EpoMedicine

NEUROANATOMY NOTES

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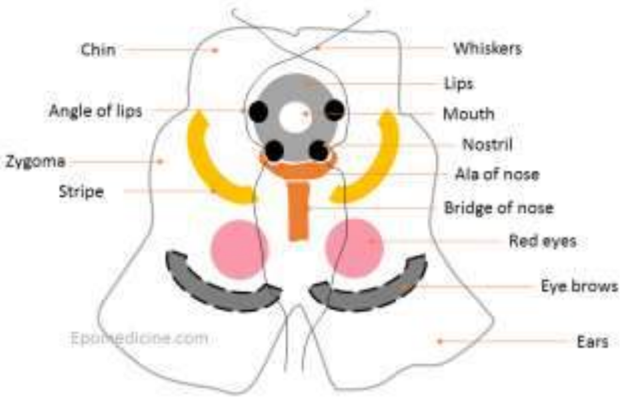
How to Draw Midbrain Cross-section?

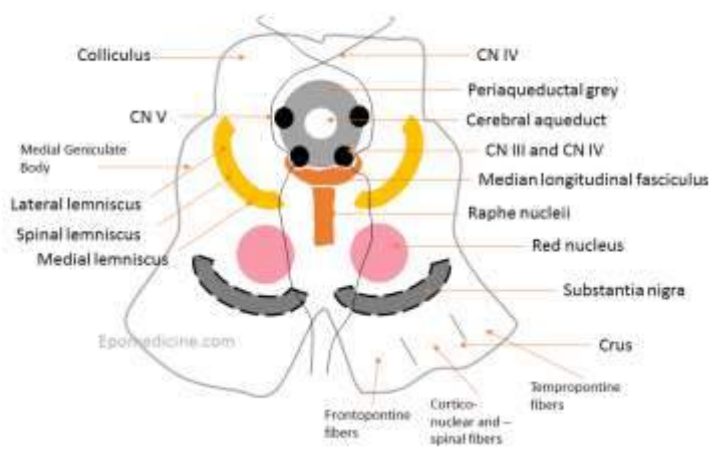
The cross-section of midbrain can be compared to the "*upside down striped face of a red-eyed demon*".



Using this analogy of a demon face, let's assign the structures found on the cross-section of midbrain:

1. Ear = Crus cerebri
   - Medial – frontopontine fibers
   - Middle – corticonuclear and corticospinal tract
   - Lateral – temporopontine fibers
2. Eye brows = Substantia nigra
3. Red eyes = Red nucleus
4. Bridge of nose = Raphe nucleus
5. Ala of nose = Median longitudinal fasciculus (MLF)
6. Nostrils = Cranial nerve nucleus
   - CN III in superior section
   - CN IV in inferior section
7. Whiskers = Cranial nerves
   - CN III – towards head
   - CN IV – towards chin
8. Stripe = Lemniscus
   - Towards head – Medial lemniscus
   - Middle – Spinal lemniscus (Spinothalamic tract)
   - Towards chin – Lateral lemniscus
9. Zygoma = Medial geniculate body
10. Mouth = Cerebral Aqueduct
11. Lips = Peri-aqueductal grey
12. Angle of mouth = Mesencephalic trigeminal nucleus
13. Chin = Colliculus
    - Superior colliculus in superior section
    - Inferior colliculus in inferior section

Now, let's label them:



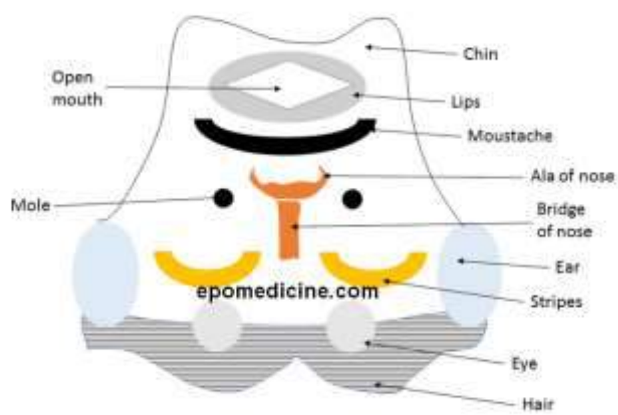
Another important mnemonic that everyone must remember is that: **M**otor tracts are towards **M**idline and **S**ensory tracts are towards **S**ide.

How to Draw Pons Cross-Section?

The cross-section of pons is similar to the midbrain as described earlier but few things must be kept in mind:

1. The orientation of lemnisci in midbrain is more or less vertical, but in pons it is horizontal.
2. Cranial nerve III and IV arises from midbrain and mainly Cranial nerve V, VI, VIII and VIII arises from pons.
3. Cerebral aqueduct lies in midbrain and 4th ventricle lies in pons.

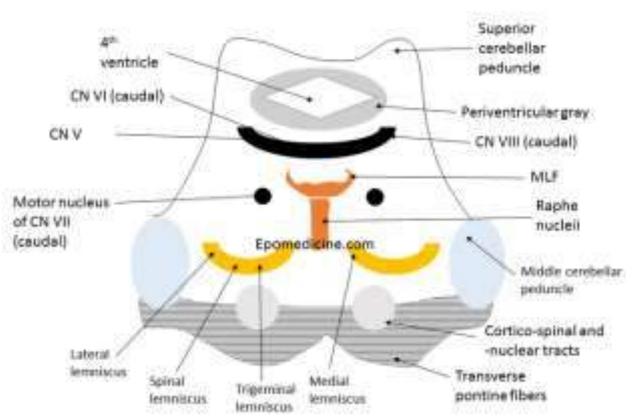
We will use the analogy of an "*inverted face of a human*" to draw the cross-section of pons.



Now, let's label the structures shown above.

1. Hair = Transverse pontine fibers
2. Eye = Corticospinal and Corticonuclear tracts
3. Ear = Middle cerebellar peduncle
4. Stripes = Lemnisci
   - Medially: Medial lemniscus
   - Middle: Trigeminal lemniscus medially and Spinal lemniscus laterally
   - Lateral: Lateral lemniscus
5. Bridge of nose = Raphe nucleii
6. Ala of nose = Medial Longitudinal Fasciculus
7. Mole = Facial nerve motor nucleus (In caudal pons)
8. Moustache = Cranial nerve nucleii
   - Medial most = CN VI or Abducens nerve (In caudal pons)
   - Middle = CN V or Trigeminal nerve – motor and sensory (In rostral pons)
   - Lateral most = CN VIII – Superior vestibular nucleus (In rostral pons)
9. Lips = Periventricular gray
   - Contains locus coeruleus
10. Open mouth = 4th ventricle
11. Chin = Superior cerebellar peduncle

Now, let's look at the real picture:



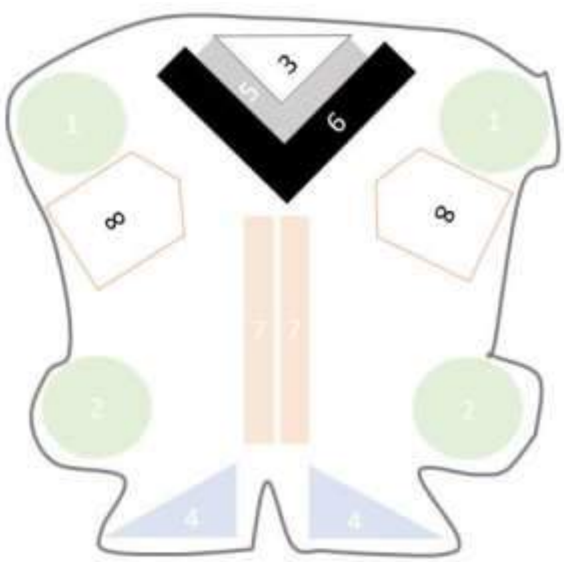
How to Draw Medulla Oblongata Cross-section?

Like in Midbrain and Pons:

1. Corticospinal tract passes ventrally.
2. Ventricular system is dorsal in midline.
3. Cranial nerve nuclei are located just anterior to the ventricle.
4. Medial longitudinal fasciculus is present around the center.

Caudal medulla resembles "**spinal cord**":

1. Circular in shape
2. Central canal instead of 4th ventricle
3. Nucleus gracilis and nucleus cuneatus dorsally
4. Pyramids and medial lemnisci decussate

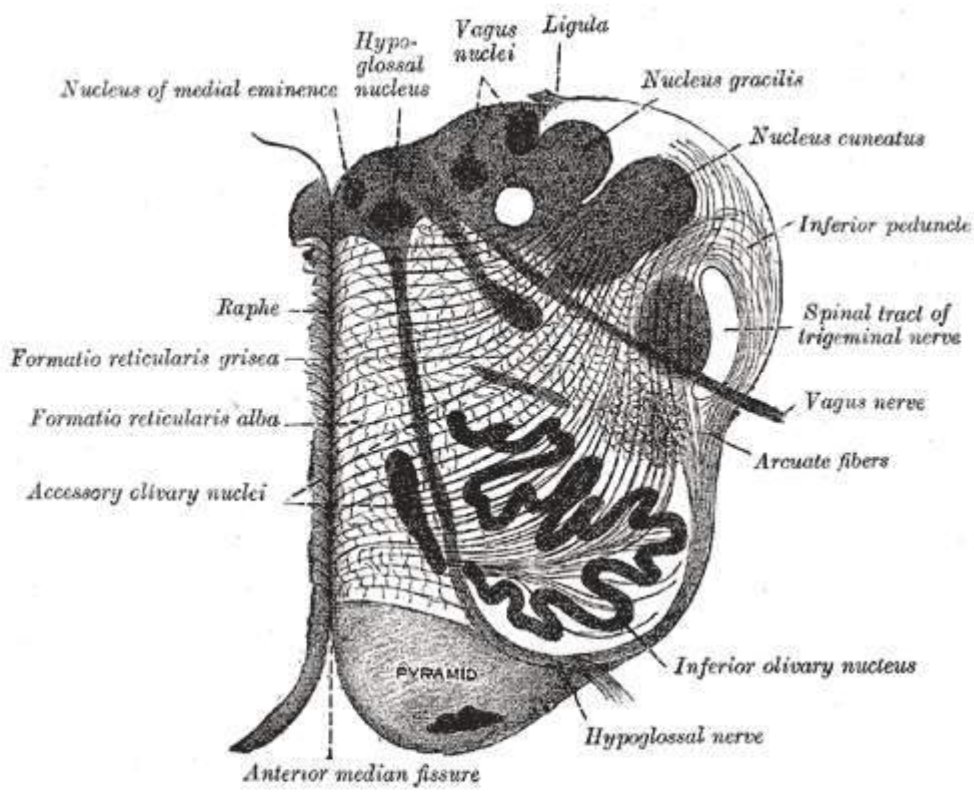


How to draw medulla cross-section?

1. Draw a pair of circles
   - Inferior cerebellar peduncle
2. Draw another pair of circles anteriorly
   - Inferior olivary nucleus
3. Draw a triangle in the center between 2 posterior circles
   - 4th ventricle
4. Draw a pair of triangles anterior to the 2 anterior circles
   - Pyramids
5. Draw a boomerang just anterior to the triangle representing 4th ventricle
   - Periventricular gray
6. Draw another boomerang anterior to the previous boomerang
   - Cranial nerve nucleii (from medial to lateral)
     - CN XII
     - Dorsal vagal nucleus
     - Nucleus tractus solitarius
     - Medial vestibular nucleus
     - Posterior cochlear nucleus
7. Draw a pair of rectangles in the center
   - Represents medial lemniscus (anteriorly) and Medial Longitudinal Fasciculus (MLF) posteriorly
8. Draw a pentagon with apex tilted medially, just anterior to the posterior pair of circles – the 5 points of the pentagon represents 5 structures (starting from apex in clockwise fashion)
   - Nucleus ambiguus
   - Trigeminal nerve nucleus and spinal tract

- Anterior cochlear nucleus
- Anterior spinocerebellar tract
- Lateral spinocerebellar tract
- Lateral spinothalamic tract inside the pentagon

Now, look how a real cross-section would look like:



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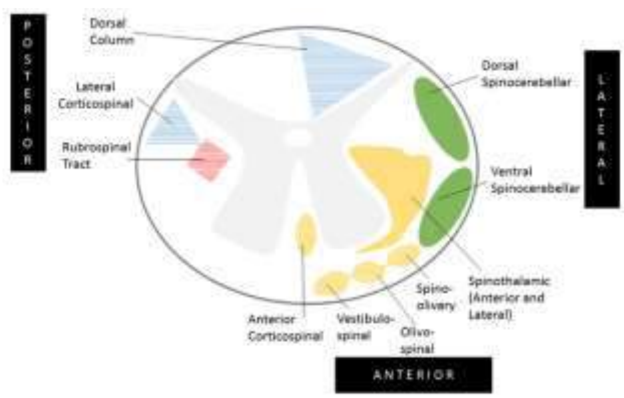
Henry Vandyke Carter [Public domain]

Spinal Cord Cross-section and Tracts Simplified



Organization of Ascending and Descending Tracts in Spinal Cord

A. 2 Posterior Tracts:

The fibers of these tracts **cross to the opposite side at the level of medulla**:

1. Dorsal column (Cross at medulla)
   - Fasciculus gracilis
   - Fasciculus cuneatus
2. Lateral corticospinal tract (Cross at medulla)

B. 2 Lateral Tracts:

The fibers of these tracts **remain on ipsilateral side**:

1. Dorsal spinocerebellar tract (Do not cross)
2. Ventral spinocerebellar tract (Crosses 2 times to lie on ipsilateral side)
   - 1st crossing in the spinal cord
   - 2nd crossing in the cerebellum

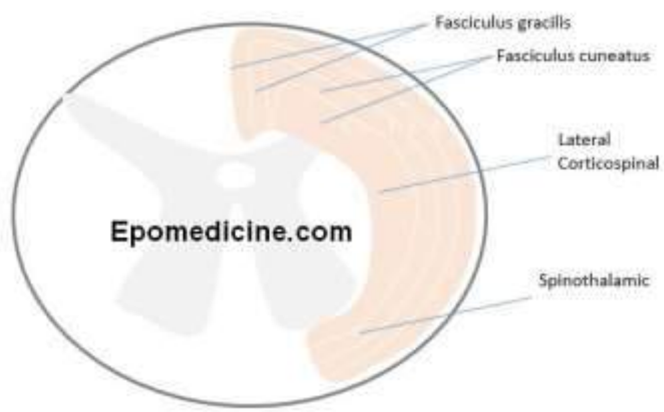
C. 2 Anterior Tracts:

The fibers of these tracts **cross at the level of spinal cord**:

1. Anterior corticospinal tract
2. Anterior and Lateral spinothalamic tract

D. Extrapyramidal tracts:

1. Rubrospinal tract (Cross at midbrain)
2. Vestibulospinal tract: Uncrossed
3. Reticulospinal tract: Uncrossed
4. Olivospinal tract: Uncrossed



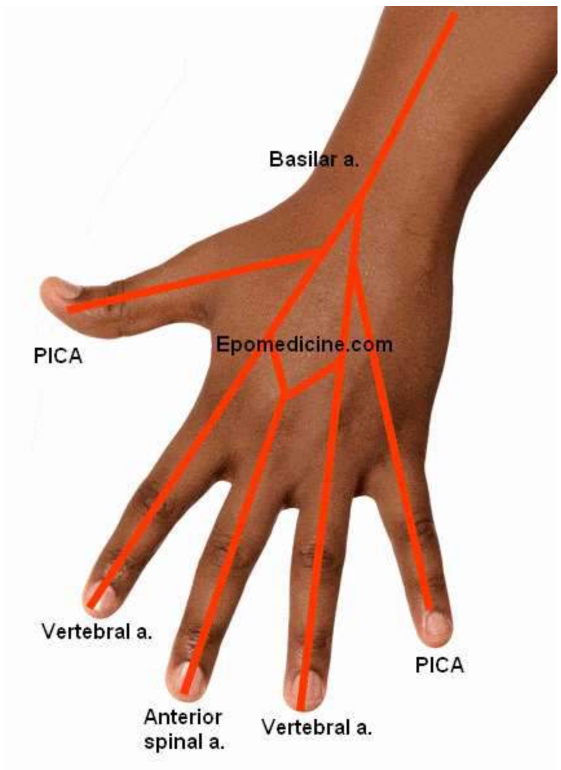
Now, look at the somatotropic arrangement of the various tracts:

- **Fasciculus gracilis:** lower limbs
- **Fasciculus cuneatus:** upper limbs
- **Corticospinal tract:** upper limbs medially and lower limbs laterally
- **Spinothalamic tract:** upper limbs medially and lower limbs laterall

Vertebrobasilar Arterial System and Syndromes

Vertebral Artery

I use the analogy of hand to remember the vertebral artery and its branches:



Index and ring fingers – Vertebral arteries of 2 sides; Middle finger – Anterior spinal artery; Thumb and pinky fingers – Posterior Inferior Cerebellar Artery (PICA) of 2 sides; Wrist – Pontomedullary junction where 2 vertebral arteries converge; Forearm – Basilar artery; Remember if there is anterior spinal artery, there is also posterior spinal artery (not shown here) which can arise wither from vertebral artery or PICA.

Origin: Branch of subclavian arteries

Course:

1. Ascends through transverse foramina on C6 through C1 and enters posterior fossa through foramen magnum
2. Continue up the ventral surface of medulla
3. Converge at the ponto-medullary junction to form single basilar artery
4. Branches are given inside cranial vault, once it has entered through foramen magnum

Supplies: Spinal cord, Medulla and Inferior cerebellum

Branches:

1. Anterior spinal artery (Single artery):

- Run down the front of the spinal cord
- Supplies ventrolateral 2/3rd of cervical spinal cord and ventrolateral medulla

2. Posterior spinal arteries:

- Bilaterally run down dorsolateral to spinal cord
- Supplies posterior 1/3rd of cervical spinal cord and posterior medulla

Clinical Correlate
1. 10 medullary arteries arising from segmental branches of aorta feeds anterior and posterior spinal artery along their course. In lower thoracic/upper lumbar region, **large** segmental artery exists and usually on Left side – named as Adamkiewicz. It's injury can result in paraplegia due to its lower thoracic/upper lumbar location.

2. Anterior spinal infarct can only affect the arm fibers of the lateral corticospinal tracts without affecting the leg fibers and vice versa (a posterior spinal artery infarct can affect the leg and not the arm fibers), because the border of the anterior and posterior spinal arterial territories lies within the corticospinal tract systems in the lateral funiculi.

3. Occlusion of vertebral artery or Anterior spinal artery can result in Medial medullary or Dejerine's syndrome.

3. Posterior Inferior Cerebellar Artery (PICA):

- Supplies all of medulla except antero-median part
- Supplies all of the inferior cerebellum and medial part of middle cerebellum

Clinical Correlate: PICA injury leads to PICA or Wallenberg Syndrome.

4. Meningeal branch:

- Supplies falx cerebri

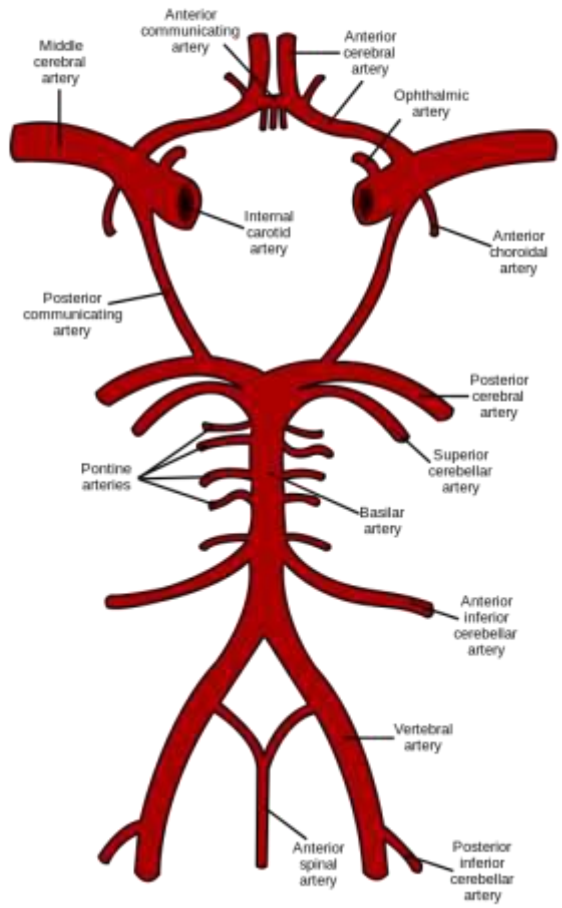
Basilar Artery

Origin: Joining of 2 vertebral arteries at ponto-medullary junction

Course:

1. Ascends along the midline of pons
2. Terminates near rostral border of pons by dividing into 2 Posterior cerebral arteries

Supplies: Pons, Anteroinferior and superior cerebellum and Inner ear



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Clinical correlate
Obstruction of basilar artery damaging the bilateral ventral pons give rise to **Locked-in Syndrome**. Because the tegmentum of the pons is spared, the patient has a spared level of consciousness, preserved vertical eye movements, and blinking. The corticospinal and corticonuclear tracts are affected bilaterally. The oculomotor and trochlear nerves are not injured. Patients are conscious and may communicate through vertical eye movements.

Branches:

Since, there is Posterior Inferior Cerebellar Artery – there must also be Anterior Inferior Cerebellar Artery (AICA) and Superior Cerebellar Artery (SCA). The branches from down to up are:

1. AICA:

- Supplies dorsolateral part of caudal pons and antero-inferior region of cerebellum
- Gives rise to labyrinthine artery in 85% cases

Clinical correlate
Occlusion of AICA can result in **Lateral Pontine Syndrome or Marie-Foix syndrome**. It is similar to Lateral medullary syndrome but can be localized by lesions of CN VII, CN VIII and other nucleus of CN V except spinal nucleus of CN V which is also injured in medullary syndromes. AICA occlusion is more specifically localized by presence of CN VII and CN VIII lesions as it is present in the caudal pons.

2. Labyrinthine artery:

- Usually originates from AICA but can originate from the basilar artery
- Follows the course of CN VIII and supplies the internal ear

3. Pontine branches:

- Supplies anterior and lateral part of pons through paramedian and circumferential branches

Clinical correlate
Occlusion of paramedian branches of basial artery results in **Medial pontine syndrome (Foville syndrome)**. This is similar to medial medullary syndrome but can be localized by the findings of CN VI (medial strabismus due to lateral rectus paralysis and lateral gaze paralysis if PPRF is involved) and VII lesions (LMN type of facial palsy).
Occlusion of the paramedian and circumferential branches can result in Ventral pontine syndrome (Millard-Gubler Syndrome). It presents with contralateral limb weakness (corticospinal tract involvement) and ipsilateral CN VI and VII defects.

4. Superior cerebellar artery (SCA):

- Supplies dorsolateral part of rostral pons and caudal midbrain
- Supplies superior cerebellum and lateral region of mid-cerebellum

Clinical correlate
Occlusion of SCA can result in **Lateral Pontine Syndrome or Marie-Foix syndrome**. It is similar to Lateral medullary syndrome but can be localized by lesions of CN VII, CN VIII and other nucleus of CN V except spinal nucleus of CN V which is also injured in medullary syndromes. SCA occlusion is more specifically localized by presence of CN V lesions as it is present in the rostral pons.

5. Posterior cerebral arteries:

- Paramedian and circumferential branches supply the midbrain.

- Forms circle of willis to supply brain

Clinical correlate:
Occlusion of posterior cerebellar arteries can result in **Medial midbrain syndrome (Weber syndrome)**. It is characterized by contralateral limb weakness (corticospinal tract involvement), contralateral lower facial weakness (corticobulbar fiber involvement i.e. UMN type of facial palsy) and ipsilateral CN III lesion.

Parinaud syndrome (Dorsal midbrain syndrome): This is caused due to pineal tumor compressing the superior colliculi. It compresses the vertical gaze center at the rostral interstitial nucleus of medial longitudinal fasciculus (riMLF) leading to vertical gaze palsy. It is accompanied by bilateral pupillary abnormalities and signs of elevated ICP (cerebral aqueduct compression).

Arterial Supply of Brainstem

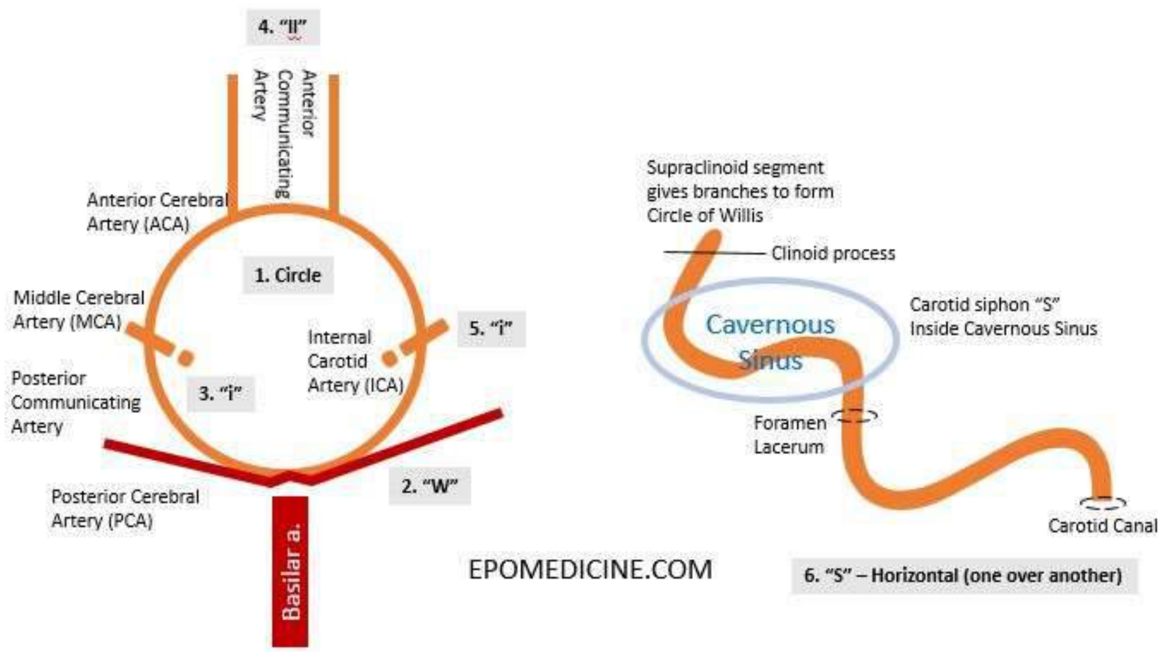
	Medulla	Pons	Midbrain
Paramedian vessels (anteromedial group)	Anterior spinal artery Vertebral artery	Paramedian branches of the basilar	Posterior cerebral artery
Short circumferential vessels (anterolateral group)	Anterior spinal artery Posterior inferior cerebellar artery	Short circumferential branches of the basilar	Collicular artery Posteromedial choroidal artery
Long circumferential vessels (lateral group)	Anterior spinal artery Posterior inferior cerebellar artery	Long circumferential branches of the basilar	Collicular artery Posteromedial choroidal artery
Large vessels (posterior group)	Posterior spinal artery Posterior inferior cerebellar artery	Superior cerebellar artery Anterior inferior cerebellar artery	Superior cerebellar artery Collicular artery Posteromedial choroidal artery

Circle of Willis – Mnemonic and Drawing

Circle of Willis is an important arterial communication that supplies the forebrain (telencephalon, diencephalon and optic vesicle) and often frequently tested in the exams. Circle of Willis receives blood from:

1. Vertebrobasilar system: Basilar artery which gives off Posterior Cerebral Arteries (PCA) and Posterior communicating arteries which are the branches of PCA
2. **Internal Carotid Artery System:** Gives off other arteries of Circle of Willis

Here, we will learn a mnemonic to draw the circle of Willis and intracranial course of Internal Carotid Artery (ICA).



Step-wise instructions for drawing the circle of Willis:

1. Draw a **Circle** – Circle of Willis is a circle of arteries.

Now write the "**Willis**" around this circle.

2. Write a large "**W**" at the inferior of circle – this represents **Posterior Cerebral Arteries (PCA)** which arises from a **single basilar artery.**

3. Write a **horizontal "i"** at the sides of the circle – this represents **Middle Cerebral Artery (MCA)** outside the circle and **Internal Cerebral Artery (ICA)** inside the circle.

4. Write "I I" at the superior of the circle – this represents the **Anterior Cerebral Arteries (ACA)** along with the part of circle between the MCA-ICA and Anterior communicating artery.

5. Write a **horizontal "i"** at the sides of the circle – this represents **Middle Cerebral Artery**

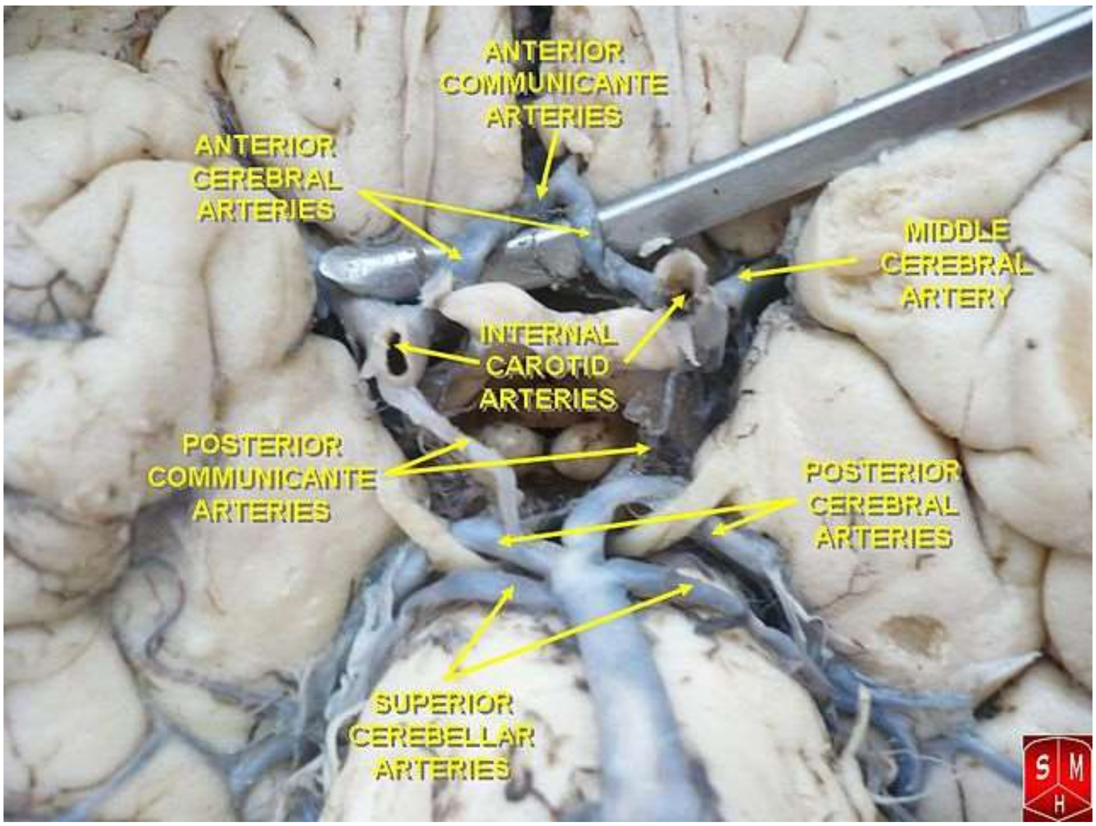
(MCA) outside the circle and **Internal Cerebral Artery (ICA)** inside the circle.

