flanked medially by the **linea alba** and laterally by the **linea semilunaris**. Because its composition changes at two levels — the costal margin and the **arcuate line** — and because it carries the segmental neurovascular supply of the rectus muscle within it, the sheath is one of the most surgically important planes of the abdominal wall, traversed in almost every laparotomy incision and central to modern abdominal-wall reconstruction.

Extent and boundaries

- ▶ Encloses rectus abdominis (and pyramidalis) on each side, from the 5th, 6th and 7th costal cartilages and xiphoid process superiorly to the pubic crest and pubic symphysis inferiorly.
- ▶ Medial boundary: the **linea alba**, a tendinous raphe formed by decussation of fibres from both sheaths across the midline; it is broader above the umbilicus, narrows below it, and is relatively avascular.
- ▶ Lateral boundary: the **linea semilunaris**, a gently curved groove marking the lateral edge of rectus abdominis, extending from the tip of the 9th costal cartilage to the pubic tubercle; it is a useful surface landmark (site of Spigelian hernia, transrectus/muscle-cutting incisions).
- ▶ The three flat muscles, acting through their aponeuroses, function as "**digastric**" muscles with the **linea alba as a common central tendon** — fibres decussate both across the midline and anteroposteriorly (anterior sheath to posterior sheath).

Formation of the rectus sheath

Each of the three flat-muscle aponeuroses is itself **bilaminar**, so the composition of the sheath differs at three levels along its length:

Level	Anterior wall	Posterior wall
Above the costal margin	Aponeurosis of external oblique only	Deficient — rectus abdominis rests directly on the 5th–7th costal cartilages

Level	Anterior wall	Posterior wall
Between costal margin and arcuate line (the greater part of the sheath)	External oblique aponeurosis + anterior lamina of internal oblique aponeurosis	Posterior lamina of internal oblique aponeurosis + aponeurosis of transversus abdominis
Below the arcuate line	Aponeuroses of all three muscles (external oblique separate; internal oblique and transversus abdominis fused)	Deficient — rectus abdominis rests directly on fascia transversalis, extraperitoneal fat and peritoneum

- ▶ The **arcuate line** (linea semicircularis, fold of Douglas) is the free, crescentic, downward-concave lower margin of the posterior wall, situated **midway between the umbilicus and the pubic symphysis**; below it all three aponeuroses pass anterior to the muscle.
- ▶ Anterior wall is complete throughout and firmly adherent to the **tendinous intersections** of rectus abdominis (three, at the xiphoid, umbilical and mid-way levels); the posterior wall is free from the muscle.
- ▶ Above and below, fibres from the two sides decussate at the linea alba, so the sheath and linea alba together act as a continuous fibrous corset that checks the "bowing" of the contracting rectus and maintains anterior abdominal wall tone.

Contents of the rectus sheath

- ▶ **Muscles:** rectus abdominis (chief content) and pyramidalis (if present), lying anterior to the lower part of rectus abdominis.
- ▶ **Arteries:** the **superior epigastric artery** (terminal branch of the internal thoracic artery, entering between the costal and xiphoid slips of the diaphragm and running down on the posterior wall) and the **inferior epigastric artery** (branch of the external iliac artery, entering the sheath by crossing anterior to the arcuate line); the two anastomose within the sheath posterior to the muscle at a variable level above the umbilicus. The inferior epigastric artery is dominant (average diameter ≈ 3 mm vs ≈ 1.6 mm for the superior epigastric), explaining why it provides the principal blood supply to rectus abdominis.
- ▶ **Veins:** superior epigastric venae comitantes (to the internal thoracic vein) and inferior epigastric venae comitantes (to the external iliac vein).
- ▶ **Nerves:** terminal ventral rami of the lower six thoracic nerves — the lower five intercostal nerves (T7–T11) and the subcostal nerve (T12).

Nerve supply within the sheath

- ▶ The T7–T12 ventral rami run forward in the **neurovascular plane between internal oblique and transversus abdominis**, then enter the rectus sheath at its **lateral margin** by piercing the posterior lamina of the internal oblique aponeurosis.
- ▶ Within the sheath they pass **posterior to rectus abdominis**, intercommunicating with adjacent nerves, then pierce the muscle from its deep surface near the midline, giving muscular branches (and, from the subcostal nerve, a branch to pyramidalis), and finally emerge through the **anterior wall** as the **anterior cutaneous nerves** supplying the overlying skin (T9 above the umbilicus, T10 at the umbilicus, T11 below it).

- **Applied point:** the iliohypogastric and ilioinguinal nerves (L1) do NOT enter the rectus sheath — they remain in the neurovascular plane and supply internal oblique/transversus abdominis and suprapubic/inguinal skin only. Because the segmental nerves of rectus abdominis enter from the **lateral side** and have little cross-communication, this is the anatomical basis for retracting the rectus muscle **laterally** (not medially) in a paramedian incision, preserving its nerve supply.

□ Fig 14.17A–C — Schematic transverse sections through the rectus abdominis muscle and its sheath at upper, middle and lower levels (IB Singh — *Textbook of Anatomy Vol 2* — 6e, p.178)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw three transverse (cross-sectional) diagrams through the anterior abdominal wall at the three levels above, each labelled:

- Rectus abdominis (centre)
- Linea alba (medial midline fusion)
- External oblique / its aponeurosis
- Internal oblique / its two laminae (anterior and posterior)
- Transversus abdominis / its aponeurosis
- **Level A** (above costal margin): anterior wall = external oblique aponeurosis only; posterior wall absent, rectus on costal cartilage
- **Level B** (between costal margin and arcuate line): anterior wall = external oblique + anterior lamina of internal oblique; posterior wall = posterior lamina of internal oblique + transversus abdominis aponeurosis
- **Level C** (below arcuate line): all three aponeuroses anterior to rectus; posterior wall absent — label fascia transversalis, extraperitoneal fat and peritoneum directly deep to the muscle
- Mark the arcuate line as the transition point between B and C

Recent advances in the surgical anatomy of the rectus sheath

- A 2025 meta-analysis (8 studies, 2,293 patients) comparing anterior component separation with posterior component separation/transversus abdominis release (PCSTAR) for large incisional hernias found PCSTAR — working through the posterior rectus sheath rather than the external oblique layer — had significantly fewer wound complications (24.7% vs 31.3%; OR 2.58, 95% CI 1.37–4.89, $p = 0.004$) and fewer infections (8.1% vs 11.8%), with similar recurrence, favouring the posterior-sheath route for large defects (Mohamedahmed et al., *Hernia*, 2025) [DOI](<https://doi.org/10.1007/s10029-025-03487-5>).
- A 2024 meta-analysis (7 studies, 780 patients) comparing **robotic** with **open** transversus abdominis release — both mobilising the posterior rectus sheath medial to the linea semilunaris into the Rives–Stoppa–Wantz/Novitsky retromuscular plane — found the robotic approach had fewer complications (9% vs 24.6%; RR 0.43) and infections (2.5% vs 7.8%), shorter stay (3.9 days), but a longer operating time, confirming minimally invasive access preserves outcomes at this same anatomical plane (Lima et al., *Surgical Endoscopy*, 2024, PMID 39528659) [DOI] (<https://doi.org/10.1007/s00464-024-11382-w>).

- ▶ A 2024 report described the "**hypoechoic triangle**" — a sonographic target between adjacent rectus abdominis segments, superior to the umbilicus in the **watershed zone between the superior and inferior epigastric territories** — as a more reliable ultrasound landmark for the **rectus sheath block**, since conventional blocks often fail from difficulty identifying the correct fascial plane (UCSF group, *A&A Practice*, 2024) [DOI](<https://doi.org/10.1213/XAA.0000000000001761>).

(According to PubMed.)

Applied / Clinical anatomy

- ▶ **Abdominal incisions through the sheath:** a **midline incision** (linea alba) is bloodless and cuts no muscle or nerve but heals relatively poorly when supraumbilical; a **paramedian incision** (anterior wall opened ~2.5 cm from the midline, rectus retracted laterally with its nerve supply intact, posterior wall/fascia transversalis/peritoneum opened separately, closure in layers) causes least postoperative weakness and is the most frequently used vertical incision. **McBurney's (grid-iron)** incision splits the flat muscles for appendicectomy; **Kocher's** (subcostal) and **Pfannenstiel** (transverse suprapubic) incisions serve biliary and pelvic surgery respectively.
- ▶ **Rectus sheath haematoma:** rupture of the epigastric vessels (coughing, pregnancy, anticoagulation, trauma) bleeds into the closed sheath, producing a tender mass **confined to one rectus compartment**; lying within the sheath rather than the peritoneum, it stays palpable/tender on tensing the recti by raising the head (Carnett's sign) — distinguishing it from intraperitoneal pain.
- ▶ **Divarication (diastasis) of the recti:** chronic thinning/widening of the linea alba (multiparity, obesity, straining) separates the recti with a midline bulge on straining; all layers remain intact, so this is not a true hernia.
- ▶ **Epigastric hernia:** extraperitoneal fat ($\pm$ a peritoneal sac with omentum) protruding through the wider upper linea alba above the umbilicus.
- ▶ **Spigelian hernia:** an interstitial hernia through the transversus abdominis aponeurosis, bounded by the linea semilunaris laterally and the rectus border medially, staying deep to the intact external oblique aponeurosis; it arises near where the linea semilunaris crosses the arcuate line (Spiegel described the semilunar line in 1645; Klinkosch first defined the hernia in 1764).
- ▶ **Incisional hernia and component separation:** incisional hernia now causes up to 20% of anterior wall hernias after laparotomy; repairing large defects aims to reapproximate the rectus sheaths via **component separation** — anterior (Ramirez: bilateral external oblique release lateral to the linea semilunaris) or posterior (Rives–Stoppa–Wantz retrorectus repair, extended by transversus abdominis release medial to the linea semilunaris) — reinforced with mesh placed onlay, sublay or underlay.
- ▶ **Flaps and laparoscopic safety:** the superior epigastric pedicle supports the upper rectus abdominis myocutaneous flap (breast reconstruction) and the inferior epigastric pedicle the lower flap/its perforators — the DIEP flap (pelvic/perineal reconstruction); the same deep epigastric vessels are a recognised hazard during laparoscopic trocar insertion, so ports are sited laterally.

- ▶ **Regional anaesthesia:** the TAP block (neurovascular plane between internal oblique and transversus abdominis) and the rectus sheath block (plane posterior to rectus, within the sheath) exploit this anatomy for post-laparotomy analgesia.

High-yield exam pointers

- ▶ Sheath composition changes at **two levels**: costal margin and arcuate line — learn the three-level table (above costal margin / between costal margin and arcuate line / below arcuate line).
- ▶ **Arcuate line** = free lower margin of the posterior wall, midway between umbilicus and pubic symphysis; below it, rectus rests on fascia transversalis + peritoneum only.
- ▶ Contents: rectus abdominis + pyramidalis; superior and inferior epigastric vessels (anastomosing within the sheath); terminal T7–T12 ventral rami.
- ▶ **Iliohypogastric and ilioinguinal nerves do NOT enter the rectus sheath** — a favourite negative fact and the basis for safe lateral retraction of rectus in a paramedian incision.
- ▶ Linea semilunaris = 9th costal cartilage to pubic tubercle; site of Spigelian hernia and of transrectus/lateral incisions.
- ▶ Paramedian incision (nerve-sparing, low hernia risk) vs midline incision (fast, avascular, but poorer healing when supraumbilical) — classic viva comparison.
- ▶ Rectus sheath haematoma mimics an acute abdomen but is confined to one sheath and tender on tensing the recti (Carnett's sign).
- ▶ Component separation (anterior — Ramirez; posterior — Rives–Stoppa–Wantz/TAR) is built entirely on the anatomical planes of the rectus sheath.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2 (8e); Vishram Singh's Textbook of Anatomy Vol 2 (4e); IB Singh's Textbook of Anatomy Vol 2 (6e).



Trendelenburg's Test for Varicose Veins

Asked in: Paper IV Oct 2009 — RGUHS MD/MS Anatomy

Definition / Introduction Trendelenburg's test (described by the German surgeon **Friedrich Trendelenburg**, 1890) is a bedside clinical test used to localise the site of incompetent venous valves in a limb with **varicose veins** of the great (long) saphenous system. It exploits the normal one-way, superficial-to-deep valve mechanism of the **perforating veins** and the guarding function of the **saphenofemoral valve**, and separately identifies whether reflux originates at the **saphenofemoral junction** (SFJ) or through incompetent **perforators** lower in the limb. It tests only the superficial and perforating veins — not the deep venous system, for which Perthes' (tourniquet) test is used.

1. Applied anatomy of venous drainage of the lower limb — the basis of the test

Set	Vessels	Key features
Superficial veins	Great (long) saphenous vein (GSV) and short (small) saphenous vein (SSV), with their tributaries	Lie in superficial fascia; thin-walled but muscular; valves more numerous distally; drain skin and subcutaneous tissue
Deep veins	Anterior tibial, posterior tibial, peroneal, popliteal and femoral veins (paired venae comitantes distally)	Lie within deep fascia alongside arteries; carry ~85–90% of limb venous return; soleal venous sinuses act as a "peripheral heart"
Perforating (communicating) veins	~5 constant perforators along the GSV, 1 along the SSV	Pierce the deep fascia; valved at both ends; valves permit flow only from superficial → deep

- **Muscle (calf) pump:** contraction of calf muscles, especially soleus, squeezes blood from the deep venous sinuses proximally towards the heart; on relaxation, blood is sucked from the superficial veins into the deep system through the perforators. Unidirectional flow is maintained entirely by competent valves.
- **Exception:** in the **foot**, flow is reversed — from deep (plantar) veins to the superficial dorsal venous arch — so that weight-bearing on the sole empties blood into the dorsum.
- Loss of this valvular one-way mechanism (at the SFJ and/or in the perforators) converts the perforators into "high-pressure leaks," transmitting the high pressure generated in the deep veins during muscle contraction directly into the superficial veins — the fundamental mechanism of **varicose veins**. This is precisely what Trendelenburg's test is designed to demonstrate.

