NEUROANATOMY

Part-1: Anatomy of the Forebrain

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INTRODUCTION

The nervous and endocrine systems are responsible for regulation of body functions in response to internal and external stimuli. They act by reception, interpretation and response to different changes in the inner and outer environment. While the response of the endocrine system (via) hormones is delayed and prolonged, the nervous response (via nerve electrical impulses) is more rapid and short-termed.

Arrangement of the nervous system

Anatomically, the nervous system is divided into the **Central Nervous System (CNS)** and **Peripheral Nervous System (PNS)**. The **CNS** consists of the **brain** (enclosed in the cranium of the skull) and the **spinal cord** (enclosed in the vertebral canal of the vertebral column). The **PNS** is composed of **12** pairs of **cranial nerves** (which emerge directly from the brain through openings in the skull) and **31** pairs of **spinal nerves** (which emerge from the spinal cord at the intervertebral foramina between each two vertebrae). The nerves of the peripheral nervous system may be **afferent**, **efferent** or in most cases **mixed**.

Functionally, the nervous system can be divided into the **Somatic** nervous system and the **Autonomic** Nervous System **(ANS)**.

The somatic nervous system consists of afferent and efferent nerves. The **afferent** nerves are concerned with **sensory** perception that may be general (from the skin and joints) or special. **General** sensory modalities include the sensation of temperature, touch, pain, pressure, vibration (via cutaneous nerves) and proprioception (joint position sense via articular nerves). **Special** sensory modalities are carried along the cranial nerves and include smell, vision, taste, hearing and equilibrium.

The **ANS** is subdivided into the **sympathetic** and **parasympathetic** systems. The ANS is also composed of afferent and efferent nerve fibers that are termed **visceral** nerve fibers. **Afferent visceral** nerves are concerned with **visceral sensory perception** from the viscera (e.g feelings of visceral fullness, distension or irritation). **Efferent visceral** nerves control the three involuntary structures of the body; **glands**, **smooth muscles** and **cardiac muscle** (heart).

The nervous system contains **higher centers** for control of different body functions. These centers send their orders or impulses via efferent nerve fibers that run in **descending pathways** (from the brain or spinal cord down to the lower parts of the nervous system and to other body organs). The centers also react to different peripheral stimuli and information carried to them via **afferent nerve fibers** that run in **ascending pathways**. The terms **tract**, **bundle**, **fasciculus** and **lemniscus** are used to name these pathways (whether ascending or descending). The pathways are composed of nerve fibers that are mostly **myelinated** and form the **white matter** of the nervous system. Some fibers are **unmyellinated** and represent part of the grey matter. The **grey matter** is mainly composed of the **cell bodies** of nerve cells.

The arrangement of the white and grey matter in the **cerebral hemispheres** and **cerebellum** is similar. They have a **cortex of grey matter** and a **core of white matter**. Grey matter aggregations called **nuclei** are found in the white matter core. In the **brainstem** and **spinal cord**, the arrangement is reversed. These areas have a thick **mantle** of **white matter** and a defined **core** of **grey matter**.

The terms used in describing the position and relation of different parts of the nervous system; differ in their uses from other parts of the body. To understand these terms and the different parts of the nervous system, proper basic knowledge of the embryological development of the CNS is essential.

Embryological development of the central nervous system

The nervous system is derived from the neural plate (a thickened slipper-shaped layer of **ectoderm**) at the 18th day of gestation. The underlying **notochord** causes the plate to undergo invagination at its center forming the **neural groove**. The edges of the groove grow toward each other until they fuse at the cervical region. Fusion progresses cranially and caudally and the groove is converted into the **neural tube** with the **neural cavity** within. The tube has **rostral** and **caudal** openings (**neuropores**) which close at the 25th and 27th days respectively. Once the tube is closed, vascularization is established and the primitive nerve cells of the neuroepithelium undergo rapid growth. The **cephalic part** of the tube (lying rostral to the 4th somite) forms the **future brain** while the **caudal part** forms the **spinal cord [figure 1].**

At the 4th week of intrauterine life, the cephalic end shows 3 dilatations called the **primary brain vesicles**:

- The **prosencephalon** is the future **forebrain**.
- The **mesencephalon** is the future **midbrain**.
- The **rhombencephalon** is the future **hindbrain**.

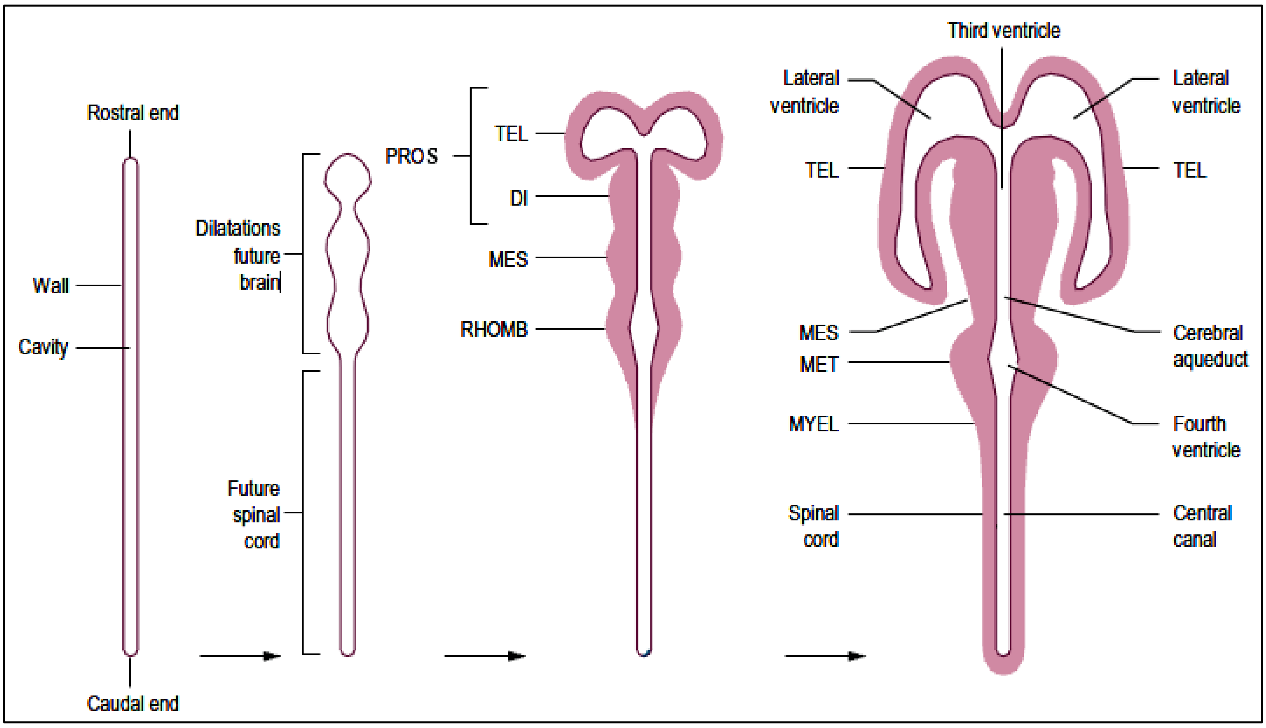


Figure 1: Stages of development of the central nervous system. Add the suffix "encephalon" to each part to know its full name.

At the 5th week of gestation, further dilatation and bending occurs and five **secondary brain vesicles** are recognized:

- The single **diencephalon** and paired **telencephalons** are three derivatives of the prosencephalon. The **telencephalons** form the **cerebral hemispheres** and the **diencephalon** comprises the **thalamus, hypothalamus, epithalamus, subthalamus** and related structures in the fully developed brain.
- The **mesencephalic** dilation persists and forms the **midbrain** in the mature brain.
- The **metencephalon** and the **myelencephalon** are two derivatives of the **rhombencephalon**. The **metencephalon** differentiates into the **pons** and

cerebellum in the mature brain. The **myelencephalon** becomes the **medulla oblongata** in the fully developed brain.