Now, the intra-cranial course of Internal Carotid Artery:

6. Write a **horizontal "S"** – starting from **carotid canal** and ending in **foramen lacerum.**

7. Write another **horizontal "S"** beginning from the end of previous "S" –

- starting from **foramen lacerum** and then
- forming **"S" shaped carotid siphon** within **cavernous sinus** and then
- ending at the level of **anterior clinoid process**
- **supraclinoid segment** of ICA gives of branches to form Circle of Willi



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Circle of Willis and Blood Supply of Forebrain

General Concepts of Blood Supply of Brain and Spinal Cord

1. **Spinal cord, Hind-brain and Mid-brain:** Veterbro-basilar system

2. **Forebrain:** Circle of willis which comprises of:

- Vertebrobasilar system: Posterior Cerebral Arteries (PCA) and it's branch Posterior communicating artery
- Internal carotid system: Other arteries of circle of willis including Anterior Cerebral Arteries (ACA), Middle Cerebral Arteries (MCA) and Posterior Cerebral Arteries (PCA)

> Forebrain derivatives are Telencephalon, Diencephalon and Optic vesicle.

3. The major vessels have 2 branches:

- Leptomeningeal branches: supply superficial regions (cortical and subcortical regions)
- Perforating branches: supply deep structures like diencephalon, basal ganglia and internal capsule)

4. Segments of the arteries:

- Proximal segments (A1 of ACA and P1 of PCA) are proximal to the respective communicating arteries, i.e. Anterior communicating artery and Posterior communicating artery respectively.
- Proximal segment of MCA (M1) is proximal to the bifurcation of trifurcation of the artery.
- Distal segments (A3 of ACA, M4 of MCA and P4 of PCA) are the cortical segments that supply the cortex.

Territories of Major arteries of Circle of Willis ICA enters through carotid canal to the cavernous sinus as shown in picture above.

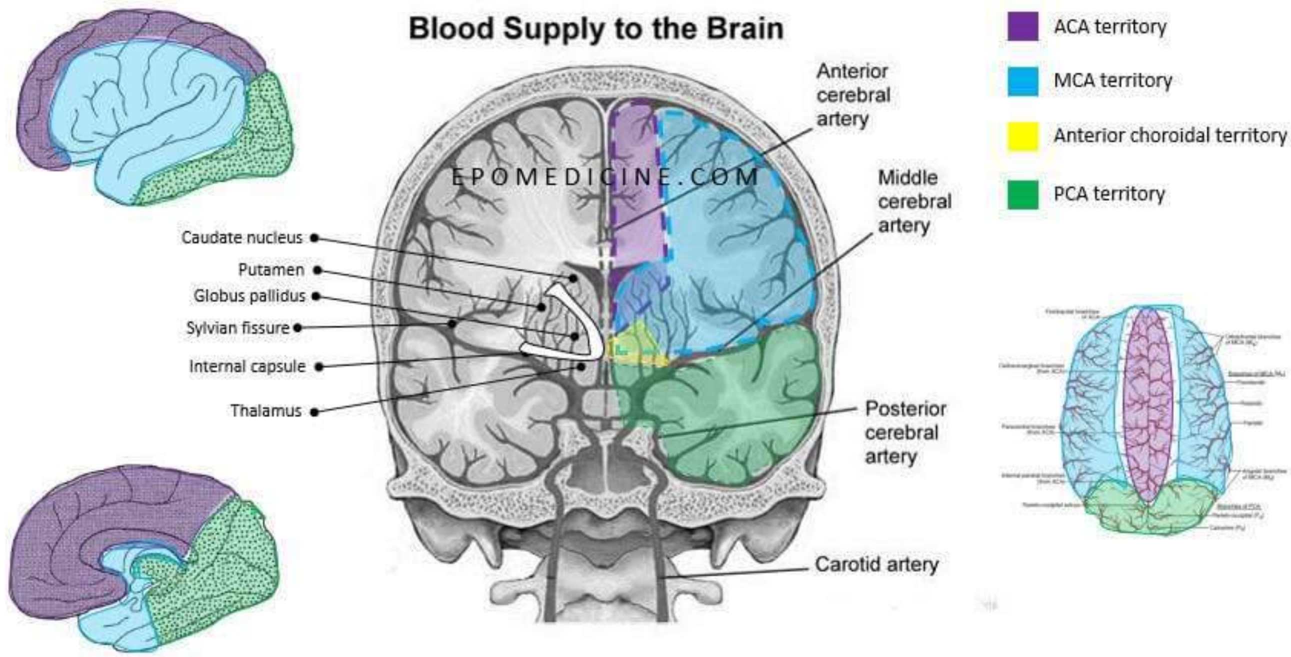
5. Leptomeningeal territories of arteries in general:

- PCA: supplies posterior and inferior surfaces
- ACA: supplies antero-medial surface
- MCA: supplies lateral surface

Location of Circle of Willis

The arteries get interconnected around the interpeduncular fossa which is a rhomboid (diamond) is shaped space in the ventral surface of the brain formed by the 2 Optic tracts anteriorly and 2 cerebral peduncles from pons posteriorly. It encloses tuber-cinerum, mammillary bodies, posterior perforated substance and the occulomotor neve from anterior to posterior.

> Interpeduncular cistern or Basal cistern = Interpeduncular fossa + Cerebral peduncles + Circle of Willi



Importance of Circle of Willis: Collateral circulation

Anterior Cerebral Artery (ACA)

ACA runs in the interhemispheric fissure and arches anterior to the genu of corpus callosum and then along the cingulate sulcus to give off branches.

Remember: The course of ACA is more on **medial** and hence, have major supply on **medial brain surface** and also gives of **medial striate branch** as deep perforating branch.

Supplies:

1. Medial surface of cerebral hemispheres
2. Medial, infero-medial and supero-lateral parts of frontal lobe and medial parietal lobe
3. Corpus callosum except splenium
4. Caudate nucleus head, anteromedial and inferior basal ganglia, anterior limb and genu of inferior internal capsule

Middle Cerebral Artery (MCA)

MCA courses laterally on lateral sulcus or sylvian fissure (overlies the insula) and emerges out on the lateral surface of the brain. Suprasylvian branches supply lateral and inferior frontal lobe and anterior lateral parts of parietal lobe. Infrasylvain branches supply lateral temporal lobe including its anterior tip and the amygdala and posterior parietal.

Remember: The course of MCA is more on **lateral** and hence, have major supplies on **lateral brain surface** and also gives **lateral striate branch** as deep perforating branch.

Supplies:

1. Supplies lateral portion of basal ganglia.
2. Superior surface of whole internal capsule

3. Anterior temporal lobe and most of the lateral surface of the cerebral hemispheres

Posterior Cerebral Artery (PCA)

PCA courses backwards, beneath the splenium of corpus callosum, to the calcarine fissure and to the lateral occipital surface.

Remember: The course of PCA is **backwards** and hence, have major supply on the **posterior brain surface**. It gives thalamoperforating artery, thalamogeniculate artery and posterior chorodial artery as deep branches to supply the thalamus.

Supplies:

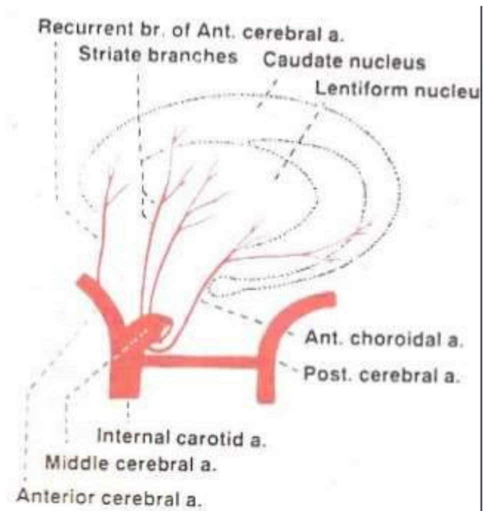
- Medial surface of parietal lobe
- Medial and inferior surface of temporal lobe including hippocampal formation
- Occipital lobe
- Splenium of corpus callosum
- Choroid plexus of ventricles
- Thalamus, hypothalamus and subthalamic nuclei
- Midbrain

Anterior Choroidal Artery

Branch of Internal Carotid Artery (ICA). It supplies:

- Posterior limb of inferior part of internal capsule
- Anterolateral thalamus
- Globus pallidus
- Posterior part of caudate nucleus and putamen
- Choroid plexus of anterior part of lateral ventricles

Deep Perforating Branches and Blood Supply of Basal Ganglia and Diencephalon



Circle of Willis Lesions

Berry Aneurysms

Commonest site is the branch point between anterior communicating artery and anterior cerebral artery (40%). Other common sites are the bifurcations/trifurcations of MCA (34%) and junction between posterior communicating artery and MCA (20%).

Branching points are the sites where arterial media are congenitally attenuated.

Remember the relations in interpeduncular fossa:

- Aneurysms in anterior communicating artery: compresses the optic tract (visual field defect – bitemporal lower quardantopia)

Aneurysms in the posterior communicating artery: compresses the occulomotor nerve (CN III palsy – down and out eye)

Watershed Zones

Watershed zones are the border zones that receive dual blood supply from terminal or distal branches of the 2 large arteries. Strokes in these areas (watershed stroke or infarction) occurs during severe hypotension when the cerebral autoregulation fails and these border zones are starved of blood.

The somatotopic sensorimotor area between the middle and anterior cerebral arteries encodes the proximal arms and legs. So patients with watershed strokes often manifest with "man in a barrel syndrome," meaning they have trouble lifting their arms and legs but their hands and feet are fine.

Anterior Cerebral Artery (ACA)

The sensorimotor homnculus for leg and foot are in the paracentral lobule in the medial aspect of brain. Hence, the lesion leads to contralateral leg-foot motor and sensory loss.

ACA also supplies the majority of anterior portion of corpus callosum, the damage of which leads to transcortical apraxia (a disconnect syndrome). There is no motor weakness, but the patient cannot execute a command to move their left arm.

- Wernicke's area intact in left hemisphere: can understand the command
- Callosal lesion: disconnection of Wernicke's area from right primary motor cortex – cannot execute left arm movement on command.
- Connection between Wernicke's area and left primary motor cortex intact: can execute a command to move right arm

Middle Cerebral Artery (MCA)

MCA supplies the lateral convexity (parietal region) of the brain including:

1. Broca's and Wernicke's speech areas
2. Arcuate fasciculus or Superior longitudinal fasciculus
3. Sensorimotor homonculus of remaining areas, i.e. face and arms
4. Frontal eye field
5. Splenium of corpus callosum

Lesion leads to:

1. Contralateral face and arm paralysis and sensory loss
2. Dominant hemisphere (Speech centers): Aphasia
3. Non-dominant hemisphere (Supramarginal gyrus and angular gyrus – body and spatial awareness): Contralateral hemisensory neglect

Posterior Cerebral Artery (PCA)

Supplies occipital cortex, diencephalon and rostral midbrain.

Lesion leads to contralateral homonymous hemianopia with macular sparing and alexia without agraphia if the lesion is on left side (dominant hemisphere). Alexia results as the visual information from intact right (non-dominant) cortex is blocked by the lesion and cannot reach the language area. This is due to damage of splenium of corpus callosum.

Lateral Striate Artery

Branch of MCA which supplies the anterior limb of the internal capsule (supply superior portion of internal capsule including posterior limb which project corticospinal fibers) and ventral thalamus (relays sensory tracts).

- Isolated infarction of internal capsule: Pure motor stroke (contralateral hemiparesis)
- Isolated infarction of thalamus: Pure sensory stroke (contralateral sensory loss

Dural reflections and Venous sinuses

Dura mater (pachymenix) is the outer meningeal layer consisting of:

1. **Outer endosteal/periosteal layer:** Firmly attached to the periosteum of the calvarium
2. **Inner meningeal layer:** Gives rise to dural reflections and continues into foramen magnum as spinal dura

Dural Reflections

These are the infoldings formed by the inner meningeal layer reflecting away from the fixed periosteral dural layer.

Two vertical reflections – Separate the right and left hemisphere:

1. Falx cerebri (Cerebral falx): Extends from crista galli of ethmoid bone anteriorly to inner occipital protuberance posteriorly and projects over longitudinal cerebral fissure.
2. Falx cerebelli (Cerebellar falx): Extends from tentorium cerebelli superiorly to inner occipital protuberance inferiorly in the posterior cranial fossa.

Two horizontal reflections:

1. Tentorium cerebelli (Cerebellar tentorium):
   - separates cerebellum and brainstem from cerebrum (occipital lobes)
   - attached to clinoid process anteriorly, upper edge of petrous temporal bone anterolaterally and to the occipital bone posterolaterally
   - falx cerebri is attached to the tentorium cerebelli and pulls it up – tent like appearance
2. Diaphragma sellae (Sellar diaphragm): Extends between anterior and posterior clinoid processes
   - partially covers the pituitary gland allowing the infundibulum and vessels

Dura is pain sensitive:

Dura is sensitive to pain, especially where it is related to the dural venous sinuses and meningeal arteries. Headaches can occur due to stimulation of the sensory nerve endings in the dura. It is innervated by all 3 divisions of the trigeminal nerve, sensory fibers of C2, C3 and meningeal branches of CN X and CN XII.

Epidural hematoma:

Rupture of high-pressure arteries (middle meningeal artery) running through the dura mater

Tearing of the dura separates bone & periosteal layer of dura creating an epidural space

"Lenticular" or "biconvex" in shape – the dural attachments provide more resitance to the collected blood to spread along than the underlying brain which get compressed

Doesn't cross the suture line – hematoma is between the periosteal sublayer and the bone.

Cross the dural reflections – hematoma is outside the periosteal sublayer

May have a lucid interval

Subdural or "Dural border" hematoma.

Shearing of low-pressure bridging veins is all that is necessary to create a subdural hematoma.

Subdural space is actually filled with the loosely arranged dural border cell sublayer. Pathologic bleeding into the border cell sublayer creates a subdural fluid space; otherwise, no true space actually exists.

"Crescent" shaped – the underlying brain provides more resistance to the collected blood than the loosely arranged dural border cells allowing it to spread along

Crosses the suture line as it is unaffected

Doesn't cross dural reflections – pool at the site of dural reflections

Dural Venous Sinuses

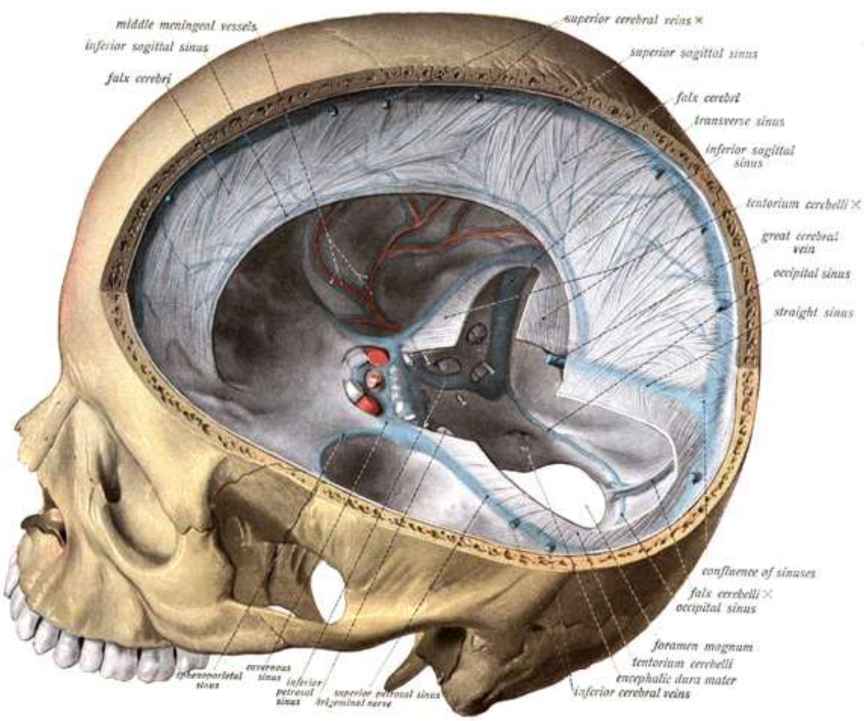
1. Superior sagittal sinus: lies at the superior attached border of falx cerebri

- Receives blood from superior cerebral veins (bridging veins) and emissary veins (connects extracranial venous system with intracranial venous sinuses – potential route of infection).
- Receives CSF from arachnoid granulations.

2. Inferior sagittal sinus: lies at the inferior free border of falx cerebri

3. Straight sinus: lies at the line of attachment of falx cerebri and tentorium cerebelli

- Formed by the union of **inferior sagittal sinus** and the **great cerebral vein of galen**



https://commons.wikimedia.org/wiki/File:Sobo_1909_589.png
Dr. Johannes Sobotta [Public domain]

4. Occipital sinus: lies in the attached border of tenorium cerebelli

- Communicates inferiorly with the internal vertebral venous plexus.

5. Confluence of sinuses (torcular Herophili): It is lies at the inner occipital protuberance and is formed by the union of:

- Superior sagittal sinus
- Straight sinus
- Occipital sinus

It drains into the transverse sinuses.

6. Transverse sinuses: runs transversely at the posterolateral margin of tentorium cerebelli

- Drains venous blood from transverse sinus into the sigmoid sinus.
- Normally, one transverse sinus can be smaller than the other – usually the left is larger.

7. Sigmoid sinus: as the name suggests, it follows "S" shaped pathway – inferomedially from the transverse sinus (parietal to temporal bone) and then anterolaterally (temporal to occipital bone) into the jugular foramen where it continues as **Internal Jugual Vein (IJV)**.

- forms deep grooves in the bones along its course

8. Cavernous sinus:

- The inter-cavernous sinuses lie on the body of sphenoid. These connect the cavernous sinuses of the 2 sides which sits on the side of the body of sphenoid.
- It contains the siphon of Interncal Carotid Artery (ICA).
- Receives venous blood from superior and inferior ophthalmic veins, superficial middle cerebral vein and sphenoparietal sinus.
- Drains into superficial and inferior petrosal sinuses.

9. Superior petrosal sinus: runs along petrous part of temporal bone (anterolateral attachment of tentroium cerebelli)

- Drains cavernous sinus into sigmoid sinus

10. Inferior petrosal sinus: runs in the groove between petrous temporal bone and basilar occipital bone

- Drains cavernous sinus into sigmoid sinus

Basilar venous plexus: lies over the basilar part of occipital bone and connects the 2 inferior petrosal sinuses and communicates with the intervertebral venous plexus.

Dural Venous Sinus Thrombosis

Venous occlusion presents with a myriad of symptoms with variable severity. Sometimes the symptoms are as mild as simple headaches and othertimes they are severe enough to produce confusion, stupor, or even coma, along with paralysis and other focal neurologic deficits. Superior sagittal sinus or the dominant transverse sinus thrombosis can affect the arachnoid granulations absorption of cerebrospinal fluid, a consequently increase of cerebral swelling may occur. The subsequent venous hypertension can lead to oedema, and even haemorrhage.

Microanatomy of Cerebral Cortex

The neocortex have 6 layers and allocortex have only 3 layers.

The 6 layers of Neocortex:

Orientation of layers:

- Outer: Towards meninges
- Inner: Towards white matter

Idea about the layers:

- Molecular or plexiform: Only cell processes
- Granular layer: Densely packed stellate cells
- Pyramidal layer: Medium and Large pyramidal cells
- Multiform layer: Different types of cells
- Pyramidal cells are absent in inner granular layer

The 3 layers of Allocortex:

1. Molecular layer
2. Pyramidal layer
3. Multiform layer

Allocortex is found in: Limbic system

1. Olfactory cortex
2. Hippocampal formation
3. Subiculum

Mesocortex: A transitional type of 3 to 6-layered cortex between neocortex and allocortex

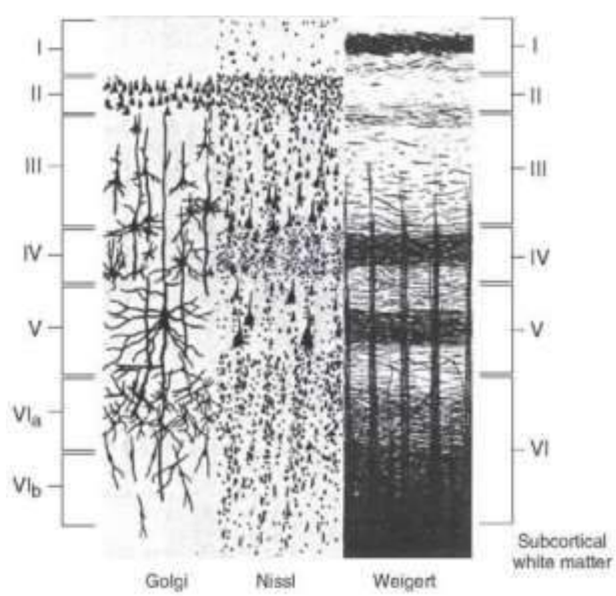
1. Parahippocampal gyrus
2. Pre- and Para-subiculum
3. Insula

Neurons of the cortex:

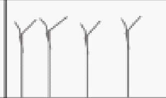
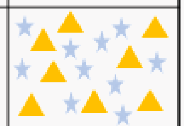
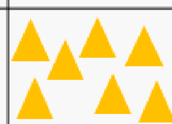
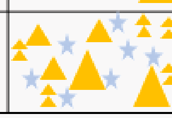
1. Pyramidal cells:
   - Large layer V pyramidal cells project axons to brainstem and spinal cord.
   - Smaller layer II and III pyramidal cells project axons to other cortical areas.
2. Stellate cells: Interneurons whose axons remain within the cortex
3. Fusiform cells (in deeper layers): Gives rise to corticothalamic projections
4. Horizontal cells of Cajal
5. Cells of Martinotti

Bands of Baillarger: Formed by high concentration of horizontally arranged nerve fibers.

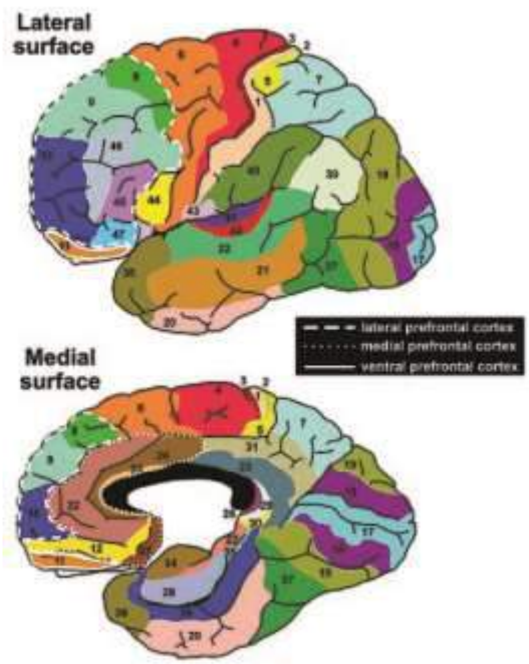
- External band: In layer IV
- Internal band: In layer V



Schematic Diagram and Connection

Layers	Components	Schematic	Afferents	Efferents
I – Molecular	Axons and Dendrites (Cell processes)		From other regions of Cortex and Brainstem	To other regions of cortex (Intra-cortical Association functions)
II - External granular	Densely packed Stellate cells + Small pyramidal cells			
III – External pyramidal	Loosely packed Stellate cells + Medium pyramidal cells			
IV – Internal granular	Densely packed Stellate cells only		+ From Thalamus	
V – Internal pyramidal	Large pyramidal cells only (few stellate cells) – Giant Pyramidal cells of Betz		+ From Brain stem	To Brain stem & Spinal cord (Projection fibers)
VI - Multiform	Multiple sized pyramidal cells + Loosely packed stellate cells			To Thalamus

Brodmann Areas and Lesions



https://commons.wikimedia.org/wiki/File:Brodmann_areas.jpg
Attribution: Vysha [CC0]

Frontal Lobe

Area 4 (Precentral gyrus): Primary motor cortex (gigantopyramidal – only area that contains giant pyramidal cells of Betz)

- **Lesion:** Contralateral spastic paralysis (UMNL)

Area 6 (Superior frontal gyrus; agranular frontal): Premotor cortex and Supplementary motor cortex (Motor planning)

- **Lesion:** Apraxia (Unable to perform movements in correct sequence)

Area 8 (Middle frontal gyrus; intermediate frontal): Frontal eye field (Contralateral horizontal conjugate eye movements)

- **Lesion:** Contralateral horizontal conjugate gaze palsy

Area 44 (Inferior frontal gyrus; pars opercularis) and Area 45 (Inferior frontal gyrus; pars triangularis): Broca's area (Motor speech center only in Dominant hemisphere)

- **Lesion:** Comprehends language well but fails to express thoughts verbally or in written
    - Nonfluent, motor or expressive aphasia
    - Agraphia (inability to write)

Areas 9, 10, 46 (Prefrontal cortex) and Area 11, 47 (Orbitofrontal cortex): Part of limbic system regulating emotions and higher mental functions. Area 11 is associated with general olfaction.

- **Lesion:** Deficits in concentration, orientation, abstracting ability, judgement, problem-solving ability, loss of initiative, inappropriate behavior, frontal release of sucking and grasping reflexes.

Parietal Lobe

Areas 3,1 and 2 (Postcentral gyrus): Primary somatosensory cortex (Discriminative touch, vibration, position sense, pain and temperature)

- **Lesion:** Impairment of all somatic sensations in contralateral side of body.

Area 43 (Inferior parietal lobule, just below somatosensory cortex in postcentral gyrus): Primary gustatory area (sensory)

Areas 5 and 7 (Superior parietal lobule): Somatosensory association cortex

(Spatial awareness and Awareness of body in general)

- **Lesion:** Contralateral astereognosis and sensory neglect (damage in nondominant hemisphere)

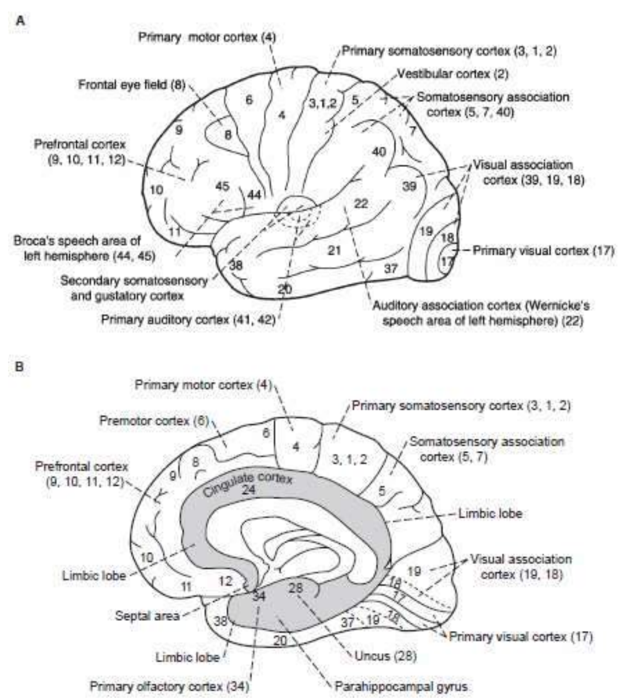
Area 40 (Inferior parietal lobule – Supramarginal gyrus) and Area 39 (Inferior parietal lobule – Angular gyrus): Multimodal association areas that receives input from visual, auditory and tactile modalities

These areas are also regarded as the part of Wernicke's area along with area 22. Area 40 has strong connections with sensory areas and also regarded as somatosensory association area and Area 39 to the visual areas and also regarded as visual association cortex. Area 39 is also called "reading center" and also plays important role in arithmetic functions.

- **Lesion in dominant hemisphere:** Gerstmann syndrome
  - o Destruction of supramarginal gyrus (area 40): Disruption of connection to other sensory association cortices –
    - ▪ Right and left confusion
  - o Destruction of angular gyrus (area 39): Disruption of connection to visual areas and arithmetic functions
    - ▪ Finger agnosia (not a sensory agnosia but failure of recognition)
    - ▪ Dysgraphia and dyslexia
    - ▪ Dyscalculia
  - o Destruction of Baum's loop. Contralateral hemianopia or lower quadrantanopia (pie in the floor).
- **Lesion in non-dominant hemisphere:**
  - o Topographic memory loss
  - o Anosognosia (lack of insight)
  - o Construction apraxia
  - o Dressing apraxia
  - o Contralateral sensory neglect
  - o Contralateral hemianopia or lower quadrantopia

Arcuate fasciculus: Connects Wernicke's area with Broca's area.

- **Lesion:** Conductive aphasia
  - o Comprehension is intact but repetition is poor and speech is fluent but paraphasic (word sounding the same as correct word but often making no sense)



Temporal lobe

Area 41 and 42 (Medial to Superior temporal gyrus – Transverse temporal gyrus of Heschl): Primary auditory cortex (Basic sound processing)

- **Lesion:** Unilateral lesion results in slight loss of hearing and bilateral lesion results in cortical deafness.