2. Anatomy of the great saphenous vein and the saphenofemoral junction

- **Origin:** continuation of the medial marginal vein of the foot / dorsal venous arch.
- **Course:** ascends immediately anterior to the medial malleolus, obliquely crosses the distal third of the medial tibial surface, runs along the medial border of the tibia, passes a hand's breadth posterior to the medial border of the patella at the knee, then ascends the medial thigh.

- ▶ **Termination:** pierces the **cribriform fascia** at the **saphenous opening** in the deep fascia of the thigh and drains into the **femoral vein** — the **saphenofemoral junction** — located approximately 3–4 cm inferolateral to the **pubic tubercle**.
- ▶ **Valves:** the GSV contains **10–20 valves**, more numerous in the leg than the thigh; a constant valve lies just before the vein pierces the cribriform fascia, and a **terminal (saphenofemoral) valve** guards its junction with the femoral vein.
- ▶ **Protective valve of the external iliac vein:** present in about **80%** of individuals just proximal to the SFJ, shielding the saphenofemoral valve from high central venous pressure; in the remaining **20%** who lack it, the saphenofemoral valve alone bears this load and is the common site where primary varicosity first develops, extending gradually downward.

3. Sites tested — the named perforators of the lower limb

Perforator	Location	Connects
Hunterian (mid-thigh/adductor canal) perforator	Lower part of the adductor (Hunter's) canal	GSV ↔ femoral vein
Knee perforator (Boyd's perforator)	Just below the knee, near medial border of tibia	GSV ↔ posterior tibial vein
Three medial ankle perforators (of Cockett) — upper, middle, lower	Medial border of lower third of leg, between mid-calf and medial malleolus	Posterior arch vein ↔ posterior tibial vein
Lateral ankle perforator	Junction of middle and lower third of leg	SSV ↔ peroneal vein

- ▶ Perforators are classed as **direct** (connecting a superficial vein straight to a deep vein — e.g. the named perforators above) or **indirect** (connecting via intramuscular venous plexuses).
- ▶ The three medial ankle perforators join each other through venous arcades to form the **posterior arch vein**, a common site of incompetence and venous ulceration.

4. Technique of Trendelenburg's test (two-part manoeuvre)

- ▶ **Preparation:** the patient lies supine; the affected limb is raised (elevated) and the varicose veins are **stroked/massaged proximally** to empty them of blood completely.
- ▶ **Occlusion:** with the limb still elevated, firm pressure is applied with the **thumb (or a tourniquet)** over the GSV at the **saphenofemoral junction**.
- ▶ The patient is then asked to **stand up quickly** while the occlusion is maintained.
- ▶ **Part I — test for the saphenofemoral/superficial valve:** the pressure at the SFJ is now **released**.
 - **Positive (Trendelenburg I positive):** rapid, sudden filling of the GSV and its tributaries **from above downward** — indicates an **incompetent saphenofemoral valve**.
 - **Negative:** no rapid filling on release — the SFJ valve is competent.
- ▶ **Part II — test for the perforating veins:** in a fresh attempt, the SFJ pressure is **not released but maintained** (for about 30–60 seconds) while the patient stands.

- **Positive (Trendelenburg II positive):** gradual filling of the varices from below upward, despite SFJ occlusion — indicates **incompetent perforating veins**, allowing reflux from deep to superficial veins.
- **Negative:** no filling despite maintained occlusion — perforators are competent.

□ Fig 11.2b — Tributaries and perforating veins of the great saphenous vein (BD Chaurasia — Human Anatomy Vol 2 — 8e, p.179)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A two-panel schematic of the test on the medial aspect of the lower limb, labelled with:

- ▶ **Position 1 (supine, limb elevated ~45°):** veins stroked proximally to empty
- ▶ **Occlusion point:** examiner's thumb/tourniquet at the **saphenofemoral junction** (~3–4 cm inferolateral to the pubic tubercle)
- ▶ **Position 2 (patient standing, occlusion maintained)**
- ▶ **Part I — pressure released:** arrow showing rapid retrograde fill **from above** → label "SFJ/superficial valve incompetence"
- ▶ **Part II — pressure maintained ~30–60 s:** arrow showing gradual fill **from below** → label "perforator incompetence"
- ▶ **Named perforator sites** along the course of the GSV: **Hunterian (adductor canal)**, **Boyd's (below knee)**, **three Cockett's (medial ankle)**
- ▶ **Great saphenous vein** coursing anterior to the medial malleolus, along the medial border of the tibia, to the saphenous opening

5. Interpretation summary

Part I (release)	Part II (maintained)	Inference
Positive	Negative	Isolated saphenofemoral valve incompetence ; perforators competent
Negative	Positive	Perforator incompetence ; saphenofemoral valve competent
Positive	Positive	Both SFJ and perforator valves incompetent — the commonest pattern in long-standing primary varicose veins ("double positive")
Negative	Negative	No reflux demonstrated through the SFJ or the perforators tested by this manoeuvre — deep venous incompetence/other source should be considered and confirmed with Perthes' test

6. Complementary test — Perthes' test (tourniquet test)

- ▶ **Purpose:** assesses the **patency and competence of the deep veins**, distinguishing primary (superficial-valve) varicose veins from secondary varicose veins due to deep venous obstruction.

- ▶ **Technique:** a tourniquet is tied around the upper thigh, tight enough to occlude the GSV but **not** the femoral vein; the patient is asked to walk briskly/exercise the calf with the tourniquet in place.
 - If perforators and deep veins are **normal**, the calf-muscle pump empties the limb through the competent deep system and the varicosities **shrink**.
 - If the deep veins/perforators are **blocked**, the superficial veins have no outlet during exercise and the varicosities become **more distended** (and often painful) — a warning against saphenous stripping without further deep-vein assessment.

Applied / Clinical anatomy

- ▶ **Sites of varicose veins:** the GSV territory (medial thigh and leg) is affected far more often than the SSV territory, reflecting its greater length, higher number of tributaries and the vulnerable saphenofemoral valve.
- ▶ **Causes/predisposing factors:** incompetency of the saphenofemoral valve and/or perforator valves (commonest cause); prolonged standing (occupational — bus conductors, traffic police, nurses, surgeons); pregnancy, especially the third trimester, from pressure of the gravid uterus on pelvic veins and hormonal effects on the vein wall (usually regresses post-partum); raised intra-abdominal pressure (abdominal tumours, multiple pregnancy); deep vein thrombosis (secondary varicose veins, in which recanalised deep veins are left without functioning valves).
- ▶ **Mechanism of dilatation:** incompetent valves convert perforators/SFJ into "high-pressure leaks," transmitting deep venous pressure generated during calf contraction into the thin-walled superficial veins, producing progressive dilatation, tortuosity and wall degeneration.
- ▶ **Complications:** pigmentation and dryness of skin over the medial malleolus (site of the lowest — Cockett's — perforators and maximal gravitational venous stasis, causing local hypoxia); **varicose (venous stasis) ulcer**; thrombophlebitis; haemorrhage from a ruptured varix.
- ▶ **Trendelenburg's operation:** the surgical correlate of the test — the GSV is detached (flush-ligated) from the femoral vein at the SFJ, **all its tributaries in the groin are individually ligated**, and the incompetent length of vein is stripped; failure to ligate every tributary individually is a recognised cause of recurrent varicosity.
- ▶ **Venesection/graft use:** the GSV's constant position anterior to the medial malleolus makes it the standard site for emergency venesection; when harvested as a coronary/peripheral arterial bypass graft, the vein segment must be **reversed** so its numerous valves do not obstruct arterial flow.
- ▶ **Modern correlate:** hand-held Doppler and duplex (colour) ultrasonography have now largely supplemented these clinical manoeuvres for precisely localising reflux at the SFJ and at individual perforators before definitive surgery, but the clinical tests remain the classical bedside method taught and examined in anatomy.

High-yield exam pointers

- ▶ Trendelenburg's test — bedside test for **site of valvular incompetence** in varicose veins; tests **superficial veins and perforators only**, not deep veins.
- ▶ Two-part technique: empty veins → occlude SFJ → stand → (I) **release** pressure (tests SFJ/superficial valve) → (II) **maintain** pressure ~30–60 s (tests perforators).

- ▶ Rapid fill from **above** on release = SFJ valve incompetence; gradual fill from **below** despite occlusion = perforator incompetence.
- ▶ SFJ lies ~3–4 cm inferolateral to the pubic tubercle; GSV has 10–20 valves, terminal valve guards the SFJ.
- ▶ External iliac vein valve protects the SFJ in ~80% of people; its absence (20%) predisposes to primary varicosity starting at the SFJ.
- ▶ Named perforators: **Hunterian** (adductor canal, GSV–femoral), **Boyd's** (below knee, GSV–posterior tibial), **Cockett's** ×3 (medial ankle, posterior arch vein–posterior tibial).
- ▶ All perforator valves permit **superficial** → **deep** flow only; incompetence reverses this, producing "high-pressure leaks."
- ▶ **Perthes' (tourniquet) test** complements Trendelenburg's test by assessing **deep vein patency**.
- ▶ Surgical correlate = **Trendelenburg's operation** (flush ligation of SFJ + tributaries + stripping).

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 2, 8e; AK Datta — Human Anatomy Vol 3 (Upper & Lower Limb); Vishram Singh — Textbook of Anatomy Vol 2, 4e; Moore's Clinically Oriented Anatomy, 9e.



Various approaches to the prostate gland

Asked in: Paper IV May 2011 — RGUHS MD/MS Anatomy

Definition / Introduction — The prostate is an inverted-cone-shaped fibromuscular glandular organ lying in the lesser pelvis below the bladder neck, behind the pubic symphysis and in front of the rectal ampulla, surrounding the prostatic urethra. Because it sits at the crossroads of the retropubic space anteriorly, the rectum posteriorly, the urethra centrally, and the neurovascular bundles posterolaterally, it can be surgically reached by several different routes — each route defined by the plane or capsule it opens and the structure it must spare. "Various approaches to the prostate" therefore means the classical open approaches (transvesical/suprapubic, retropubic, perineal), the endoscopic transurethral approach, and the modern laparoscopic/robotic extension of the retropubic route — all of which are dictated by the gland's relations, capsules and fascial planes described below.

1. Anatomical basis of the approaches — relations, capsules and fascial planes

Surface/pole	Relation	Surgical significance
Base	Continuous with the bladder neck; circular groove at the junction lodges venules of the vesicoprostatic plexus	Entered in the transvesical approach; preserved intact and re-anastomosed to the urethra in radical prostatectomy

Surface/pole	Relation	Surgical significance
Apex	Surrounds the junction of the prostatic and membranous urethra; rests on/is continuous with the external urethral sphincter; separated from the anal canal by the perineal body and rectourethralis	Site of the vesicourethral anastomosis at radical prostatectomy — the plane of apical dissection determines whether the external sphincter is preserved (continence)
Anterior surface	Narrow, convex; lies ~2 cm behind the pubic symphysis, separated from it by the retropubic space (of Retzius) , the dorsal vascular (Santorini's) plexus and the puboprostatic ligaments	The plane developed in the retropubic and robotic-assisted (transperitoneal or extraperitoneal) approaches
Posterior surface	Flat, triangular; separated from the rectal ampulla by Denonvilliers' fascia (obliterated rectovesical pouch); pierced near its upper border by the ejaculatory ducts; palpable per rectum	The plane opened in the perineal approach; also the plane protected in every other approach to avoid rectal injury
Inferolateral surfaces	Embraced by the anterior fibres of levator ani (pubourethral sling); carry the lateral prostatic fascia and, within it, the neurovascular bundles	The plane preserved (nerve-sparing) or deliberately included (wide excision) at radical prostatectomy

- **Capsules:** a **true capsule** (fibromuscular condensation of the gland's own stroma) lies against the parenchyma; a **false capsule/prostatic sheath** (derived from the endopelvic/pelvic fascia, continuous anteriorly with the puboprostatic ligaments and posteriorly with Denonvilliers' fascia) lies outside it. The **prostatic venous plexus occupies the space between the true and false capsules** — this is why, in "open" prostatectomy for benign enlargement, the adenoma is **enucleated from within the surgical (compressed) capsule**, leaving both true and false capsules and the intervening venous plexus undisturbed, giving a relatively bloodless plane.
- **Supports:** the medial and lateral **puboprostatic ligaments** (false capsule to the back of the pubic bone), the **urogenital diaphragm/perineal membrane** (on which the apex rests), and Denonvilliers' fascia posteriorly.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

□ Fig 17.2 — Location, features and relations of the prostate gland: (A) sagittal section, (B) coronal section (Vishram Singh — Textbook of Anatomy Vol 2 — 4e, p.720)

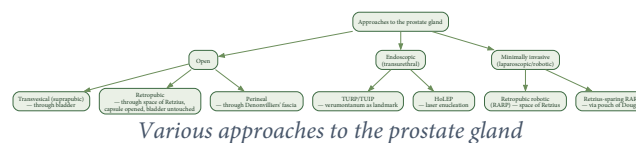
Reproduce this figure by hand with the following labels:

- ▶ Pubic symphysis and retropubic space (of Retzius) — anterior plane
- ▶ Puboprostatic ligament
- ▶ Urinary bladder and bladder neck (base of prostate)
- ▶ Prostatic urethra traversing the gland
- ▶ Ejaculatory duct and prostatic utricle
- ▶ True capsule and false capsule (prostatic sheath), with the prostatic venous plexus between them
- ▶ Denonvilliers' fascia and rectal ampulla — posterior plane
- ▶ Perineal body/urogenital diaphragm at the apex — perineal plane
- ▶ Levator ani (pubourethral sling) on the inferolateral surface, carrying the neurovascular bundle

2. Classification of the surgical approaches to the prostate gland

Approach	Route of entry	Plane/structure exploited or spared	Typical indication
Transvesical (suprapubic)	Lower abdominal incision → bladder opened → adenoma enucleated through the internal urethral orifice	Uses the base/bladder-neck continuity; does not open the anterior prostatic capsule directly	Open removal of a large benign adenoma, especially with a coexisting bladder stone/diverticulum
Retropubic	Lower abdominal incision → retropubic space of Retzius developed → anterior true capsule incised without opening the bladder	Anterior capsular plane; bladder mucosa left intact	Open enucleation of BPH adenoma; also the classical route for open radical retropubic prostatectomy
Perineal	Inverted-U perineal incision between scrotum and anus → Denonvilliers' fascia opened → posterior surface of the gland exposed	Posterior plane; rectum retracted, protected by Denonvilliers' fascia	Perineal (simple or radical) prostatectomy; perineal prostatic biopsy
Transurethral (endoscopic)	Resectoscope passed along the urethra; colliculus seminalis (verumontanum) used as the landmark for the external sphincter	Adenoma resected from within the preprostatic/transition-zone urethra, sparing the capsule	TURP/TUIP — now the commonest operation for BPH; also Holmium laser enucleation (HoLEP) , a laser-based transurethral variant

Approach	Route of entry	Plane/structure exploited or spared	Typical indication
Radical prostatectomy (retropubic/perineal/laparoscopic-robotic)	Whole gland + capsule + seminal vesicles + ampullae of vasa removed, with vesico-urethral anastomosis	Deliberately excises the capsule and, where indicated, the postero-lateral neurovascular bundle ; a nerve-sparing modification (Walsh's technique) preserves the bundle where oncologically safe	Carcinoma of the prostate confined to the gland



3. Landmarks and structures at risk during each approach

- **Verumontanum (colliculus seminalis)**: a rounded elevation on the urethral crest bearing the opening of the prostatic utricle flanked by the two ejaculatory duct openings; used at **TURP** as the fixed landmark proximal to which the external urethral sphincter lies — resection distal to it protects continence, while injudicious resection through it disrupts the preprostatic sphincter.
- **TURP bleeding points**: the inferior vesical artery gives **capsular branches (of Flocks)** entering antero-laterally at the **1 and 11 o'clock** positions, and **urethral branches (of Badenoch)** entering postero-laterally at the **5 and 7 o'clock** positions, at the prostatovesical junction — this arterial pattern is the reason haemorrhage during transurethral resection classically occurs at these four clock-positions.
- **Neurovascular bundle**: paired bundles of cavernous (autonomic) nerves and vessels running postero-lateral to the capsule within the lateral pelvic (prostatic) fascia, continuing to the corpora cavernosa; deliberately identified and preserved in **nerve-sparing radical prostatectomy** to retain erectile function, or resected with a wide margin if tumour abuts the capsule at that point.
- **Pudendal nerve to the external sphincter**: enters at the **5 and 7 o'clock** positions — at risk during apical dissection in radical prostatectomy and during over-vigorous transurethral resection, producing stress incontinence.
- **Apex shape**: the small, "croissant-shaped" gland has its external sphincter flush with the antero-medial defect of the gland, so an inaccurate perpendicular apical incision here removes sphincter tissue and causes incontinence; the enlarged, "doughnut-shaped" gland allows a safer perpendicular cut — a key point when planning the vesico-urethral anastomosis.
- **Rectum**: protected in every approach by **Denonvilliers' fascia**; deliberately opened only in the perineal route, where the rectourethralis muscle is divided in the midline to reach the posterior surface without breaching the rectal wall.

4. Zonal anatomy and its bearing on the choice of approach

Zone (McNeal)	Proportion of gland	Disease association	Relevance to approach
Peripheral zone	~70%	Commonest site of carcinoma ; palpable on digital rectal examination	Justifies radical excision (retropubic/perineal/robotic) with wide capsular margins for cancer
Central zone	~25%	Rarely diseased	Bypassed by enucleation-type procedures
Transitional zone	~5%	Site of origin of benign prostatic hyperplasia (BPH)	Justifies the transurethral/enucleation approaches (TURP, HoLEP, open retropubic/transvesical enucleation), which remove only this central adenomatous tissue
Anterior fibromuscular stroma	—	No glandular tissue	Traversed anteriorly in the retropubic/robotic route

Recent advances in the surgical/anatomical approaches to the prostate

- ▶ A 2025 systematic review and meta-analysis of 9 studies (775 patients per arm) comparing **Retzius-sparing robot-assisted radical prostatectomy** (an anterior approach performed through the pouch of Douglas that deliberately preserves the endopelvic fascia, arcus tendineus, puboprostatic ligaments, detrusor apron and Santorini's/dorsal venous plexus, in contrast to the conventional route through the space of Retzius) with standard RARP found significantly faster return of continence (odds ratio 11.3 at catheter removal, 3.6 at 3 months) but a higher positive-margin rate in locally advanced ($\geq pT3$) disease, illustrating the direct trade-off between anatomical-plane preservation and oncological clearance (Gong et al., *Frontiers in Oncology* 2025;15:1547687) [DOI](<https://doi.org/10.3389/fonc.2025.1547687>).
- ▶ A meta-analysis of 13 studies (2,387 patients) comparing the **transperitoneal versus extraperitoneal route** for laparoscopic/robot-assisted radical prostatectomy — the modern equivalents of the classical transvesical and retropubic distinction — found the extraperitoneal approach carried a significantly lower operative complication risk (RR 0.78), reaffirming that staying outside the peritoneal cavity, as in the traditional open retropubic operation, remains advantageous even with robotic instrumentation (Purnomo et al., *Urology Research and Practice* 2023;49(5):285–292) [DOI](<https://doi.org/10.5152/tud.2023.23008>).
- ▶ A 2024 meta-analysis of 13 randomised controlled trials comparing **Holmium laser enucleation of the prostate (HoLEP)** with conventional TURP for BPH found HoLEP achieved a shorter catheterisation time (–19.5 hours) and hospital stay (–27.5 hours) with a lower haemoglobin drop and fewer transfusions, at the cost of a longer operating time — evidence that the transurethral route is itself evolving from resection to laser enucleation along the same true-

capsule plane (Daryanto et al., *Current Urology* 2024;19(1):6–16)

[DOI](https://doi.org/10.1097/CU9.0000000000000257).

(According to PubMed.)

Applied / Clinical anatomy

- ▶ **Digital rectal examination (DRE):** the posterior surface is palpated through the anterior rectal wall; loss of the median groove and a hard, irregular, fixed gland suggest carcinoma (peripheral zone), while a smooth, firm, symmetrically enlarged gland suggests BPH.
- ▶ **BPH:** hyperplasia of the transitional zone (classically described as the subcervical glands of Albarran) compresses the prostatic urethra and causes elevation of the uvula vesicae, forming a **postprostatic pouch** of residual urine and producing the LUTS triad — frequency, urgency, and a poor/interrupted stream with incomplete emptying.
- ▶ **Retrograde ejaculation:** because the preprostatic (internal urethral) sphincter mechanism guards against reflux of semen into the bladder, its disruption during transurethral or transvesical resection of the bladder neck region characteristically causes retrograde ejaculation.
- ▶ **Impotence and incontinence as approach-specific complications:** injury to the postero-lateral neurovascular bundle (cavernous nerves) during radical prostatectomy causes erectile dysfunction — the rationale for Walsh's nerve-sparing technique; injury to the external sphincter (at the apex, or via the pudendal branches entering at 5 and 7 o'clock) causes stress incontinence.
- ▶ **Vertebral spread of carcinoma:** the prostatic venous plexus communicates valvelessly with the internal and external **vertebral venous plexus (of Batson)** through the anterior sacral foramina, allowing prostatic carcinoma to metastasise directly to the lumbar vertebrae and skull without first passing through the lungs or liver — a classical cause of back pain as a presenting complaint, and the basis of raised serum PSA and acid phosphatase as tumour markers.
- ▶ **Perineal approach and continence:** because the perineal route does not traverse the pelvic floor sling as extensively as the retropubic route, it is traditionally associated with good visualisation for the vesico-urethral anastomosis, but poorer access for pelvic lymph node dissection, which is why it is now less commonly used for cancer staging than the retropubic/robotic routes.

High-yield exam pointers

- ▶ Four classical routes to the prostate: **transvesical (suprapubic)**, **retropubic**, **perineal**, **transurethral (TURP)** — plus modern **laparoscopic/robotic (retropubic-based)** extensions, including Retzius-sparing RARP.
- ▶ The **prostatic venous plexus lies between the true and false capsules** — the reverse of the thyroid, where the venous plexus lies deep to the true capsule alone; this is why prostatic enucleation is done deep to both capsules.
- ▶ **Verumontanum/colliculus seminalis** = landmark for the external urethral sphincter during TURP.
- ▶ **TURP bleeding points:** capsular arteries at 1 and 11 o'clock; urethral arteries at 5 and 7 o'clock.
- ▶ **Neurovascular bundle** lies postero-lateral to the capsule; nerve-sparing radical prostatectomy (Walsh's technique) preserves it for potency.

- ▶ **Denonvilliers' fascia** separates the prostate from the rectum — the plane entered in the perineal approach and protected in all others.
- ▶ **McNeal's zones**: peripheral (70%, carcinoma), central (25%), transitional (5%, BPH) — zone of pathology dictates whether an enucleating (TURP/HoLEP/open) or radical approach is chosen.
- ▶ Valveless communication of the prostatic venous plexus with **Batson's vertebral venous plexus** explains skeletal metastasis of prostatic carcinoma.
- ▶ Retrograde ejaculation follows disruption of the preprostatic sphincter during bladder-neck/transurethral surgery.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia's Human Anatomy Vol 2 (8e); Vishram Singh's Textbook of Anatomy Vol 2 (4e); IB Singh's Textbook of Anatomy Vol 2 (6e); Moore's Clinically Oriented Anatomy (9e).



Wallenberg's syndrome

Asked in: Paper IV May 2018 — RGUHS MD/MS Anatomy

Definition / Introduction. Wallenberg's syndrome — also called the **lateral medullary syndrome** or the **posterior inferior cerebellar artery (PICA) syndrome** — is the clinical picture produced by thrombosis or occlusion of the PICA, or of the segment of the vertebral artery from which it usually arises. The occlusion infarcts a **wedge-shaped zone in the dorsolateral (posterolateral) part of the medulla oblongata**, together with the inferior surface of the cerebellum, sparing the ventromedial medulla. It is named after **Adolf Wallenberg (1862–1949)**, the German physician who first correlated the clinical picture with the underlying lesion, and remains the single most common brainstem vascular syndrome and a classic exam question linking vascular territory to internal medullary anatomy.

1. Vascular anatomy — origin, course and territory of the PICA

- ▶ The PICA is the largest branch of the vertebral artery; it arises near the lower end of the olive.
- ▶ It ascends dorsal to the roots of the glossopharyngeal (IX) and vagus (X) nerves to reach the inferior border of the pons, then curves and descends along the inferolateral border of the fourth ventricle.
- ▶ It turns laterally into the cerebellar vallecule between the cerebellar hemispheres and divides into a **medial branch** (supplying the inferior vermis and adjoining hemisphere) and a **lateral branch** (supplying the inferior cerebellar surface, anastomosing with the anterior inferior and superior cerebellar arteries).
- ▶ Before dividing, the **trunk of the PICA supplies the medulla oblongata dorsal to the olivary nucleus and lateral to the hypoglossal nucleus and its emerging rootlets** — precisely the wedge damaged in Wallenberg's syndrome — and also the choroid plexus of the fourth ventricle, with a separate branch to the dentate nucleus.

- The PICA is **occasionally absent**; because it is a branch of the vertebral artery, occlusion of the parent vertebral artery itself can produce the identical clinical picture even without direct PICA thrombosis.

2. Structures in the infarcted wedge and the anatomical basis of the signs

The dorsolateral medullary wedge contains several nuclei and tracts in close proximity; each gives a distinct, teachable sign —

Structure affected	Anatomical basis	Clinical effect
Spinal nucleus and tract of the trigeminal nerve (V)	Descending first-order pain/temperature afferents from the face	Ipsilateral loss of pain and temperature sensation over the face
Lateral spinothalamic tract	Already-crossed second-order pain/temperature fibres from the trunk and limbs	Contralateral loss of pain and temperature sensation over the trunk and limbs
Nucleus ambiguus	Motor nucleus of the cranial parts of IX, X and XI	Ipsilateral paralysis of the palate, pharynx and larynx — dysphagia, dysarthria, hoarseness, absent gag reflex
Vestibular nuclei	Vestibular (CN VIII) relay	Vertigo, nausea, vomiting, nystagmus
Inferior cerebellar peduncle and adjoining cerebellum	Afferents to the cerebellum (dorsal spinocerebellar, olivocerebellar, vestibulocerebellar fibres)	Ipsilateral limb and gait ataxia
Descending (hypothalamospinal) sympathetic fibres in the reticular formation	Oculosympathetic pathway	Ipsilateral Horner's syndrome — ptosis, miosis, enophthalmos, anhidrosis, loss of the ciliospinal reflex

This combination — crossed pain/temperature loss (ipsilateral face + contralateral body) together with ipsilateral bulbar, cerebellar and oculosympathetic signs — is the anatomical signature of the syndrome.