The **midbrain**, **pons** and **medulla** collectively form the **brainstem**. This part of the brain connects the cerebrum to the spinal cord and cerebellum.

As these dilations grow they draw the **cavity of the neural tube** with them so that each dilatation contains part of the neural cavity. The **cerebral hemispheres** contain the **lateral ventricles**. The **diencephalon cavity** is the called the **third ventricle**. The **midbrain cavity** is reduced to the narrow **cerebral aqueduct of Sylvius**. The **hindbrain cavity** (wedged between the **cerebellum**, **pons** and **medulla**) is called the **fourth ventricle**. The cavity of the **spinal cord** is reduced to the narrow **central canal**. These cavities are filled with the **cerebrospinal fluid (CSF)** that flows from one cavity to another.

A structure closer to the **cranial end** of the neural tube or nervous system is termed **rostral** while the structure closer to the **caudal end** is termed **caudal**. Because of bending of the neural tube and its parts, the **dorsal** surface becomes **superior** in some areas and the **ventral** surface becomes **inferior**. However, the terms dorsal and ventral are used in relation to the original embryological origin **[figure 2].**

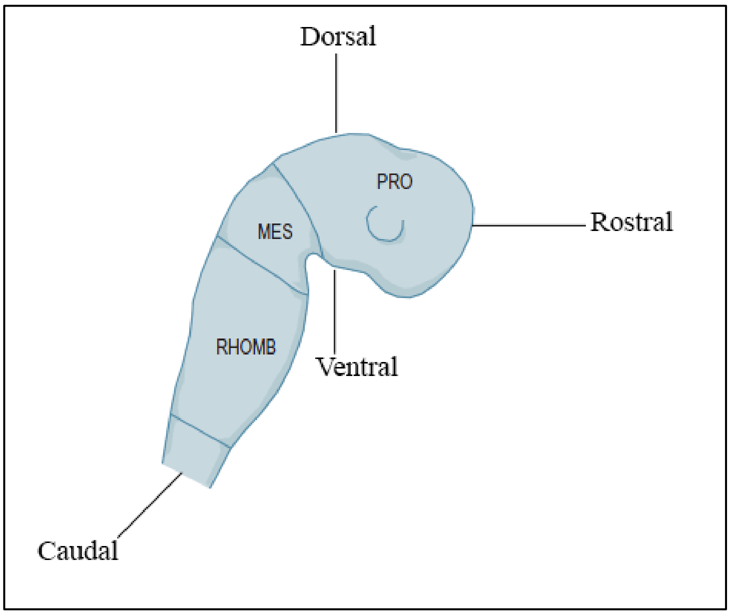


Figure 2: terms of relation in the CNS always refer to the original embryological position of the neural tube.

Summary of the nomenclature of the divisions of the CNS			
Greek system (Embryological origin)	**Mature part**	**Common English**	**Related cavity**
• **Prosencephalon:**		Forebrain	
Telencephalon	Cerebrum		Lateral ventricles
Diencephalon			Third ventricle
• **Mesencephalon**	Midbrain *	Midbrain	Cerebral aqueduct
• **Rhombencephalon:**		Hindbrain	
Metencephalon	Cerebellum		Fourth ventricle
Pons	Pons *		
• **Myelencephalon**	Medulla oblongata *		
• **Spinal medulla**	Spinal cord	Spinal cord	Central canal
The three parts marked with an asterisk (*) form the brainstem			

THE FOREBRAIN

The forebrain or cerebrum is composed of the two **cerebral hemispheres** and the area in between known as the **diencephalon**.

THE CEREBRAL HEMISPHERES

The two cerebral hemispheres occupy most of the cranial cavity and are separated from each other by the longitudinal cerebral fissure where the falx cerebri of the dura matter descends. In most people (the right-handed people), the left hemisphere is slightly larger and is the dominant hemisphere. Each cerebral hemisphere has four lobes, three poles and three surfaces.

Lobes and Poles

The lobes of each cerebral hemisphere are named according to the bones that lie adjacent to them when the brain is in situ.

- The **frontal lobe** is the **largest** lobe. It lies anteriorly overlying the orbital plate of the frontal bone. Its pointing anterior extremity is the **frontal pole** of the hemisphere.
- The **parietal lobe** lies caudal to the frontal lobe forming most of the lateral surface.
- The **temporal lobe** is directed inferomedially against the petrous part of the temporal bone. Its anterior convex projection is the **temporal pole**.
- The **occipital lobe** lies posteriorly against the part of the occipital bone superior to the groove of the transverse sinus. It is separated from the cerebellum below by the tentorium cerebelli. The pointing posterior extremity of the occipital lobe is the **occipital pole** of the hemisphere.

Surfaces

- The **superolateral surface** is baldly **convex** in conformity with the shape of the concavity of the parietal eminence.

- The **medial surface** of each hemisphere is **flat** and lies against the falx cerebri. Below the falx, the two hemispheres are joined by the **corpus callosum**, a thick bundle of nerve fibers that join reciprocal areas in the two cerebral cortices.
- The **inferior surface** is **irregular** in shape in relation to the floors of the anterior and middle cranial fossae and to the upper surface of the tentorium cerebelli in the posterior cranial fossa.

Surface Features

The hemispheres are covered with a cortex of grey matter, which is thrown into a complicated series of tortuous folds called the **gyri**. The gyri are separated by grooves called the **sulci [figure 3]**. Although no two brains are identical, there is a general pattern of arrangement of the main sulci and gyri.

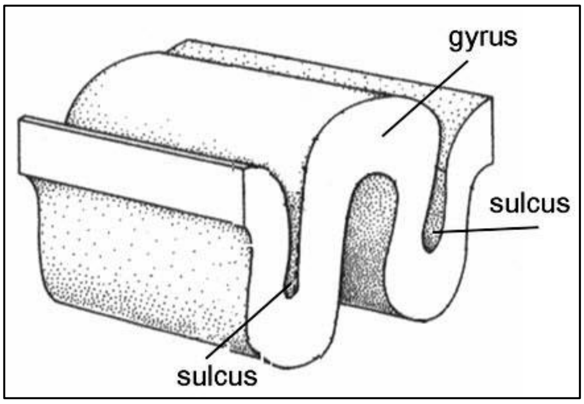


Figure 3: Sulci and gyri.

Topography of the Superolateral Surface

A. Major Divisions [figure 4]

- The **lateral sulcus** (lateral cerebral fissure) is a deep fissure that passes backwards from the anterior border of the hemisphere and separates the frontal from the temporal lobes. At its anterior end, it divides into **ascending** and **anterior rami** that penetrate the frontal lobe. The greater part of the sulcus is considered the **posterior ramus**. The parts of the frontal, parietal and temporal lobes that bind the lateral sulcus form the **opercula**. The opercula overlies the burried part of the cortex of the lateral sulcus called the **insula**. When opened, the insul appears surrounded by the **circular sulcus**.

- The **central sulcus** passes from just behind the midpoint of the upper border of the superolateral surface and runs obliquely downwards and backwards to end a short distance from the lateral sulcus. It separates the frontal from the parietal lobes.