Area 22 (Posterior part of Superior temproal gyrus): Wernicke's area of sensory speech in dominant hemisphere (Auditory association cortex – Complex sound processing)

- **Lesion:** Sensory or fluent or receptive aphasia (failure to comprehend language but no problem in expression)

Area 21 (Middle temporal gyrus) and Area 20 (Inferior temproal gyrus): Part of auditory association cortex

Area 34 (Hippocampal – entorhinal area): Primary olfactory cortex

- **Lesion:** Ipsilateral anosmia

Area 28 (Hippocampal – uncal area):

- Uncal fits can lead to olfactory and gustatory hallucinations

Area 37 (Fusiform gyrus – occipitotemporal cortex): Familiar face recognition

- **Lesion (Bilateral):** Prosopagnosia (deficit for recognition of familiar faces, such as those of family, friends, and colleagues)

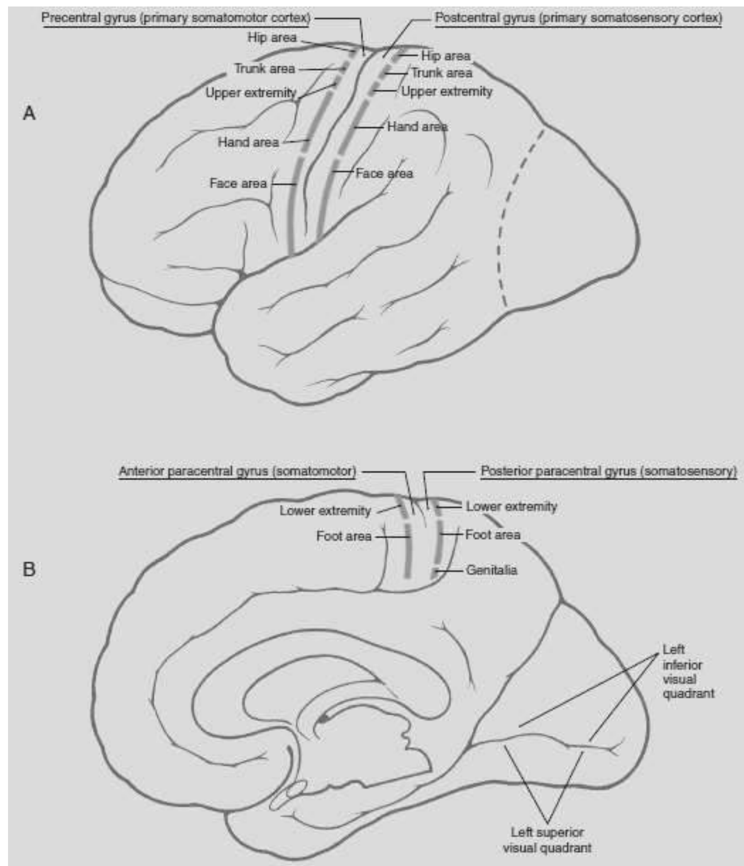
Occipital Lobe

Area 17 (striate cortex): Primary visual cortex

- **Lesion:** Contralateral homonymous hemianopia with macular sparing

Area 18 (peristriate cortex) and Area 19 (parastriate cortex): Visual association areas

Motor and Sensory Homonculus or Somatotropy



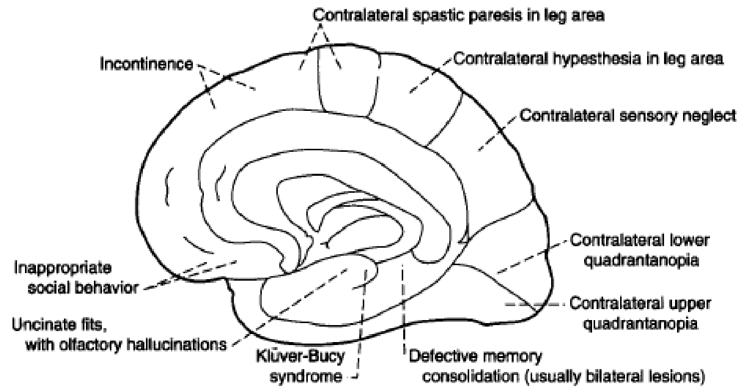
The lower extremity and foot areas are located on medial aspects of the hemisphere in the anterior paracentral (motor) and the posterior paracentral (sensory) gyri.

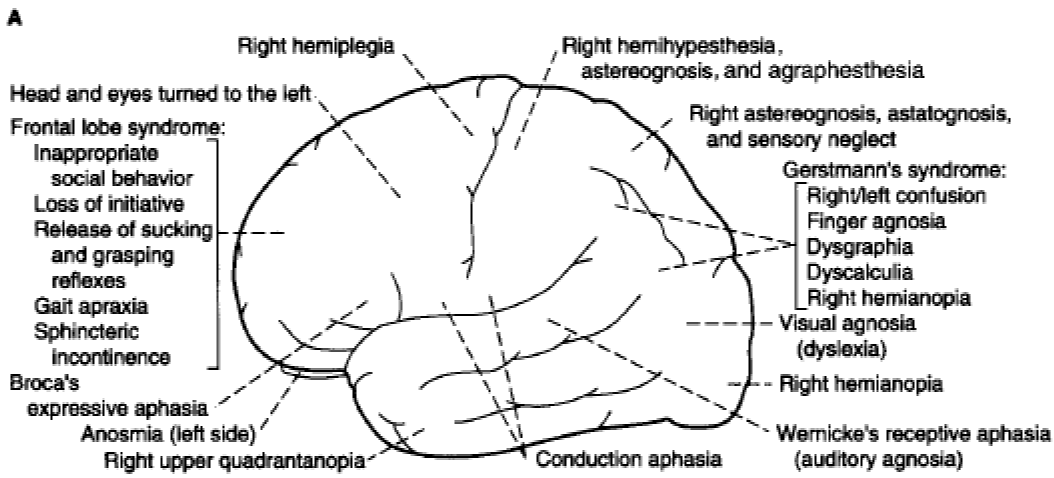
The remaining portions of the body extend from the margin of the hemisphere over the convexity to the lateral sulcus in the precentral and postcentral gyri. An easy way to remember the somatotopy of these important cortical areas is to divide the precentral and postcentral gyri generally into thirds:

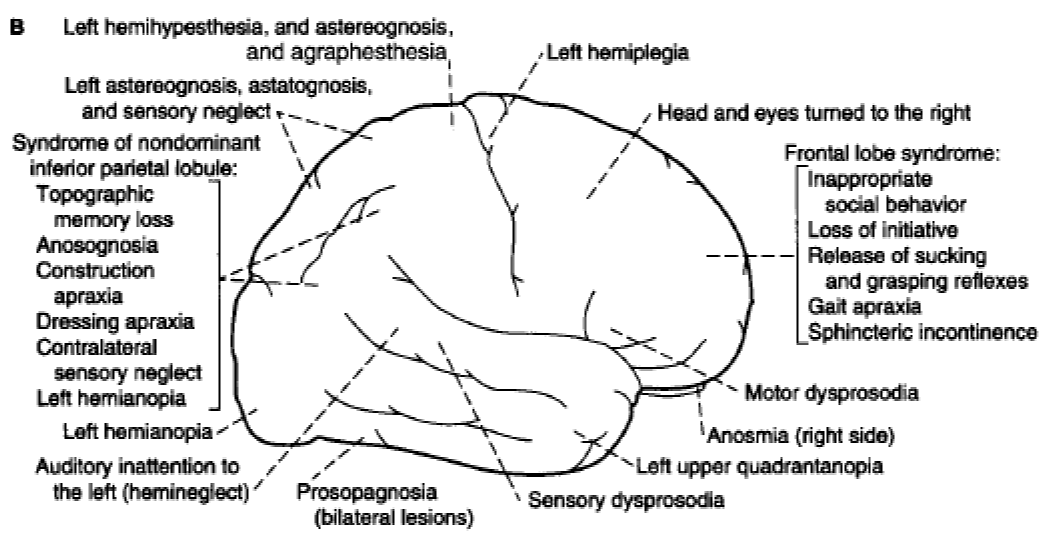
- Lateral 1/3rd: face area
- Middle 1/3rd: upper extremity and hand with particular emphasis on the hand
- Medial 1/3rd: trunk and hip

The mouth and hand, for instance, are disproportionately large because so much nervous system tissue is devoted to fine motor and sensory innervation.

Lesions of Various Areas in Bird Eye View







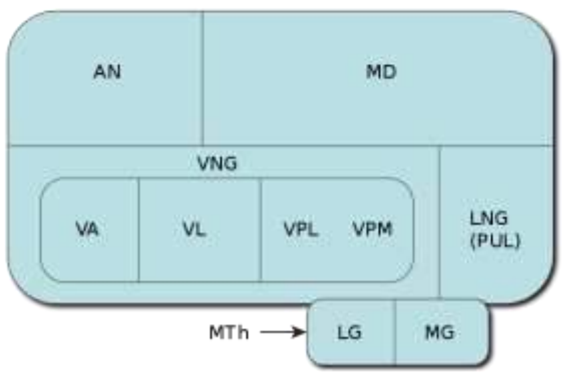
Thalamic Connections

Structure of Thalamus

A vertical "Y" shaped white mater – internal medullary lamina divides thalamus into:

1. Anterior nuclear groups
2. Medial nuclear groups
3. Lateral nuclear groups

Thalamic Nuclei (lateral view - MNG on other side)



https://commons.wikimedia.org/wiki/File:ThalamicNuclei.svg

ThalamicNuclei.png: Arcadianderivative work: Hazmat2 [Public domain]

In anatomical position:

- Dorsal surface of brain: faces towards sky
- Ventral surface of brain: faces towards floor

Pulvinar = Posterior end or posterior pole of thalamus

Thalamic Connections

Remember the schematic diagram drawn below showing important parts of thalamus in an anticlockwise fashion:

1. Anterior nucleus
2. Ventral nuclear group:
    - Anterior
    - Lateral
    - Posterior
        - Medial
        - Lateral
3. Lateral and Medial geniculate body
4. Medial-Dorsal nucleus

Now, we assign alphabets "A, B, C, D, E, F" sequentially to these important structures in anticlockwise fashion starting from anterior nucleus.

"A" for Anterior nucleus

A for: Alertness, Attention, Affect, Acute memory

These are the functions of limbic system – Papez circuit:

- Afferent: Mamillary body
- Efferent: Cingulate gyrus

"B" for Ventral-anterior nucleus

B for: Basal ganglia

- Afferent: Globus pallidus and Substantia nigra
- Efferent: Brodmann Area 6 (Prefrontal and premotor cortex)

"C" for Ventral-lateral nucleus

C for: Co-ordination and Cerebellum

- Afferent: Cerebellum (Dentate nucleus) and Basal ganglia
- Efferent: Brodmann Area 4 (Primary motor cortex)

"D" for Ventral-Posterior nucleus

D for: Dermatome (Sensory)

- Afferent:
  - Ventro-postero-medial (VPM) nucleus: Trigemino-thalamic tract
    - Medial = Mask (face)
  - Ventro-postero-lateral (VPL) nucleus:
    - Spinothalamic tract
    - Medial lemniscus
    - Nucleus tractus solitarius (taste)
- Efferent: Brodmann Area 3, 1, 2 (Sensory cortex)

> Thalamic pain syndrome: Involvement of primary somatosensory thalamic nucleus (ventral posterior lateral [VPL]/ventral posterior medial thalamus [VPM]) and the anterior pulvinar, a major spinothalamic target gives rise to thalamic pain syndrome. Approximately 25% of patients with a sensory stroke due to a thalamic lesion will develop central post-stroke pain. Thalamic pain is a severe, treatment-resistant pain syndrome. The pain is often described as burning or constrictive and is frequently accompanied by evoked pain (allodynia/hyperalgesia), paresthesias, or summation hyperpathia.

"E" for Geniculate Bodies

E for: Eyes and Ears

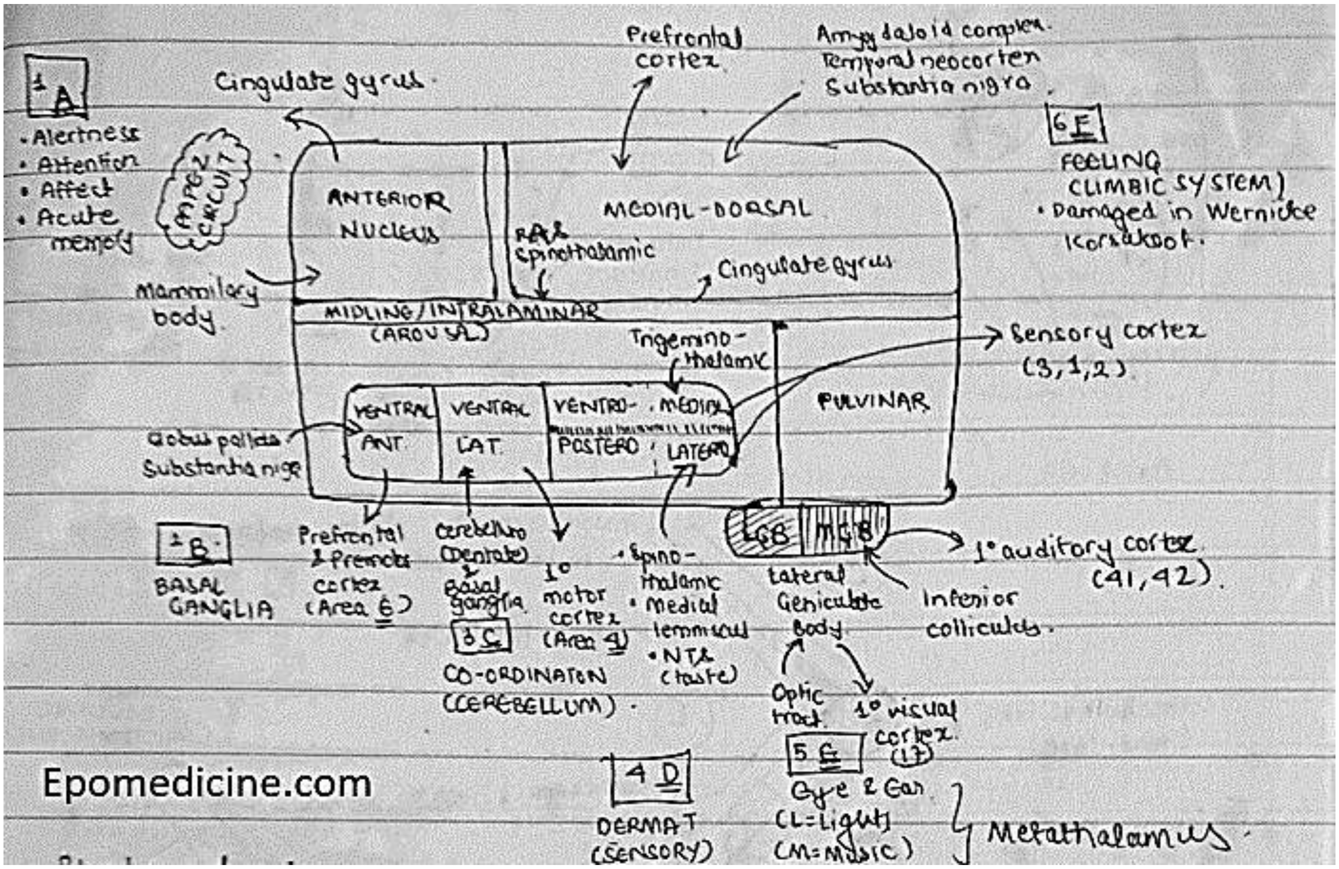
- Lateral geniculate body = Light (Eyes)
  - Afferent: Optic tract
  - Efferent: Primary visual cortex (Area 17)
- Medial geniculate body = Music (Ears)
  - Afferent: Inferior colliculus
  - Efferent: Primary auditory cortex (Area 41, 42)

"F" for Medial-Dorsal Nucleus

F for: Feelings (Limbic system)

- Afferent:
  - Amygdala
  - Olfactory cortex
- Efferent:
  - Prefrontal cortex
  - Limbic system

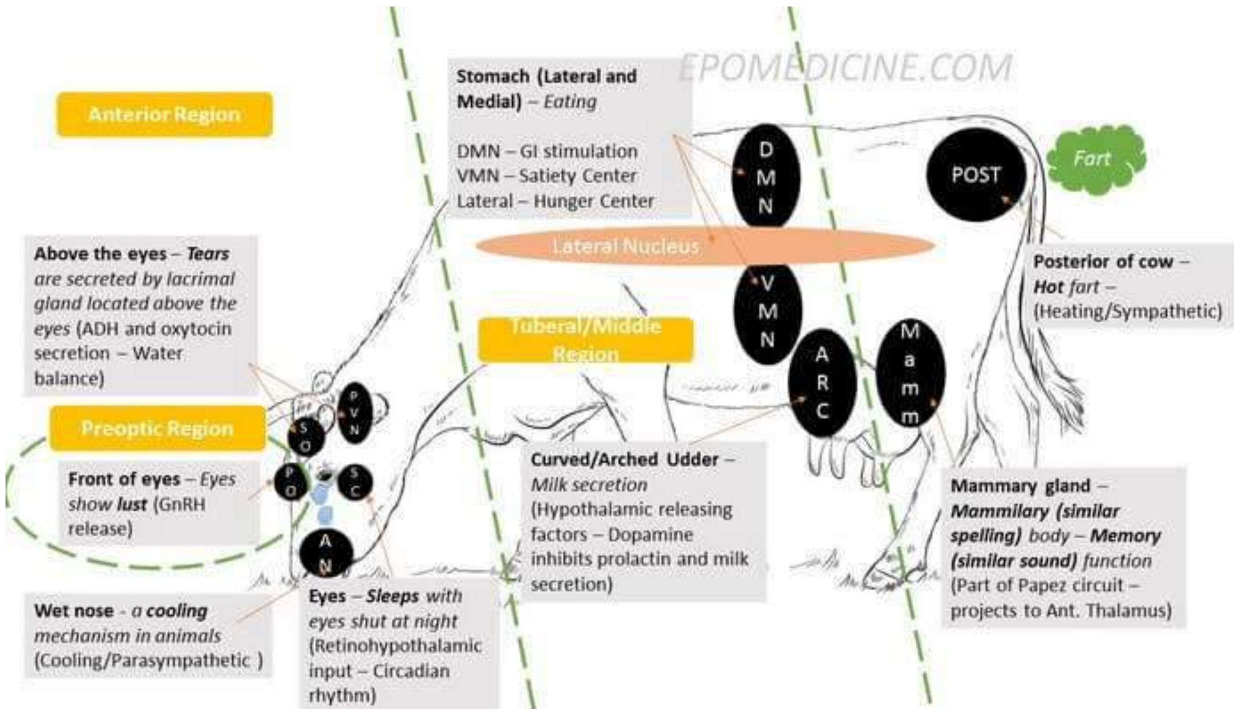
> Thiamine deficiency in alcoholics (**Wernicke-Korsakoff syndrome**) results in degeneration of the medial-dorsal nucleus of thalamus, mammillary bodies, hippocampus and vermis of cerebellum.


1 A
Alertness
Attention
Affect
Acute memory
PAPEZ CIRCUIT
Cingulate gyrus
Prefrontal cortex
Amygdaloid complex
Temporal neocortex
Substantia nigra
6 F
FEELING
(LIMBIC SYSTEM)
Damaged in Wernicke Korsakoff
ANTERIOR NUCLEUS
MEDIAL-DORSAL
Mammillary body
Cingulate gyrus
MIDLINE/INTRALAMINAR
(AROUSAL)
Trigemino-thalamic
Sensory cortex
(3,1,2)
PULVINAR
VENTRAL ANT.
VENTRAL LAT.
VENTRO-POSTERO
MEDIAL
LATERO
Globus pallidus
Substantia nigra
1 B
BASAL GANGLIA
Prefrontal & Premotor cortex (Area 6)
Cerebellum (Dentate) & Basal ganglia
3 C
CO-ORDINATION (CEREBELLUM)
1° motor cortex (Area 4)
Spino-thalamic
Medial lemniscus
NTS (taste)
4 D
DERMAT (SENSORY)
LGB
MGB
1° auditory cortex (41,42)
Lateral Geniculate Body
Inferior colliculus
Optic tract
1° visual cortex (17)
5 G
Eye & Ear
(L=Light)
(M=Music)
Metathalamus
Epomedicine.com

Nuclei of Hypothalamus

Hypothalamus is composed of several nuclei with different important functions – hence, it is important and confusing at the same time. I have devised a pictorial or visual mnemonic to make things easier for you.

Hypothalamus is a Cow: Imagine a Crying and Farting Cow when recalling the Hypothalamus.



Preoptic: Front of eyes (Eyes show lust)

- GnRH secretion

Supra-optic: Above eyes (Lacrimal gland is Above eyes and secrete tears)

- Water balance

Supra-chiasmatic: The eyes (Closes when sleeping during night)

- Circadian rhythm

Anterior nucleus: Wet nose (Cooling system in animals)

- Cooling/parasympathetic

Medial and Lateral nuclei: Stomach (Eating)

- Lateral nuclei – Hunger center
- Ventromedial nuclei (VMN) – Satiety center
- Dorsomedial nuclei (DMN) – Gastrointestinal stimulation

Arcuate nucleus: Curved or Arched Udder (Milk secretion)

- Hypothalamic releasing factors including Dopamine which inhibits Prolactin and milk secretion

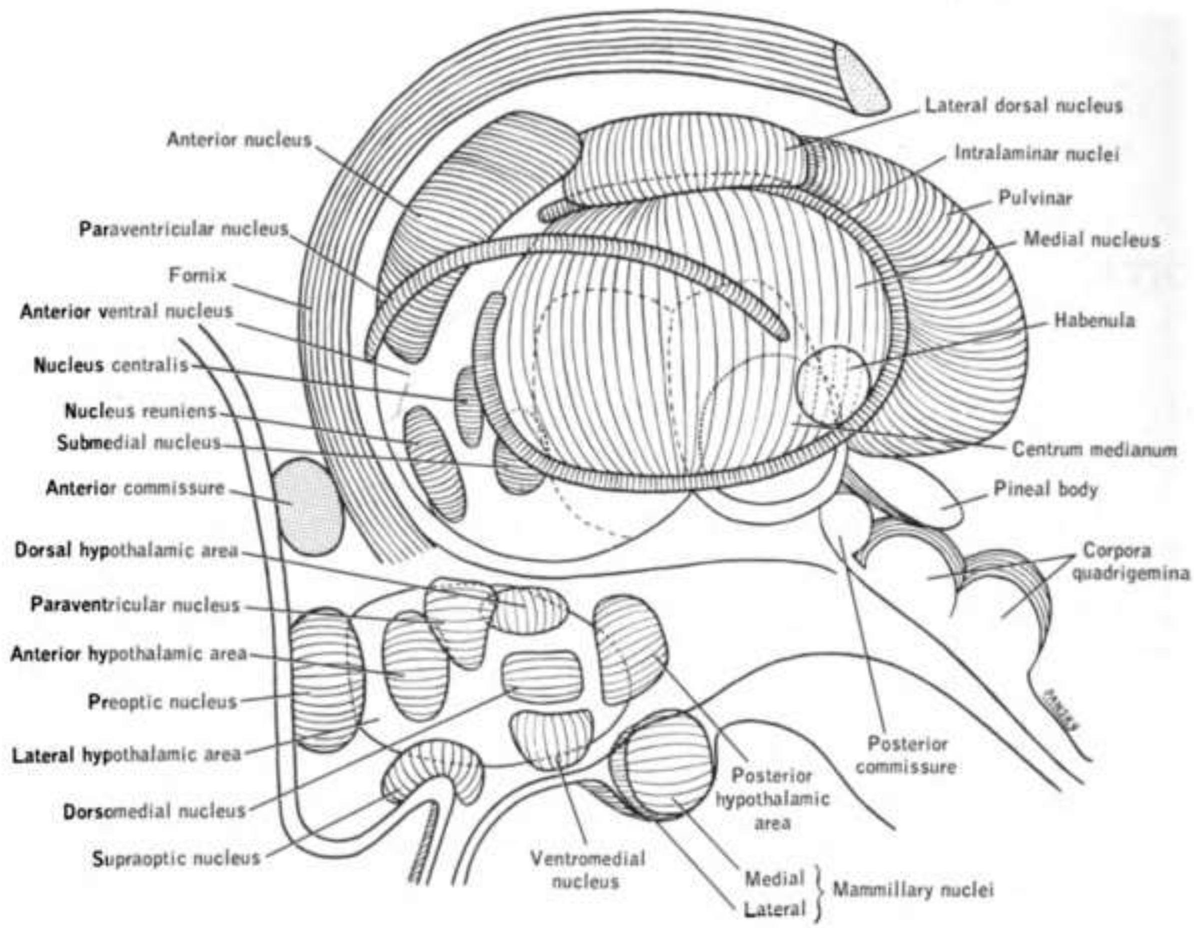
Posterior nucleus: Farting posterior of cow (Heat)

- Heating/Sympathetic

Mammillary bodies: Mammary of Cow (Memory)

- Mammillary and Mammary have similar looking spellings
- Mammary and Memory have similar sounds.
- It is a part of papez circuit involved in Memory. Mammillary bodies receives efferent from hippocapmpus via fornix and project efferent fibers to Anterior nucleus of Thalamus via Mammilothalamic tract.

Match with the real hypothalamus now:



https://commons.wikimedia.org/wiki/File:Lawrence_1960_22.3.png

House, Earl Lawrence. Pansky, Ben. [Public domain]

Lesions of Hypothalamus

1. Lateral nucleus:

- Hunger center inhibited by Leptin

- Damage leads to Anorexia and Aphagia.

2. Ventromedial nucleus (VMN):

- Satiety center stimulated by Leptin
- Damage leads to Hyperphagia and Obesity.

3. Anterior hypothalamus:

- Cooling center which senses elevated body temperature and mediates response to dissipate heat via parasympathetic input.
- Damage leads to Hyperthermia.

4. Posterior hypothalamus:

- Heating center which senses decreased body temperature and mediates the conservation of heat via sympathetic input.
- Damage leads to Poikilothermia (inability to regulate temperature).

5. Mammillary bodies:

- Part of papez circuit involved in memory.
- Damaged in Korsakoff syndrome (thiamine deficiency in chronic alcoholism) leading to both anterograde and retrograde amnesia with confabulations.

5. Arcuate nucleus:

- Produce releasing hormones and inhibitory factors, which pass through hypophyseal-portal veins to reach anterior pituitary gland.
- Dopaminergic projections from arcuate nuclei inhibit prolactin secretion from anterior pituitary.
- Damage leads to galactorrhea (milk discharge) and amenorrhea.

6. Preoptic nucleus:

- GnRH release which stimulates release of LH and FSH.
- Damage before puberty leads to arrest of sexual development.
- Damage after puberty leads to amenorrhea and impotence.

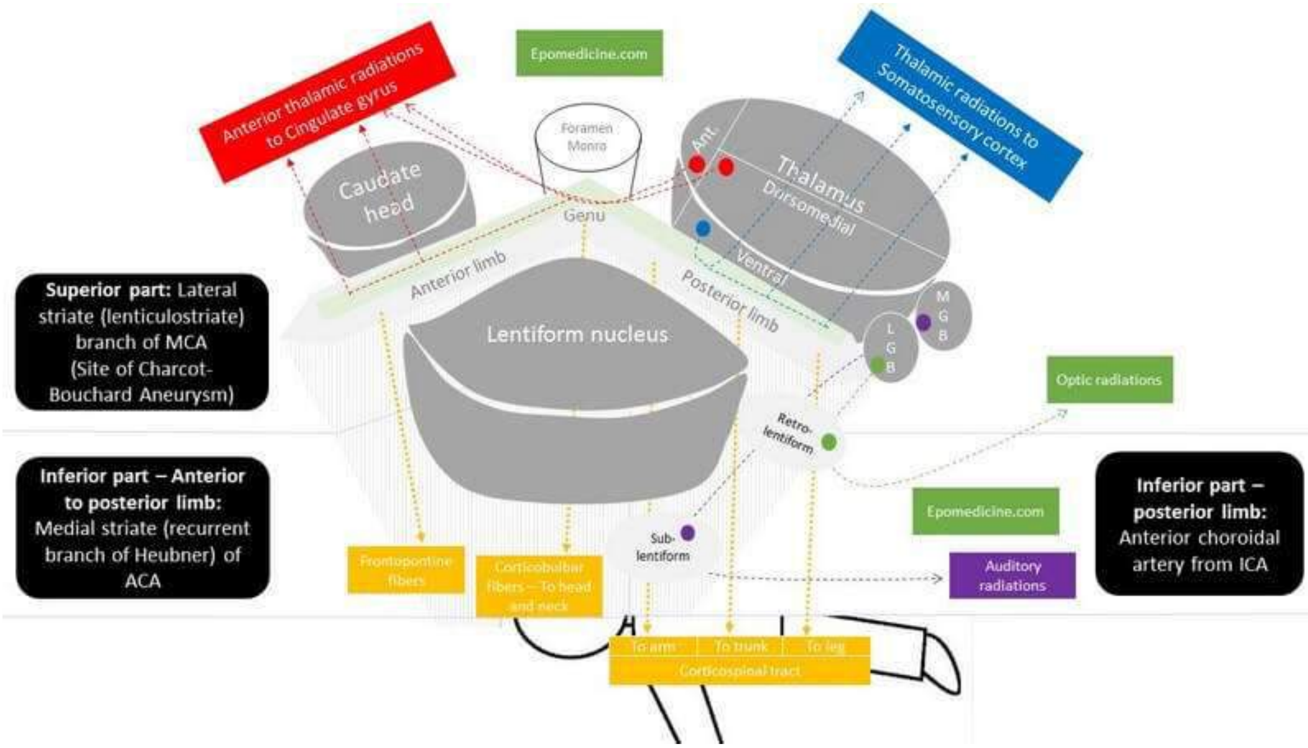
7. Paraventricular and Supraoptic nuclei:

- Synthesizes neuropeptides ADH and oxytocin which are transported via supraopticohypophyseal tract to Posterior pituitary and stored there.
- Damage leads to Diabetes insipidus characterized by polydipsia and polyuria.

8. Suprachiasmatic nucleus:

- Some of the periodic activities of mammals controlled by the Suprachiasmatic Nucleus are length and time of sleep, hormone levels, activity, body temperature, digestive functions etc.
- Damage leads to damage to the periodicity of these activities.

Internal Capsule



Internal Capsule is a "boomerang" shaped (on horizontal section) and "funnel" shaped, i.e. tapering from superior to inferior (on sagittal section) white matter structure sandwiched between:

- Medially: Head of Caudate nucleus and Thalamus
- Laterally: Lenticular nucleus (Globus pallidus and Putamen)

Parts of Internal Capsule

1. Anterior limb:

- Carries fibers to and from the prefrontal cortex and cingulate gyrus.
- Fronto-pontine fibers descend through it.

2. Posterior limb: Carries fibers to and from the parietal lobe

- Through it, corticospinal tract descend from cerebral cortex to the anterior horn of spinal cord.
- The somatotropy from anterior to posterior is Arm, Trunk and Leg.

3. Intervening genu (knee):

- Through it, corticonuclear fibers descend from cerebral cortex to the motor nuclei of cranial nerves, i.e. to the muscles of head and neck.

4. Retrolenticular part (behind lenticular nucleus):

- Carries visual fibers to and from the visual cortex of the occipital lobe.

5. Sublenticular part (below lenticular nucleus):

- Carries auditory system fibers to and from the auditory cortex of the temporal lobe.