3. Structures spared, and why

The infarct is strictly dorsolateral, so the **ventromedial (paramedian) structures of the medulla** are characteristically spared:

- **Corticospinal fibres (pyramid)** — lie ventromedially and are supplied by the anterior spinal artery/paramedian branches of the vertebral artery, a different territory → **no contralateral hemiplegia**.
- **Hypoglossal nucleus and its emerging rootlets** — also paramedian, adjacent to the pyramid → **no ipsilateral tongue weakness or deviation**.
- **Medial lemniscus** — ventral and paramedian → **fine touch, vibration and joint-position sense are preserved**.

The **absence of limb weakness and tongue involvement**, despite prominent sensory, bulbar, cerebellar and autonomic signs, is the key discriminator that separates the lateral medullary syndrome from the medial medullary (Dejerine's) syndrome and from a hemispheric stroke.

4. Distinction from the medial medullary (Dejerine's anterior bulbar) syndrome

Both syndromes are classically taught together because they affect the same organ from opposite vascular territories —

Feature	Lateral medullary (Wallenberg)	Medial medullary (Dejerine's)
Artery occluded	PICA (or vertebral artery)	Anterior spinal artery / paramedian branches of the vertebral artery
Region of medulla	Dorsolateral	Ventromedial (paramedian)
Corticospinal tract	Spared	Contralateral hemiplegia
Hypoglossal nucleus/nerve	Spared	Ipsilateral LMN tongue paralysis, deviates to the side of the lesion on protrusion
Medial lemniscus	Spared	Contralateral loss of fine touch, vibration, position sense
Spinothalamic tract + spinal V	Involved — crossed pattern	Usually spared
Cerebellar/vestibular signs	Present	Absent
Horner's syndrome	Present	Absent

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

- Fig 5.4 — Transverse section through the medulla at the level of the olive (IB Singh — Textbook of Human Neuroanatomy, p.81)
- Fig 5.7 — Occlusion of posterior inferior cerebellar artery which causes lateral (IB Singh — Textbook of Human Neuroanatomy, p.82)

Reproduce a transverse section of the medulla at the level of the olive and shade the **dorsolateral wedge** affected in Wallenberg's syndrome, labelling within the shaded zone:

- ▶ Spinal nucleus and tract of the trigeminal nerve
- ▶ Lateral spinothalamic tract
- ▶ Nucleus ambiguus
- ▶ Vestibular nuclei
- ▶ Inferior cerebellar peduncle
- ▶ Descending sympathetic fibres (in the reticular formation)
- ▶ Emerging rootlets of IX, X and XI

and, outside the shaded zone (ventromedial/paramedian, to show what is spared):

- ▶ Pyramid (corticospinal tract)
- ▶ Hypoglossal nucleus and its rootlets
- ▶ Medial lemniscus
- ▶ Inferior olivary nucleus (landmark for the level)

Applied / Clinical anatomy

- ▶ The **crossed sensory dissociation** (ipsilateral face, contralateral trunk/limbs) is the single most important localizing sign distinguishing a brainstem vascular lesion from a hemispheric stroke, where face and body are affected on the same side.
- ▶ MRI with diffusion-weighted imaging is the imaging investigation of choice; it classically shows a **wedge-shaped area of restricted diffusion in the dorsolateral medulla**, whereas CT is frequently normal early because of posterior-fossa bone-hardening artefact.
- ▶ **Dysphagia from nucleus ambiguus involvement** carries a real risk of aspiration, so early bedside swallow assessment is an important applied point.
- ▶ Because the **PICA also supplies part of the cerebellum**, a large-territory infarct can be complicated by cerebellar oedema with secondary brainstem compression, occasionally requiring surgical decompression.
- ▶ Vertebral artery dissection is a recognised cause in younger patients, in addition to the atherothrombotic PICA/vertebral disease more typical of older patients with vascular risk factors.
- ▶ Contrast throughout with the **medial medullary (Dejerine's) syndrome**, which damages the ventromedial territory of the anterior spinal artery and gives the mirror-image deficit (contralateral hemiplegia, contralateral loss of fine touch/position sense, ipsilateral tongue weakness) without sensory dissociation, cerebellar signs or Horner's syndrome.

High-yield exam pointers

- ▶ Wallenberg's syndrome = **lateral medullary syndrome** = **PICA syndrome**.
- ▶ Caused by thrombosis of the **posterior inferior cerebellar artery**, or of the vertebral artery from which it usually arises.
- ▶ Infarct is a **wedge-shaped dorsolateral medullary zone** + part of the inferior cerebellar surface.
- ▶ **Crossed sensory loss**: ipsilateral face (spinal nucleus/tract of V) + contralateral trunk/limbs (lateral spinothalamic tract).
- ▶ **Ipsilateral bulbar palsy** (nucleus ambiguus) → dysphagia, dysarthria, absent gag reflex.
- ▶ **Ipsilateral cerebellar ataxia** (inferior cerebellar peduncle) and **vertigo/nystagmus/vomiting** (vestibular nuclei).
- ▶ **Ipsilateral Horner's syndrome** (descending sympathetic fibres in the reticular formation).
- ▶ **No limb weakness, no tongue weakness** — pyramid and hypoglossal nucleus are ventromedial and lie outside PICA territory.
- ▶ Named after **Adolf Wallenberg**; do not confuse with the ventromedial **medial medullary** (Dejerine's) syndrome of the anterior spinal artery territory.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Snell's Clinical Neuroanatomy 7e; IB Singh's Textbook of Human Neuroanatomy; Vishram Singh's Clinical Neuroanatomy 4e; BD Chaurasia's Human Anatomy Vol 3-4 8e.



Wrist drop

Asked in: Paper IV Oct 2006 — RGUHS MD/MS Anatomy

Definition / Introduction Wrist drop is the clinical deformity in which the wrist cannot be actively extended and hangs flexed, with the fingers flexed at the metacarpophalangeal (MCP) joints (though the interphalangeal joints may still be extended by the lumbricals and interossei) and the forearm held pronated. It results from paralysis of the extensor muscles of the wrist and fingers — almost always due to a lesion of the **radial nerve** or its deep terminal branch, the **posterior interosseous nerve (PIN)** — allowing the unopposed tone of the flexor muscles to pull the wrist into flexion. Because the radial nerve lies in direct contact with the humeral shaft for much of its course and winds around bone at three separate sites, its anatomical relations are the entire basis of how and where it is injured, and the level of the lesion determines the exact clinical picture.

Radial nerve — origin, root value and course

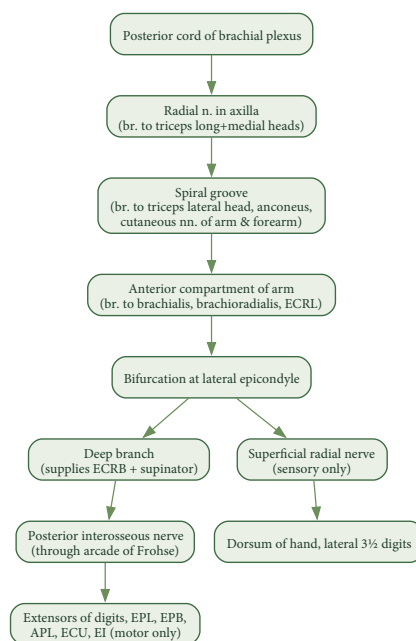
- ▶ **Origin**: continuation of the **posterior cord of the brachial plexus**; the largest branch of the plexus and the largest nerve of the upper limb.
- ▶ **Root value**: C5, C6, C7, C8 (T1 fibres inconstant).

Region	Relations / course
Axilla	Lies posterior to the third part of the axillary artery, anterior to the muscles forming the posterior wall of the axilla (subscapularis, latissimus dorsi, teres major)
Arm (upper part)	Enters the arm at the lower border of teres major; passes between the long and medial heads of triceps through the lower triangular space (triangular interval) — bounded above by teres major, medially by the long head of triceps, laterally by the humeral shaft — accompanied by the profunda brachii artery, to reach the spiral (radial) groove
Spiral groove	Lies in direct contact with the humerus; boundaries of the groove — above: origin of the lateral head of triceps; below: origin of the medial head of triceps; anteriorly: middle one-third of the humeral shaft; posteriorly: fibres of the lateral and long heads of triceps
Lower arm	Pierces the lateral intermuscular septum to enter the anterior compartment; descends first between brachialis and brachioradialis, then between brachialis and extensor carpi radialis longus (ECRL), into the cubital fossa
Elbow / cubital fossa	Terminates anterior to the lateral epicondyle by dividing into a deep (motor) branch , which becomes the posterior interosseous nerve after supplying extensor carpi radialis brevis (ECRB) and supinator, and a superficial (sensory) branch

Branches and motor distribution

Level	Branches	Muscle(s) / structures supplied
Axilla	Nerve to long head of triceps; nerve to medial head of triceps; posterior cutaneous nerve of arm (sensory)	Triceps (long, medial heads); skin of back of arm
Spiral groove	Nerve to lateral head of triceps; continuing nerve to medial head; nerve to anconeus; lower lateral cutaneous nerve of arm; posterior cutaneous nerve of forearm (both sensory)	Triceps (lateral head), anconeus; skin of lower lateral arm and back of forearm
Anterior compartment, above elbow	Nerve to brachialis (lateral part); nerve to brachioradialis; nerve to ECRL	Brachialis (part), brachioradialis, ECRL
Deep branch at elbow (before entering supinator)	Muscular twigs	ECRB, supinator

Level	Branches	Muscle(s) / structures supplied
Posterior interosseous nerve (after passing through supinator, at the arcade of Frohse)	Muscular + articular branches	Extensor digitorum, extensor digiti minimi, extensor carpi ulnaris, abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, extensor indicis; articular branches to wrist, distal radio-ulnar and carpal joints
Superficial radial nerve (purely sensory)	Cutaneous branches	Skin of lateral two-thirds of dorsum of hand and dorsal aspect of lateral 3½ digits (proximal to the nail beds)



Wrist drop

□ Fig 13.4 — Wrist drop resulting from radial nerve injury (Vishram Singh — Textbook of Anatomy Vol 1 — 4e, p.569)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A posterior view of the arm and forearm showing the radial nerve's course, labelled with:

- ▶ **Posterior cord of brachial plexus and lower border of teres major** (nerve entering the arm)
- ▶ **Lower triangular space (triangular interval)** — teres major, long head of triceps, humeral shaft
- ▶ **Spiral (radial) groove** on the posterior humeral shaft, with the nerve and profunda brachii artery in contact with bone
- ▶ **Lateral intermuscular septum** (nerve piercing it to enter the anterior compartment)
- ▶ **Interval between brachialis and brachioradialis, then brachialis and ECRL**
- ▶ **Lateral epicondyle** — site of bifurcation into deep and superficial branches
- ▶ **Arcade of Frohse** (proximal edge of supinator) — entry of the posterior interosseous nerve into the posterior compartment
- ▶ **Superficial radial nerve** deep to brachioradialis, emerging 7 cm above the wrist
- ▶ **Shaded sensory distribution** — dorsum of hand and lateral 3½ digits

Sites and anatomical basis of injury

Site	Structures at risk	Common causes
Axilla	Nerve close to shaft/head of humerus and posterior axillary wall	Pressure of a crutch in the axilla (crutch palsy); shoulder dislocation
Spiral groove	Nerve in direct bony contact with the humeral shaft	Mid-shaft fracture of the humerus; prolonged pressure of the arm against a hard edge (armchair) in a drunken sleep — " Saturday night palsy "; a wrongly placed intramuscular injection into the arm
Elbow / proximal forearm (radial tunnel)	Deep (posterior interosseous) branch entrapped as it passes through the arcade of Frohse and between the two heads of supinator	Monteggia fracture-dislocation; fracture/dislocation of the radial head; surgical exposure of the radial head; entrapment by fibrous bands, the tendinous edge of ECRB, or the leash of the radial recurrent artery

Clinical features according to level of the lesion

Feature	Axilla (high lesion)	Spiral groove	Elbow — deep branch/PIN (low lesion)
Elbow extension	Lost (triceps paralysed)	Preserved/minimally weak (triceps branches given off proximal to lesion)	Preserved
Wrist extension	True wrist drop	True wrist drop	Wrist can still extend, but deviates radially (ECRL/brachioradialis spared, ECU paralysed) — no true wrist drop
Finger (MCP) extension	Lost	Lost	Lost — "finger drop"
Supination (elbow extended)	Lost (supinator + brachioradialis out)	Lost	May be weak
Sensory loss	Back of arm & forearm, dorsum of hand/lateral 3½ digits	Narrow strip on back of forearm + dorsum of hand near thumb base	None — deep branch/PIN is purely motor
Pain	Usually absent	Usually absent	Often present over extensor forearm (radial tunnel syndrome)

- The most **constant** area of sensory loss in any radial nerve lesion above the elbow is the small patch over the dorsum of the hand at the base of the thumb (first dorsal web space), because of overlap from adjacent cutaneous nerves elsewhere.
- Note the "double dissociation": the finger metacarpophalangeal joints stay flexed (extensors paralysed) while the interphalangeal joints can still be extended by the intact lumbricals and interossei (median/ulnar innervated) — the fingers are never completely straight or completely clawed.