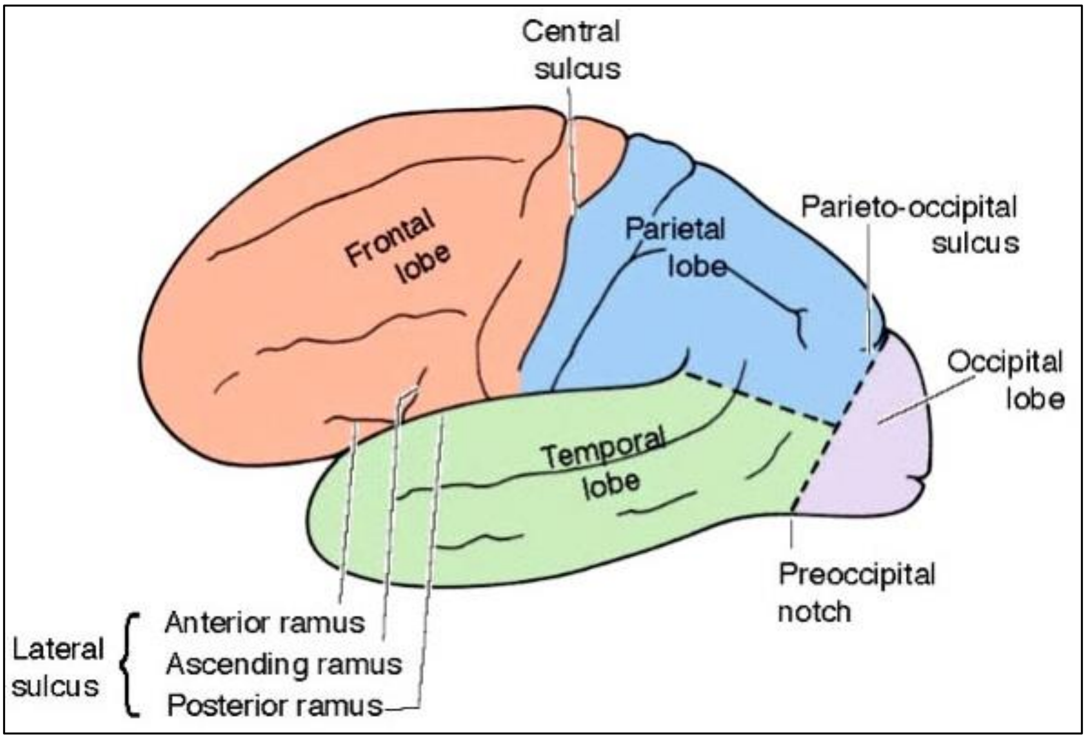


Figure 4: Major divisions of the superolateral surface of the cerebral hemisphere

- The **preoccipital notch** lies at the lower border of the Superolateral surface, between the temporal and occipital lobes. The terminal part of the **parieto-occipital sulcus** is visible at the posterior part of the upper border of the superolateral surface. An imaginary line drawn obliquely at an angle of 45° from the preoccipital notch to the parieto-occipital sulcus separates the occipital lobe from the parietal and temporal lobes.

B. Superolateral topography of the frontal lobe [figure 5]

- The **precentral gyrus** (anterior central gyrus) lies immediately anterior to the central sulcus. It is limited anteriorly by the **precentral sulcus**.
- In front of the precentral sulcus, the frontal lobe is divided by two horizontal sulci into three gyri. The sulci are termed **superior** and **inferior frontal sulci**. The gyri are the **superior**, **middle** and **inferior frontal gyri**.

- The **inferior frontal gyrus** is further subdivided by the ascending and anterior rami of the lateral sulcus into three areas: the **orbital part** anteriorly, the **triangular part** in the middle and the **opercular part** posteriorly.

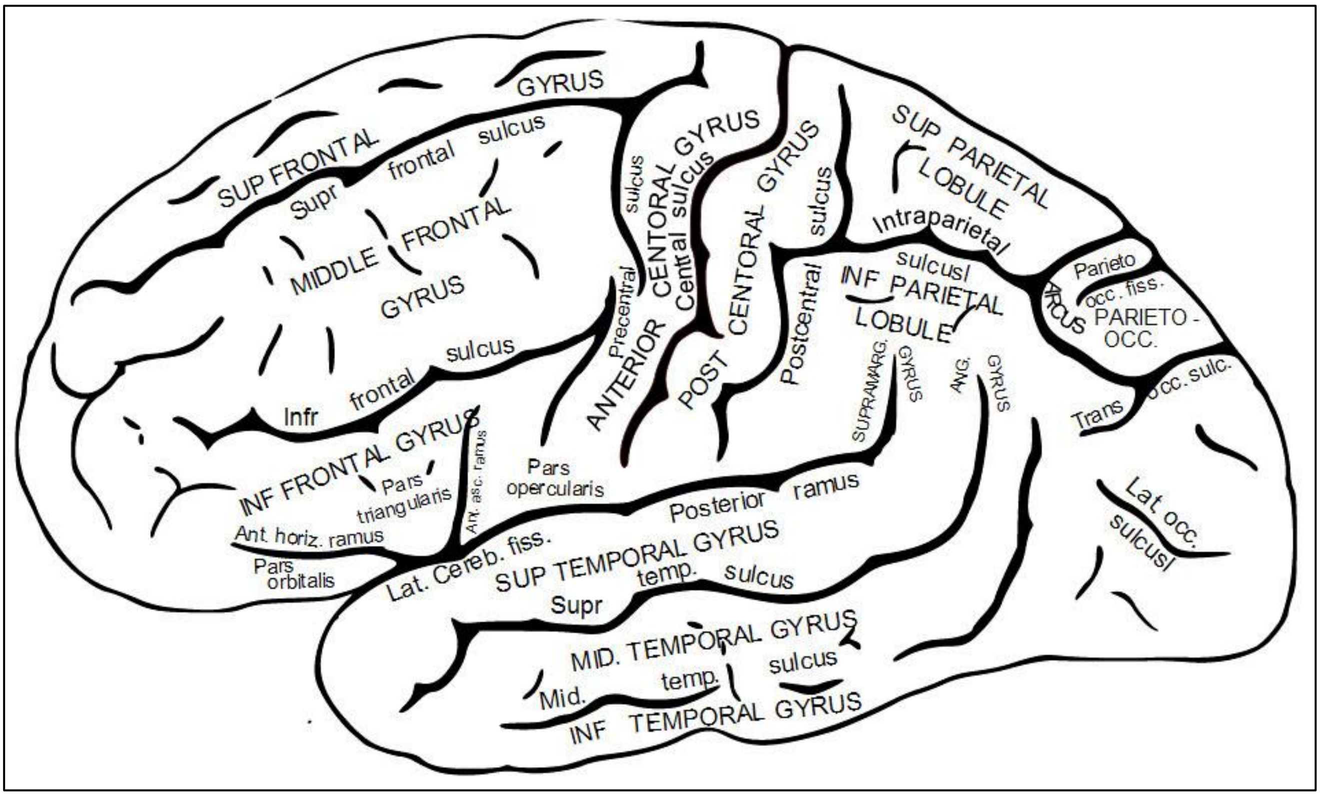


Figure 5: Detailed topography of the superolateral surface of the cerebral hemisphere.

C. *Superolateral topography of the temporal lobe* [figure 5]

- The temporal lobe is also divided by two horizontal sulci into three gyri. The **superior** and **middle temporal sulci** divide the lobe into **superior, middle** and **inferior temporal gyri**. The inferior temporal gyrus is continued onto the inferior surface of the hemisphere.

D. *Superolateral topography of the parietal lobe* [figure 5]

- The **postcentral gyrus** (posterior central gyrus) lies immediately behind the central sulcus. It is limited posteriorly by the **postcentral sulcus**.
- The rest of the parietal lobe is divided by the **intraprietal sulcus** into **superior** and **inferior parietal lobules**. The part of the inferior parital lobule surrounding the posterior end of the lateral sulcus is the **supramarginal gyrus**. A similar part

surrounds the posterior end of the superior temoral sulcus and is called the **angular gyrus**.

E. *Superolateral topography of the occipital lobe* [figure 5]

- The occipital lobe is bisected by the terminal part of the **parieto-occipital sulcus** (fissure). Occasionally, a **transverse** and/or **lateral occipital sulcus** may be seen.

Topography of the Medial Surface

A. *Major Divisions* [figure 6]

- The main feature of the medial surface is the cut edge of the **corpus callosum** curving around the middle of the medial surface. It consists of **four parts**: the **rostrum** (anterior curved tip), the **genu** (anterior bend), the **body** (upper horizontal trunk) and the **splenium** (posterior rounded end).