Thalamo-cortical fibers:

- Run from anterior to posterior of internal capsule.
- Anterior limb: Carries fibers from anterior and dorsomedial thalamus to prefrontal cortex and cingulate gyrus.
- Posterior limb: Carries fibers from ventral (sensory) thalamus to somatosensory cortex.

Blood Supply of Internal Capsule

Superior part: Lateral striate (lenticulostriate) branch of MCA (Site of Charcot-Bouchard Aneurysm)

- Lenticulostriate branches also supply the basal ganglia.

Inferior part:

- **Anterior to posterior limb:** Medial striate (recurrent branch of Heubner) of ACA
- **Posterior limb:** Anterior choroidal artery from ICA

Lesions of Internal Capsule

Upper Motor Neuron Lesions (UMNL) with contralateral hemiparesis (lesion is above the crossing of corticospinal tract which occurs in medulla) and contralateral lower facial palsy.

Arms and legs are equally affected.

Sensory loss is contralateral as the fibers cross below the internal capsule.

Charcot Bouchard Microaneurysm of Lenticulostriate branches of Middle Cerebral Artery:

Lacunar syndromes

Pure motor hemiparesis (Hemiparesis): Corticospinal tract invovlement in posterior limb of internal capsule

Mixed sensorimotor stroke (Hemiparesis + Hemisensory loss): Additional involvement of spinothalamic tract in posterior limb of internal capsule

Thrombosis of Recurrent branch (Heubner's) of Anterior Cerebral Artery:

Affects the genu

Paralysis of contralateral lower face, tongue and upper limb (UMNL).

If the lesion is on left: also motor dysphasia.

Obstruction of Anterior choroidal artery:

Affects the posterior limb of internal capsule.

Depends upon the severity of infarction: Produces syndrome involving one of the many features listed below.

May be symptomless due to collateral circulation.

Contralateral hemiparesis – UMNL (Corticospinal tract)

Contralateral homonymous hemianopia – Involvement of retrolenticular part which carries visual fibers

Contralateral hemianesthesia – Involvement of thalamic radiation

Pure sensory stroke:

It is a rare form of lacunar stroke.

Can occur with exclusive involvement of thalamic radiations in internal capsule or ventral thalamus.

Simplified Basal Ganglia

The combination of excitatory and inhibitory signals in the basal ganglia circuit is pretty confusing. Let's break the circuit and make them easy to understand.

There are 2 pathways in Basal ganglia circuit:

1. Excitatory pathway
2. Inhibitory pathway

Let's declare 2 things first:

1. Dopaminergic nigrostriatal projection increases motor activity.
2. Cholinergic striatal projections decreases motor activity.

How does this happen?

Both the Excitatory and Inhibitory Pathway Begin in Same Way.

Excitatory input from the Cortex projects to the striatal neurons in the Caudate nucleus and Putamen.

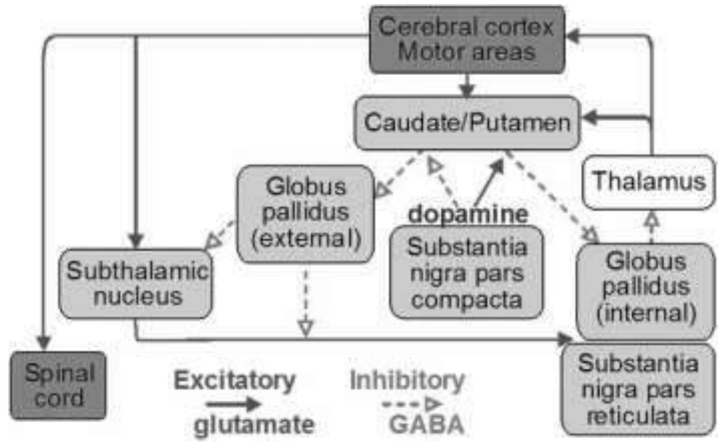
Cortex —⊕> Neostriatum (Caudate nucleus and Putamen)

Both the Excitatory and Inhibitory Pathway Ends in Same Way.

1. Globus Pallidus interna projects inhibitory fibers to Ventrolateral Thalamus.

2. Ventro-lateral thalamus sends excitatory fibers to Motor cortex.

GPi —⊖> VL Thalamus —⊕> Motor cortex



Inhibit GPi to release inhibition from VL Thalamus to Promote Movement

This is what occurs in the Direct Pathway.

Cortex —⊕> Neostriatum —⊖> **GPi** —⊖> VL Thalamus —⊕> Motor cortex

Inhibition of inhibitory fibers = Stimulation

Simple mathematics: Minus X Minus = Plus

Stimulate GPi to inhibit VL Thalamus and Inhibit Movement

This is what occurs in the Indirect Pathway.

We need an intermediate pathway between the beginning and end of the common pathway to stimulate the Globus pallidus interna.

1. Striatum projects inhibitory fibers to the Globus Pallidus externa (GPe).
2. GPe projects inhibitory fibers to the Subthalamic nucleus (STN).
3. STN projects excitatory fibers to the Globus Pallidus interna (GPi).

Cortex —⊕> Neostriatum —⊖> **GPe** —⊖> STN —⊕> **GPi** —⊖> VL Thalamus —⊕> Motor cortex

Again, the same equation:

Minus X Minus = Plus (i.e. release of inhibition from subthalamic nucleus and excitation of GPi)

Puls X Minus = Minus (i.e. stimulation of inhibitory GPi inhbitis thalamus and movement)

What did you notice till now?

Direct pathway: Stimulates motor cortex

Indirect pathway: Inhibits motor cortex

Let's come back to what we declared at the start

A. Dopamine facilitates movement:

2 Dopamine receptors in Putamen (Striatum): D1 and D2

Dopaminergic neurons projecting from Substantia nigra to Striatum:

Act on D1 receptor —⊕→ Movement facilitating Direct pathway

Act on D2 receptor —⊖→ Movement inhibiting Indirect pathway (i.e. facilitation of movement)

B. Acetylcholine inhibits movement:

Cholinergic actions INHIBIT striatal cells of the direct pathway and EXCITE striatal cells of the Indirect pathway.

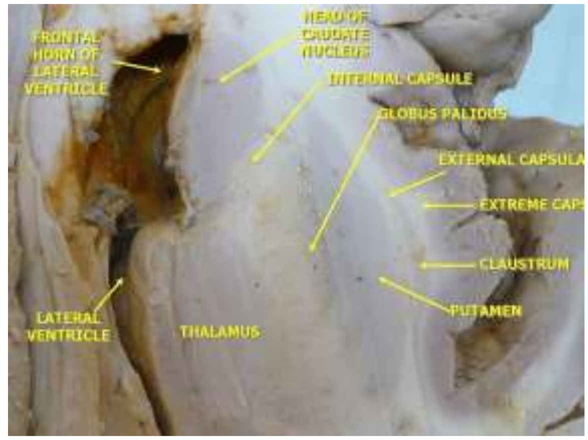
Thus the effects of ACh are OPPOSITE the effects of dopamine on the direct and indirect pathways so the ACh effects on motor activity are opposite those of dopamine.

Neurotransmitters in the Pathway

Excitatory = Glutamate

Inhibitory = GABA

Summary



https://commons.wikimedia.org/wiki/File:Basal_ganglia_-_horizontal_section.jpg
Anatomist90 [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)]

The circuits do not cross i.e. they lie on the same side of the brain.

Direct pathway inhibits Globus Pallidus interna.

Indirect pathway stimulates Globus Pallidus interna.

Lesions of Basal Ganglia

Clinical signs in basal ganglia lesion are contralateral to the side of lesion. This is because:

- Basal ganglia circuit doesn't cross
- But, the corticospinal tract crosses to the contralateral side and Basal ganglia modulates the motor cortex.

A. Hypokinetic disorders – Lesions of Direct Pathway: Parkinsonism Disease

Degeneration of Dopaminergic neurons of Substantia nigra and accumulation as Lewy bodies

Inhibition of D1 receptor (Excitatory pathway) and Stimulation of D2 receptor (Inhibitory pathway)

Also, ongoing unopposed ACh activity leading to activation of inhibitory pathway

Inhibition of motor cortex and movement

Accompanied by: **TRAP**

1. Tremor (Resting pill-rolling)
2. Rigidity (Lead-pipe and cog-wheel)
3. Akinesia
4. Posture (Stooped)

B. Hyperkinetic disorders – Lesions of Indirect Pathway:

1. Hemiballismus:

- Lesion of subthalamic nucleus
- No stimulation of GPi
- Violent projectile movement of limb seen contralateral to the lesion.

2. Chorea:

- Lesion of striatum (putamen)
- Initially, loss of GABAergic cells in the striatum that project only to GPe (inhibition of indirect pathway)
- Later, striatal cholinergic cells also begin to die
- Rapid, involuntary and purposeless jerks of irregular and variable location on the body
- Huntington's chorea – due to excessive CAG (trinucelotide) repeats on chromosome 4

3. Athetosis:

- Lesion in the Globus pallidus
- Spontaneous and often continuous writhing movements of a hand, an arm, the neck, or the face.

4. Wilson's Disease (Hepatolenticular degeneration):

- As the name suggests – lenticular dengeneration due to copper accumulation
- Lenticular or lentiform nucleus = Putamen + Globus pallidus
- Dystonia and Tremor are the most common hyperkinetic movement disorders in Wilson's Disease.

5. Dystonia:

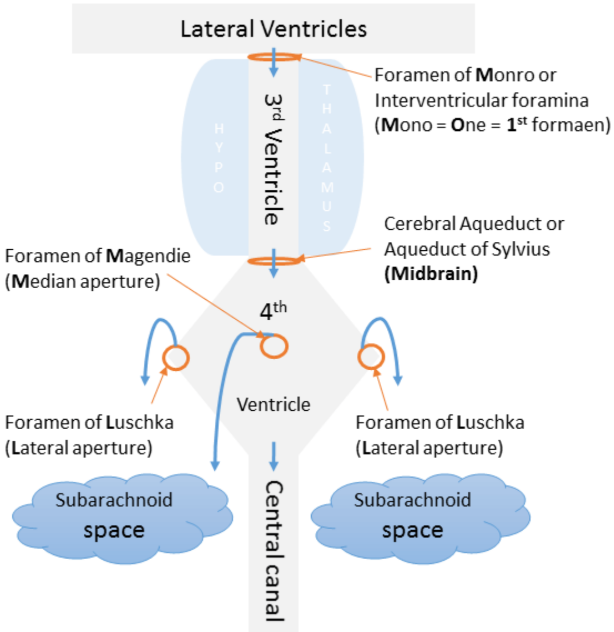
- Lesions in the lentiform nucleus (Putamen > Globus pallidus)
- Increased/sustained muscle contractions, twisting of the trunk or extremities, and abnormal postures.

The site of the lesions in various disorders is a subject of confusion as various sources have mentioned them differently. The lesion sites mentioned here are taken from the **Textbook of Medical Physiology by Guyton and Hall**.

C. UMNL vs LMNL vs Basal ganglia sings vs Cerebellar signs:

	LMNL	*UMNL*	*Basal ganglia lesion*	*Cerebellar lesion*
Side of signs	Ipsilateral	Contralateral or Ipsilateral	Contralateral	Ipsilateral
Paralysis	Flaccid	Spastic	None	None
Muscle atrophy	Present	Absent (present if disuse)	None	None
Tone	Decreased	Increased	Increased	Decreased
Tendon Reflexes	Suppressed	Suppressed	Normal	Normal Or Suppressed and pendular

CSF circulation



Cerebrospinal Fluid (CSF) Production and Absorption

CSF is produced by the choroid plexus that lines the ventricles.

Choroid plexus = Infoldings of blood vessels of piamater + Modified ciliated ependymal cells

Tight junctions of the choroid plexus cells form Blood-CSF barrier.

CSF is reabsorbed by arachnoid granulations to enter dural venous sinuses.

Turnover of entire volume of CSF is 3-4 times per day.

- There is approximately 120mL (average 90-150 ml) of CSF at any one time.
- It is formed and reabsorbed at a rate of 0.33 mL/min.
- During Lumbar puncture (LP), depending on the purpose, the amount of fluid withdrawn ranges few milliliters to as much as 40 ml; however, in a typical lumbar puncture roughly 12mL of fluid is withdrawn.
- What percent of the CSF in the nervous system is this? 10%.
- And how quickly is it replaced? In about half-an-hour (or, more exactly, in 36 min).

Normal Composition of CSF

Clear fluid, isotonic with serum (290-295 mOsm/L)

Mononuclear cells upto 4 cells/µl

Glucose levels = 66% of blood glucose level (50-75 mg/dl)

Protein levels = 15-45 mg/dl

CSF pressure = 80-180 mm of water

Compared to serum:

- ↓↓ protein and immunoglobulins
- ↓ [glucose]
- ↓ pH (7.33 compared to arterial blood 7.4 and venous blood 7.36)
- equal [Na+]
- ↑ [Cl-] and [Mg2+]
- ↓ [K+], [Ca2+], [HCO_3-]

Ventricular System and CSF circulation

1. CSF from the lateral ventricles passes through the interventricular foramina of Monro into the 3rd ventricle.
2. CSF from the 3rd ventricle passes through the cerebral aqueduct into the 4th ventricle.
3. 4th ventricle is continuous with the spinal canal which progressively obliterates by the 2nd decade.
4. CSF from the 4th ventricle passes through the 2 lateral (foramen of Luschka) and 1 middle (formane of Magendie) into the subarachnoid space.

Functions of CSF

1. Cushion of the brain
2. Transports hormones and hormone releasing factors
3. Removes metabolic waste products through absorption

Clinical Relevance

CSF composition in Meningitis

	Normal	Viral	Pyogenic	Tuberculosis
Appearance	Crystal clear	Clear/turbid	Turbid/purulent	Turbid/viscous
Mononuclear cells	<5/mm^3	10–100/mm^3	<50/mm^3	100–300/mm^3
Polymorph cells	Nil	Nil[a]	200–300/mm^3	0–200/mm^3
Protein	0.2–0.4 g/L	0.4–0.8 g/L	0.5–2.0 g/L	0.5–3.0 g/L
Glucose	⅔–½ blood glucose	>½ blood glucose	<½ blood glucose	<½ blood glucose

[a]Some CSF polymorphs may be seen in the early stages of viral meningitis and encephalitis.

Hydrocephalus

Choroid plexus papilloma = Overproduction of CSF = Communicating hydrocephalus

Arachnoid granulations adhesions (post-meningitis) = Decreased CSF absorption = Communicating hydrocephalus

Obstruction at foramen of monro or cerebral aqueduct or formane of Magendie or Luschka = Non-communicating hydrocephalus

CSF not absorbed by arachnoid villi = Chronic dilation of ventricles and normal CSF pressure = Normal pressure hydrocephalus

Wet: Urinary incontinence

Wobbly: Apraxic gait

Wacky: Dementia

Brain atrophy = Increased CSF = Hydrocephalus Ex-vacuo

It is caused by Stroke, Alzheimer's disease, Advanced HIV and Trauma.

Pseudotumor Cerebri (Benign Intracranial Hypertension)

Due to increased resistance to CSF at arachnoid villi

Occurs in obese young women

Papilledema without mass, elevated CSF pressure, deteriorating vision

Upper motor neuron and Lower motor neuron lesion

	UMNL	LMNL
Lesion	Above the anterior horn cell in the spinal cord or above the nuclei of the cranial nerves	Anterior horn cell, motor nerve fibre or neuromuscular junction
Tone	Increased (spasticity) ± clonus	Reduced
Muscle weakness	All muscle groups of the lower limb – more marked in the flexor muscles. In the upper limb weakness is more marked in the extensors	More distally than proximally. Both flexors and extensors affected
Deep tendon reflexes	Increased (but superficial reflexes such as abdominal reflexes are usually absent)	Reduced or absent
Plantar response	Extensor (upgoing toe)	Normal or absent
Fasciculation	Absent	May be present in anterior horn cell lesions
Wasting	Late; mainly because of disuse	Usually present

Upper Motor Neuron Lesion (UMNL) Syndrome

Acute Manifestations

1. Spinal shock: Hypotonia and loss of all reflexes on contra-lateral side:

- Gamma-motor neurons by stretching muscle spindle bodies, activate alpha-motor neurons leading to extrafusal muscle contraction.
- In upper motor neuron lesion, supraspinal excitatory input to gamma-neurons is lost.

2. Relative sparing of trunk muscles:

- Trunk muscles are bilaterally innervated by anterior corticospinal tract, so that a lesion of one side of the tract has minimal/imperceptible manifestations.
- Distal muscles, fingers, toes, fine articulations and flexors more than extensors are handled by lateral corticospinal tract and affected more.

Late Manifestations

1. Babinski sign:

- It is a primitive response present normally in newborns.
- The extensor response is modified to flexor response by developing corticospinal tract.
- Upper motor neuron lesion results in reappearance of primitive extensor response.

2. Spasticity:

- Spasticity is increased muscle tone, hyperactive stretch reflexes and clonus.
- Due to removal of inhibitory influences exerted by cortex on postural centers of vestibular nuclei and reticular formation.
- The mechanism has already been discussed in detail in Clonus.

3. Hyporeflexia of superficial reflexes:

- Superficial reflexes are absent in infants and appear after about 6 months to 1 year.
- Their appearance may depend upon the myelination of the corticospinal tract.
- Hence, in upper motor neuron lesion, superficial reflexes may be lost.
- It may even be absent in normal individuals, hence, correlation with other corticospinal signs is necessary.

4. Contralateral or Ipsilateral Involvement:

- Pyramidal decussation occurs at the level of medulla-spinal cord junction.
- Lesion above pyramidal decussation leads to contralateral signs.
- Lesion below pyramidal decussation leads to ipsilateral signs.

5. Involvement below the lesion:

- Damage of UMN below the level of lesion.

6. Decorticate posture:

- Occurs in UMNL above the red nucleus – hence, rubrospinal tract still working.
- This leads to release of cortical inhibition of the rubro-, reticulo-, and vestibulospinal tracts. In this circumstance, the action of rubrospinal tract supercedes that of the reticulo- and vestibulospinal tracts, which results in arm flexion at the elbows and lower extremity extension, so-called decorticate posturing.

> Rubro-spinal tract regulate flexor tone in upper limb.
>
> Reticulo- and vestibulo-spinal tracts regulate extensor tone in the neck and both the upper and lower limbs.

7. Decerebrate posture:

- Occurs in UMNL below the red nucleus – hence, rubrospinal tract not working.
- This releases inhibition of the reticulo- and vestibulospinal tracts, which results in extension of the neck and all four limbs, so-called decerebrate posturing.

Lower Motor Neuron Lesion (LMNL) Syndrome

A. Ipsilateral involvment:

Lower motor neuron comprises of motor neurons in the anterior neurons and the fibers originating from them, which innervates the skeletal muscles.

These fibers go uncrossed to the same side.

B. Involvement at the level of lesion:

Damage of LMN at the level of lesion.

C. Flaccid paralysis, Loss of Deep Tendon Reflexes and Hypotonia:

<u>In voluntary muscle contraction:</u> UMN → LMN

<u>In reflex muscle contraction:</u> Muscle sensory neuron → LMN

<u>Tone:</u> γ efferent → Regulates baseline Ia afferent discharge → Regulates baseline α-motor neuron discharge

- Alpha motor neurons and axons from them activate extrafusal fibers and contract them.
- So, destruction of this leads to:
  - Loss of efferent limb in monosynaptic stretch or deep tendon reflexes
  - Information from motor cortex doesn't reach muscles due to defect in Lower motor neuron – leading to flaccid paralysis
  - Loss of gamma and alpha motor neurons lead to decrease in baseline Ia and alpha motor neuron discharge – leading to hypotonicity

D. Muscle atrophy:

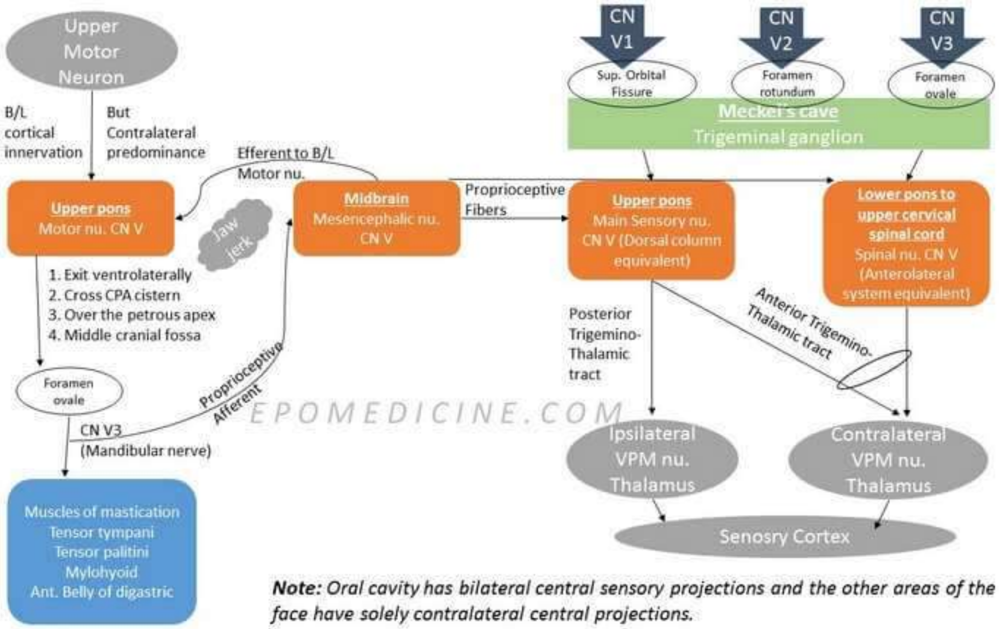
- Denervation (deprived of necessary trophic factors)
- Disuse

E. Fasciculations and Fibrillations:

- Damaged α-motor neuron → Spontaneous action potential → Motor unit fires → Visible twitching of muscle fibers group (fasciculations)
- Increased excitability of muscle fibers due to denervation → Spontaneous contraction of single muscle fiber visible in EMG (fibrillations)

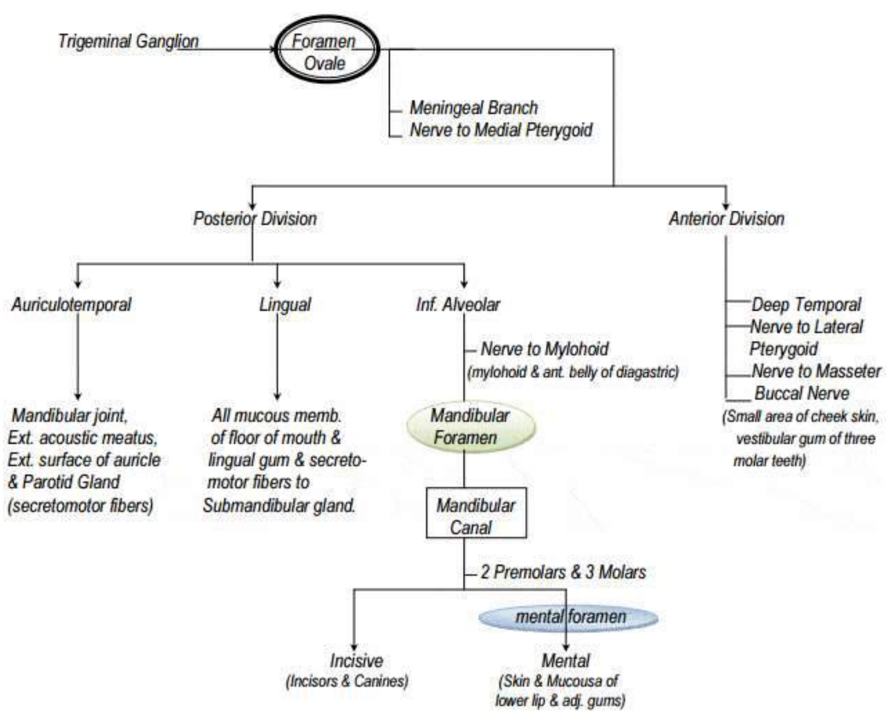
Trigeminal Nerve (Cranial Nerve V)

Course of Trigeminal nerve and Trigeminothalamic pathway

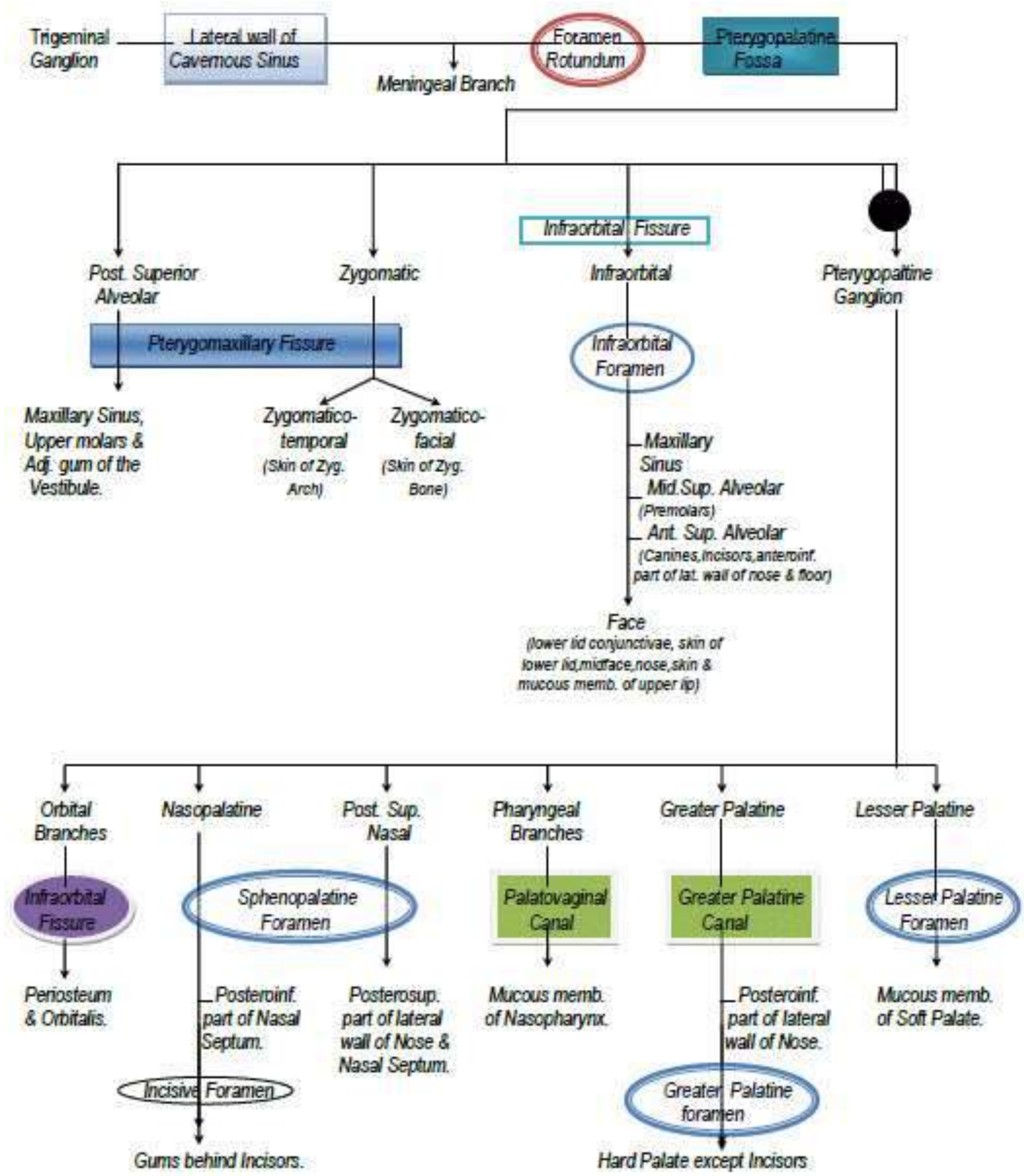


***Note:** Oral cavity has bilateral central sensory projections and the other areas of the face have solely contralateral central projections.*

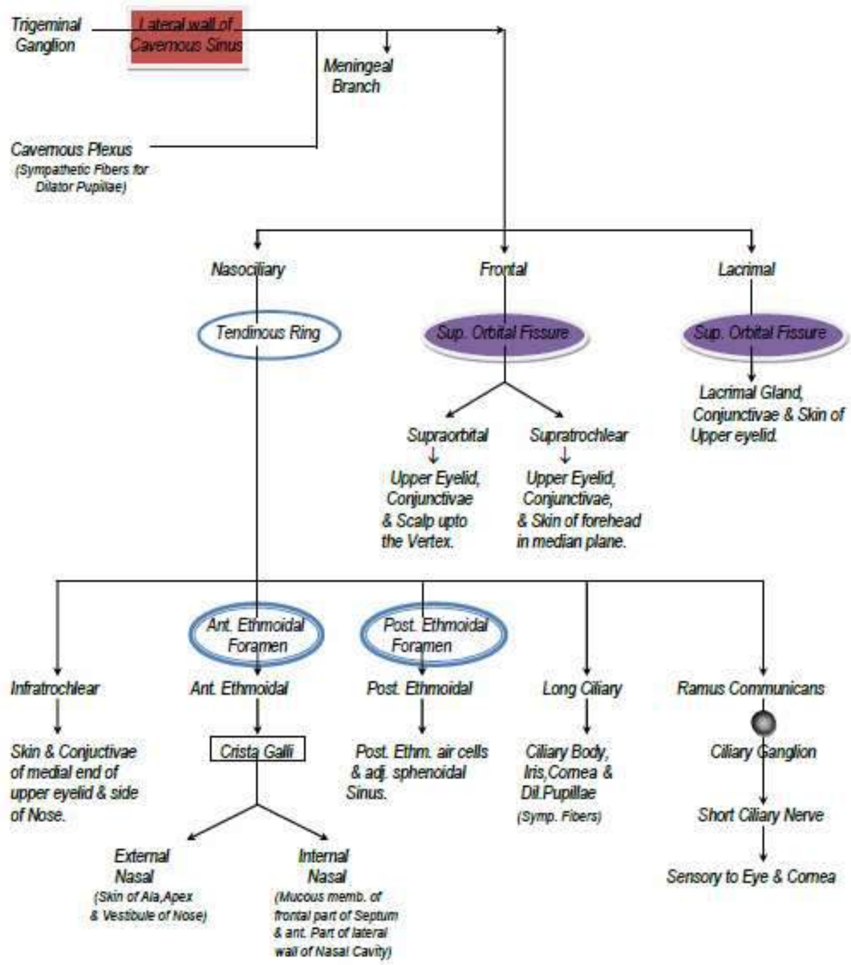
Mandibular Division of Trigeminal Nerve (CN V3)



Maxillary Division of Trigeminal Nerve (CN V3)



Ophthalmic Division of Cranial Nerve (CN V1)



Sensory Map of Trigeminal Nerve on Face

Area of Ophthalmic division: Line joining –

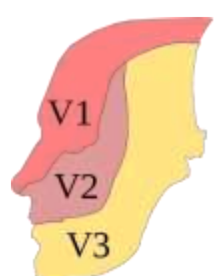
1. Just behind the top of head
2. Corner of eyes
3. Tip of nose

Area of Maxillary division: Line joining –

1. Same point as above in head
2. Maxilla
3. Angle of mouth

Area of Mandibular division: Line joining –

1. Same point as above in head
2. Tragus of ear
3. Mentum



https://commons.wikimedia.org/wiki/File:Trig_innervation.svg

> **Important point to note:**
>
> Mandibular division neither covers the angle of mandible, nor the outer ear. These areas are often tested to differentiate neurologic and functional (non-neurologic symptoms) as Trigeminal nerve doesn't have sensory supply to these regions. These regions are supplied by:
>
> Outer ear: Cranial nerve VII, IX and X
>
> Angle of Mandible: C2, C3

Lateral Pterygoids

While the other muscles of mastication closes the jaw, the lateral pterygoids open the jaw. Like, genioglossus of tongue, the fibers crosses and inserts to the angle of jaw on the opposite side. Hence, dysfunction of lateral pterygoid at one side leads to deviation of jaw in the same side due to the action of opposite lateral pterygoid.