Applied / Clinical anatomy

- **Why wrist drop is disabling:** normal power grip depends on synergistic wrist extension (the "tenodesis" mechanism that keeps finger flexor tendons at optimal length); with wrist drop the patient cannot grip an object firmly even though the long flexors themselves are intact.
- **Posterior interosseous nerve (PIN) syndrome vs radial tunnel syndrome:** both are entrapments at the arcade of Frohse; PIN syndrome presents with motor weakness of finger and thumb extensors (no true wrist drop, no sensory loss), whereas radial tunnel syndrome presents mainly with pain over the lateral elbow/proximal forearm without significant weakness.
- **Wartenberg's syndrome (cheiralgia paraesthetica):** isolated compression/entrapment of the purely sensory **superficial radial nerve** (e.g., by a tight wristwatch strap or handcuffs) causes pain and paraesthesia over the dorsum of the thumb/first web space with **no motor loss and no wrist drop** — an important differential from radial/PIN palsy.

- ▶ **Examination:** ask the patient to extend the wrist and fingers against resistance; observe radial deviation of the wrist on attempted extension in a low (PIN) lesion versus complete wrist drop in a high (axillary/spiral groove) lesion; map the sensory loss over the first dorsal web space.
- ▶ **Splintage and treatment:** a cock-up (wrist-extension) splint holds the wrist extended so the fingers can still be used for grip while nerve recovery is awaited; open injuries need nerve exploration/repair; in irrecoverable radial nerve palsy, standard tendon-transfer surgery restores function (classically: pronator teres to ECRB, a wrist/finger flexor such as flexor carpi ulnaris or flexor carpi radialis to the finger extensors, and palmaris longus to extensor pollicis longus).
- ▶ **Surface marking:** the radial nerve in the arm can be marked along a line from the posterior axillary fold spiralling around the humerus to reach the lateral intermuscular septum about the junction of the upper two-thirds and lower one-third of the arm — useful in localising the level of a fracture-associated palsy.
- ▶ **Radial nerve and fracture management:** because the nerve lies directly on bone in the spiral groove, a mid-shaft humeral fracture is deliberately examined for radial nerve function (wrist/finger extension and dorsal thumb-web sensation) before and after any manipulation or fixation.

High-yield exam pointers

- ▶ Wrist drop = paralysis of wrist + finger extensors due to a radial nerve or posterior interosseous nerve lesion; unopposed flexor tone flexes the wrist.
- ▶ Radial nerve = continuation of the posterior cord (C5–C8, T1 inconstant); largest branch of the brachial plexus.
- ▶ Three classical sites of injury: **axilla** (crutch palsy), **spiral groove** (mid-shaft humeral fracture; Saturday night palsy), **elbow/radial tunnel** (Monteggia fracture; arcade of Frohse entrapment — posterior interosseous nerve syndrome).
- ▶ Triceps (elbow extension) is spared in spiral-groove and lower lesions because its nerve supply arises proximal to those levels.
- ▶ A lesion of the deep branch/PIN at or below the elbow spares ECRL and brachioradialis, so there is **no true wrist drop**, only radial deviation on attempted extension and finger drop — and, being purely motor, **no sensory loss**.
- ▶ Most constant sensory loss: dorsum of hand at the base of the thumb (first dorsal web space).
- ▶ Grip strength fails in wrist drop because normal grip needs synchronous wrist extension (tenodesis effect), not because the flexors themselves are weak.
- ▶ Wartenberg's syndrome (superficial radial nerve entrapment) mimics sensory symptoms without any motor loss or wrist drop — key differential.
- ▶ Management: cock-up splint for functional support during recovery; tendon transfers (e.g., pronator teres → ECRB) for irrecoverable palsy.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; BD Chaurasia — Human Anatomy Vol 1, 8e; Vishram Singh — Textbook of Anatomy Vol 1, 4e; AK Datta — Human Anatomy Vol 3 (Upper & Lower Limb); IB Singh — Textbook of Anatomy Vol 1, 6e; Moore's Clinically Oriented Anatomy, 9e.



Recent advances in anatomical sciences



Frozen embryo

Asked in: Paper IV Oct 2010 — RGUHS MD/MS Anatomy

Definition / Introduction

A **frozen embryo** is a human pre-implantation embryo — produced by in vitro fertilisation (IVF) or intracytoplasmic sperm injection (ICSI) — that is preserved by **cryopreservation** (storage in liquid nitrogen at -196°C after loading with a cryoprotectant) instead of being transferred fresh to the uterus, so that it can be thawed and transferred in a later cycle. Embryos are surplus to the one or two transferred fresh in an assisted reproductive technology (ART) cycle because controlled ovarian stimulation typically yields several mature oocytes and, therefore, several fertilised embryos. Embryo cryopreservation is one of the cornerstone techniques of modern ART and is the applied-embryology basis of "frozen embryo transfer" (FET).

1. Rationale and indications

- ▶ **Surplus embryos from a stimulated IVF/ICSI cycle:** only one (occasionally two) embryo is transferred fresh; the remainder, if of good quality, are cryopreserved rather than discarded.
- ▶ **Avoidance of ovarian hyperstimulation syndrome (OHSS):** in a hyperstimulated cycle, a "freeze-all" strategy (cryopreserving every embryo and deferring transfer to a later, unstimulated cycle) avoids exposing an OHSS-prone patient to the added physiological load of an early pregnancy.
- ▶ **Preimplantation genetic diagnosis/screening (PGD/PGS):** a biopsy is taken from the oocyte (polar body), a blastomere, or the trophectoderm of the blastocyst and sent for genetic/chromosomal testing; the embryo is cryopreserved while the result is awaited, and only a genetically unaffected/euploid embryo is thawed and transferred.
- ▶ **Staggered/elective single embryo transfer:** transferring one embryo at a time reduces the risk of multiple pregnancy; cryopreservation banks the remaining embryos for sequential future attempts without repeating ovarian stimulation.
- ▶ **Fertility preservation:** banking embryos (or oocytes) before gonadotoxic treatment such as chemotherapy/radiotherapy, analogous to the established practice of oocyte cryopreservation.
- ▶ **Medicolegal/consent framework:** cryopreservation requires informed consent from both gamete-providing partners covering duration of storage and disposition of unused embryos, governed nationally by ART regulatory law.

2. Developmental stage at which embryos are frozen

Stage	Approx. day post-fertilisation	Feature
Pronuclear (2PN) stage	Day 1	Two pronuclei (male + female) visible before syngamy
Cleavage stage	Day 2–3	4- to 8-cell embryo; blastomeres held within an intact zona pellucida
Morula	Day 3–4	Compacted ball of ≥ 16 blastomeres
Blastocyst	Day 5–6	Differentiated into inner cell mass (embryoblast) and trophectoderm , with a fluid-filled blastocoele

- Both **cleavage-stage embryos (4- to 8-cell)** and **blastocysts** can be successfully cryopreserved, thawed and transferred — extending embryo culture to the blastocyst stage before freezing allows better morphological selection of the embryo(s) most likely to implant.
- Cryopreservation prior to the blastocyst stage exploits the fact that the zona pellucida is still intact, protecting blastomeres during the freeze–thaw cycle.

3. Cryoprotectants and freezing methods

- Cryoprotectants used: **propanediol** (1,2-propanediol, PROH) and **dimethyl sulphoxide** (DMSO) are the standard agents for early cleavage-stage embryos; **glycerol** is used for both early embryos and blastocysts. These permeate the blastomeres and displace intracellular water, preventing lethal intracellular ice-crystal formation during cooling.
- **Two methods:**

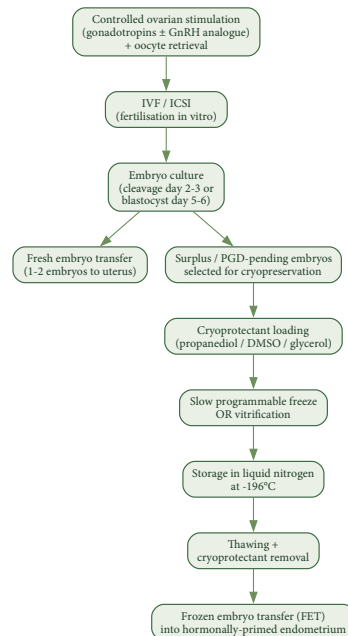
Feature	Slow (programmable) freezing	Vitrification
Principle	Gradual, controlled-rate cooling with a lower cryoprotectant concentration	Ultra-rapid cooling with a high cryoprotectant concentration, producing a glass-like amorphous solid with no ice-crystal formation
Equipment	Programmable freezing machine	Direct plunge into liquid nitrogen
Time required	Hours	Minutes
Ice-crystal damage	A recognised limitation, especially for the blastocyst	Minimised — the basis of its preferential use for blastocysts today

- Storage is in **liquid nitrogen** at -196°C , at which all metabolic and biochemical activity is arrested, permitting indefinite storage in principle.

- Successful transfer of thawed cleavage-stage embryos and blastocysts is now common clinical practice; conception rates using ovarian stimulation, IVF, and successive transfer of fresh and cryopreserved embryos exceed those of natural, non-assisted conception.

4. Protocol — from oocyte retrieval to frozen embryo transfer

The freezing arm is a branch of the standard IVF/ICSI pathway, diverging after embryo culture:



Frozen embryo

□ Fig 5.1 — In vitro fertilisation. It involves six stages as follows: Stage 1, ovarian stimulation and monitoring; Stage 2, oocyte retrieval; Stage 3, fertilisation; Stage 4, embryo development; Stage 5, embryo transfer; Stage 6, luteal phase support. (Sontakke — Textbook of Human Embryology, p.44)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Draw the freeze–thaw pathway as a vertical flow branching off the standard IVF pipeline, with these exact labels top to bottom:

- ▶ **Controlled ovarian stimulation + oocyte retrieval**
- ▶ **IVF / ICSI → fertilisation in vitro**
- ▶ **Embryo culture — cleavage stage (4–8 cell, day 2–3) or blastocyst (day 5–6)**
- ▶ **Branch point: Fresh embryo transfer (1–2 embryos) vs Surplus embryos → cryopreservation**
- ▶ **Cryoprotectant loading (propanediol / DMSO / glycerol)**
- ▶ **Freezing method: slow programmable freeze OR vitrification**
- ▶ **Storage in liquid nitrogen at -196°C**
- ▶ **Thawing + cryoprotectant removal**
- ▶ **Frozen embryo transfer (FET) into a hormonally-prepared endometrium**

5. Thawing and transfer

- ▶ Thawed embryos are assessed for **post-thaw survival** (proportion of blastomeres/inner cell mass intact) before transfer; only embryos with adequate survival are transferred.
- ▶ The endometrium is prepared beforehand with a natural or hormone-replacement (oestrogen–progesterone) protocol so that its receptivity is synchronised with the developmental stage of the thawed embryo at the time of transfer.
- ▶ Transfer technique is identical to fresh embryo transfer — the embryo is loaded into a fine catheter and introduced through the cervical canal into the uterine cavity under, where available, ultrasound guidance.

6. Comparison — fresh versus frozen embryo transfer

Feature	Fresh embryo transfer	Frozen embryo transfer (FET)
Timing	Same stimulated cycle as oocyte retrieval	A later, separate (natural or hormone-primed) cycle
OHSS risk	Present, since transfer occurs in the hyperstimulated cycle	Avoided — the freeze-all strategy defers transfer past the OHSS-risk window
Endometrial synchrony	May be adversely affected by supraphysiological hormone levels of stimulation	Endometrium prepared independently, allowing better synchrony
Use with PGD/PGS	Not possible within the same cycle (testing takes time)	Standard — embryo is frozen while genetic result is awaited
Repeat attempts	Requires repeating full ovarian stimulation each time	Banked embryos allow repeat transfer attempts without repeating stimulation

Applied / Clinical anatomy

- ▶ **Multiple pregnancy prevention:** cryopreservation is what makes **elective single embryo transfer** practicable — the clinical strategy of choice for reducing the twin/triplet pregnancy rate (and its attendant risks of prematurity and low birth weight) inherent to ART.
- ▶ **OHSS avoidance:** deferring transfer in a "freeze-all" cycle removes the additional physiological burden of an early pregnancy from a patient with ovaries already at risk of hyperstimulation.
- ▶ **Oncofertility:** cryopreservation of embryos (or oocytes, in unpartnered women) before chemotherapy/radiotherapy preserves reproductive potential ahead of gonadotoxic treatment.
- ▶ **Genetic screening window:** PGD/PGS for aneuploidy or a known familial mutation requires the embryo to be held in cryopreservation while trophectoderm/blastomere biopsy results are analysed, so that only genetically unaffected embryos are subsequently transferred.
- ▶ **Consent and regulation:** because a cryopreserved embryo persists as a stored biological entity independent of either partner, its future use, storage duration and disposal require informed consent from both partners and are governed by national ART regulatory legislation.