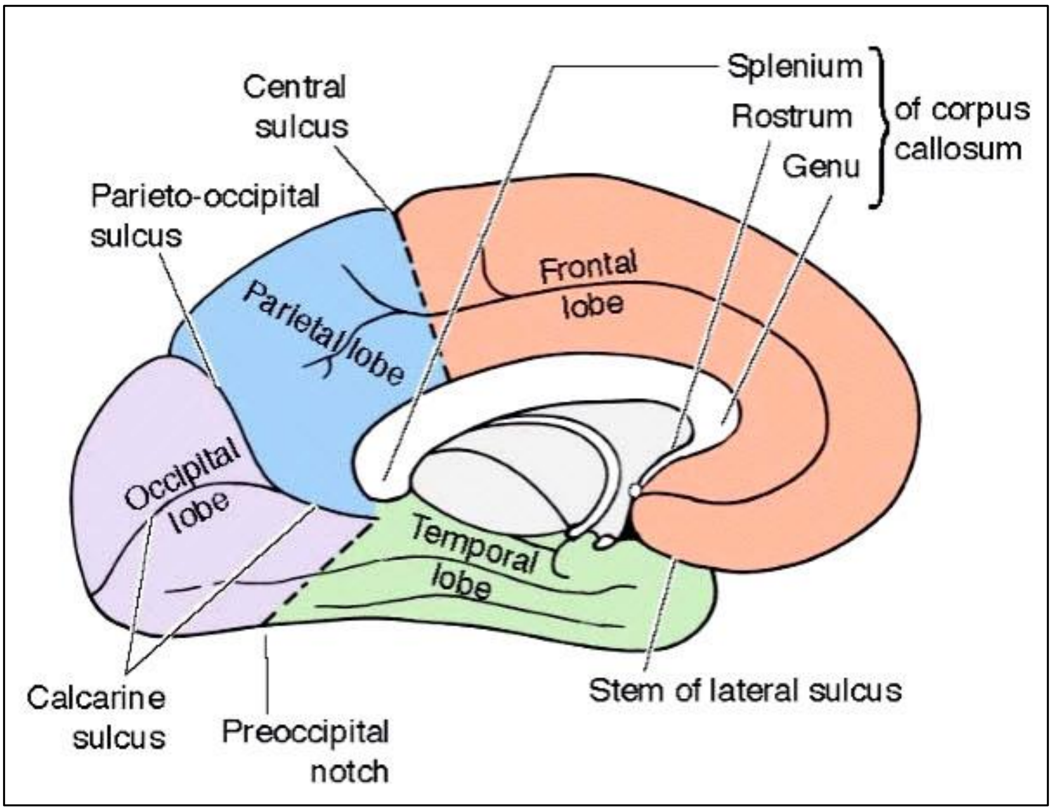


Figure 6: Major divisions of the medial surface of the cerebral hemisphere.

- The medial end of the **central sulcus** continues for a short distance from the superolateral surface. An imaginary line drawn from this end to the body of the corpus callosum separates the frontal from the parietal lobes.

- Another imaginary line drawn from the **preoccipital notch** to the **splenium** of the corpus callosum separates the temporal from the occipital lobes.
- The occipital lobe is separated from the parietal lobe by the **parieto-occipital sulcus**.

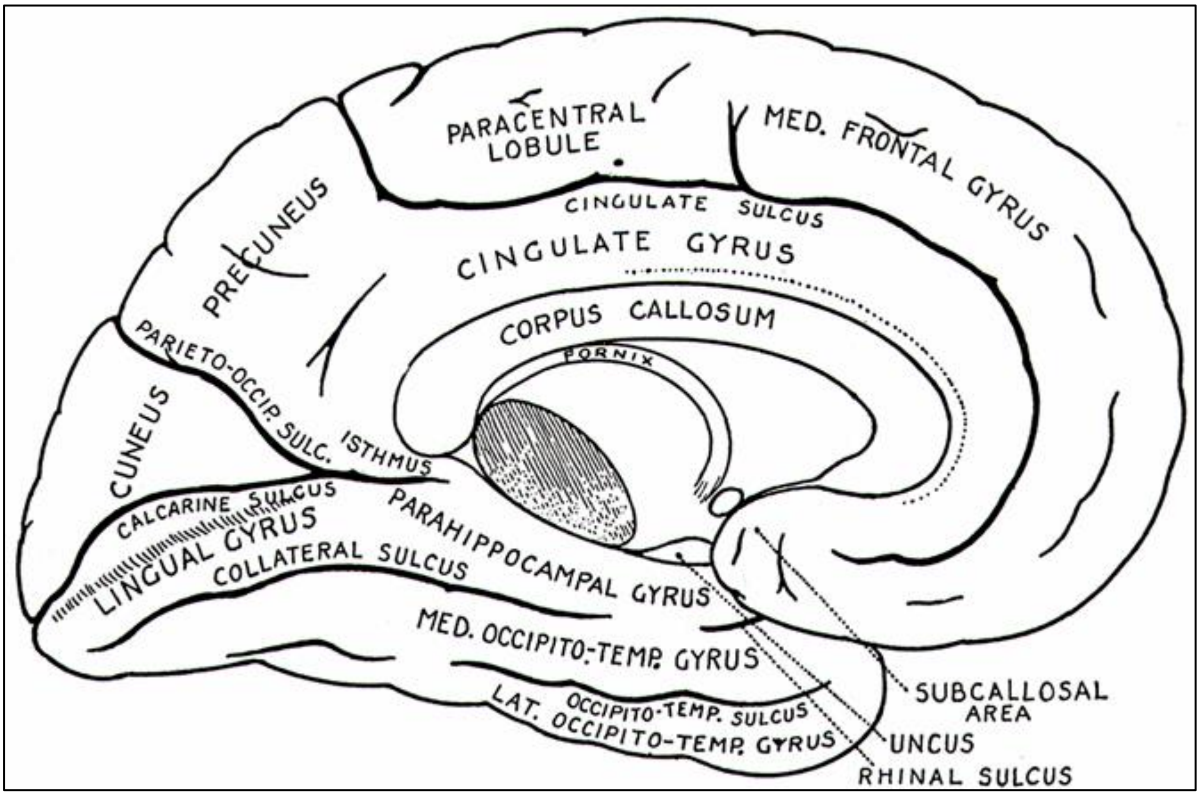


Figure 7: Main sulci and gyri of the medial surface of the cerebral hemisphere. The inferior surface of the temporal lobe is also visible.

B. *Main sulci and gyri* [figure 7]

- The **cingulate gyrus** curves above the corpus callosum. It is bound caudally by the **callosal sulcus** and rostrally by the **cingulate sulcus** which may extend to the upper border and ends a short distance behind the medial end of the central sulcus. The area above the cingulate sulcus is divided by a short sulcus into two parts: the **medial frontal gyrus** lies anterosuperiorly and the **paracentral lobule** lies posterosuperiorly. The paracentral lobule is the area of the cerebral cortex that surrounds the indentation produced by the central sulcus on the superior border. The anterior part of this lobule is a continuation of the precentral gyrus on the superior lateral surface, and the posterior part of the lobule is a continuation of the postcentral gyrus. The **subcallosal gyrus** (the parolfactory area) lies on the medial surface of the frontal lobe, underneath the rostrum of the corpus callosum.

- The **calcarine sulcus** passes from the occipital pole to the medial surface of the temporal lobe. The triangular area between the calcarine and parieto-occipital sulci is the **cuneus**. The area between the cuneus and the paracentral lobule is the **precuneus**.
- The **lingual gyrus** lies at the border between the medial and inferior surfaces of the occipital lobe. It is limited by the calcarine sulcus on the medial surface and by the collateral sulcus on the inferior surface.

Topography of the Inferior Surface

The inferior surface is composed of the orbital surface of the frontal lobe and the sloping inferior surface of the temporo-occipital part of the brain.