In Upper Motor Neuron lesion:

They have bilateral cortical innervation with **contralateral predominance**.

Hence, there may be no visible deviation of jaw during clinical examination.

If deviation is seen: Deviation of jaw to the side contralateral to the UMN lesion

Deviation at one side > Dysfunction of lateral pterygoid in same side > Contralateral UMN lesion

In Lower Motor Neuron lesion:

Deviation of the jaw to the side ipsilateral to the LMN lesion.

Jaw Jerk

Stimuli: Stretch applied by reflex hammer on relaxed jaw

Sensory receptors: Muscle spindles of muscles of mastication

Afferent: Proprioceptive fibers from CN V3

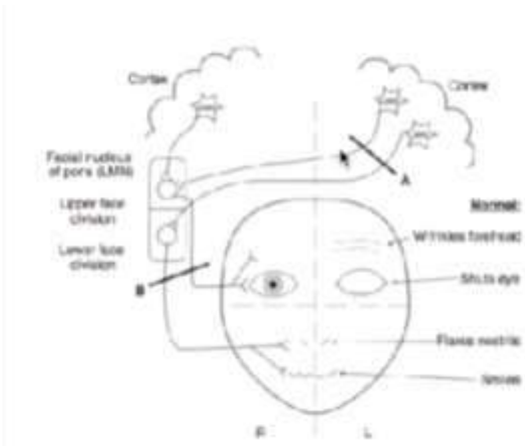
Center: Mesencephalic nucleus of trigeminal nerve (**Not the trigeminal ganglion**)

Efferent: Bilateral innervation to the motor nucleus of facial nerve

Response: Closure of jaw

Facial Nerve (CN VII)

Supranuclear pathways



1. Somatomotor cortex: Precentral gyrus

2. Volitional component: Corticonuclear tracts descend and cross to supply both ipsilateral and contralateral facial (mainly to the contralateral side) nucleus, i.e. frontal branch components of the facial nucleus receives bilateral cortico-nuclear tract innervation

3. Emotional component: Input to the facial nucleus from the basal ganglia and limbic system control involuntary facial expression associated with emotion.

4. Other inputs:

- Visual system (involved in blink reflex)
- Trigeminal nerve and nuclei (involved in corneal reflex)
- Auditory nuclei (involuntary closure of eye in response to loud noise)

Clinical correlation:

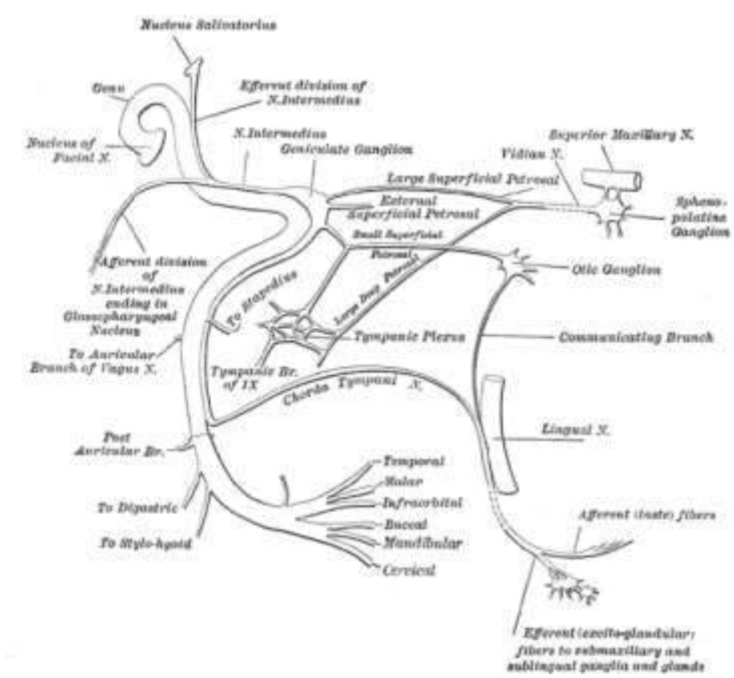
1. Wrinkling of forehead is a function of frontalis muscle and this is preserved in Upper motor neuron lesions (UMNL) of facial nerve. This is because, the frontal branch components of facial nucleus receives innervation from the cortex of both the sides.

2. Emotional (Involuntary) smile may be preserved in supranuclear palsy, while volitional (forced) smile is lost as the pathway for both are different.

3. Upper motor neuron lesion results in contralateral weakness while the lower motor neuron lesion results in ipsilateral weakness. Bell's palsy and Ramsay Hunt sydrome (Herpes zoster oticus) are the examples of lower motor neuron type of facial nerve palsy.

Intracranial part (15-17 mm)

Pons to Internal Acoustic Meatus



https://commons.wikimedia.org/wiki/File:Gray788.png

Henry Vandyke Carter [Public domain]

1. Nucleus:

- Motor nucleus (pons) – to motor fibers
- Superior salivatory nucleus (pons) – parasympathetic component to nerve of Wrisberg or Nervus intermedius

- Nucleus of solitary tractus (medulla) – receives sensory component from nerve of Wrisberg or Nervus intermedius

2. Before leaving brainstem: motor fibers wind around the abducens nucleus (CN VI) to form an internal genu

3. Leaves brainstem: at pontomedullary junction

4. After leaving brainstem: motor fibers align with nervus intermedius and together enters Internal acoustic meatus, along with vestibulo-cochlear nerve (CN VIII)

> **Clinical Correlation:**
>
> Facial nerve leave brainstem in close association with vestibulocochlear nerve at Cerebello-pontine angle (CP angle). Vestibular schwannoma and other tumors arising in the region of the cerebellopontine angle, may compress the facial nerve.

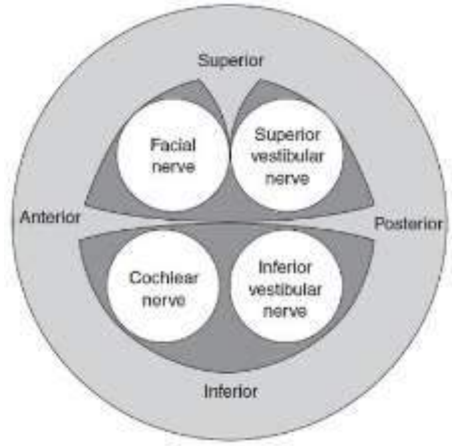
Intratemporal part

Internal acoustic meatus to Stylomastoid foramen

> **Mnemonic for segments:** MLTM

1. Meatal segment (8-10 mm): Within internal acoustic meatus – upto fundus

- *Location:* At the fundus or lateral end of the internal auditory canal (IAC), the transverse or falciform crest divides the IAC into superior and inferior portions. The superior portion is in turn further divided by the smaller and more laterally located vertical crest or "Bill's bar." The nerve lies in the anterior superior quadrant, above the falciform crest and anterior to Bill's bar.



2. Labyrinthine segment (4 mm): Fundus of Internal acoustic meatus to geniculate ganglion

- *Fallopian canal:* the nerve leaves internal acoustic meatus through the meatal foramen and enters fallopian or facial canal
- *Geniculate ganglion:* travels anteriorly until geniculate ganglion is reached, and at this point –
  - *Completion of nerve:* Intermedius nerve and motor nerve fibers join
  - *Greater Superficial Petrosal Nerve (GSPN):* branches off, which travels to pterygopalatine ganglion to innervate lacrimal, minor salivary glands and mucosal glands of nose and palate and receives taste from palate
  - *Skin of external acoustic meatus:* few cells of the geniculate ganglion supply skin in and around the external acoustic meatus
  - *1st genu:* is formed as it turns sharply backward to continue as Tympanic segment

Note:

1. Vidian nerve (Nerve of pterygoid canal) = Greater superficial petrosal nerve + Deep petrosal nerve

Greater petrosal nerve carries parasympathetic fibers and Deep petrosal nerve carries sympathetic fibers (sympathetic plexus of Internal Carotid Artery). The Vidian nerve forms at the junction of these nerves on the base of the skull and enters the vidian (pterygoid) canal in the anterior wall of foramen lacerum. The nerve enters the pterygopalatine ganglion from its posterior surface and the sympathetic and parasympathetic information is distributed to all locations communicating with the ganglion.

2. The facial or fallopian canal is narrowest (< 0.7 mm in diameter) in the labyrinthine segment and hence, most prone to palsy following edema of nerve caused by infection or inflammation.

3. Tympanic or Horizontal segment (11 mm): Geniculate ganglion to just above the pyramidal eminence

- *Medial wall of middle ear:* Runs horizontally on medial wall of medial ear cavity within fallopian canal
- *Relations:* lies above oval window and below lateral semicircular canal

Note: Tympanic segment is the commonest site of dehiscence of facial canal – both acquired (cholesteatoma) and natural, which makes it susceptible to injury.

4. Mastoid or Vertical segment (13 mm): Pyramid to stylomastoid foramen

- *2nd genu:* Turns vertically downwards at ~ 90° at the level of pyramid forming 2nd genu
- *Nerve to stapedius* branches off, at 2nd genu
- *Sensory nerve to skin of External Auditory Canal* branches off
- *Chorda tympani* (terminal branch of the nervus intermedius carrying both secretomotor fibres to the submandibular gland and sublingual gland and taste to the anterior two thirds of the tongue) branches off near, the stylomastoid foramen
- *Mastoid:* Courses within fallopian canal in mastoid bone until stylomastoid foramen is reached

Note: Facial recess is a triangular space bounded by fossa incudis, facial nerve and chorda tympani (which branches from facial nerve making approximately 30°). This is an important surgical route for entry into middle ear, especially in combined approach tympanoplasty.

Extracranial part

1. Exits: the skull base through the stylomastoid foramen, between the mastoid tip laterally and the styloid process medially.
The surgical landmarks necessary to identify facial nerve during parotid surgery will be discussed later.

2. Branches in neck:

- *Posterior auricular branch:* to auricular muscles and occipitalis muscle
- *Digastric branch:* to posterior belly of digastric muscle
- *Stylohyoid branch:* to stylohyoid muscle

3. Passes into the parotid gland: where it branches at Pes anserinus, into temporofacial and cervicofacial division

Mnemonic to remember peripheral branches:

Mnemonic in English: Two Zombies Buggered My Cat
If you understand Hindi language: Tum Zyada Bakbak Mat Caro

- The upper temporofacial division gives:
  - *Temporal branch:* Muscles of auricle, Frontalis(voluntary raising of eyebrows), Corrugator, Procerus
  - *Zygomatic branch:* Orbicularis oculi (proper eye closure), Zygomatic major
- Lower cervicofacial division gives:
  - *Buccal branch:* Buccinator and orbicularis oris (proper mouth closure and muscle cheek activity), Nasalis, Levator labii superioris, aleque nasi, zygomatic major and minor, levator angularis oris
  - *Marginal mandibular branch:* Depressor angularis oris, Orbicularis oris, Mentalis, Depressor labii inferioris, risorius
  - *Cervical branch:* Platysma (move lower lip and jaw downwards and to the side)

Clinical correlation:

1. Motor function of facial nerve is tasted for these peripheral branches by asking the patient to wrinkle forehead, open closed eyelids against resistance, whistle and clench the teeth. How to examine facial nerve?

2. Injury to the parotid or any parotid mass or swelling can lead to the injury of facial nerve.

3. Sensory innervation to the skin of face is through the trigeminal nerve (CN V), hence general sensation from face remains intact in facial nerve palsy.

Note:

1. Facial nerve supplies the muscles of facial expression which are derived from the 2nd branchial arch.

2. The word "pes anserinus" refers to "goose-foot-like". Pes anserinus is also used for the conjoined insertion of sartorius, gracilis and semitendinosus into the proximal tibia, medial to tibial tuberosity.

Summary

1. Course: Pontomedullary junction → Posterior cranial fossa → Internal acoustic meatus → Fundus of Internal acoustic meatus → Bone facial canal → Stylomastoid foramen

2. Facial Nerve Subdivision and Functions:

- Branchial motor: Muscles of facial expression, Posterior belly of digastric muscle, Stylohyoid muscle, Stapedius muscle
- Visceral motor: Salivation (lacrimal, submandibular, and sublingual), Nasal mucosa or mucous membrane
- General sensory: Sensory to auricular concha, External auditory canal, Tympanic membrane
- Special sensory Chorda tympani nerve (taste to anterior 2/3 of the tongue)

3. Donor nerve: The most common donor nerve for facial nerve grafting is Greater auricular nerve.

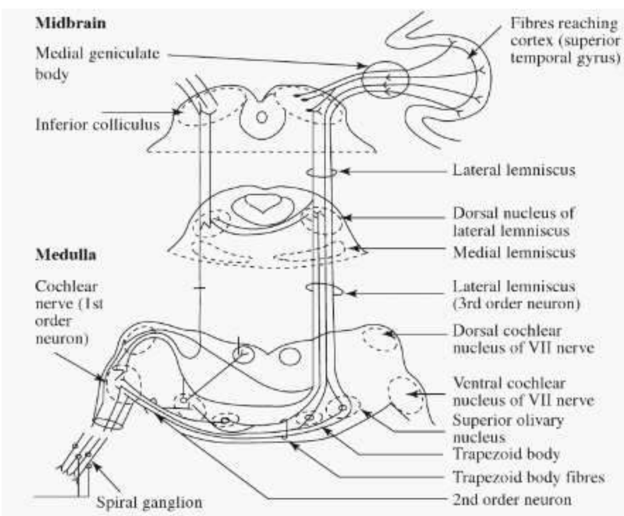
Auditory Pathway

Pathway Component Mnemonic

E.C.O.L.I.M.A

Ascending from peripheral to central the components are:

1. **E**ar receptors (Hair cells) in Cochlea and **E**ighth Cranial nerve (CN VIII)
2. **C**ochlear nucleus
3. Superior **O**livary nucleus
4. **L**ateral lemniscus
5. **I**nferior colliculus
6. **M**edial geniculate body
7. **A**uditory cortex



Explanation of the Mnemonic

Ear receptors and Eighth cranial nerve (Organ of Corti)

- **Cochlear hair cells are located on basilar membrane (In Organ of Corti):**
    - At the base of cochlea (thinner basilar membrane): encodes high-frequency sounds
    - At the apex of cochlea (thicker basilar membrane): encodes low-frequency sounds

Remember a guitar and compare the strings with the basilar membrane – thinner strings are tighter and produce high frequency like in base of cochlea and thicker strings are loose and produce low frequency sounds like in apex of cochlea. This localization of sound by cochlea is known as **Tonotopic localization**.

- Sound waves entering scala vestibuli and back to scala tympani causes vibration of basilar membrane.
- Vibration of basilar membrane leads to **movement of sterocilia** of hair cells against the tectorial membrane that leads to generation of action potential and production of electrical impulses that travel down the CN VIII (cochlear division).
- Axons of **spiral ganglion** bipolar axons form the cochlear nerve.

Cochlear Nuclei (Pontomedullary junction)

- Cochlear nuclei is divided into 2 divisions: Ventral cochlear nuclei and Dorsal cochelar nuclei in relation to the inferior cerebellar peduncle in Ponto-medullary junction.
    - **A**nterior (ventral) cochlear nucleus is dedicated to low frequency (**A**pical) sounds.
    - Posterior (dorsal) cochlear nucleus is dedicated to high frequency (Basal) sounds.

- Anterior cochlear nucleus > Anterior acoustic stria > Bilateral superior olivary nucleus (Binaural sound localization pathway)
    - Crossing over of anterior acoustic stria due to bilateral projection form a trapezoidal shape (**trapezoid body**).
- Posterior cochlear nucleus > Posterior acoustic stria > Contralateral lateral lemniscus and inferior colliculus (Monoaural sound localization pathway)
    - Skips superior olivary nucleus

Superior Olivary Nuclei (Pons)

- Located in pons
- 1st auditory nuclei to reveive binaural input and use the binaural input to localize sound forces.

***Note:** Inferior olivary nucleus is involved in motor control and provides major projection to the cerebellum.*

Lateral Lemniscus (Midbrain)

- Projection fibers from Ipsilateral Superior olivary nucleus.

Neurons order	Ascending auditory pathways
First-order neurons	Bipolar neurons of spiral ganglion in cochlear nerve
Second-order neurons	Dorsal and ventral cochlear nuclei
Third-order neurons	Superior olivary complex in pons. From here fibers travel in lateral lemniscus in pons
Fourth-order neurons	Inferior colliculus in midbrain
Fifth-order neurons	Medial geniculate body in thalamus. From here fibers go to auditory cortex in temporal lobe of the cerebrum through the auditory radiations in sublentiform part of internal capsule

Note: Medial lemniscus is a part of dorsal column pathway.

Inferior Colliculus (Midbrain)

- Receives fibers from ipsilateral superior olivary nuclei through lateral lemniscus

Note: Superior colliculus is a part of visual pathway.

Medial Geniculate Body (Thalamus)

- Receives projections from ipsilateral inferior colliculus via brachium of inferior colliculus

Note: Lateral Geniculate body is a part of visual pathway.

Auditory Cortex

- Auditory radiations from MGB to respective **transverse gyri of Heschl (Brodmann areas 41 and 42)**, deep to the superior temporal gyrus in the Sylvian fissure via **sublentiform part of internal capsule**.
- The auditory association cortex surrounds the primary auditory cortex.

Clinical Relevance

Since, the projection is bilateral to the superior olivary nucleus –

Lesions of cochlear part of CN VIII or cochlear nuclei at pontomedullary junction cause profound unilateral sensory hearing loss.

All other lesions to the auditory pathway above the cochlear nuclei cause bilateral suppression of hearing and decreased ability to localize a sound source.

Vestibular Pathway

Vestibule and Sensory receptors

Location: Medial to tympanic membrane and Posterior to Cochlea

Sensory receptors

1. Macula:

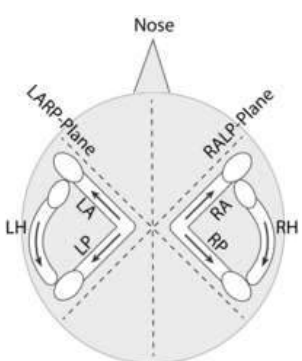
Present in otolith (calcium carbonate crystals) organs – **saccule** (anteriorly) and **utricle** (posteriorly)

Both are connected by corresponding ducts, which together will form **endolymphatic duct**, this passes through a bony canal (the vestibular aqueduct), and expands into flattened endolymphatic sac, blending into posterior cranial fossa dura.

Picks up **linear acceleration**:

- **U**tricle have **U**pright orientation of hair cells and hence, the cilia is displaced in horizontal plane (left-right, front-back)
- **S**accule have **S**lanted orientation hair cells and hence, the cilia is displaced in vertical plane (up-down)

2. Crista:



https://commons.wikimedia.org/wiki/File:Semicircular_Canals.png Thomas.haslwanter [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)]

Present in **semicircular canals**

3 semicircular canals – 2 vertically and 1 horizontally arranged

- Anterior/Superior semicircular canal (vertically; anterolateral)
- Posterior semicircular canal (vertically, posterolateral)
- Horizontal semicircular canal (horizontally)

Corresponding semicircular canals in right and left are at 90° to eachother.

Each semi-circular canal has 2 ends:

- Dilated ampullary end (contains **crista**)
- Non-dilated non-ampullary end (joined to anterior and posterior semicircular canal to form **crus-commune**)

Picks up **c**ircular acceleration (rotatory motion)

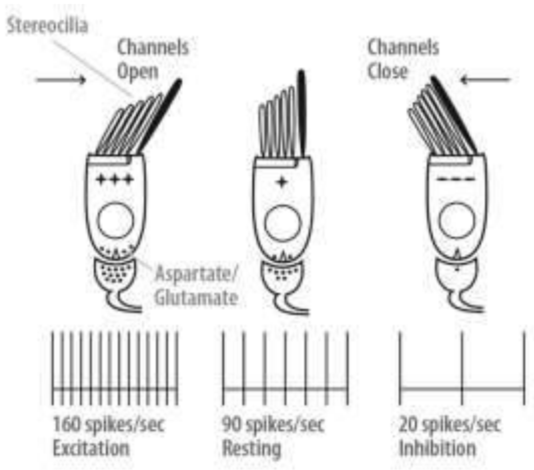
Remember: “C” for **c**rista, **“C”** for **c**anals and **“C”** for **c**ircular motion

Both macula and crista have sensory hair cells graded in height:

- Tallest: Kinocilium
- Others: Sterocilia

Firing:

- Deflection of sterocilia towards kinocilium: depolarization
- Deflection of sterocilia away from kinociluim: hyperpolarization



Stimulation of semicircular canal as per head motion:

Horizontal semicircular canal: Kinocilium is lateral to sterocilia

- Left head-turn depolarizes left horizontal semicircular canal and hyperpolarizes right horizontal semicircular canal
- Right head-turn depolarizes right horizontal semicircular canal and hyperpolarizes left horizontal semicircular canal

In Anterior semicircular canal – Kinocilium is anterior to sterocilia and In Posterior semicircular canal – Kinocilium is posterior to sterocilia

- Forward head tilt (without left or right) depolarizes anterior semicircular canal and hyperpolarizes posterior semicircular canal
- Forward-left head tilt depolarizes left anterior semi-circular canal and right posterior semicircular canal and hyperpolarizes left posterior semi-circular canal and right anterior semi-circular canal and vice-versa

Note:

Semi-circular canal towards the direction of head turn is activated (right or left and anterior or posterior).

Activation of one semicircular canal in a side, deactivates corresponding semicircular canal in other side.

Activation of anterior semicircular canal in a side, deactivates posterior semicircular canal in the same side and vice-versa.

Pairing A/P semicircular canals: Left anterior and Right posterior; Right anterior and Left posterior

Vestibular Nerve

The nerves from the semicircular canals and the otolithic organs project to the Scarpa's Ganglion in Internal acoustic meatus.

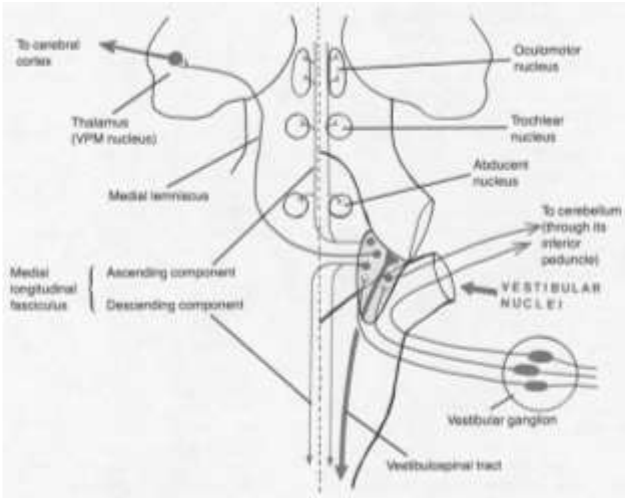
Axons of the Scarpa's ganglion form the **vestibular nerve** (CN VIII).

Vestibular Nuclei

Location: Ponto-medullary junction

4 divisions of vestibular complex:

- Superior vestibular nuclei of Bechterew
- Medial vestibular nuclei of Schwalbe (Least specialized) – sends afferent and efferent to all the pathways
- Lateral vestibular nuclei of Dieter
- Inferior vestibular nuclei



Vestibular fibers

Medial vestibular nuclei is involved in all the pathways; besides, we will discuss only the major pathway of efferents from the specific vestibular nucleus:

1. **Superior vestibular nucleus:** Vestibulo-occular reflex pathway (Stabilize eye gaze)

2. **Medial vestibular nucleus:** Medial vestibulo-spinal pathway (Stabilize posture)

3. **Lateral vestibular nucleus:** Lateral vestibulo-spinal pathway (Stabilize posture)

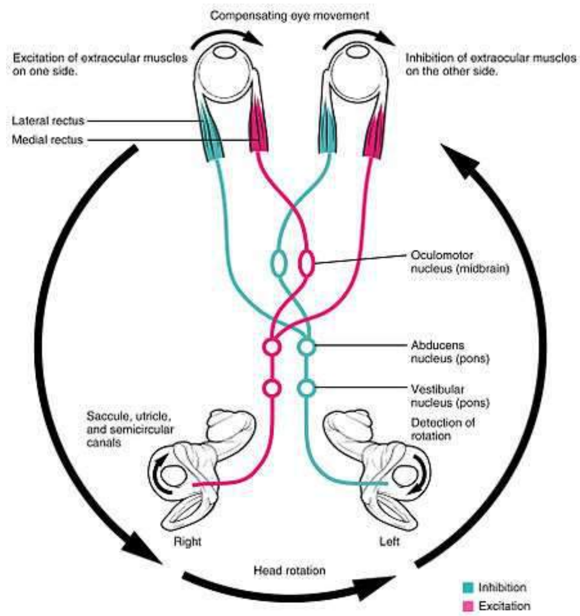
4. **Inferior cerebellum nucleus:** Vestibulo-cerebellar pathway (Cerebellum)

Vestibulo-Ocular Reflex (VOR)

Fibers activate **CONTRALATERAL CN VI** nucleus and inhibiti **IPSILATERAL CN VI** nucleus

CN VI will activate CONTRALATERAL CN III (i.e. ipsilateral to vestibular system stimulated) through **Medial Longitudinal Fasciculus (MLF)**

https://commons.wikimedia.org/wiki/File:1419_Vestibulo-Ocular_Reflex.jpg



Function: stabilizes images on the retina during head movement by producing an eye movement in the direction opposite to head movement, thus preserving the image on the center of the visual field.

Example:

Left head turn > Left vestibular nuclei and nerve stimulated > Right CN VI nuclei and lateral rectus stimulated > Left CN III and medial rectus stimulated > Right lateral rectus turns right eye to right and Left medial rectus turns left eye also to the right i.e. when head is turned to left, both the eyes fix gaze to right.

Nystagmus in Unilateral Vestibular Damage:

Unopposed action of Contralateral Vestibular nerve and nuclei leads to:

Vestibulo-ocular reflex (Slow component): Eyes slowly look to side of vestibular damage

Attempt of cerebral correction (Fast component): Eyes rapidly move back to side away from vestibular damage

Caloric testing:

Lateral or horizontal semicircular canal is oriented vertical by elevating the head 30° from horizontal.

Warm water → Stimulates horizontal semicircular canal on same side and inhibits the same on opposite side → Eye moves to opposite side by vestibulo-ocular reflex (slow component) → Correction by moving eye back to same side (fast component) i.e. Nystagmus to the **same side**

Cold water → Inhibits horizontal semicircular canal on same side and stimulates the same on opposite side → Eye moves to the same side by vestibuo-ocular reflex (slow component) → Correction by moving eye to the oppoiste side (fast component) i.e. Nystagmus to the **opposite side**

> **Mnemonic:** COWS (Cold Opposite and Ward Same side)

Vestibulo-Spinal Pathway

Medial vestibulospinal pathway:

Efferent medial vestibular nucleus fibers → descend in MLF → become medial vestibulo-spinal tract → cervical and upper thoracic motor nuclei

Function: Stabilize Head and neck posture

Lateral vestibulospinal pathway:

Efferent lateral vestibular nucleus fibers → descend on anterior horn of spinal cord as lateral vestibulospinal tract

Function: Forelimb antigravity posture

Vestibulo-cerebellar Pathway

Involved part of cerebellum: Mildine cerebellum (Archicerebellum)

Direct vestibulocerebellar tract:

Vestibular labyrinth → fibers directly to vermis in the midline cerebellum

Indirect vestibulocerebellar tract:

Vestibular labyrinth → Inferior vestibular nucleus → ipsilateral inferior cerebellar peduncle → uvula and flocculonodular lobe in midline cerebellum

Midline cerebellum → Efferent fibers → Bilateral vestibular nucleus complex

Vestibulo-cerebral Pathway

Efferent vestibular projections to bilateral Ventral Posterior group of thalamus

Cortical regions of the brain known to be involved with vestibular processing:

Frontal eye fields: control eye movements and receive vestibular motion information

Primary somatosensory cortex (Areas 2v and 3a): map body location and movement signals

PIVC (Parieto-Insular Vestibular Cortex): responds to body and head motion information

Posterior parietal cortex: motion perception and responds to both visual and vestibular motion cues

Hippocampus and parahippocampul regions: spatial orientation and navigation functions

Vestibulo-autonomic Pathway

- Some vestibular efferent projections to reticular formation, dorsal pontine nuclei, and nucleus of solitary tract.
- **Function:** Stabilize respiration and blood pressure during body motion and changes relative to gravity
- Role in motion sickness

10 Retinal Layers

The ten layers of retina – this microscopic anatomy is frequently asked in examinations and also important from the physiological viewpoint. There are plenty of mnemonics around the web, but we will proceed in a different approach to remember the 10 retinal layers easily.

A. Retina is 3 neuron system composed of 3 layers of cells:

From out to in –

1. Photo**R**eceptor layer
    - Pigmented epithelium with Zona occludens (outer blood-retina barrier)
    - Photoreceptors
    - Outer limiting membrane
    - Outer nuclear layer
    - Outer plexiform later
2. **B**ipolar cell layer (1st order neuron)
    - Inner nuclear layer
3. **G**anglion cell layer (2nd order neuron)
    - Inner plexiform layer
    - Ganglion cell layer
    - Nerve fiber layer (Axons of ganglion cell layer that form optic nerve)
    - Inner limiting membrane

> Remember: **RBG** (Red, Blue, Green) – the color model for color vision
>
> **Where are the 3rd order neurons?** In the Lateral Geniculate Body (LGB).