High-yield exam pointers

- ▶ **Definition:** pre-implantation embryo preserved in liquid nitrogen after cryoprotectant loading, for later thaw and transfer.
- ▶ **Cryoprotectants:** propanediol (PROH) and DMSO for cleavage-stage embryos; glycerol for early embryos and blastocysts.
- ▶ **Storage:** liquid nitrogen at -196°C .
- ▶ **Stages frozen:** cleavage stage (4- to 8-cell, day 2–3) and blastocyst (day 5–6).
- ▶ **Two freezing methods:** slow programmable freezing (older) vs **vitrification** (ultra-rapid cooling, no ice-crystal formation — now preferred, especially for blastocysts).
- ▶ **Key indications:** surplus embryos after fresh transfer, PGD/PGS turnaround, OHSS avoidance ("freeze-all"), fertility preservation before gonadotoxic therapy.
- ▶ **Where it sits in the ART cycle:** branches off after embryo culture (stage 4 of the six-stage IVF sequence), before fresh transfer would otherwise occur.
- ▶ Conception rates with fresh + cryopreserved embryo transfer together exceed natural conception rates per cycle.
- ▶ Contrast with **oocyte cryopreservation ("egg freezing")** — the unfertilised gamete, rather than the embryo, is frozen; used when there is no partner/sperm source at the time of freezing.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Sontakke — Textbook of Human Embryology; Moore — The Developing Human 9e; Larsen — Human Embryology 6e; IB Singh — Human Embryology (CBME 2021).



Sono elastography

Asked in: Paper IV 13-May-2022 — RGUHS MD/MS Anatomy

Definition / Introduction

Sono-elastography (ultrasound elastography, USE) is a real-time, non-invasive extension of conventional B-mode ultrasonography that maps the mechanical **stiffness (elasticity)** of soft tissue rather than only its echotexture. It exploits the physical fact that diseased tissue — most importantly malignant, fibrotic or scarred tissue — is mechanically **stiffer** than the surrounding normal parenchyma; applying a small mechanical stress and measuring the resulting tissue displacement (strain) or the speed of an induced shear wave lets the machine estimate regional stiffness and display it as a colour-coded "**elastogram**", superimposed on or alongside the grey-scale image. Because ultrasound already underpins cross-sectional/applied anatomy teaching, sono-elastography — moving USG from a purely morphological to a combined morphological-and-mechanical tool — is one of the important recent advances in anatomical/imaging science asked under Paper IV.

Physical principle

- ▶ Basis: **Young's (elastic) modulus, $E = \text{stress} / \text{strain}$** — the resistance of a tissue to deformation under an applied mechanical force.
- ▶ Malignant and fibrotic tissue has a higher collagen content and cell density, so it is mechanically **stiffer** than surrounding normal soft tissue — **cancer may be 5–28 times stiffer** than the background tissue (Gray's Anatomy, Commentary 7.1).
- ▶ When a **mechanical compression or vibration** is applied to the tissue, a stiff lesion **deforms/displaces less** than adjacent normal tissue.
- ▶ The ultrasound system tracks this relative **displacement (strain)**, or measures the **propagation velocity of a shear wave** travelling transversely through the tissue, and converts the result into a stiffness value or a colour map.
- ▶ Ultrasound is now the most widely used modality for producing such **elastograms**, used to detect and classify tumours and to grade diffuse fibrotic disease (classically, liver fibrosis/cirrhosis); a correlation between liver elasticity and cirrhosis score is well established (Yeh et al 2002; Foucher et al 2006 — the original transient-elastography/FibroScan validation study).

Types of ultrasound elastography

Type	Force applied	What is measured	Output
Strain (compression) elastography	Manual freehand probe compression-release, or intrinsic physiological motion (cardiac pulsation, respiration)	Relative tissue displacement (strain) of the lesion compared with adjacent reference tissue	Qualitative colour-coded strain map $\pm$ a semi-quantitative strain ratio (lesion strain $\div$ reference-tissue strain)

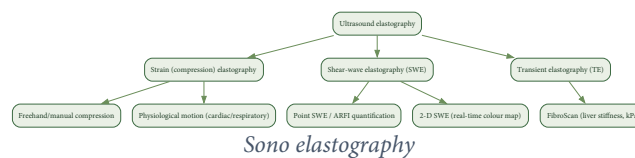
Type	Force applied	What is measured	Output
Shear-wave elastography (SWE)	Machine-generated acoustic radiation force impulse (ARFI) "pushes" the tissue, launching a transverse shear wave	Velocity (c, m/s) of the propagating shear wave; converted to Young's modulus, $E = 3\rho c^2$ (ρ = tissue density)	Quantitative — a single point value (point-SWE / ARFI quantification) or a real-time 2-D colour stiffness map (2D-SWE), reported in kPa or m/s
Transient elastography (TE)	An external, probe-mounted mechanical vibrator generates a low-frequency shear wave	1-D pulse-echo ultrasound tracks shear-wave velocity through a fixed cylindrical volume of liver parenchyma	Liver stiffness measurement in kPa; the commercial device is FibroScan

- Strain elastography is fast and needs no special hardware but is **operator- and compression-force-dependent** and only semi-quantitative; SWE and TE give a genuinely **quantitative, largely operator-independent** stiffness value that has been validated against histology/biopsy as the reference standard.

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A labelled schematic of the elastography examination, showing exactly:

- **Ultrasound probe** on the skin surface, with the **B-mode image** of the organ/lesion below it
- **Pre-compression** and **post-compression** frames side by side (for strain elastography) — showing the lesion deforming less than surrounding tissue
- For SWE: an ARFI "**push**" pulse arrow into the tissue and the resulting **shear-wave wavefront** propagating outward, with a velocity (m/s) label
- A **region of interest (ROI)** box over the lesion and a second ROI over adjacent normal ("reference") tissue
- The **colour-coded elastogram** overlay (e.g. red/green = soft, blue = hard — the exact colour convention is vendor-dependent) with a **strain ratio** or **kPa** value box alongside



Organ-specific applications and grading systems

Organ / tissue	Clinical use	Scoring / cut-off system
Thyroid	Distinguishing benign from malignant thyroid nodules	Rago score (5-point, adapted from Ueno's breast scale): 1 = elastic throughout, 2 = mostly soft, 3 = soft periphery/hard centre, 4 = entirely hard nodule, 5 = hard, extending beyond nodule margin (infiltration); the Asteria score (4-point): 1 = entirely elastic to 4 = entirely hard. Higher scores (Rago 4–5 / Asteria 3–4) are suspicious for malignancy
Breast	Characterising solid breast masses alongside BI-RADS B-mode assessment	Tsukuba (Itoh/Ueno) elasticity score , 5-point: 1–2 benign (soft, "green"), 3 probably benign, 4–5 malignant ("blue"/hard); a malignant lesion also typically appears larger on elastography than on B-mode
Liver	Non-invasive staging of hepatic fibrosis/cirrhosis and portal-hypertension risk stratification	Transient elastography (FibroScan) and 2D-SWE liver-stiffness measurement (kPa); higher stiffness correlates with a higher METAVIR fibrosis stage and cirrhosis risk (original correlation: Yeh et al 2002, Foucher et al 2006; cut-offs refined by WFUMB 2024)
Prostate	Targeting biopsy to stiffer foci within the peripheral zone	Real-time strain- or SWE-guided prostate biopsy
Musculoskeletal	Tendinopathy (Achilles, patellar), muscle tears, plantar fasciitis	SWE Young's modulus (kPa) — reduced stiffness in a degenerate or torn tendon compared with normal tendon
Lymph nodes	Differentiating reactive from metastatic/lymphomatous nodes	A stiffer cortex favours malignant infiltration
Cervix (obstetric)	Predicting risk of preterm labour via cervical tissue stiffness	SWE-based cervical elasticity mapping (emerging application)

Recent advances in sonoelastography

- **WFUMB 2024 update on liver ultrasound elastography:** the World Federation for Ultrasound in Medicine and Biology issued its update to the 2018 guidelines, giving graded, evidence-based recommendations on shear-wave elastography for fibrosis staging, prognostication across aetiologies, and interpretation of liver/spleen stiffness in portal hypertension (Ferraioli G et al, *Ultrasound Med Biol* 2024;50(8):1071–87) [DOI: 10.1016/j.ultrasmedbio.2024.03.013].

- **Breast cancer early-detection applications:** a 2025 review consolidates technological refinements (multiparametric strain + shear-wave combinations) and clinical-validation data supporting elastography's incremental value over B-mode/BI-RADS alone for characterising indeterminate solid breast masses (Zhou J et al, *Front Oncol* 2025;15:1589142) [PMID: 40641918].
- **Obstetric applications:** sonoelastography is being extended to cervical, placental, pelvic-floor and fetal-tissue stiffness assessment, with early evidence for predicting preterm labour risk and placental dysfunction (Alfuraih AM, *Diagnostics* 2024;15(1):47) [PMID: 39795575].
- **Improved biomechanical modelling:** newer continuum-mechanics models (hyperelasticity, biphasic/poroelastic and nonlocal viscoelastic models) are being incorporated into elastography software to improve the accuracy of stiffness estimation and its correlation with true tissue biomechanics (Farajpour A, Ingman WV, *Bioengineering* 2024;11(10):991) [PMID: 39451367].

(According to PubMed/WFUMB; DOIs:
[\[10.1016/j.ultrasmedbio.2024.03.013\]](https://doi.org/10.1016/j.ultrasmedbio.2024.03.013)(<https://doi.org/10.1016/j.ultrasmedbio.2024.03.013>),
[\[10.3389/fonc.2025.1589142\]](https://doi.org/10.3389/fonc.2025.1589142)(<https://doi.org/10.3389/fonc.2025.1589142>),
[\[10.3390/diagnostics15010047\]](https://doi.org/10.3390/diagnostics15010047)(<https://doi.org/10.3390/diagnostics15010047>),
[\[10.3390/bioengineering11100991\]](https://doi.org/10.3390/bioengineering11100991)(<https://doi.org/10.3390/bioengineering11100991>).)

Applied / Clinical anatomy

- **Liver:** stiffness is conventionally measured through an intercostal window into the **right lobe** (segments VII/VIII), at least 1 cm below the capsule and away from large vessels/the gallbladder fossa, to avoid falsely elevated readings from vascular pulsation or capsular artefact.
- **Thyroid:** the **isthmus and both lobes**, related posteriorly to the **recurrent laryngeal nerve** in the tracheo-oesophageal groove and to the **parathyroid glands**, are scanned nodule-by-nodule; elastography helps triage which nodules need fine-needle aspiration.
- **Breast:** assessment follows the standard **quadrant/clock-face** localisation of a lesion relative to the nipple-areolar complex and its relation to the **retromammary space** and axillary tail — elastography is performed as an adjunct at the same sitting as B-mode/BI-RADS scanning.
- **Prostate:** most cancers arise in the **peripheral zone** (vs the more central transition zone, which enlarges in benign prostatic hyperplasia); elastography-guided biopsy targets stiff peripheral-zone foci close to the neurovascular bundles, relevant to nerve-sparing surgical planning.
- **Musculoskeletal:** the **Achilles tendon**, **patellar tendon** and **plantar fascia** are superficial, easily accessible structures ideal for high-frequency SWE probes; reduced stiffness correlates with degeneration/partial tear.
- **Limitations tied to anatomy:** overlying bowel gas, obesity/thick subcutaneous fat, ascites, and proximity to bone or an air-filled viscus attenuate the shear wave and degrade reliability; strain elastography is confounded by adjacent pulsatile vessels or by inconsistent operator compression force.

High-yield exam pointers

- Physical basis: **Young's modulus = stress/strain**; stiff (often malignant/fibrotic) tissue deforms less under compression or shows faster shear-wave velocity.

- ▶ Three types: **strain (compression) elastography** (qualitative/semi-quantitative), **shear-wave elastography** — SWE (point/ARFI or 2D, quantitative, $E = 3\rho c^2$), **transient elastography** (FibroScan, liver-specific).
- ▶ Foucher et al (2006) validated **transient elastography (FibroScan)** for diagnosing cirrhosis; correlation of liver elasticity with cirrhosis score also shown by Yeh et al (2002).
- ▶ Thyroid nodules: **Rago score** (5-point) and **Asteria score** (4-point); higher score = more suspicious for malignancy.
- ▶ Breast masses: **Tsukuba (Itoh/Ueno) score** (5-point, 1–2 benign, 4–5 malignant) $\pm$ strain ratio.
- ▶ Liver: elastography **stages fibrosis/cirrhosis non-invasively**, avoiding liver biopsy; WFUMB updated its liver-elastography guideline in 2024.
- ▶ Applied uses beyond liver/thyroid/breast: **prostate biopsy targeting, musculoskeletal tendon/muscle stiffness, lymph-node characterisation, emerging obstetric (cervix) applications.**
- ▶ Key limitation: **operator dependence** (strain elastography) and **attenuation by bowel gas/obesity/ascites** limiting shear-wave-based techniques.
- ▶ Elastography complements, but does not replace, conventional B-mode/Doppler ultrasound and histopathological confirmation.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e (Commentary 7.1, "Technical aspects and applications of diagnostic radiology"); Weir & Abrahams — Imaging Atlas of Human Anatomy 6e; Moore's Clinically Oriented Anatomy 9e; BD Chaurasia — Human Anatomy Vol 1/2/3-4 8e (breast, liver, thyroid and prostate gross anatomy used for the Applied anatomy correlations). Recent-advances citations are from PubMed/WFUMB (2024–2025) per the answer-bank's recency-enrichment method.