- The medial margin of the orbital surface of the frontal lobe is formed by the straight **gyrus rectus** which is limited laterally by the **olfactory sulcus [figure 8]**. The olfactory bulb lies on the anterior end of the olfactory sulcus while the olfactory tract runs backward on the sulcus itself. Lateral to the olfactory sulcus, the slightly concave orbital surface is divided by an H-shaped **orbital sulcus** into foure **orbital gyri** (anterior, medial, posterior and lateral).

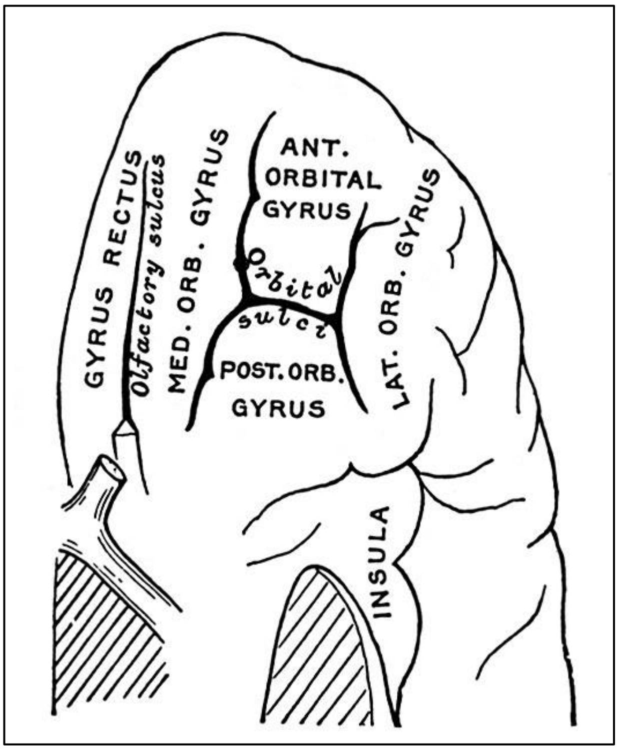


Figure 8: Orbital (inferior) surface of the frontal lobe.

- Two sulci lie on the inferior surface of the temporal lobe **[figure 7]**. The **occipitotemporal sulcus** lies laterally and the **collateral sulcus** medially. They run anteropsteriorly between the temporal and occipital poles. The **medial occipitotemoral gyrus** lies between these two sulci. The **lateral occipitotemporal gyrus** lies lateral to the **occipitotemporal sulcus**. The **parahippocampal gyrus** lies medial to the collateral sulcus on the inferior surface of the temporal lobe. The parahippocampal gyrus is curved at its anterior end to form the **uncus**. At its posterior end, the parahippocampal gyrus is continuous with **the lingual gyrus**. The anterior part of the collateral sulcus near the uncus is called the **rhinal sulcus**.

❖ The Interpeduncular Fossa **[figure 9]**

The interpeduncular fossa can be seen on the inferior surface of the cerebrum with the brainstem attached. It is a rhomboidal in shape and is bound by:

- The **pons** posteriorly,
- The **crura cerebri** (**cerebral peduncles**) posterolaterally,
- The **optic tracts** anterolaterally,
- The **optic chiasma** anteriorly.

The crura cerebri are two bundles of descending fibers that pass from the cerebral hemispheres to the midbrain and pons. The optic tracts arise from the posterior end of the optic chiasma, cross the crura and curve on their lateral aspect.

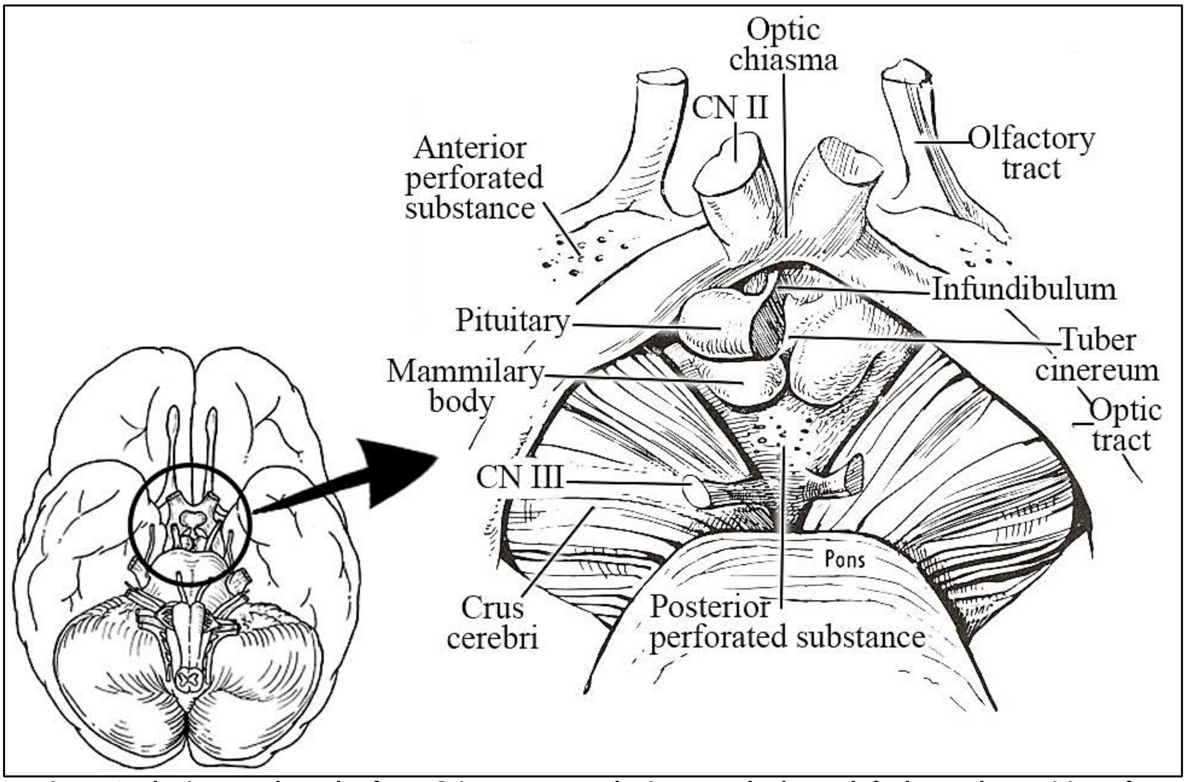


Figure 9: The interpeduncular fossa & its contents. The inset to the lower left shows the position of the fossa on the inferior surface of the brain.

Contents of the interpeduncular fossa

The interpeduncular fossa contains, from rostral to caudal: (1) the tuber cinereum and the infundibulum of the hypophysis cerebri (pituitary gland), (2) the mamillary bodies, (3) the posterior perforated substance and (4) the occulomotor nerves.

- The **tuber cinereum** is a slightly raised area of grey matter between the mamillary bodies and the optic chiasma. The **infundibulum** descends from the tuber. The infundibulum is the narrow stalk that connects the hypothalamus to the pituitary gland.
- The **mamillary bodies** are a pair of small spherical bodies protruding from the ventral surface of the hypothalamus.
- The **posterior perforated substance** is a layer of grey matter at the angle between the crura cerebri. It's perforated by central branches of the posterior cerebral arteries.
- Each **oculomotor nerve** emerges from the midbrain immediately posteromedial to the corresponding crus cerebrum.

The interpeduncular fossa is related anterolaterally to the **anterior perforated substance**. This is a small area of grey matter perforated by the central branches of the middle and anterior cerebral arteries. It is bound anteriorly by the diverging **striae** (posterior end) of the **olfactory tract**, medially by the optic chiasma and posteriorly by the uncus.