B. Orientation:

1. Inner – refers to layers which are close to the vitreous humor
2. Outer – refers to layers which are close to the choroid

C. Nuclei of Retinal cells:

These nuclei are arranged in a layer known as Nuclear layer.

- Nuclei of Photoreceptors – forms Outer Nuclear Layer
- Nuclei of Bipolar cells (1st order neuron), Horizontal cells (outer to Bipolar cells), Amacrine cells (inner to Bipolar cells) and Muller cell (supporting glial cells) – forms Inner Nuclear Layer

> **Horizontal cells:** help sharpen the receptive field of bipolar cells
>
> **Amacrine cells:** help sharpen the response of ganglion cells

D. Axons and Dendrites of Retinal cells:

These axons and dendrites (synapses) are arranged in a layer known as Plexiform layer.

Plexiform layer lies just inside the corresponding Nuclear layer:

- **Outer plexiform layer (OPL):** Between outer nuclear layer and inner nuclear layer
    - Synapses between Photoreceptors and Bipolar cells forms Middle Limiting Membrane (MLM).
    - Retina external to MLM is avascular (dependent upon choroidal vasculature) and Internal to MLM is vascular (Central retinal artery).

- o Hence, outer plexiform layer is a watershed zone between dual vascular supply – role in localization of edema fluid and hard exudates in this layer.
- **Inner plexiform layer (IPL):** Between inner nuclear layer and ganglion cell layer
  - o Synapses between Bipolar cells, Ganglion cells and Amacrine cells.

E. Axons of Ganglion Cells form Nerve Fiber Layer:

- Which go on to Optic nerve (CN II)

F. Inner Limiting Membrane:

- The only true basement membrane.
- Synthesized by foot process of Muller cells.

G. Shape of Photoreceptors:

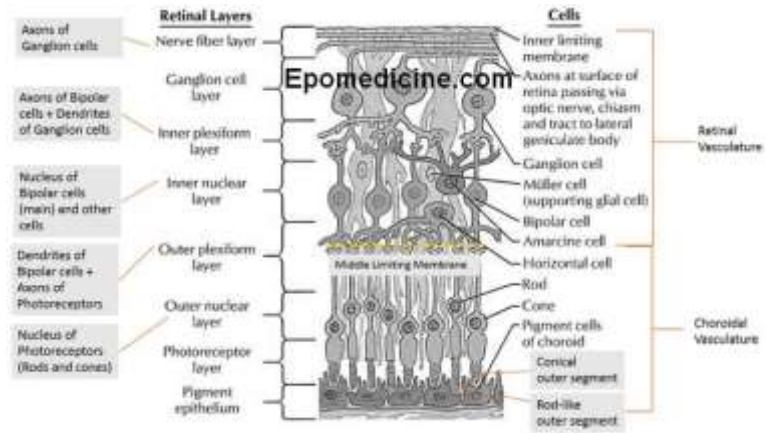
The name comes from the outer segment of these receptors, which contains photopsin:

- Rods: Outer segment is Rod-like cylindrical
- Cones: Outer segment is Conical

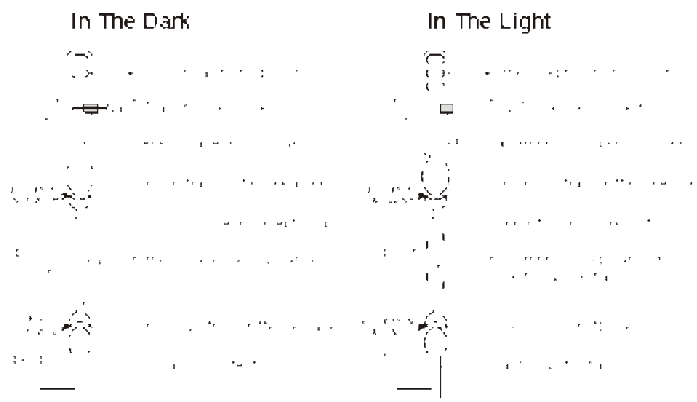
Rods: Dark vision and Motion
Cones: Light vision, Sharp vision and Color discrimination
3 types of cones: Red, Blue and Green

With this Knowledge, now let's draw the microanatomy of retina:

Schematic Drawing of Retinal Layers



Rod cells in Light and Dark



1. Rods – Bipolar cells synapse = Inhibitory
2. Bipolar cells – Ganglion cells synapse = Excitatory
3. Hence, to generate action potential in Ganglion cells: Rod cells must be inhibited (Inhibition of inhibitory fibers)
4. There are cGMP gated Na+ channels on rods.

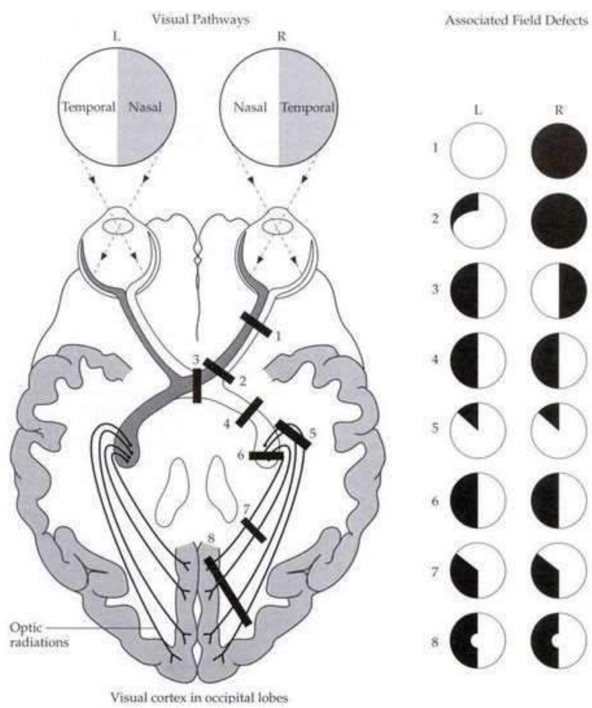
- cGMP is abundant in dark and decreased in light.

5. Depolarization of rods occurs in dark and repolarization in light.

Hence, action potential is generated in ganglion cells in light but not in the dark.

Visual Pathway – Supplement Knowledge

Everyone must be aware of the normal visual pathway and their defects. Here, I've tried to enlist the topics related to the visual pathway that are "**nice to know**" but you may have missed it or failed to understand properly. Below is the basic visual pathway:



Loss of 1/2 field of vision: **Hemianopia**

Loss of field of vision in both eyes: **Homonymous or Heteronymous**

Homonymous: Bilaterally involving same side of vision (right or left) i.e. nasal of one side and temporal of other

Heteronymous: Involving different side of vision (right and left) i.e. bilaterally nasal or temporal

Lesions from optic tract to visual cortex cause contralateral **homonymous hemianopia** (i.e. defect of vision in right when left pathway is impaired and vice-versa).

Central lesion of chiasma: **Bitemporal heteronymous hemianopia**

Lateral lesion of chiasma (bilateral): **Binasal heteronymous hemianopia**

Wilbrand's knee

Anterior Wilbrand's Knee

After the nasal retinal fibers cross in the optic chiasma, and before projecting down the optic tract:

Inferior nasal hemiretinal fibers loop into the proximal contralateral optic nerve – anterior Wilbrand's knee.

The inferior nasal hemiretinal field corresponds to superior temporal visual field.

Posterior Wilbrand's Knee

Before crossing in the optic chiasma:

Superior nasal fibers form a redundant loop in the ipsilateral optic tract – posterior Wilbrand's knee.

Anterior Junction or Anterior Chiasmal Syndrome

Lesion of optic nerve just anterior to the optic chiasma –

1. Ipsilateral optic nerve involvement
2. Anterior Wilbrand's knee (Contralateral inferior nasal retinal fiber) involvement

Posterior Junction or Posterior Chiasmal Syndrome

Lesions of optic tract just posterior to the optic chiasma –

> **Remember:** Macular fibers that cross do so in the central and posterior portions of chiasma.

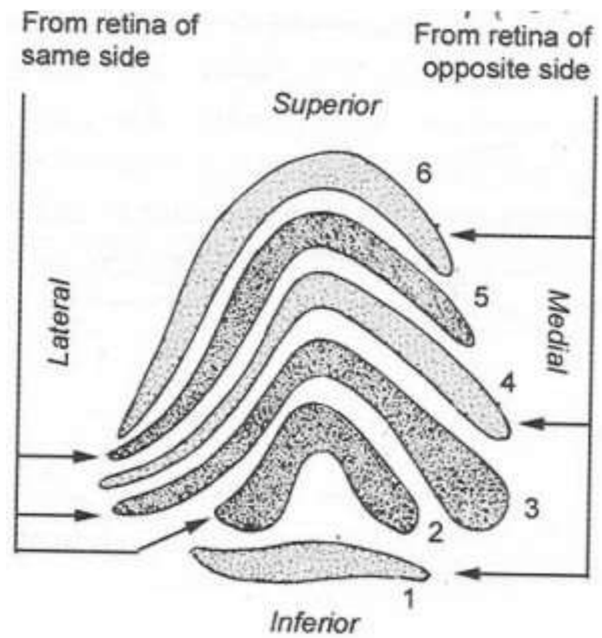
1. Ipsilateral temporal retinal fibers involvement
2. Contralateral nasal retinal fibers involvement
3. Posterior Wilbrand's knee (Ipsilateral superior nasal retinal fibers) involvement

They produce centrally placed bitemporal scotomas.

6 Laminae of Lateral Geniculate Body (LGB)

Grey matter is split into 6 parts by the white matter.

- Axons from the ipsilateral eye end in laminae 2, 3 and 5.
- Axons from the contralateral eye end in laminae 1, 4 and 6.



They divide into parvocellular and magnocellular subtypes.

- Parvocellular subtypes – projections from small ganglion cells sensitive to color and shape
- Magnocellular subtypes – projections from larger ganglion cells sensitive to motion

2 Eponymous Optic Radiations

Optic radiations extend from Lateral Geniculate Body (LGB) to Visual cortex.

- **Meyer's loop (Inferior retinal fibers)** – pass through temporal lobe looping around inferior horn of lateral ventricle to the lingual gyrus (occipital lobe below calcarine sulcus).
- **Baum's loop (Superior retinal fibers)** – pass through the parietal lobe to the cuneus (occipital lobe above calcarine sulcus).

Lesions:

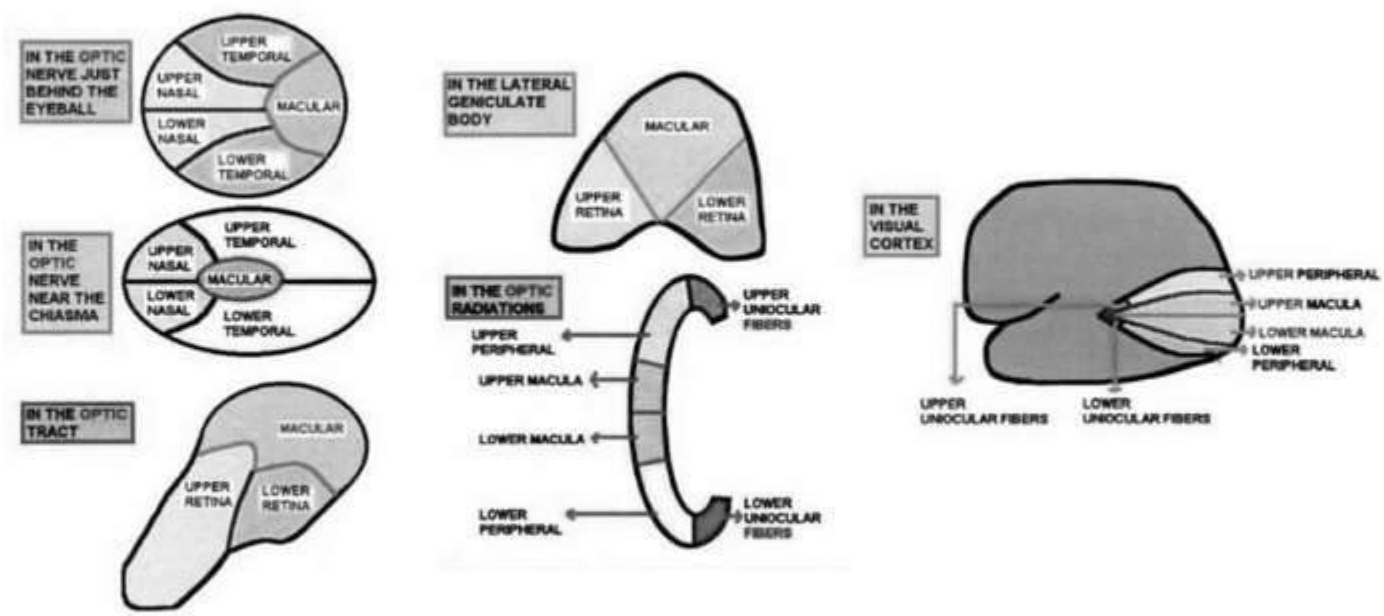
Temporal lobe: Inferior retinal fibers involved (Superior qudrantic hemianopia – pie on sky contralateral to lesion)

Parietal lobe: Superior retinal fibers involved (Inferior quadrantic hemianopia – pie on floor contralateral to lesion)

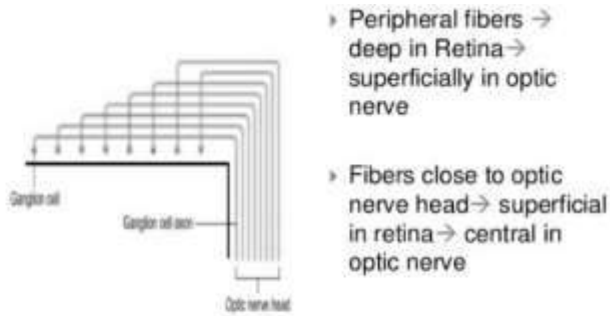
Optic radiation pass through Internal Capsule

These fiber pass through retrolentiform part of internal capsule.

Orientation of Retinal Fibers



	OPTIC TRACT	LATERAL GENICULATE BODY	OPTIC RADIATION	CEREBRAL CORTEX
MACULAR FIBERS	Dorsolaterally	Posterior 2/3rd	Center	Posterior
UPPER RETINAL FIBERS	Medially	Medial Anterior 1/3rd	Upper part	Anteriorly – above calcarine sulcus
LOWER RETINAL FIBERS	Laterally	Lateral Anterior 1/3rd	Lower part	Anteriorly – below calcarine sulcus



Macular sparing in Posterior Cerebral artery Occlusion:

Due to bilateral projection to occiput and collateral blood supply from Middle Cerebal Artery (MCA)

Posterior tip of occipital cortex unaffected

Macular involvement if tip of Occipital cortex involved:

In head injury or gunshot injury

Wernicke's Hemianopic Pupil

Everyone probably knows this defect. It is the defect seen in optic tract lesion which receives crossed nasal fibers and uncrossed temporal fibers:

Ipsilateral temporal retinal fibers involvement: Ipsilateral nasal visual field defect

Contralateral nasal retinal fibers involvement: Contralateral temporal visual field defect

This is called contralateral homonymous hemianopia and also Wernicke's Hemianopic pupil.

Optic atrophy

Present in lesions of Lateral Geniculate Body (LGB) and pathway anterior to it – Descending optic atrophy.

Absent in lesions posterior to LGB (i.e. optic radiations and cortex).

This is because 2nd order neurons synapse in LGB.

Pupillary reflexes

Defect in lesions anterior to LGB.

Normal in lesions of LGB and pathway posterior to it (i.e. optic radiations and cortex).

Afferent pupillary defect

Lesions upto pre-tectal nucleus –

Absolute:

- No light perception in eye
- No direct reflex in ipsilateral eye and no consensual reflex in opposite eye
- Normal direct in opposite eye and normal consensual in involved eye
- Pupils are equal
- Normal near reflex (Like light reflex, near reflex is also consensual and hence, normal)

Relative (RAPD): Marcus-gunn pupil in Swinging flash light test

- Pupils constrict to brighter light and dilate to dimmer light
- The affected eye instead of being completely blind, perceives as if the light is dimmer
- Hence, pupils appear to be dilated when light is shown on affected eye relative to the normal eye.

Near reflex: Comprises of –

1. Convergence reflex: Convergence of visual axis and associated pupillary constriction

(mediated by fibers projecting from medial rectus via mesencephalic nucleus of CN V to the E-W nucleus)

2. <u>Accomodation reflex:</u> E-W nucleus activation leads to pupillary constriction and contraction of ciliary muscles makes lens more spherical and powerful.

Unlike in the light reflex, projections are from the supranuclear level (corticonuclear fibers from frontal eyefield) in near reflex.

Efferent pupillary defect: Lesions behind pre-tectal nucleus i.e. from E-W nucleus to short ciliary nerves to both constrictors of the eyes

- Ipsilateral absence of direct and consensual light reflex
- Ipsilateral absence of near reflex (E-W nucleus and tracts further are also the part of accomodation reflex).
- Ipsilateral fixed and dilated pupil leading to Anisocoria (Affected eye is unresponsive and apparently perceiving dimmer environment with impaired consensual light reflex from the opposite eye as well).

> The 2nd order neurons (Ganglion cells) do not synapse in LGB in the pathway of light reflex. It passes between the LGB and MGB to end in ipsilateral pretectal nucleus. The internuncial fibers project to bilateral Edinger-Westphal nucleus from the pretectal nucleus which forms the basis of consensual light reflex.
>
> https://commons.wikimedia.org/wiki/File:1509_Pupillary_Reflex_Pathways.jpg
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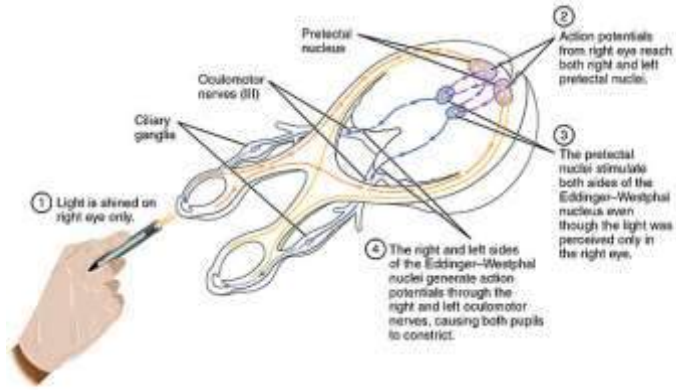


Near-Light Dissociation

This is a condition when light reflex is absent and near reflex is present.

Light reflex: retina > optic nerve > optic chiasm > optic tract > pretectal area > bilateral E-W nucleus

Near reflex: frontal eye field > corticonuclear fibers > bilateral E-W nucleus

For near-light dissociation to be present:

Consensual near reflex must be intact

Consensual light reflex must be impaired

The consensual light reflex is mediated by the internuncial fibers from pretectal nucleus to bilateral E-W nucleus. Hence, afferent lesions around this region gives rise to near-light dissociation because the afferent fibers of near-reflex that enter E-W nucleus more rostrally in midbrain and are spared.

Causes of near-light dissociation:

Lesion in dorsal midbrain:

- Damage to pre-tectal nuclei (demyelination): Argyll-Robertson pupils (Syphilis, Diabetes)

- Damage to posterior commisure (compression by pineal tumor): Parinaud syndrome (Dorsal midbrain syndrome)

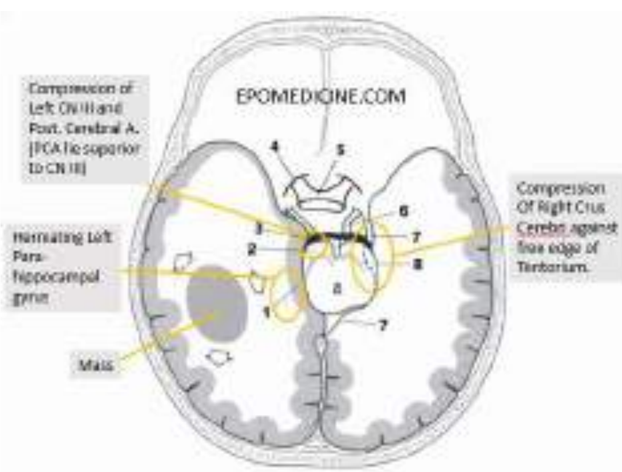
Bilateral total afferent defect:

- Convergence reflex pathway is unaffected as it starts from the medial recti, leading to near-light dissociation.

Adie's tonic pupil:

- Injury to ciliary ganglion and or post-ganglionic fibers resulting in abnormal regrowth of short ciliary nerves.
- Near-reflex is not spared but restored later and hence, also called pseudo-near light dissociation.
- In short ciliary nerves – Accommodative fibers : Sphincter fibers = 30:1
- Hence, with random regeneration of fibers, power of accommodation is likely to recover, whereas the light reaction will not.
- Like a single eye Argyll-Robertson pupil.

Kernohan's Notch

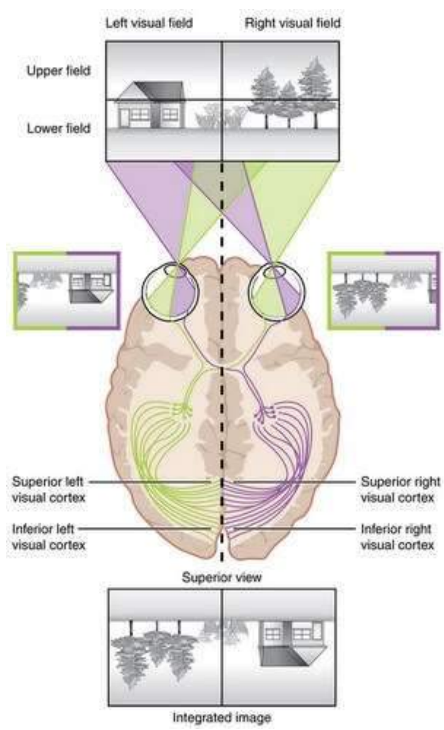


In transtentorial (uncal) herniation, due to mass effect there is compression of the contralateral crus cerebri of midbrain against the free edge of tentorium cerebelli. This is known as Kernohan's notch. This may also put pressure on the ipsilateral CN III and posterior cerebral artery. The neurologic defects in this setting are:

1. Contralateral corticospinal tract involvement in crus cerebri: Ipsilateral hemiparesis (False localizing sign, i.e. UMN sign is expected on side contralateral to the lesion but seen in the ipsilateral side).
2. Ipsilateral occulomotor nerve involvement: Ipsilateral fixed-dilated pupil, ptosis, "down and out" eye
3. Ipsilateral posterior cerebral artery involvement (visual cortex): Contralateral homonymous hemianopia

Left sided lesion → Kernohan's notch on right → Right corticospinal lesion → Left hemiparesis

Central Visual Processing



https://commons.wikimedia.org/wiki/File:1422_Topographical_Image_on_Retina.jpg

The visual field projects onto the retina through the lenses and falls on the retinae as an inverted, reversed image. The topography of this image is maintained as the visual information travels through the visual pathway to the cortex.

Area V1 (aka striate cortex) is the primary cortical processing area for macular retinal images.

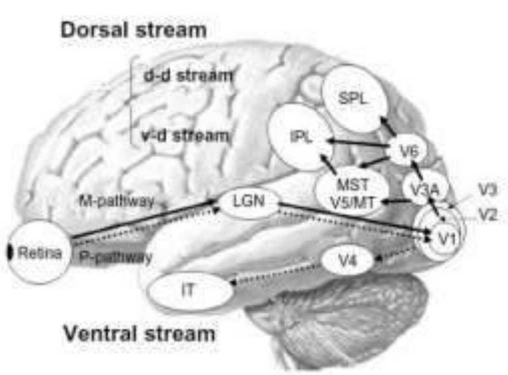
Areas V2 and V3 (aka extrastriate cortex) are the primary cortical processing areas for peripheral retinal images.

Areas V4/V8 (aka occipito-temporal region corresponding to lingual and fusiform gyri) is the center for color processing.

- Lesion leads to achromatopsia (defect in color perception).

Area V5 (aka temporo-parietal-occipital junction) is the motion detection area.

- Lesion leads to akinetopsia (disorder of motion perception).



Midway along Medial-lateral plane of inferior occipital-temporal surface: Visual object recognition

- Lesion leads to visual object agnosia (loss of object recognition).

Lateral inferior occipito-temporal fusiform gyrus: Familiar face recognition

- Lesion leads to prosopagnosia (deficit for recognition of familiar faces).

Medial inferior occipito temporal parahippocampal gyrus: Place recognition

- Lesion leads to difficulty in recognition of familiar environment.

Caudal portion of the intraparietal sulcus: Stereoscopic processing

Remaining portion of intraparietal sulcus: Reach area

- It tells the motor cortex where to move to produce a desired effect.
- Lesion leads to optic ataxia (impairment of reaching for objects in the environment) and oculomotor apraxia (impairment of voluntary eye movements to command).

Superior and inferior parietal lobule: Body spatial awareness

- Lesion results in hemineglect.

Anton Syndrome:

Bilateral lesions in V1 have bilateral blindness but are unaware of their deficit (anosognosia).

When asked directed questions about their environment, they confabulate confidently.

Suggests right frontoparietal disorder.

Bálint syndrome:

Simultagnosia (only able to visualize one object at a time) along with optic apraxia and optic ataxia

Suggests widespread bilateral occipito-parietal lesions

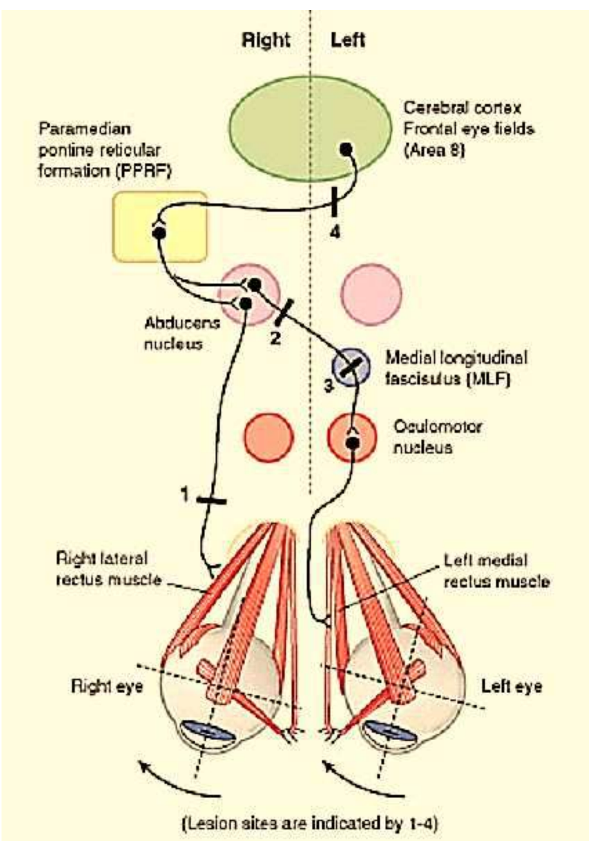
Horizontal Conjugate Gaze Pathway

Components of Pathway

For both eyes to look at a side:

1. Contralateral Frontal Eye Field (Area 8)
2. Ipsilateral PPRF (Paramedial Pontine Reticular Formation)
3. Ipsilateral CN VI Nucleus
4. Contralateral Medial Longitudinal Fasciculus (MLF)
5. Contralateral CN III Nucleus

Horizontal Conjugate Gaze Pathway



Lesions of Pathway

CN VI nerve: Affected side cannot abduct

Lesion site 1 in figure – Right abducens nerve (Right eye cannot look right)

CN VI nucleus or PPRF: Both the eyes cannot look towards the affected side (Lateral gaze paralysis)

Lesion site 2 in figure – Right abducens nucleus

- Right eye cannot look right or abduct (Right Lateral rectus dysfunction)
- Left eye cannot look right or adduct (Left Medial rectus dysfunction – as abducens nucleus activates contralateral CN III through contralateral MLF)

Medial Longitudinal Fasciculus (MLF): Eye on affected side cannot adduct when the eye on unaffected side can abduct (Internuclear ophthalmoplegia)

Lesion site 3 in figure – Left MLF

- Left eye cannot adduct or look right when right eye looks to the right
- Convergence intact
- Right eye exhibits nystagmus

Can be differentiated from the Occulomotor nerve lesion by the absence of ptosis and mydriasis seen with occulomotor nerve lesion.

Frontal Eyefield:

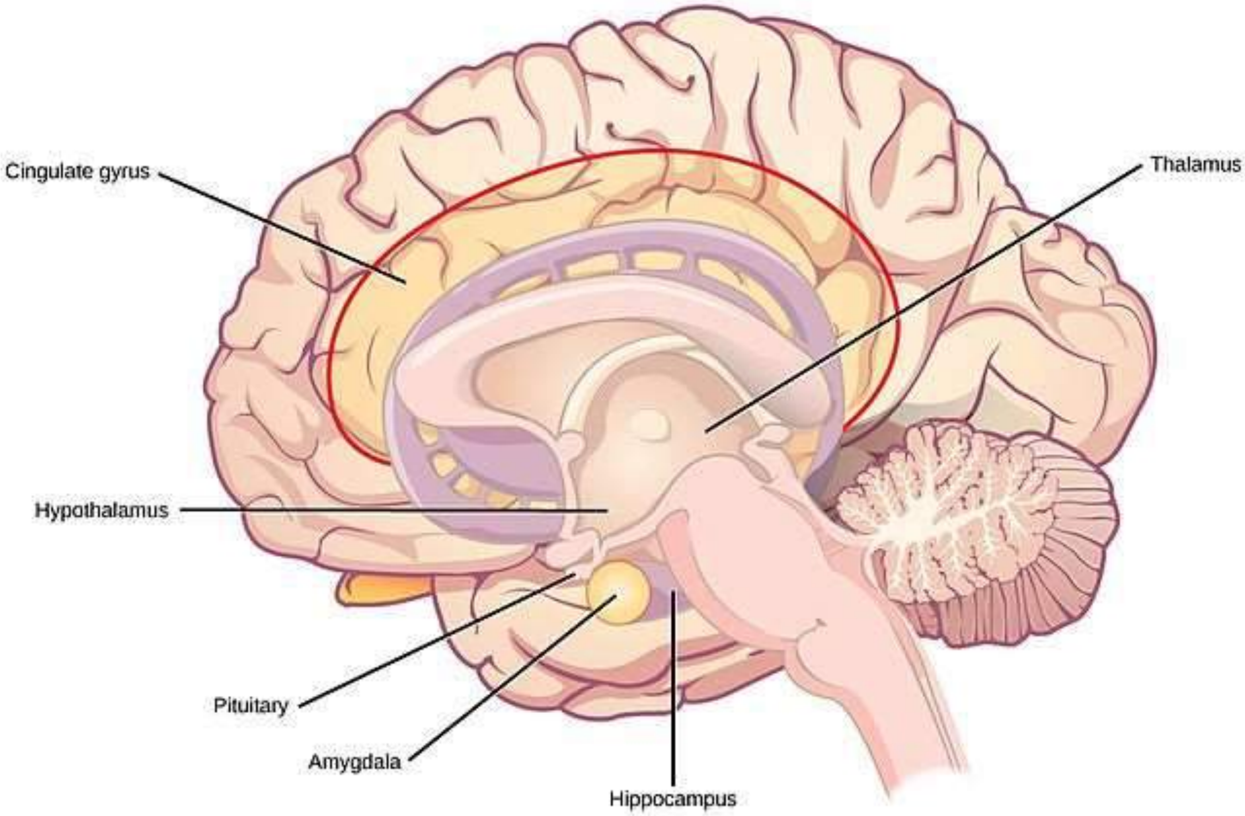
Eyes cannot look to the side opposite to the lesion

Lesion site 4 in figure – Left Frontal eye field

- Both the eyes cannot look to the right
- Slowly drift to the left

Limbic System

Limbic system is complex both structurally and functionally. It is located on either side of the thalamus, immediately below the cerebrum and consists of both the grey matter and white mater. Let us simplify the structure of limbic system:



https://commons.wikimedia.org/wiki/File:Figure_35_03_06.jpg
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Hypothalamus is central to the limbic system

Limbic cortex: 2 "C" shaped concentric gyri surrounding the corpus callosum.