Coverage note: sono-elastography is a modern imaging technique not covered in the classical gross-anatomy/histology chapters of the specialty textbooks; core physics and clinical facts here are drawn from Gray's Anatomy's imaging commentary and Weir & Abrahams' imaging atlas (both part of the bank's grounded corpus), supplemented by standard, widely-accepted radiology-curriculum knowledge (elastography scoring systems, technique classification) and the cited recent-advances literature.



Stem cell isolation and applications

Asked in: Paper IV 02-Jun-2025 — RGUHS MD/MS Anatomy

Definition / Introduction Stem cells are undifferentiated cells defined by two properties — **multilineage differentiation** (the potential to give rise to cells of ectoderm, mesoderm or endoderm) and **self-renewal** (asymmetric division that regenerates the stem cell pool while also producing committed progenitors). They are broadly grouped into **embryonic** and **adult (somatic)** stem cells, and a third laboratory-generated category, **induced pluripotent stem cells (iPSCs)**. Translating stem-cell biology from "bench to bedside" underlies modern **regenerative medicine and tissue engineering**, but each source requires a distinct isolation strategy and carries its own scientific, safety and ethical limitations.

1. Classification of stem cells

By developmental potency

Tier	Potency	Example
Totipotent	Form embryonic + extra-embryonic (placental) tissue	Zygote, blastomeres up to 8-cell stage
Pluripotent	Form all three germ layers (not placenta)	Inner cell mass cells / embryonic stem cells (ESCs), iPSCs
Multipotent	Restricted to related lineages of one germ layer	Haemopoietic stem cell (HSC), mesenchymal stem cell (MSC)
Unipotent	Differentiate into a single cell type only	Committed progenitor (e.g., erythroid progenitor, CFU-E)

By source

- **Embryonic stem cells (ESCs)** — derived from the inner cell mass of the blastocyst.
- **Adult/somatic stem cells** — haemopoietic stem cells (HSC), mesenchymal stem cells (MSC), amniotic fluid stem cells (AFSC), umbilical cord blood stem cells (UCB-SC).
- **Induced pluripotent stem cells (iPSCs)** — reprogrammed somatic cells.

By immunological relationship (relevant to transplantation): **syngeneic** (identical twins), **autologous** (self), **allogeneic** (same species, different individual), **xenogeneic** (different species). Syngeneic/autologous cells are least likely to be rejected.

□ Fig 16.1 — Derivation and use of embryonic stem cell lines. (Gangane — Human Genetics — 5e, p.255)

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

Box-diagram of ESC line derivation (label each step): **Blastocyst** → **inner cell mass separated into individual cells** → **single cell placed in culture dish with growth factors/feeder layer** → **stimulated to divide** → **self-renewing colony of embryonic stem cells** → **directed differentiation into ectoderm/mesoderm/endoderm derivatives (e.g., neurons, cardiac muscle, hepatocytes).**

2. Isolation of embryonic stem cells and iPSCs

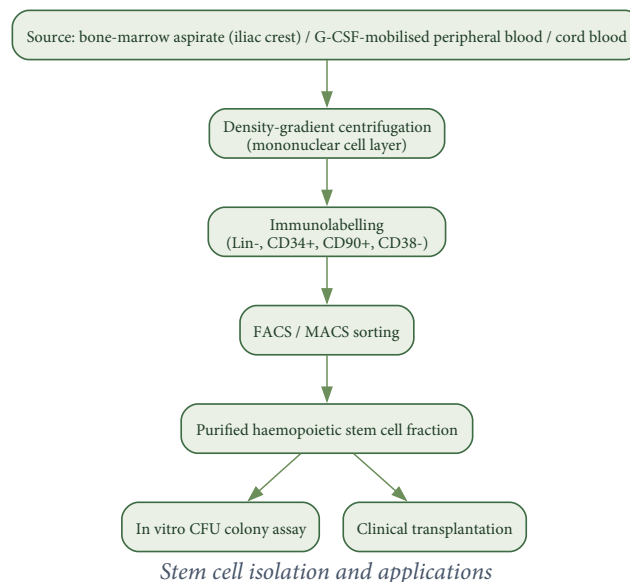
- **ESC derivation:** the blastocyst is disaggregated and the inner cell mass is separated into individual cells; a single cell is cultured in a dish with growth factors (and traditionally a feeder layer), which stimulates division into a self-renewing colony — an ESC line.
- **Somatic cell nuclear transfer (SCNT/"therapeutic cloning"):** the nucleus of a patient's somatic cell is introduced into an enucleated oocyte; the reconstructed oocyte is stimulated to develop into a blastocyst from which patient-matched ESCs are harvested. Because the resulting ES cells are genetically identical to the donor, they are immunologically compatible and — since fertilisation is not involved — the technique is regarded as less ethically contentious than using surplus IVF/aborted-fetus embryos.
- **Induced pluripotent stem cells (iPSCs):** a differentiated somatic cell (e.g., a fibroblast) is reprogrammed to a pluripotent state by introducing four transcription factors — **Oct3/4, Sox2, Klf4, c-Myc** ("Yamanaka factors") — usually via viral transduction. Discovered in 2006 (Takahashi & Yamanaka), this earned the 2012 Nobel Prize. Limitations include low reprogramming efficiency (<1%), risk of insertional mutagenesis/tumour formation from viral vectors, and immunogenicity concerns — although being autologous, iPSCs are probably non-immunogenic. Non-viral reprogramming using small-molecule drugs is under active development.

3. Isolation of adult (somatic) stem cells

Source	Method of isolation	Marker/selection
Bone marrow (HSC + MSC)	Aspiration from the iliac crest (posterior superior iliac spine) or sternum → density-gradient centrifugation to obtain the mononuclear cell layer	HSC: immunolabelling for Lin⁻, CD34⁺, CD90⁺, CD38⁻ surface markers, followed by fluorescence-activated cell sorting (FACS) or magnetic-activated cell sorting (MACS)
Peripheral blood (PBSC)	Stem cells mobilised out of marrow into circulation using granulocyte colony-stimulating factor (G-CSF) , then collected by apheresis	Same HSC marker panel; less invasive than marrow harvest but yields are sparse, needing mobilisation
Umbilical cord blood (UCB-SC)	Collected from the placenta/umbilical cord vein immediately after delivery; cryopreserved in cord-blood banks	Displays embryonic-like markers but is lineage-marker negative

Source	Method of isolation	Marker/selection
Amniotic fluid (AFSC)	Harvested by amniocentesis	Selected as c-kit ⁺ (CD117 ⁺); pluripotent, non-tumorigenic; ~1% of amniotic fluid cells are true stem cells
Mesenchymal (MSC)	Enriched from bone marrow, adipose tissue, synovium, skeletal muscle or placental tissue	Isolated by plastic-adherence and expansion in culture; multipotent along mesodermal lineages (bone, cartilage, fat)

Haemopoietic stem cells cannot be identified morphologically on a routine marrow smear — they resemble large lymphocytes — and must be isolated immunologically. **Research/validation techniques:** (i) *in vitro* — semisolid culture media supporting growth of colony-forming units (CFU-GEMM, CFU-GM, CFU-E, CFU-Meg) under cytokine stimulation (erythropoietin, G-CSF, GM-CSF); (ii) *in vivo* — transplantation of donor marrow into lethally irradiated recipients, where only true stem cells reconstitute haemopoietic colonies — the experimental basis of clinical bone marrow transplantation.



4. Comparison of stem-cell types — advantages and disadvantages

Type	Advantages	Disadvantages
ESC	Pluripotent	Immunological rejection; teratoma risk; ethical dilemmas (aborted fetuses); requires oocytes
AFSC	Pluripotent, non-tumorigenic; can correct fetal defects in utero or at birth	Low yield (~1% of amniotic cells are c-kit ⁺); origin/characterisation still under study
UCB-SC	Easy, low-morbidity procurement; cryopreservable/bankable; minimal ethical concern	Low cell yield, finite quantity; storage/quality-control/cost issues

Type	Advantages	Disadvantages
MSC	Multipotent; large numbers harvestable from several tissues; easily expanded in culture; autologous, immunomodulatory; minimal ethical concern	Differentiation depends on microenvironment; optimal delivery route unclear; limited long-term potential
iPSC	Pluripotent; derivable from any cell type; probably non-immunogenic	Low reprogramming efficiency (<1%); viral-vector safety concerns; tumour risk

5. Applications of stem cells

□ Fig 16.2 — Applications of stem cells. (Gangane — Human Genetics — 5e, p.256)

- ▶ **Haematological:** bone marrow transplant remains the best-established stem cell therapy — used for leukaemia, lymphoma, inborn errors of metabolism and other blood disorders.
- ▶ **Tissue engineering / regenerative medicine:** stem cells are seeded onto natural or synthetic scaffolds within a bioreactor to build "off-the-shelf" tissues/organs — trachea, heart valves, cartilage, bladder, skin, chest wall, urethra and others have been engineered experimentally; the **trachea was the first stem-cell-based, tissue-engineered organ successfully transplanted into a human**, using the patient's own (autologous) marrow- and epithelium-derived stem cells seeded on a decellularised or synthetic scaffold.
- ▶ **Neurological:** potential in stroke, traumatic brain injury and Alzheimer disease; embryonic stem cell transplantation has succeeded in animal models of Parkinson disease, motor-neuron disease and spinal cord injury.
- ▶ **Cardiac:** mesenchymal stem cells are in numerous clinical trials for myocardial infarction, with encouraging initial results.
- ▶ **Endocrine/metabolic:** diabetes mellitus (islet cell regeneration).
- ▶ **Musculoskeletal:** muscular dystrophy.
- ▶ **Ophthalmic:** limbal stem cells used to repair corneal surface disorders.
- ▶ **Autoimmune disease:** Crohn disease, multiple sclerosis, rheumatoid arthritis.
- ▶ **Oncological:** multi-site cancers.
- ▶ **Frontier application — blastocyst complementation:** human iPSCs injected into blastocysts of large animals (e.g., pigs) genetically modified to lack a specific organ home to the deficient niche and regenerate that organ (demonstrated for the pancreas in pig models), raising the prospect of growing transplantable human organs in livestock — though immunological (porcine vasculature) and ethical (human–animal hybrid) concerns remain unresolved.

Applied / Clinical anatomy

- ▶ **Bone marrow aspiration/biopsy site:** the **iliac crest** (posterior superior iliac spine) is the standard site for harvesting bone marrow stem cells; the sternum is an alternative site.
- ▶ **Cord blood banking:** umbilical cord/placental blood is collected non-invasively at delivery and cryopreserved — a growing private and public banking industry in India.

- ▶ **Limbal stem cell transplantation** restores the corneal epithelium in bilateral limbal stem cell deficiency (chemical injury, Stevens-Johnson syndrome) — practised in India at centres such as the LV Prasad Eye Institute, Hyderabad.
- ▶ **Tissue-engineered trachea:** autologous stem cells seeded on a decellularised/synthetic tracheal scaffold have been transplanted clinically, avoiding donor-organ shortage and immune rejection.
- ▶ **Regulatory anatomy of practice:** stem cell research/therapy in India is governed by ICMR guidelines (first issued 2007); stem cell therapy (other than bone marrow transplant) is still investigational, not routine clinical practice, anywhere in the world.
- ▶ **Cautionary example:** the 2014 STAP-cell (stimulus-triggered acquisition of pluripotency) papers claiming rapid low-pH reprogramming were retracted within weeks — illustrating why stem-cell claims require rigorous, peer-reviewed, reproducible verification before clinical application.

High-yield exam pointers

- ▶ Two defining properties of a stem cell: **self-renewal** + **multilineage (or unilineage, if unipotent) differentiation**.
- ▶ Potency hierarchy: **totipotent** > **pluripotent** > **multipotent** > **unipotent**.
- ▶ HSC immunophenotype for isolation/FACS-MACS sorting: **Lin⁻ CD34⁺ CD90⁺ CD38⁻**.
- ▶ iPSC reprogramming factors ("Yamanaka factors"): **Oct3/4, Sox2, Klf4, c-Myc** (2006; Nobel Prize 2012).
- ▶ AFSC marker: **c-kit⁺ (CD117⁺)**; harvested by amniocentesis.
- ▶ MSC sources: bone marrow, adipose tissue, synovium, skeletal muscle, placenta — multipotent, mesodermal lineage.
- ▶ Trachea = first stem-cell-based tissue-engineered organ transplanted into a human.
- ▶ Bone marrow transplant = only stem cell therapy in routine clinical use; other applications remain largely trial-based.
- ▶ Iliac crest (posterior superior iliac spine) = standard site of bone marrow aspiration/biopsy.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e — Commentary 1.2 "Stem cells in regenerative medicine"; Gangane Human Genetics 5e (Chapter — Stem Cell Therapy); Ross Histology — A Text and Atlas 7e (Chapter — Blood); Junqueira's Basic Histology 17e (Chapter — Hemopoiesis); BD Chaurasia Human Anatomy Vol 2 8e.



Comparative & applied embryology



In vitro fertilization

Asked in: Paper IV Nov 2017 · Paper II Oct 2009 (2×) — RGUHS MD/MS Anatomy

Definition / Introduction

In vitro fertilization (IVF) is a process of assisted reproductive technology (ART) in which a mature oocyte is fertilised by a spermatozoon **outside the female body**, in a culture medium, and the resulting embryo is transferred back into the uterus for implantation. It is popularly called the "**test-tube baby**" technique. The first IVF baby, **Louise Brown**, was born on **25th July 1978**; the technique was developed by **Robert Edwards** (awarded the **Nobel Prize in Physiology or Medicine, 2010**) and **Patrick Steptoe**. IVF, with its variants (ICSI, GIFT, ZIFT) and adjuncts (artificial insemination, oocyte/embryo cryopreservation), is now the standard treatment for most causes of infertility, correcting for a defective step in the normal fertilisation-implantation sequence.