❖ Superficial Attachments of the Cranial Nerves **[figure 10]**

The area of attachment of a cranial nerve to the surface of the brain is termed its **superficial** or **apparent origin.** The fibers of the nerve can be traced into the substance of the brain to a special **nucleus** of gray substance. The motor or efferent cranial nerves arise within the brain from groups of nerve cells which form their **nuclei of origin.** The sensory or afferent cranial nerves arise from groups of nerve cells outside the brain; these nerve cells may be grouped to form ganglia on the trunks of the nerves or may be situated in peripheral sensory organs such as the nose (olfactory epithelium) and eye (retina). The central processes of these cells run into the brain, and there end by synapsing with other nerve cells, which are grouped to form **nuclei of termination.**

- The **first two** pairs of cranial nerves are attached to the **forebrain**, the **3rd** and **4th** attach to the **midbrain**, the **5th** to the **pons** and the rest to the medulla oblongata.
- Another classification of the superficial attachment of cranial nerves is according to their orientation. Cranial nerves with **ventral attachments** include the olfactory, optic, oculomotor, abducent and hypoglossal (**I, II, III, VI, XII**). The trochlear nerve (**IV**) is the only cranial nerve with **dorsal attachment**. The rest have **lateral attachments** (**V, VII, VIII, IX, X, XI**).

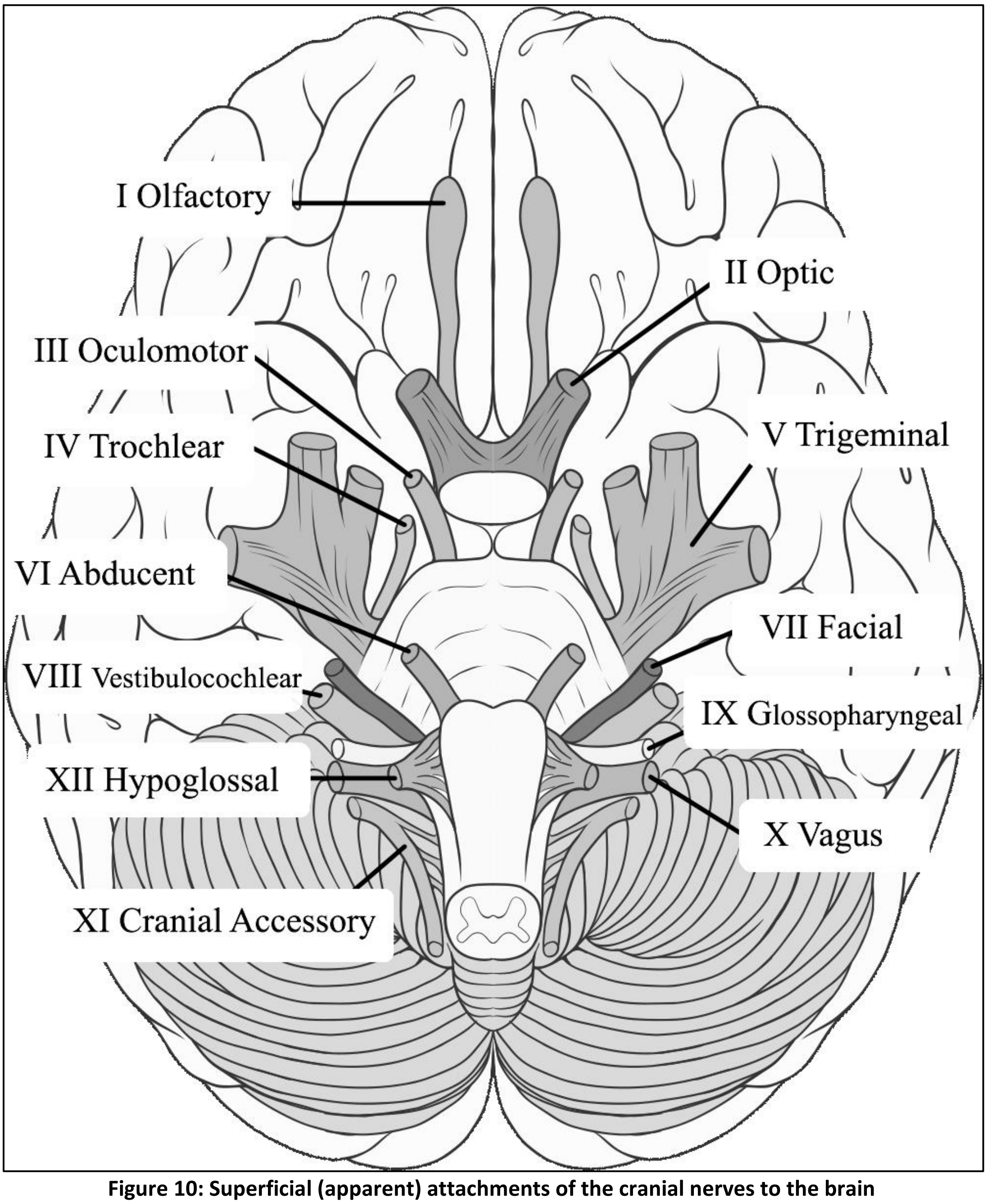


Figure 10: Superficial (apparent) attachments of the cranial nerves to the brain

- The **olfactory nerve (I)** fibers penetrate the cribriform plate of the ethmoid, attach to the olfactory bulb, and then run in the olfactory tract to reach the cerebral cortex.
- The two **optic nerves (II)** join at the optic chiasma in the anterior part of the interpeduncular fossa and then continue in the optic tracts.
- The **oculomotor nerve (III)** arises from a groove on the medial aspect of the cerebral peduncle (crus cerebri) in the posterior part of the interpeduncular fossa.
- The **trochlear nerve (IV)** arises from the dorsal surface of the brainstem just inferior to the midbrain and decussates with its fellow then winds around the lateral aspect of the midbrain.
- The **trigeminal nerve (V)** is the largest cranial nerve. It is attached to the junction of the pons with the middle cerebellar peduncle by **two roots**: a **large** posterolateral **sensory root** and a **small** anterosuperior **motor root**.
- The **abducent nerve (VI)** emerges at the lower border of the pons just cranial to the pyramid of the medulla oblongata.
- The **facial (VII)** and **vestibulocochlear (VIII)** nerves with the small **nervus intermedius** in between, emerge on the lower border of the pons just cranial to the olive of the medulla oblongata.
- The **glossopharyngeal (IX), vagus (X)** and **cranial accessory (XI)** nerves arise as a vertical series of rootlets from a groove posterior to the olive of the medulla oblongata. The spinal rootlets of the accessory nerve continue as far downward as the fifth cervical spinal segment.
- The **hypoglossal nerve (XII)** emerges from a row of rootlets on the anterior surface of the medulla oblongata in the groove between the pyramid and olive.

❖ Functional Localization of the Cerebral Cortex **[figure 11]**

Functional specialization suggests that different areas in the cerebral cortex are specialized for different functions. In 1909, the Germa neurologist **Korbinian Brodmann** divided the cerebral cortex into numbered areas according to the histological appearance of the cortical areas. The classical Brodmann classification of cortical areas according to cytoarchitectonics (into a grid of numbered parts) is not applicable in this context. A more physiological approach with relation to functions and more modern understanding of the cortical areas is used instead. For example, the precentral gyrus is the traditional motor area and the postcentral gyrus is the traditional sensory area. More recently, it has been found that many motor fibers arise from areas outside the traditional motor areas and some even from pure sensory areas. The same is true for sensory fibers.