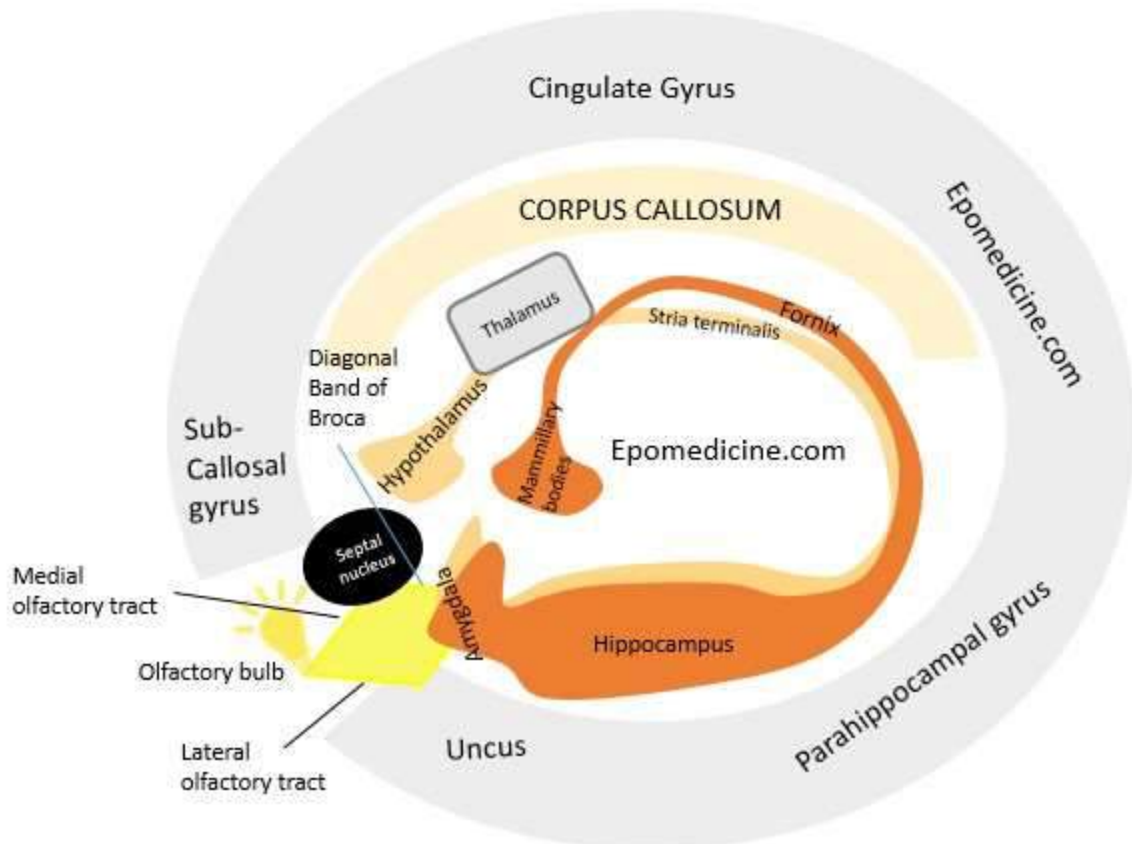
- Limbic gyrus: Above corpus callosum
    1. **Cingulate gyrus** which is continuous anteriorly as **Sub-callosal gyrus** and posteriorly has **para-hippocampal gyrus** (overlying the hippocampus)
    2. Para-hippocampal gyrus contains pyriform cortex which includes **entorhinal cortex** and **uncus**.
- Intralimbic gyrus (Hippocampal formation): Below corpus callosum
    1. Dentate gyrus
    2. Hippocampus proper
    3. Subiculum

Subcortical structures:

- Amygdala
- Septal nucleus
- Anterior nucleus of thalamus

Limbic System Mnemonic

I will provide you with a visual mnemonic to help you build limbic system in your mind and also easily remember it. Try drawing it on a piece of paper without looking after going through it. This will help you to understand the orientation of the limbic system in human brain.



Hippocampus means mythical sea monster that resembles a sea horse.

Imagine **2 Sea horses** sleeping under the light **bulb** under the **sea ("C")**.

The sea "C" is flipped horizontally and there are 2 big "C"s surrounding 2 seahorses.

- Inner smaller "C" representing Corpus callosum.
- Outer larger "C" representing Cingulate gyrus and it's Continuations.

The sea horses are sleeping under the the light bulb:

- The light bulb is the **olfactory bulb**.
- The illumination of light bulb around the head of the seahorses form several structures:
    - Illumination field: **Anterior perforated substance**
    - Superior lateral border: **Lateral olfactory tract**
    - Superior medial border: **Medial olfactory tract**
    - Inferior medial border: **Diagonal band of Broca**
    - Medial to the Medial olfactory tract and just below the limbic gyrus lies **Septal nucleus**.

Now the 2 sleeping sea horses:

- Outer sea horse:
    - Body = **Hippocampus**
    - Tail = **Fornix**
    - Tail fin = **Mammillary body**
- Inner sea horse:
    - Body and tail = **Stria terminalis**
    - Tail fin = **Hypothalamus**
- Head of both sea horses = **Amygdala**
- **Thalamus** lies above hypothalamus.

Dorsomedial nucleus: Connected to amygdala

- Anterior nucleus: Connected to mammillary bodies

We have skipped unnecessary structures in this diagram. Now, we will discuss the pathways of limbic system in concise, eliminating unnecessary details

Limbic Connections

Most conspicuous are the **reciprocal connections with hypothalamus**.

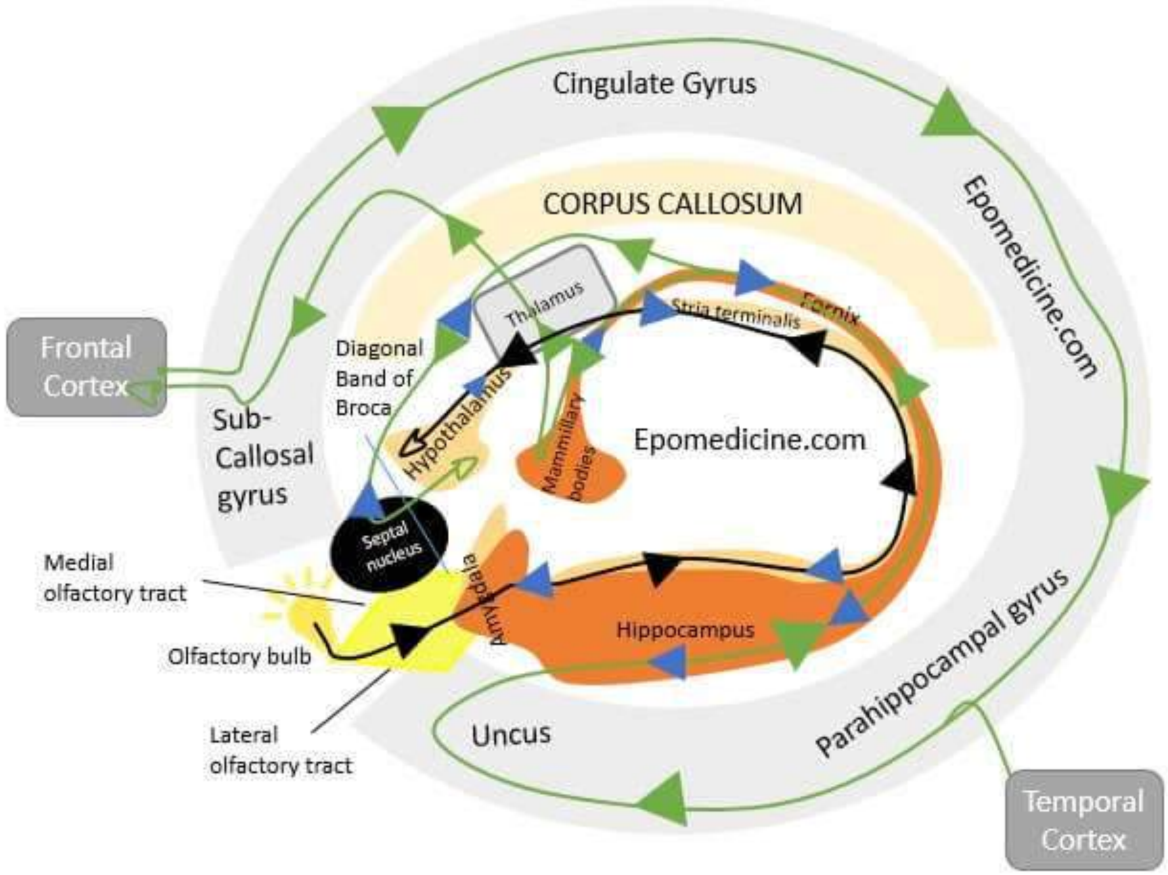
Hypothalamus and **Mammillary bodies:**

- communicate with **Hippocampus** and **Septum** via <u>Fornix</u>.
- communicate with **Amygdala** via **<u>Stria terminalis</u>** and **<u>Amygdalofugal fibers</u>**.
- communicate with frontobasal parts of **Olfactory brain** via **<u>Medial forebrain bundle</u>**.

Limbic system communicates with neocortex by the way of **Frontal** and **Temporal** regions.

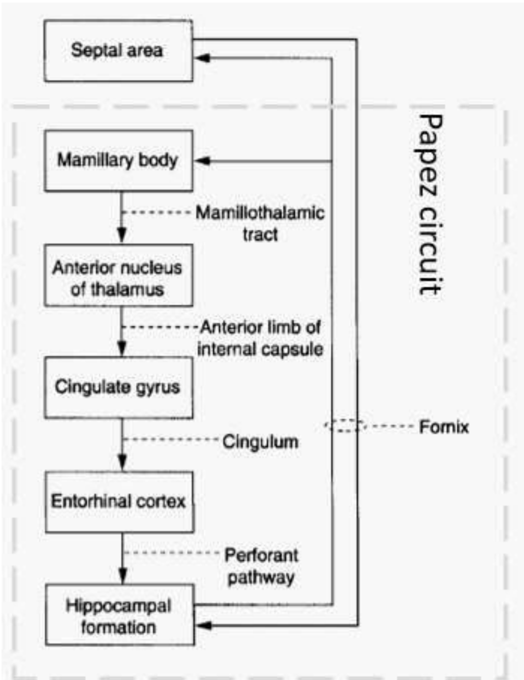
- **Temporal brain:** mediates primarily information from visual, auditory and somatosensory cortices to **Amygdala** and**Hippocampus**.

Frontal brain: only neocortical region with direct neuronal connections to hypothalamus.

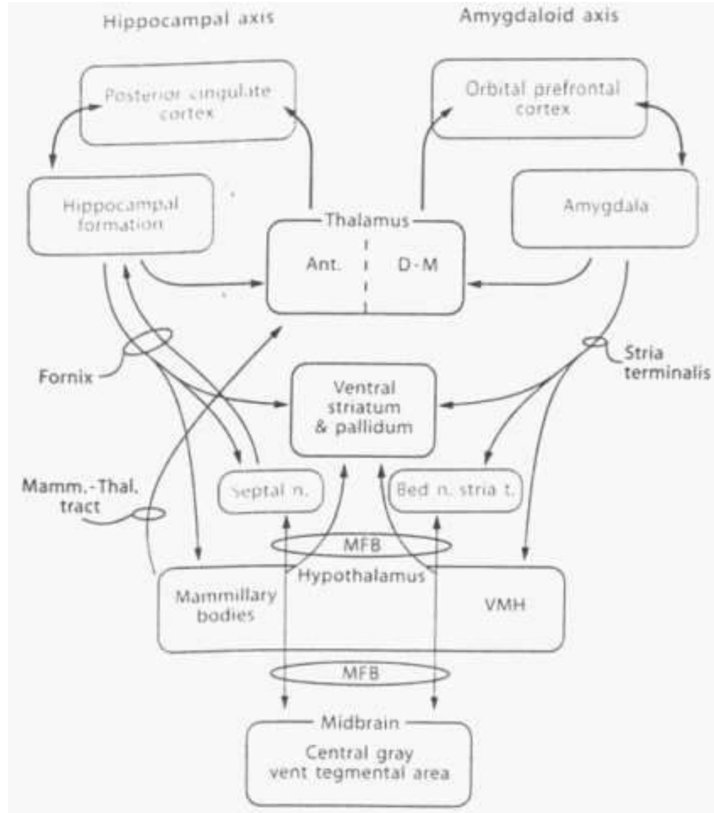


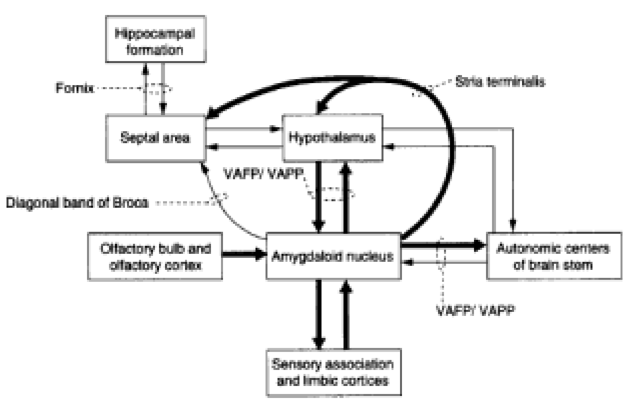
Internal circuits

	HIPPOCAMPAL AXIS	AMYGDALOID AXIS
SENSE	Extroceptive	Introceptive
FUNCTION	Congitive process – learning and memory	Generation of emotion and motivational states
AFFERENT	Receives information from cortical sensory organs	Receives information from cortical sensory organs and internal organs
THALAMIC CONNECTION	Anterior thalamus	Dorsomedial thalamus



Hippocampal circuit





Amygdaloid circuit; VAFP (Ventral Amygdalofugal pathway); VAPP (Ventral Amygdalopetal pathway)

Functions of Limbic System and Structures

Olfaction:

Amygdala plays role in emotional response to smell.

Entorhinal cortex (parahippocampal gyrus) plays role in olfactory memory.

Thalamic connections

Hypothalamic nuclei and their function

Areas	Functions
Cingulate gyrus	Autonomic functions regulating heart rate and blood pressure as well as cognitive, attentional and emotional processing.
Parahippocampal gyrus	Spatial memory
Hippocampus	Long-term memory
Amygdala	Anxiety, aggression, fear conditioning; emotional memory and social cognition.
Hypothalamus	Regulates the autonomic nervous system via hormone production and release. Secondarily affects and regulates blood pressure, heart rate, hunger, thirst, sexual arousal and the circadian rhythm sleep/wake cycle.
Mammilary body	Memory
Nucleus accumbens	Reward, Addiction

Lesions of Limbic System

Bilateral lesion of Cingulate gyrus – Abulia

Loss of initiative and inhibition and dulling of emotions.

Memory is unaffected.

Bilateral lesion of Amygdala – Kluver Bucy Syndrome

1. Hyperorality
2. Visual, tactile and auditory agnosia
3. Placidity
4. Intense desire to explore immediate environment (hypermetamorphosis)
5. Hypersexuality

Hippocampus

Most epileptogenic part

Bilateral lesion of hippocampus – Amnestic (Confabulatory) syndrome

- Anterograde amnesia (unable to learn and retain new information)
- Intellect unaffected
- Procedural memory unaffected

Fornix

Bilateral lesion of fornix leads to acute amnestic syndrome i.e. inability to consolidate short-term memory to long-term memory.

Wernicke's Encephalopathy

Cause: Thiamine (Vitamin B12) deficiency

The involved structures are:

1. Mammillary bodies
2. Dorsomedial thalamus
3. Periaqueductal grey
4. Pontine tegmentum

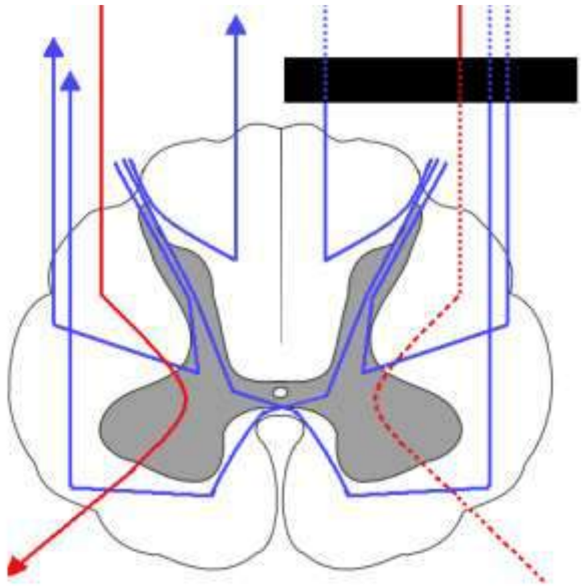
Clinical manifestations:

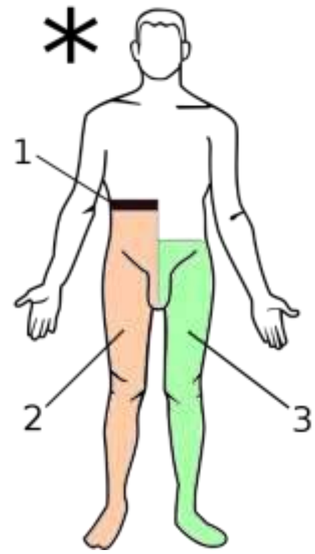
1. Ocular disturbances and nystagmus
2. Gait ataxia
3. Mental dysfunction

Sommer's sector

- Junction of Hippocampal area CA1 (Cornu Ammonis 1) and Subiculum
- Very sensitive to ischemia

Brown Sequard Syndrome: Anatomical Basis





Definition: Neurological syndrome resulting from spinal cord hemisection (damage to one lateral half of spinal cord).

1. Damage of Corticospinal tract below the level of pyramidal decussation:

Corticospinal tract crosses at the level of medulla – hence, the lesions below it will produce ipsilateral symptoms.

Ipsilateral Upper Motor Neuron Lesions below the level of injury

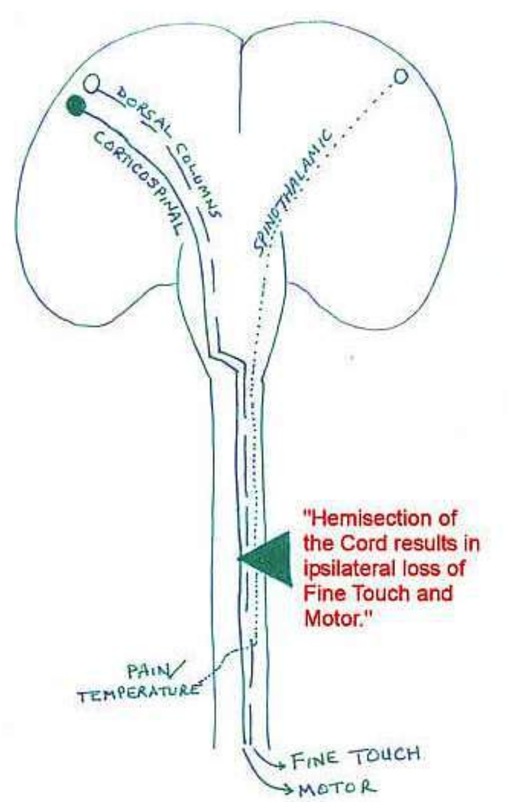
2. Damage of Lower Motor Neurons at the level of Injury:

Ipsilateral Lower Motor Neuron Lesions at the level of injury

3. Damage of Dorsal column below the level of sensory decussation:

Dorsal column crosses at the level of medulla – hence, the lesions below it will produce ipsilateral symptoms.

Ipsilateral loss of joint position sense, tactile discrimination, fine touch and vibratory sensations at and below the level of injury.



4. Damage of Spinothalamic tract:

The fibers of spinothalamic tract ascend or descend 1-2 spinal segments in Lissauer's tract to immediately cross and ascend in opposite side.

Damage leads to contralateral loss of pain, temperature and crude touch sensation starting 1 or 2 segments below the level of lesion.

5. Destruction of posterior root and its entrance into spinal cord:

Band of cutaneous anesthesia at the level of injury

6. Damage of Hypothalamospinal pathway:

In lesions at and above T1 level.

Ipsilateral Horner's syndrome.

> Bladder and bowel dysfunction may also be present in Brown-Sequard Syndrome (hemisection). But, its presence often indicates bilateral involvement of the spinal cord.

Dissociated Anesthesia

Ipsilateral loss of Dorsal column sensations

Contralateral loss of Spinothalamic tract sensations

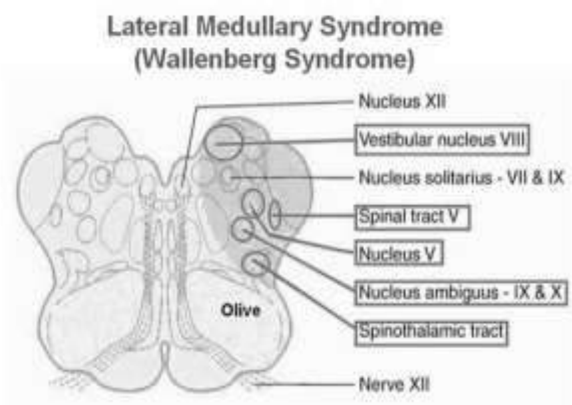
Why doesn't ataxia occur in Brown Sequard Syndrome ?

The ventral and dorsal spino-cerebellar tract also ascend laterally through the spinal cord. So, in the hemisection of the cord it is also supposed to be damaged resulting in ataxia. But you must be wondering that ataxia is not mentioned in most of the textbooks.

Ataxia does indeed occur in Brown-Sequard Syndrome but is typically masked by the weakness and hemiplegia resulting from damaged corticospinal tract.

Lateral Medullary (Wallenberg) Syndrome – Anatomical Basis

The Side (lateral) part of Medulla contains 6 "S"



1. Spinocerebellar tract

- <u>Posterior spinocerebellar tract:</u> Ascends and enters to ipsilateral cerebellum via ipsilateral inferior cerebellar peduncle
- <u>Anterior spinocerebellar tract:</u> Ascends and enters to ipsilateral cerebellum via superior cerebellar peduncle (although it crosses to opposite side on spinal cord along with antero-lateral system, it crosses back to the same side in cerebellum)
- Cerebellar zone involved is vermis and intermediate zone (paleocerebellum) and deep nuclei involved are the medial 3 nuclei (emboliform, globose and fasciculus)
- In contrast to static proprioceptive information carried by posterior column, spinocerebellar tract carry <u>dynamic (motion-related) proprioceptive information</u>.

2. Spinothalamic tract (Anterolateral system)

- <u>Crosses to opposite side of spinal cord</u> near thier level of entry (ascends or descends 2-4 levels within the posterolateral fasciculus as they enter) and ascends to enter <u>contralateral Ventro-posterior nucleus (VPL) thalamus</u>directly or indirectly
- Carries information of pain, temperature and crude/light touch from the body except face
  - o <u>Lateral spinothalamic tract:</u> Pain and temperature
  - o <u>Anterior spinothalamic tract:</u> Crude touch

3. Sensory/Spinal nucleus of trigeminal nerve (CN V)

- Receives <u>afferent from the ipsilateral face</u> and crosses midline to enter <u>opposite ventro-medial nucleus (VML) of thalamaus</u> via <u>ventral trigemino-thalamic pathway</u>
- Although, the efferent fibers cross midline, since the nucleus is damaged in medullary lesion (and not the trigeminothalamic tract), ipsilateral loss of pain and temperature occurs

Note: Trigeminal nerve also has a primary sensory nucleus located in pons, which participates in both ventral and dorsal trigemino-thalamic pathway – while the ventral trigeminothalamic pathway crosses midline, dorsal trigeminothalamic pathway enters ipsilateral thalamus

4. Sympathetic pathway to the face

- Hypothalamospinal tract carries sympathetic fibers ipsilaterally from the hypothalamus to the intermediolateral cell column of the spinal cord to provide sympathetic stimulation to the face.

5. Speech and Swallowing nucleus (Nucleus ambiguus – CN IX and X)

- Nucleus ambiguus innervates the ipsilateral muscles of the soft palate, larynx, pharynx and upper esophagus
- Corticobulbar fibers from each hemisphere project to each nucleus ambiguus but the predominance of fibers comefrom the contralateral hemisphere.
- Hence, bulbar or lower motor neuron (nucleus and efferent) injury causes ipsilateral weakness but pseudobulbar or upper motor neuron (suparnuclear or corticobulbar) lesion causes contralateral weakness

6. Schwalbe (medial) and Spinal (inferior) vestibular nulceus (CN VIII)

- The vestibular complex helps control eye movements through the vestibulo-ocular pathway and helps maintain trunk and forelimb posture through the vestibulospinal and reticulospinal tracts
- There is differential involvement of the vestibular nuclei in these different tasks:
    - medial vestibular nucleus is involved in all of the afferent and efferent pathways
    - superior vestibular nucleus is involved in the vestibulo-ocular mechanism
    - lateral (deiter) and inferior (spinal) vestibular nuclei are involved in the vestibulospinal functions.
- In lateral medullary lesions, medial and inferior vestibular nuclei may be involved:
    - medial vestibular nuclei:
        - vestibulo-ocular pathway (through median longitudinal fasciculus to the contralateral abducens nucleus and the efferent cross back midline to supply ipsilateral occumulotor and trochlear nucleus)
        - vestibulo-spinal pathway (directly descend as medial vestibulospinal tracts and innervate cervical and upper thoracic motor nuclei – responsible for head and neck posture maintenance)
    - inferior vestibular nuclei: vestibulo-spinal pathway (indirectly via reticulospinal tract to provide forelimb antigravity psoture additional to lateral vestibular nucleus)
    - vestibulo-cerebellar pathway: medial and inferior vestibular nuclei sends and receives fibers from the ipsilateral midline cerebellum (flocculonodular lobe and uvula i.e. archicerebellum; deep nucleus invovled – fastigial nucleus)

Note: Generally speaking, the superior and lateral vestibular nucleus lies in pons and the rest 2 lies in the medulla.

While the vestibulo-ocular and vestibulo-cerebellar system keeps the world straight (orientation), the spinocerebellar system keeps us straight upright (postural balance and stability).

Dentate nuclei (the lateral-most deep cerebellar nuclei) is invovled in ponto-cerebellar module (neocerebellum) which is responsible for goal-directed movements.

Except the *anteromedial portion* of medulla which is supplied by *vertebral artery*, rest of the medulla is supplied by Posterior Inferior Cerebellar Artery (*PICA*) – a branch of vertebral artery.

Now, after understanding the anatomy and physiology of the lateral medulla, it's not difficult to understand the lateral medullary or Wallenberg or PICA synfrome.