Normal fertilisation vs in vitro fertilisation

Feature	Normal (in vivo) fertilisation	In vitro fertilisation
Site	Ampullary region of the uterine (fallopian) tube, within ~24 hours of ovulation	Petri dish/culture medium in the laboratory
Gamete transport	Spermatozoa ascend the female tract to the ampulla; very few reach the oocyte	Oocyte and spermatozoa are brought together directly in medium
Capacitation	Occurs physiologically in the uterus/uterine tube, induced by tubal/uterine secretions	Induced artificially by incubating washed sperm in a defined culture medium for several hours
Ovulation trigger	Endogenous mid-cycle LH surge	Mimicked by an injectable hCG "trigger" 34–38 hours before egg retrieval
Oocyte number released	Usually a single secondary oocyte per cycle	Multiple (often 10 or more) oocytes recruited by controlled ovarian hyperstimulation
Confirmation of fertilisation	Not directly observed	Two pronuclei seen on microscopy ~12–16 hours after insemination

Indications for IVF

- ▶ **Tubal factor:** blockage/damage of the fallopian tube (the classic original indication).
- ▶ **Ovulatory disorders:** anovulation or irregular ovulation.
- ▶ **Endometriosis.**
- ▶ **Polycystic ovarian syndrome (PCOS).**
- ▶ **Cervical factor** infertility (hostile mucus, anatomical/immunological barrier to sperm ascent).
- ▶ **Severe male factor infertility** (oligo-/astheno-/teratozoospermia, obstructive/non-obstructive azoospermia) — managed by adding ICSI to the standard IVF protocol.

- **Unexplained infertility** after conventional treatment has failed.

Stages of IVF

IVF is carried out in **six sequential stages**:

- **Ovarian stimulation and monitoring**: Injectable FSH (**gonadotropin**) drives multi-follicular development. Premature LH surge/ovulation is prevented by **pituitary down-regulation** using a **GnRH agonist** (nafarelin/leuprorelin, started early in the cycle — the "long protocol") or a **GnRH antagonist** (cetorelix/ganirelix, added from day 5–6 of stimulation — the "antagonist protocol"). Follicle growth is monitored by serial **transvaginal ultrasound** and serum **oestradiol (E2)** levels.
- **Oocyte (egg) retrieval**: Ovulation is induced with an **injectable hCG (or LH) trigger** 34–38 hours before a pre-planned egg pickup, timed to mimic the natural LH surge. Oocytes are aspirated **transvaginally under ultrasound guidance** (mild sedation/local anaesthesia) using a fine needle passed through the vaginal wall into the mature follicle; **laparoscopic aspiration** is used when the ovary is not accessible transvaginally (e.g. pelvic adhesions, fibroids).
- **Fertilisation**: Semen is collected and **sperm-washed** (density-gradient centrifugation or swim-up technique) to remove seminal plasma, mucus and non-motile sperm. Washed sperm and oocytes are co-incubated overnight at 37 °C (standard insemination), or, in severe male-factor cases, a single sperm is injected directly into the oocyte cytoplasm (**ICSI** — equally successful as standard IVF). Fertilisation is confirmed the next day by the presence of **two pronuclei**; roughly 80% of mature oocytes fertilise in vitro.
- **Embryo development**: The zygote undergoes **cleavage** in culture medium; embryo quality is assessed by blastomere number/symmetry/fragmentation on day 2–3, or the embryo is cultured further to the **blastocyst stage** (day 5). **Preimplantation genetic diagnosis/screening (PGD/PGS)** can be performed at this stage — one or more cells (polar body, blastomere, or trophectoderm biopsy of the blastocyst) are removed and analysed by PCR/FISH for single-gene disorders or aneuploidy before transfer. Surplus embryos are **cryopreserved** (in glycerol, propanediol or DMSO) for future use.
- **Embryo transfer**: One or two embryos (cleavage-stage or blastocyst) are loaded into a fine catheter and transferred into the hormonally-prepared uterine cavity via the **vagina and cervical canal**, without anaesthesia.
- **Luteal phase support**: Because oocyte aspiration strips the granulosa cells that would form the corpus luteum, endogenous progesterone is deficient; **exogenous progesterone** is therefore given for at least the first two weeks after retrieval. Pregnancy is confirmed by serum **β-hCG** and later ultrasound.

□ Fig 5.1 — *In vitro fertilisation. It involves six stages as follows: Stage 1, ovarian stimulation and monitoring; Stage 2, oocyte retrieval; Stage 3, fertilisation; Stage 4, embryo development; Stage 5, embryo transfer; Stage 6, luteal phase support (Sontakke — Textbook of Human Embryology, p.44)*

DIAGRAMS TO DRAW — IMAGE SUGGESTIONS

A simple six-box flow diagram, top to bottom, labelled exactly:

- ▶ **Ovarian stimulation & monitoring** (GnRH agonist/antagonist + FSH; USG + E2 monitoring)
- ▶ **Oocyte retrieval** (hCG trigger → transvaginal USG-guided/laparoscopic aspiration)
- ▶ **Fertilisation** (sperm washing → insemination or ICSI → pronuclei check)
- ▶ **Embryo development** (cleavage → blastocyst; ± PGD/PGS; cryopreservation of spares)
- ▶ **Embryo transfer** (catheter via vagina + cervical canal into uterus)
- ▶ **Luteal phase support** (progesterone → β -hCG confirmation)

Related assisted reproductive techniques

Technique	Definition	Key indication	Success rate (per source)
ICSI (intracytoplasmic sperm injection)	Direct microinjection of a single sperm into the oocyte cytoplasm using a glass micropipette (developed by G. Palermo)	Teratozoospermia, poor motility, low sperm count, obstructive azoospermia (vasectomy), anti-sperm antibodies	As successful as routine IVF
GIFT (gamete intrafallopian transfer)	Collected oocytes and washed sperm are placed together directly into the uterine tube via laparoscope — fertilisation occurs in vivo, in the ampulla	Normal ovary + at least one patent tube; sperm dysfunction or unexplained infertility	~25–30%
ZIFT (zygote intrafallopian transfer)	An in-vitro fertilised zygote is transferred into the uterine tube via laparoscope	Tubal-factor cases wanting in-vivo cleavage	~65% (per Sontakke)
Artificial insemination	Deliberate introduction of sperm into the cervix (intracervical, ICI) or uterus (intrauterine, IUI), other than by intercourse	Donor sperm, mild male infertility, unexplained infertility	ICI 10–15%/cycle; IUI 15–20%/cycle (~60–70% cumulative pregnancy over 6 IUI cycles)
Surgical sperm extraction	Sperm retrieved directly from epididymis or testis (e.g. PESA/TESE)	Azoospermia due to ejaculatory-duct/vas obstruction or vasectomy	Used to source sperm for ICSI
Oocyte cryopreservation ("egg freezing")	Oocytes retrieved as in IVF, vitrified and stored in liquid nitrogen (–196 °C) for later thaw/fertilisation	Fertility preservation before chemotherapy/radiotherapy, or elective deferral of childbearing	14.8–31.5%, age-dependent

Recent advances in IVF

- ▶ **Artificial intelligence in embryo selection:** deep-learning models trained on time-lapse imaging and clinical metadata now grade embryo morphology, predict blastocyst formation/aneuploidy, and forecast live-birth outcome with accuracy exceeding experienced embryologists (46.1% vs 30.7% on day 3; 55.0% vs 40.7% on day 5, AUC 0.769), offering a non-invasive adjunct to conventional morphological grading (Sun et al, *Chin Med J* 2024) [DOI: 10.1097/CM9.0000000000003162]; a broader narrative review outlines AI applications across stimulation-protocol personalisation, gamete assessment and IVF-lab quality control (Olawade et al, *J Gynecol Obstet Hum Reprod* 2024) [DOI: 10.1016/j.jogoh.2024.102903], building on an earlier review of AI in the embryology laboratory (Dimitriadis et al, *Reprod Biomed Online* 2022) [DOI: 10.1016/j.rbmo.2021.11.003].
- ▶ **Refinement of PGT-A and trophectoderm biopsy:** comprehensive chromosome screening has improved detection of whole-chromosome aneuploidy, but has surfaced the unresolved problem of **embryo mosaicism** and the limits of a single trophectoderm biopsy in predicting true embryo ploidy (Morales, *Reprod Sci* 2023) [DOI: 10.1007/s43032-023-01301-0]; current biopsy technique (laser-assisted zona opening plus "pulling" or "flicking" trophectoderm excision at the expanded/hatching blastocyst stage) continues to be standardised to minimise mosaicism and safeguard neonatal outcome (De Vos & De Munck, *Genes* 2025) [DOI: 10.3390/genes16020134].
- ▶ **Fertility-preservation outcomes quantified:** a systematic review/meta-analysis of cancer survivors reports live-birth rates of **41% after embryo cryopreservation, 32% after oocyte vitrification, and 21–33% after ovarian tissue cryopreservation/transplantation**, clarifying counselling for young patients facing gonadotoxic therapy (Fraison et al, *Hum Reprod* 2023) [DOI: 10.1093/humrep/deac249].
- ▶ **In vitro gametogenesis (IVG):** an emerging, still-experimental line of research aims to reprogram somatic (e.g. dermal fibroblast) cells to induced pluripotent stem cells, then to primordial germ cell-like cells and ultimately oocytes/spermatocytes usable for embryogenesis — a potential future fertility-restoration route for oncofertility patients, though major scientific and ethical barriers remain before clinical use (Wesevich et al, *J Clin Med* 2023) [DOI: 10.3390/jcm12093305].
- ▶ **Mitochondrial replacement therapy ("three-parent IVF"):** techniques such as maternal spindle transfer, pronuclear transfer and polar-body genome transfer are being refined to prevent transmission of pathogenic mitochondrial DNA mutations to offspring conceived by IVF, alongside early exploratory work on autologous mitochondrial transplantation (AUGMENT); global ethical/legal regulation remains unsettled (Belousova et al, *Int J Mol Sci* 2025) [DOI: 10.3390/ijms26146645].

(According to PubMed.)

Applied / Clinical anatomy

- ▶ **Ovarian hyperstimulation syndrome (OHSS):** an iatrogenic complication of the gonadotropin-stimulation step — ovaries enlarge and exude fluid into the peritoneal cavity, producing abdominal pain and bloating; antagonist protocols and careful trigger choice reduce risk.

- ▶ **Multiple pregnancy:** the principal complication of IVF/ART, arising from transfer of more than one embryo; risk is reduced by limiting the number of embryos transferred (single embryo transfer where feasible).
- ▶ **Age-dependent success:** per-cycle live-birth chance falls sharply with maternal age — approximately 30% (<35 years), 25% (35–37 years), 17% (38–40 years), and <5% (>40 years); this decline reflects age-related oocyte aneuploidy and is central to patient counselling.
- ▶ **ICSI-specific risks:** ICSI carries a slightly higher reported incidence of birth defects than standard IVF, and an increased risk of transmitting **Y-chromosome microdeletions** (and hence infertility) to male offspring, since ICSI can bypass natural sperm-selection barriers.
- ▶ **PGD/PGS in practice:** allows exclusion of embryos carrying serious single-gene disorders (e.g. haemophilia A) or aneuploidy (e.g. trisomy 21) before transfer, and can identify embryo sex to avoid transferring a male embryo at risk of a severe X-linked disorder.
- ▶ **Site relevance:** because IVF/ICSI bypasses the ampulla (the normal fertilisation site) while GIFT deliberately restores fertilisation to the ampulla in vivo, IVF is applicable even with bilateral tubal block, whereas GIFT requires at least one patent, healthy tube.

High-yield exam pointers

- ▶ IVF = fertilisation of ovum **outside** the body, embryo transferred to uterus; "test-tube baby"; first baby **Louise Brown, 1978**; pioneers **Edwards & Steptoe** (Edwards — Nobel Prize 2010).
- ▶ Six stages: **stimulation** → **retrieval** → **fertilisation** → **embryo development** → **transfer** → **luteal support**.
- ▶ hCG trigger given **34–38 hours** before egg retrieval to mimic the LH surge; oocytes aspirated **transvaginally under USG guidance**.
- ▶ Normal fertilisation site = **ampulla of the uterine tube**; capacitation is natural in vivo, induced artificially in vitro.
- ▶ **ICSI** (Palermo) = single-sperm microinjection for severe male-factor infertility; **GIFT** = gametes placed in the tube (in-vivo fertilisation); **ZIFT** = zygote placed in the tube.
- ▶ **PGD/PGS:** biopsy of polar body/blastomere/trophectoderm for single-gene disorder or aneuploidy screening before transfer.
- ▶ Complications: **OHSS**, multiple pregnancy, age-related decline in success, ICSI's Y-chromosome-deletion/birth-defect risk.
- ▶ Cryopreservation of surplus embryos/oocytes uses glycerol/propanediol/DMSO as cryoprotectant; oocytes are vitrified and stored at **–196 °C**.

SOURCE & COVERAGE

Gray's Anatomy (Standring) 41e; Sontakke — Textbook of Human Embryology; Moore — The Developing Human 9e; Langman's Medical Embryology (Sadler) 14e; Ross Histology — A Text and Atlas 7e. Recent-advances citations are from PubMed (2022–2025).