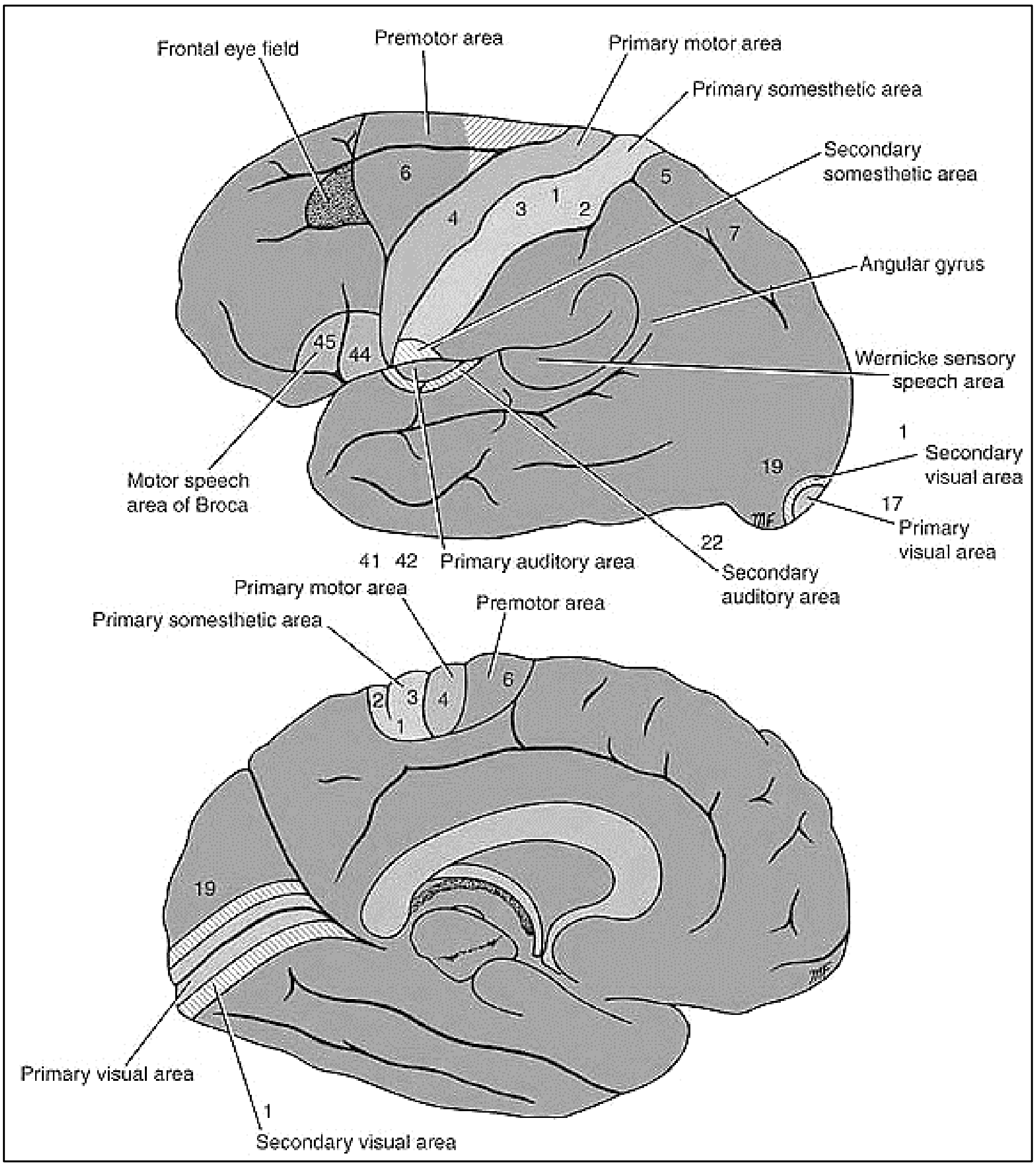


Figure 11: Main functional areas of the cerebral cortex on lateral (above) and medial (below) views

Frontal lobe areas

- The **precentral area** includes the anterior wall of the central sulcus, the precentral gyrus and the posterior parts of the superior, middle, and inferior frontal gyri. It extends over the superomedial border of the hemisphere into the paracentral lobule.

The precentral area may be divided into posterior and anterior regions. The **posterior region** known as the **primary motor area (Ms-I)** occupies the precentral gyrus. The **anterior region** known as the **secondary motor area (premotor area)** occupies the anterior part of the precentral gyrus and the posterior parts of the superior, middle, and inferior frontal gyri.

The primary motor area controls isolated movements on the opposite side of the body by stimulating the contraction of muscle groups concerned with the performance of a specific movement. The function of the premotor area is to store programs of motor activity assembled as the result of experience. Thus, the premotor area programs the activity of the primary motor area.

- The **supplementary motor area (Ms-II)** is situated in the medial frontal gyrus on the medial surface of the hemisphere; anterior to the paracentral lobule. It is thought to be concerned with postural mechanisms under influence of feedback from the basal nuclei.
- The **frontal eye field** extends forward from about the middle of the precentral gyrus into the middle frontal gyrus. It controls the conjugate movements of the eyes, especially toward the opposite side.
- The **motor speech area (of Broca)** is located in the inferior frontal gyrus, mainly in the triangular part. In the majority of individuals (right-handed people), this area is important on the left or dominant hemisphere, and its damage results in loss of speech. In those left-handed individuals, the right hemisphere is dominant and the area on the right side is of importance. The Broca speech area brings about the formation of words by its connections with the adjacent primary motor areas; the muscles of the larynx, mouth, tongue and soft palate. The **insular cortex** is believed to be important for planning and coordinating the articulatory movements necessary for speech.
- The **prefrontal area (cortex)** is a large area that includes the greater parts of the superior, middle, and inferior frontal gyri; the orbital gyri; most of the medial frontal gyrus; and the anterior half of the cingulate gyrus. It is concerned with the

makeup of the individual's **personality** by regulating the person's depth of feeling and determining initiative and judgment.

Parietal lobe areas

- The **primary somesthetic area (primary somatic sensory cortex, Sm-I)** occupies the postcentral gyrus on the lateral surface of the hemisphere and the posterior part of the paracentral lobule on the medial surface. It is mainly concerned with the appreciation of touch and kinesthetic (position) sensation from the opposite side of the body.
- The **secondary somesthetic area (secondary somatic sensory cortex, Sm-II)** is in the superior lip of the posterior limb of the lateral fissure. Its function is not fully understood but its neurons respond particularly to transient cutaneous stimuli, such as brush strokes or tapping of the skin.
- The **somesthetic association area** occupies the superior parietal lobule extending onto the medial surface of the hemisphere. Like other association areas, it receives and integrates different sensory modalities. For example, it enables one to recognize objects placed in the hand without the help of vision. In other words, it not only receives information concerning the size and shape of an object but also relates this to past sensory experiences; thus, the information may be interpreted, and recognition may occur.
- The **gustatory (taste) area** is situated at the lower end of the postcentral gyrus in the superior wall of the lateral sulcus and in the adjoining area of the insula.
- The **vestibular area** is situated near the part of the postcentral gyrus concerned with sensations of the face. It is concerned with appreciation of the positions and movements of the head in space. Through its nerve connections, the movements of the eyes and the muscles of the trunk and limbs are influenced in the maintenance of posture.

The homunculus

The movement areas of the opposite side of the body are represented in inverted form in the precentral gyrus. Starting from below and passing superiorly are structures involved in swallowing and the tongue, jaw, lips, larynx, eyelid, and brow. The next area is an extensive region for movements of the fingers, especially the thumb and hand followed by the wrist, elbow, shoulder, and trunk. The movements of the hip, knee, and ankle are represented in the highest areas of the precentral gyrus; the movements of the toes are situated on the medial surface of the cerebral hemisphere in the paracentral lobule. The movements of the anal and vesical sphincters are also located in the paracentral lobule. The area of cortex controlling a particular movement is proportional to the skill involved in performing the movement and is unrelated to the mass of muscle participating in the movement.

Similarly, in the somesthetic area, the opposite half of the body is represented as inverted. The apportioning of the cortex for a particular part of the body is related to its functional importance rather than to its size (directly proportional to the number of sensory receptors present in that part of the body). The face, lips, thumb, and index finger have particularly large areas assigned to them.