Summary of the tracts and nuclei in lateral medulla

1. Spinocerebellar tract → Ipsilateral cerebellum (Anterior tract double-crosses to return back)

2. Spinothalamic tact → Contralateral VPM nucleus of thalamus (Crosses midline near the entry)

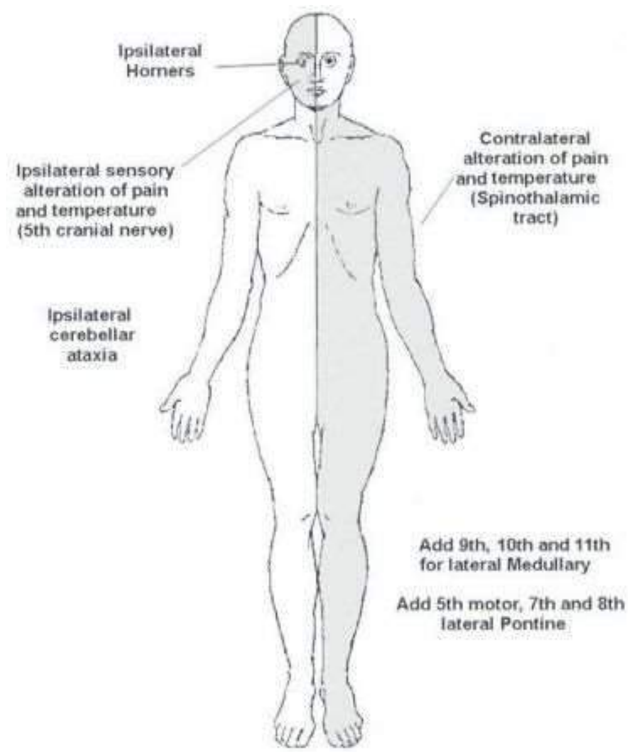
3. Spinal nucleus of trigeminal nerve → Receives afferent for pain and temperature sensation from ipsilateral face (and sends efferent to contralateral VPM nulceus of thalamus)

4. Sympathetic pathway of face → Ipsilaterally from hypothalamus to Intermediolateral cells of spinal cord gray mater

5. Schwalbe and Spinal vestibular nucleus → Vestibulo-ocular, Vestibulo-spinal and Vestibulo-cerebellar pathway

6. Speech and Swallowing nucleus → Ipsilateral innervation into muscles of soft palate, pharynx, larynx and upper esophagus (receives contralateral corticobulbar fibers)

Clinical Features of Lateral Medullary Syndrome



1. Spinocerebellar tract damage: Ipsilateral cerebellar ataxia

Cerebellar ataxia mnemonics:

Midline cerebellar lesion (Imbalance) – 4 T's

- *Truncal ataxia – unable to sit on bed without steadying themselves*
- *Titubation – bobbing motion of head or trunk*

- *Tandem gait positive or Rhomberg (with both eyes open and closed) positive*
- *Tremulous eyeballs (nystagmus)*

Hemispherical cerebellar lesion (Inco-ordination) – [illegible]

- ***T**one – **H**ypotonic and often with pendular jerk*
- ***I**ntention tremor – Coarse tremor (<5 Hz) which increases as the endpoint of intentional action*
- ***R**ebound phenomenon – Wrist when pushed quickly downward on an outstretched hand may fly back beyond original position*
- ***Dys**arthria – Scanning or staccato speech*
- ***Dys**metria – Finger to nose or Heel to knee inco-ordination*
- ***Dys**diadochokinesia – Irregular performance of rapid alternating movements*

2. <u>Spinothalamic tract damage:</u> Contralateral loss of pain, temperature and crude touch from upper and lower limbs and trunks

3. <u>Spinal nucleus of trigeminal nerve damage:</u> Ipsilateral loss of pain and temperature sensation

4. <u>Sympathetic pathway of face:</u> Ipsilateral horner's syndrome

Horner's syndrome mnemonics: PAMELa

- ***P**artial ptosis (loss of sympathetic supply to Muller's muscle)*
- ***A**nhidrosis (loss of afferent to superior cervical ganglion leading to loss of hemifacial sweating)*
- ***M**iosis (loss of sympathetic supply to Dilator muscles of iris leading to unopposed cholinergic action of occumulomotor nerve)*
- ***E**nophthalmos (this is apparent rather than true enophthalmos due to narrowing of palpebral fissure)*
- ***L**oss of Ciliospinal reflex*

5. <u>Swallowing and speech nucleus (ambiguus) damage:</u> Uvular deviation away from the side of lesion, Ipsilateral impaired palatal elevation, Dysarthria, Dysphagia and Hoarseness

6. <u>Schwalbe and Spinal vestibular nucleus damage:</u> Vertigo, Nystagmus, Nausea and vomiting

Cause and Mechanism of Lateral Medullary Syndrome

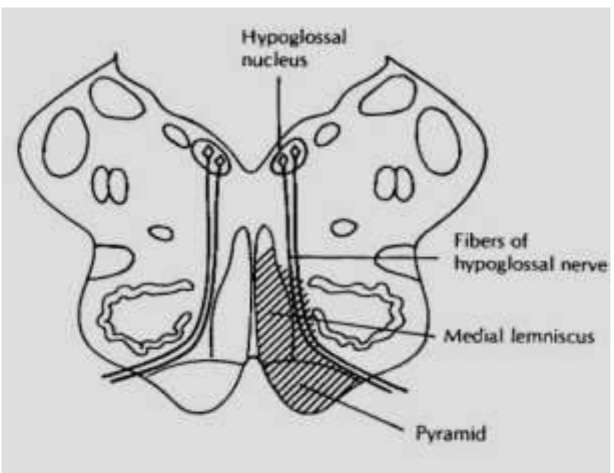
Posterior Inferior Cerebellar Artery (PICA) territory infarction or Vertebral artery insufficiency leading to dysfunction of multiple nuclei and damage of ascending and descending tracts on the lateral medulla.

Medial Medullary (Djerine’s) Syndrome – Anatomical Basis

As already discussed in the previous section about Lateral Medullary (Wallenberg) Syndrome:

1. 6 “**S**” pass/lie on the **S**ide (latetral) of Medulla
2. Except the anteromedian part supplied by vertebral artery, rest of the medulla is supplied by PICA

4 “**M**” represents the 4 **M**idline or **M**edial structures



1. Motor pathway (Corticospinal tract)

- Originate in precentral gyrus of frontal lobe and pass through ventral aspect of brainstem
- Lateral corticospinal tract: 90% fibers decussate at the medullary pyramids before entering the cervical cord as lateral corticospinal tract (necessary for fine motor)
- Anterior corticospinal tract: Remaining 10% fibers descend in the ipsilateral spinal cord as Anterior corticospinal tract and ultimately crosses later at the level of spinal cord (necessary for gross motor)

2. Medial lemniscus

- Posterior column donot cross midline: Gracile (medial and carries information from T6 and below) and cuneate (lateral and carries information from above T6 and face) fasciculus in spinal cord
  - o somatotropic orientation: medial-lateral (leg-arm i.e. – –)
- Decussation as internal arcuate fibers: posterior column now become medial lemniscus
  - o somatotropic orientation: anterior-posterior (leg-arm i.e. ‘,)
- Medial lemnsicus: After decussation, internal arcuate fibers become medial lemniscus and ascend to enter Ventral postero-lateral (VPL) nucleus of thalamus
  - o somatrotropic orientation: flips back to medial-lateral (arm-leg i.e. – –)

The somatotropic orientation rotates in a clockwise direction from down to up.

It is responsible for carrying static sensory proprioception (joint-position sensation, two-point discrimination, vibratory sensation) and pain and temperature sensation.

3. Medial longitudinal fasciculus

- Carries ascending fibers from the contralateral interneurons of the abducens nucleus to the ipsilateral oculomotor nucleus (vestibulo-ocular pathway)

- It plays role in conjugate horizontal eye movement

4. Motor nucleus of hypoglossal nerve

- Hypoglossal nerve pass ventrally through the medulla and exit between the inferior olive, laterally, and the medullary pyramid, medially – crosses the premedullary cistern and traverse the skull base through the hypoglossal canal.
- It runs near the internal carotid artery and carotid bulb as it descends in the medial nasopharyngeal carotid space
- Supplies intrinsic and extrinsic muscles of tongue except palatoglossus which is innervated by vagus nerve (CN X)
- The supply is bilateral except for genioglossus which receives only contralateral innervation
- Genioglossus is directed in opposite direction – hence, on protrusion pushes the tongue to the opposite side (i.e. towards dysfunctional genioglossus) – this means, there is neural lesion towards the deviation of tongue (genioglossus receives only contralateral innervation)
- Also innervates the muscles of floor of mouth and upper hyoid musculature (geniohyoid and thyrohyoid)

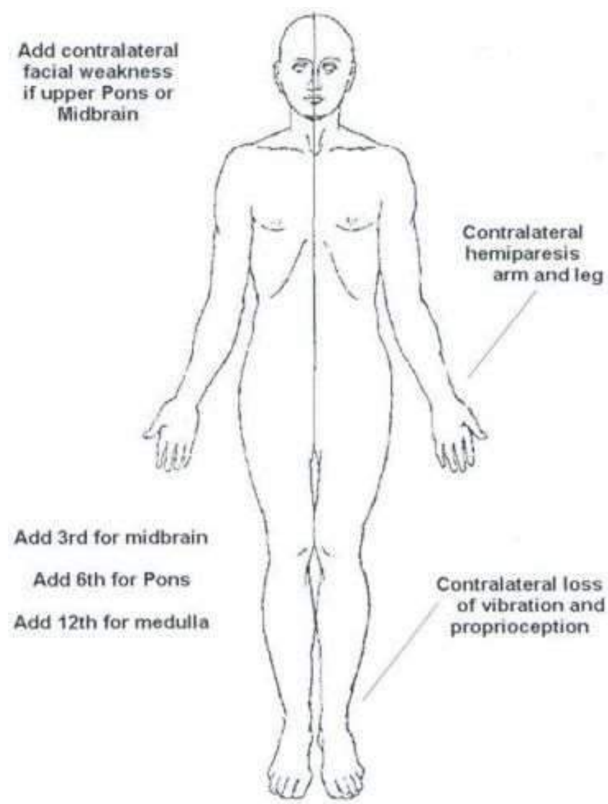
Note: *Purely cranial motor nuclei lie medially and the mixed lie laterally. These pure motor nuclei can divide 12 exactly i.e. 3, 4, 6, and 12. Since, the Cranial nerve 3, 4 and 6 lie above medulla – Cranial nerve 12 is the involved structure.*

Now, let us move onto the discussion of medial medullary syndrome (Djerine's syndrome).

Cause of Medial medullary (Djerine's) syndrome

Vascular lesion of anterior spinal or paramedian branches of the vertebral arteries leading to infarction in the medial medulla – affecting the pathways and nucleus mentioned as 4 "M".

Clinical features of Medial medullary (Djerine's) Syndrome.

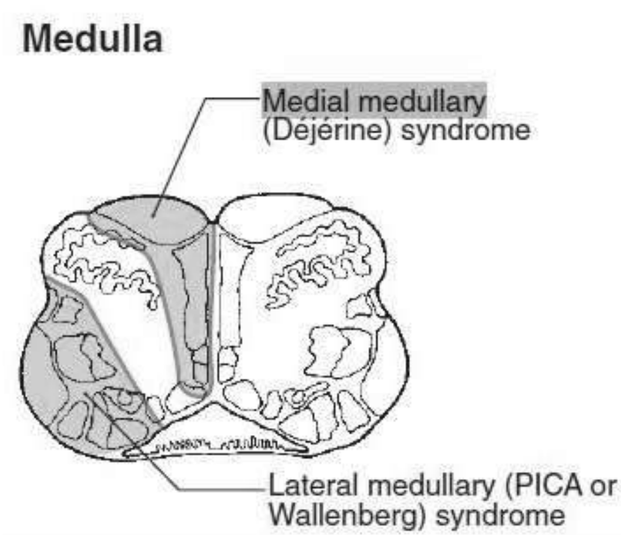


1. Motor pathway dysfunction: Contralateral upper motor neuron paralysis on body except face
2. Medial lemniscus dysfunction: Contralateral loss of

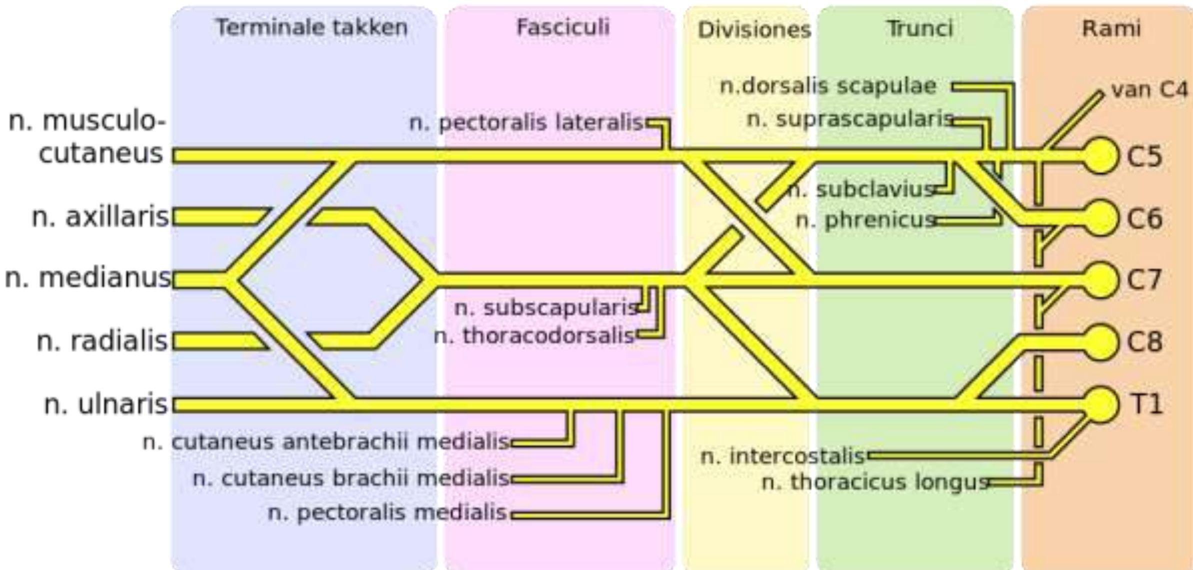
discriminative touch, vibratory and position sense on body except face

3. <u>Medial longituidnal fasciculus:</u> Ipsilateral internuclear ophthalmoplegia (failure of adduction of ipsilateral eye towards nose i.e. CN III function and nystagmus in the opposite eye as it looks laterally i.e. CN VI) – this is because CN VI of the opposite eye sends fibers to opposite medial longitudinal fasciculus (MLF) through which fiber goes to CN III
4. <u>Motor nucleus of hypoglossal nerve (CN XII):</u> Ipsilateral paralysis of tongue with tongue deviation on protrusion towards affected side

Review the difference between lateral and medial medullary syndrome



Brachial Plexus



https://commons.wikimedia.org/wiki/File:Plexus_brachialis.svg

Remember the mnemonic: ***Randy Travis Drinks Cold Beer.***

From proximal to distal, brachial plexus consists of:

1. Roots (C5-T1)
2. Trunks (Upper, Middle and Lower)
3. Divisions (Anterior and Posterior from each of 3 trunks)
4. Cords (Lateral, Posterior and Medial)
5. Branches

Divisions are formed **behind the clavicle.** Hence –

- Roots and Trunks are Supraclavicular
- Cords and Branches are Infraclavicular

Roots

Roots enter the neck between **Anterior and Medial scalene**.

2 nerves arise from the root – that supplies **muscles with attachment to medial border of scapula**:

1. **Serratus anterior:** Long thoracic nerve (C5, C6 and C7)
2. **Rhomboids:** Dorsal scapular nerve (C5)

Trunks

Trunks enter the apex of axilla through the **Cervico-axillary canal** (clavicle anteriorly, scapula posteriorly and 1st rib medially).

2 nerves arise from the superior trunk – that supplies **muscles with attachment to medial aspect of dorsal scapula or clavicle**:

1. **Supraspinatus and Infraspinatus:** Suprascapular nerve (C5, C6)
2. **Subclavius:** Nerve to subclavius (C5, C6)

> Roots and Trunks lie lateral to the 1st part of axillary artery.

Divisions

Divisions form **behind the clavicle** in Cervico-axillary canal.

- No nerves arise from the divisions.

Cords

- Posterior divisions of all 3 trunks = Posterior cord
- Anterior division of upper and middle trunk = Lateral cord
- Anterior division of lower trunk = Medial cord

Cords form **around the 2nd part of axillary artery** and are named in relation to it.

Gives **5 small nerves** to the muscles with attachment to **biccipital groove of humerus** (remember the mnemonic Lady between 2 Majors) and **lesser tubercle** (only 1 rotator cuff muscle attaches to lesser tubercle of humerus).

- **From lateral and medial cord:** Nerves to **Pectoralis major**
  - Lateral pectoral nerve (C5, C6, C7) – from lateral cord
  - Medial pectoral nerve (C8, T1) – from medial cord (also supplies pectoralis minor)
- **From posterior cord:**
  - Latissimus dorsi: Thoracodorsal or Middle subscapular nerve
  - Teres major: Lower subscapular nerve (C5, C6) – from posterior cord
  - Subscapularis (rotator cuff attaching to lesser tuberosity): Upper and lower subscapular nerve (C5,C6)

Medial cord gives **2 small sensory nerves** to medial aspect of upper limb:

- Medial cutaneous nerve of arm (T1)
- Medial cutaneous nerve of forearm (C8, T1)

> **Other cutaneous innervation of arm, forearm and hand:**

1. Superior lateral cutaneous nerve of arm: **Axillary nerve**
2. Inferior lateral cutaneous nerve of arm, Posterior cutaneous nerve of arm and forearm, Lateral 2 and 1/2 of dorsal hand and fingers: **Radial nerve**
3. Lateral cutaneous nerve of forearm: **Musculocutaneous nerve**

4. Medial 1 and 1/2 of palm and fingers and Medial 2 and 1/2 of dorsal hand and fingers: **Ulnar nerve**
5. Lateral 3 and 1/2 of palm and fingers and tips of lateral 3 and 1/2 fingers on dorsal hand: **Median nerve**

Branches

Posterior cord

1. Axillary (C5, C6) nerve passes through **Quadrangular space** (along with posterior circumflex humeral artery) – supplies:

- **Del**toid (from **De**ep Branch)
- Teres minor (from Superficial Branch)
- Regimental badge skin (Superior lateral cutaneous nerve)

2. Radial nerve (C5, C6, C7, C8, T1) passes through **Triangular space** (along with profunda brachii artery) – supplies**BEAST** muscles.

- **B**rachioradialis
- **E**xtensors of forearm
- **A**nconeus
- **S**upinator
- **T**riceps Brachii

Between the humerus and 2 Teres muscles (major and minor) anchoring it to the scapular forms a triangular space, which is further partitioned by long head of triceps) into two – lateral quadrangular and medial triangular space. Remember the 4 T's – Trunk (Shaft) of humerus, Teres major, Teres minor and Triceps (long head).

Remember: Teres minor is a rotator cuff muscle, not the teres major.

Lateral cord

Musculocutaneous nerve (C5, C6, C7): pierces coracobrachialis and innervates the anterior compartment of arm

- Coracobrachialis
- Biceps brachii

Medial cord

Ulnar nerve (C7, C8, T1)

Median nerve (C5, C6, C7, C8, T1)

- Formed by combination of lateral and medial roots from lateral and medial cords respectively.
- Continues down the arm lateral to the brachial artery.

Median nerve vs Ulnar nerve

Median nerve and Ulnar nerve have comparable similarities and differences that makes them easier to remember:

The longus portion of abductor pollicis and flexor pollicis are supplied in forearm by Posterior Interosseous Nerve or PIN (branch of radial nerve) and Anterior Interosseous nerve or AIN (branch of Median nerve) respectively.

	MEDIAN NERVE	ULNAR NERVE
COURSE		
IN ARM	Lateral to brachial artery – later crosses from lateral to medial Parallel and anterior to medial intermuscular septum No branches	Medial to brachial artery Pierces the medial intermuscular septum No branches
IN CUBITAL FOSSA	Anterior to medial epicondyle – medial to biceps tendon	Posterior to medial epicondyle
ENTERS FOREARM	Between two heads of pronator teres	Between two heads of flexor carpi ulnaris
IN FOREARM	Lateral to ulnar artery	Medial to ulnar artery
IN WRIST	Under flexor retinaculum – through Carpal tunnel	Above flexor retinaculum – through Guyon's canal
INNERVATION		
FLEXOR DIGITORUM PROFUNDUS (FDP)	Lateral half	Medial half
REMAINING ANTERIOR COMPARTMENT MUSCLES	Remaining muscles except flexor carpi ulnaris	Flexor carpi ulnaris
EMINENCE GROUP MUSCLES	Thenar (Pollicis muscle group) except Adductor Pollicis Median nerve supplies **LOAF** muscles (Lumbricals, Opponens pollicis, Abductor pollicis brevis, Flexor pollicis brevis)	Hypothenar Adductor Pollicis
LUMBRICALS	2 (1st and 2nd)	(3rd and 4th)
PALMARIS	Longus	Brevis
INTEROSSEI	None	All (Palmar and Dorsal)
MUSCLES OF HAND	2 lumbricals and thenar group	All except those supplied by median nerve

Lumbar Plexus

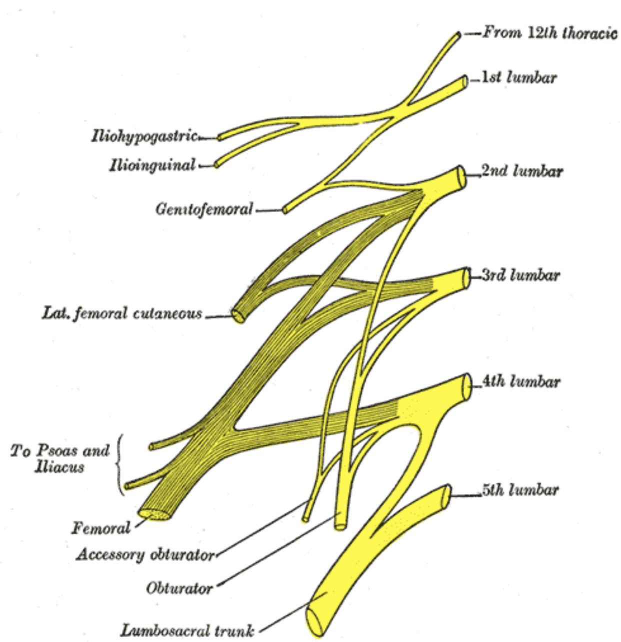
Ventral rami of L1-S4; has 2 components –

1. Lumbar plexus (L1-L4) – forms within **psoas major** anterior to lumbar transverse process
2. Sacral plexus (L4-S4) – forms anterior to **piriformis muscle**

Only in the lumbosacral plexus, these anterior rami further divide into 2 divisions – 1 anterior and 1 posterior except:

1. **L4:** Splits into 4 divisions – 2 anterior and 2 posterior
2. **S3:** Doesn't divide

Lumbar Plexus



https://commons.wikimedia.org/wiki/File:Gray822.png
Henry Vandyke Carter [Public domain]

Formed from ventral rami of L1-L4.

Course: The nerves of the lumbar plexus exit the spine just anterior to the **quadratus lumborum** muscle and travel without and within the **psoas muscle**.

2 nerves with single root value: L1

1. Iliohypogastric nerve: Pierces the internal oblique muscle and runs between the internal and external oblique.

- Lateral cutaneous branches: pierces internal and external oblique **5 cm behind ASIS** anterior superior iliac spine and just above the iliac crest – supplies skin on the **anterior part of gluteal region**.
- Anterior cutaneous branches: pierces aponeurosis of external oblique, **2 cm medial to ASIS** – supplies **skin over pubic bone (mons pubis)**.

2. Ilioinguinal nerve: Runs just inferior to iliohypogastric nerve, between transverse abdominis and internal oblique muscles.

- Pierces internal oblique **2 cm just below and medial to ASIS**, runs below external oblique and **inguinal canal** with the spermatic cord and **ends 2 cm lateral to pubic tubercle**.
- Supplies **mons pubis** and and anterior aspect of labia majora; skin of **anteromedial thigh** and surrounding musculature.

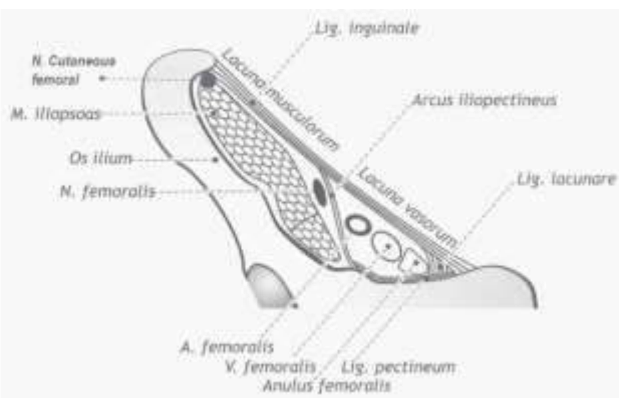
2 nerves with double root values

L1, L2: Genitofemoral nerve

- Genital branch –
  - o Sensory: Skin of **scrotum and labia majora**
  - o Motor: **Cremaster muscle**
- Femoral branch – Skin on the **antero-middle aspect of upper thigh**

L2, L3: Lateral femoral cutaneous nerve

- Exits through **lacuna musculorum** (lateral compartment of thigh just below the inguinal ligament) **along with iliopsoas muscle and femoral nerve**.
- Supplies skin of **anterolateral thigh.**



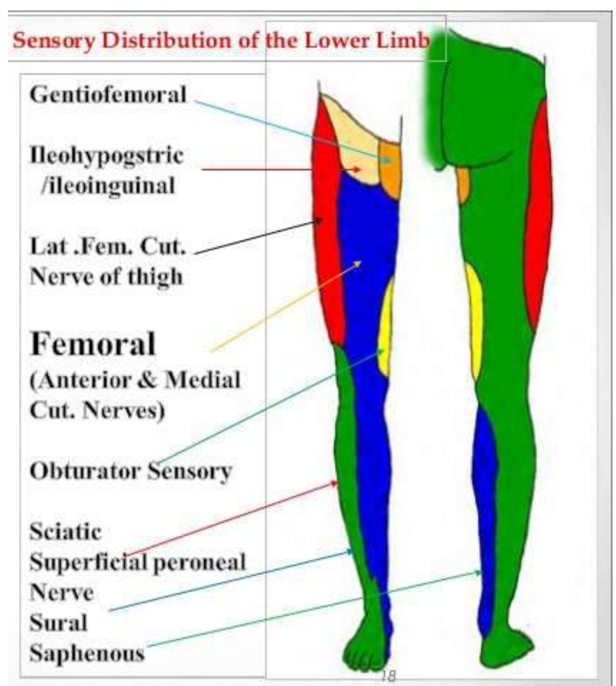
2 nerves with triple root values: L2, L3, L4

1. Anterior division: Obturator nerve

- Emerges from the medial border of psoas major and enters **obturator canal** with obturator artery and vein.
  - o Anterior branch: descends between adductor longus and adductor brevis
  - o Posterior branch: descends between adductor brevis and adductor magnus.
- Sensory: **Medial aspect of thigh**
- Motor: **Hip adductors, Obturator externus**

2. Posterior division: Femoral nerve

- Courses through psoas muscle, then **iliopsoas groove** and underneath the **midpoint of inguinal ligament** into the**lacuna musculorum** just medial to iliopsoas and lateral to femoral vessels.
- Divides into muscular and cutaneous branches in femoral triangle.
- Sensory: **Anterior part of thigh and anteromedial part of leg**.
- Motor: **Hip flexors** (Iliopsoas, Pectineus, Sartorius and Quadriceps femoris)
- Runs down as **saphenous nerve**.



A mnemonic is very popular: **I Got Lunch (Laid) On Friday**. Remember the progression of the lumbar root values:

1 – **I**lioinguinal and **I**liohypogastric nerves

1,2 – **G**enitofemoral nerve

2,3 – **L**ateral femoral cutaneous nerve

2,3,4 – **O**bturator and **F**emoral nerve

Sacral Plexus

Formed from ventral rami of L4-S4; Contribution of L4-L5 is from **Lumbosacral trunk**.

The nerves forming the sacral plexus converge towards the lower part of the greater sciatic foramen and unite to form a flattened band. The branches of the sacral plexus arise from anterior and posterior surfaces of this flattened band.

- Branches innervating the pelvis and perineum **remain in the pelvis**.
- Branches innervating the lower limb exit through **greater sciatic foramen**.

6 Branches Prior to Division of Sacral Roots

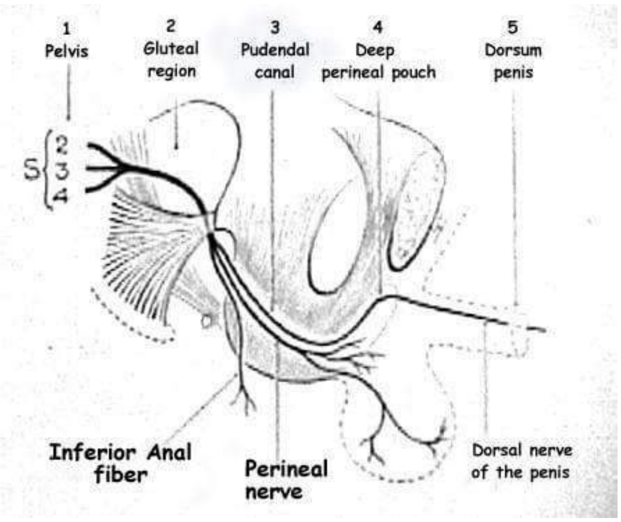
Mnemonic: *All of these start with the letter "P".*

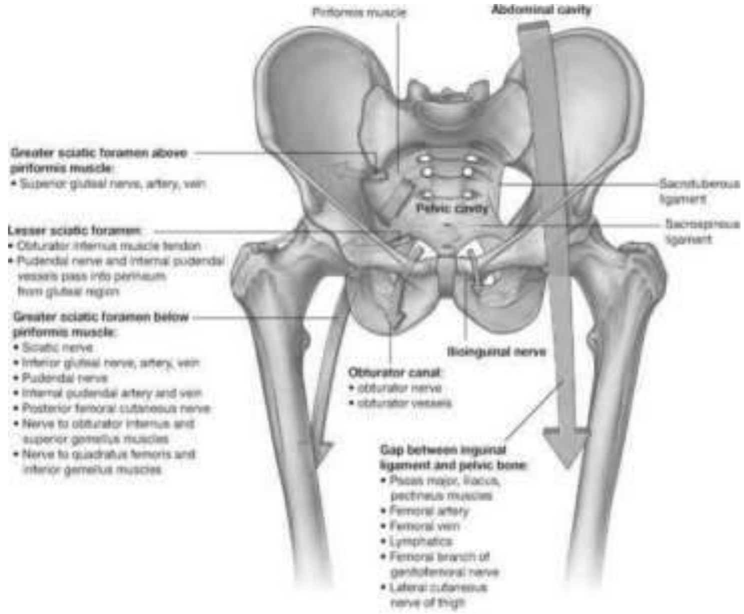
1. S1,S2: Nerve to **Piriformis**
2. S2, S3: **Perforating** cutaneous nerve – to medial part of buttock
3. S1,S2,S3: **Posterior** femoral cutaenous nerve – To buttock and uppermost medial and posterior surfaces of thigh
4. S2,S3,S4:
   - **Pudendal** nerve – **leaves the pelvis through greater sciatic foramen** but **re-enters through lesser sciatic foramen** and enters the **pudendal or alcock's canal** (a fascial canal formed by splitting of obturator fascia on lateral wall of ischiorectal fossa).
     - Inferior rectal nerve: **Perianal skin and External anal sphincter**
     - Dorsal nerve of penis or clitoris: Accompanies dorsal artery of penis and clitoris and supplies **skin of penis or clitoris and labia majora**.
     - Perineal nerve: **Superficial and Deep perineal muscles** and **External urethral sphincter**
   - **Parasympathetic pelvic** splanchnic nerves (**nervi erigentes**) – Ascend to join inferior hypogastric plexus and together supply **pelvic viscera**.
5. S4: **Perineal** branch of Pudendal nerve

Mnemonic: *Branches of* ***Pudendal nerve*** *–* ***PID*** *(Remember – Pelvic Inflammatory Disease or PID can cause Pudendal neuralgia).*

- *Perineal nerve*
- *Inferior rectal nerve*
- *Dorsal nerve of penis or clitoris*

In general, it supplies structures of perineum, is sensory to genitalia and gives muscular branches to perineal muscles, external urethral and anal sphincters (both are voluntary).





Another mnemonic: All these nerves arise from S1-S4 and have a **vowel second latter after "P"**. It progresses serially – except that the "e" and "i" are interchanged – so the sequence becomes **a, i, e, o, u**.

- Nerves with 2 roots:
  - S1,S2 – **Pi**rifromis nerve
  - S2,S3 – **Pe**rforating cutaneous nerve
- Nerves with 3 roots:
  - S1, S2, S3 – **Po**sterior femoral cutaneous nerve
  - S2, S3, S4 – **Pu**dendal nerve and **Pa**rasympathetic pelvic splanchnic nerves

After Giving Anterior and Posterior Divisions