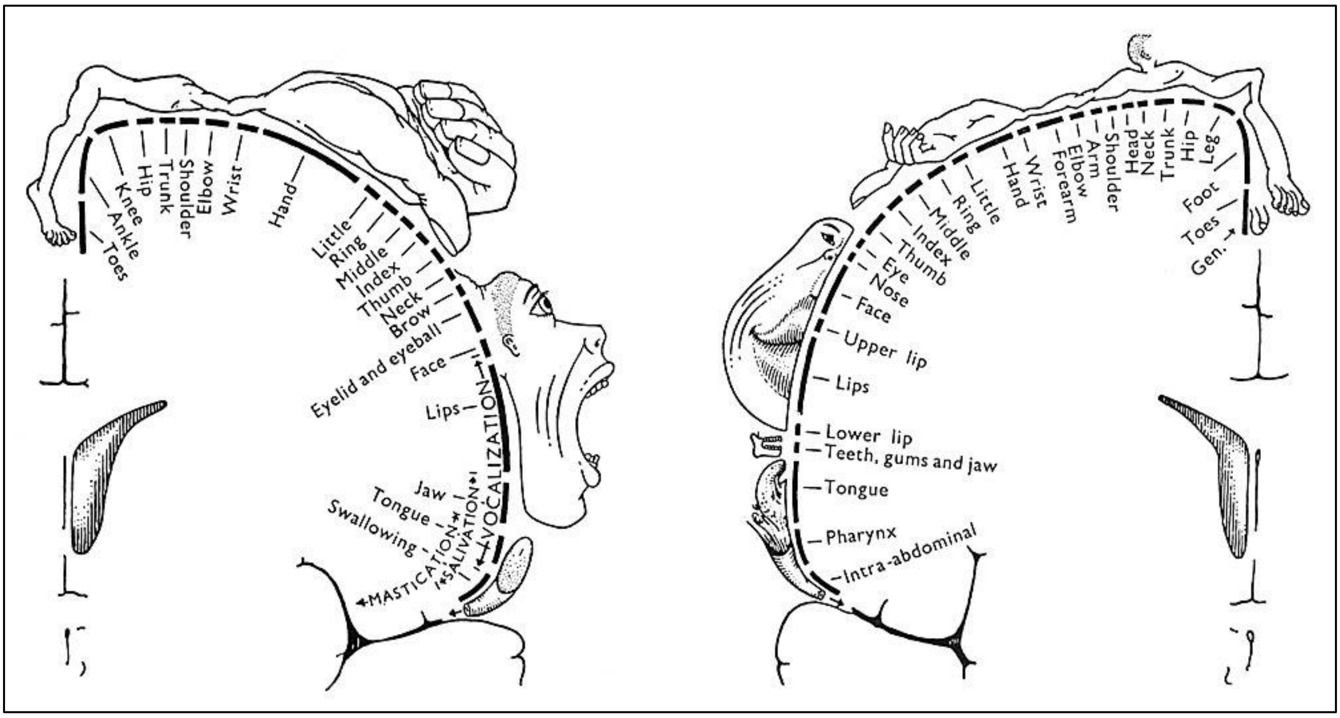


Figure 11: The homunculus is the cortical representation of different body parts according to their motor (left) and sensory (right) significance

Temporal lobe areas

- The **primary auditory area** lies buried in the lateral sulcus in what is known as the **transverse temoral gyri**. These are short gyri that run transversely (mediolaterally) across the floor of the lateral sulcus. It is concerned with the initial appreciation of sound.
- The **secondary auditory area (auditory association cortex)** is situated posterior to the primary auditory area in the lateral sulcus and extends on the superior temporal gyrus. It is concerned with the interpretation of sound.
- The **sensory speech area of Wernicke** is localized in the left dominant hemisphere, mainly in the superior temporal gyrus, with extensions into the supramarginal and angular gyri of the parietal region. The area is concerned with the understanding of the written and spoken language (i.e., enables a person to understand a written or heard sentence). The Wernicke area is connected to the Broca area by a bundle of nerve fibers called the **arcuate fasciculus**.

Occipital lobe areas

- The **primary visual area** is situated in the walls of the posterior part of the calcarine sulcus and may extend around the occipital pole onto the lateral surface of the hemisphere. It is recognized grossly by its striated appearance.
- The **secondary visual area (visual association area)** surrounds the primary visual area on the medial and lateral surfaces of the hemisphere. It relates the visual information received by the primary visual area to past visual experiences, thus enabling the individual to recognize and appreciate what he or she is seeing.

Cerebral dominance

An anatomical examination of the two cerebral hemispheres shows that the cortical gyri and fissures are almost identical. Nevertheless, certain nervous activity is predominantly performed by one of the two cerebral hemispheres. Handedness, perception of language, and speech are functional areas of behavior that in most individuals are controlled by the dominant hemisphere. By contrast, spatial perception, recognition of faces, and music are interpreted by the nondominant hemisphere. More than 90% of the adult population is right-handed and, therefore, is left hemisphere dominant. About 96% of the adult population is left hemisphere dominant for speech.

Summary of the functional areas of the cerebral cortex			
Lobe	**Area**	**Location**	**Function**
Frontal	Primary motor (Ms-I)	Precentral gyrus	Stimulate muscle groups to perform a specific function
	Secondary motor (Premotor)	Anterior part of precentral gyrus+posterior parts of superior, middle & inferior frontal gyri	Programs the activity of the primary motor area
	Supplementary motor area (Ms-II)	Medial frontal gyrus	Postural motor activity
	Frontal eye field	Middle frontal gyrus	Controls conjugate eye movements
	Motor speech (Broca's)	Triangular part of inferior frontal gyrus (dominant hemisphere)	Generation of speech (coordinated by the insular cortex)
	prefrontal	Superior, middle, inferior, medial frontal gyri, orbital gyri & anterior ½ of cingulate gyrus	Personality, reasoning, judgment, initiative
Parietal	Primary somesthetic (Sm-I)	Postcentral gyrus	Perception of touch & kinesthetic sensation
	Secondary somesthetic (Sm-II)	Superior lip of the posterior limb of lateral sulcus	? Light touch perception ?
	Somesthetic association	Superior parietal lobule	Integration of cutaneous sensation (cutaneous recognition)
	Gustatory (taste)	Lower end of postcentral gyrus and adjacent insula	Taste perception
Temporal	Vestibular	Near facial area of postcentral gyrus	Perception of head position & movements
	Primary auditory	Transverse temporal gyri	Initial appreciation of sound
	Secondary auditory (association)	Lateral sulcus and superior temporal gyrus	Interpretation of sound
	Sensory speech (Wernicke's)	Superior temporal, angular, supramarginal gyri (dominant hemisphere)	Understanding written and spoken language
Occipital	Primary visual	Walls of posterior part of calcarine sulcus	Initial appreciation of light
	Secondary visual (association)	Around the primary visual area	Recognition of images

GREY MATTER OF THE CEREBRAL HEMISPHERES

The **cerebral cortex** represents one part of the grey matter of the cerebral hemispheres. The rest of the grey matter is found deep among the white matter fibers, this part of the grey matter comprises the **basal nuclei**. They are called basal because they lie near the base of each hemisphere. The thalamus is the largest collection of grey matter in the brain but it belongs to the diencephalon not the telencephalon.

The basal nuclei are the subcortical grey masses that lie lateral to the thalamus in the inferior parts of each cerebral hemisphere. They are divided into the following parts:

- The **caudate nucleus** is the medial comma-shaped nucleus.
- The **lentiform nucleus** lies lateral to the caudate nucleus. It consists of two parts:
    - Inner part = **Globus Pallidus** (**Pallidum**).
    - Outer part = **Putamen**.
- The **Claustrum** is the most lateral nucleus.
- The **Amygdaloid body** (**Amygdala**) lies at the tip of the tail of the caudate nucleus.

The caudate nucleus is separated from the lentiform nucleus by the fibers of the **internal capsule** (ascending and descending white matter fibers). However, the caudate nucleus connects to the putamen part of the lentiform nucleus by many fibers giving the area a striated appearance. Therefore, the caudate and lentiform nuclei together with the interconnecting fibers are all referred to as the **corpus striatum**. Clinicans refer to the caudate nucleus and putamen as the **neostriatum** (striatum).

The putamen part is separated from the claustrum by the external capsule. The claustrum is separated from the cortex of the overlying insula by the extreme capsule.

The basal nuclei are best studied on horizontal and coronal cross sections of the brain **[figure 12]**.

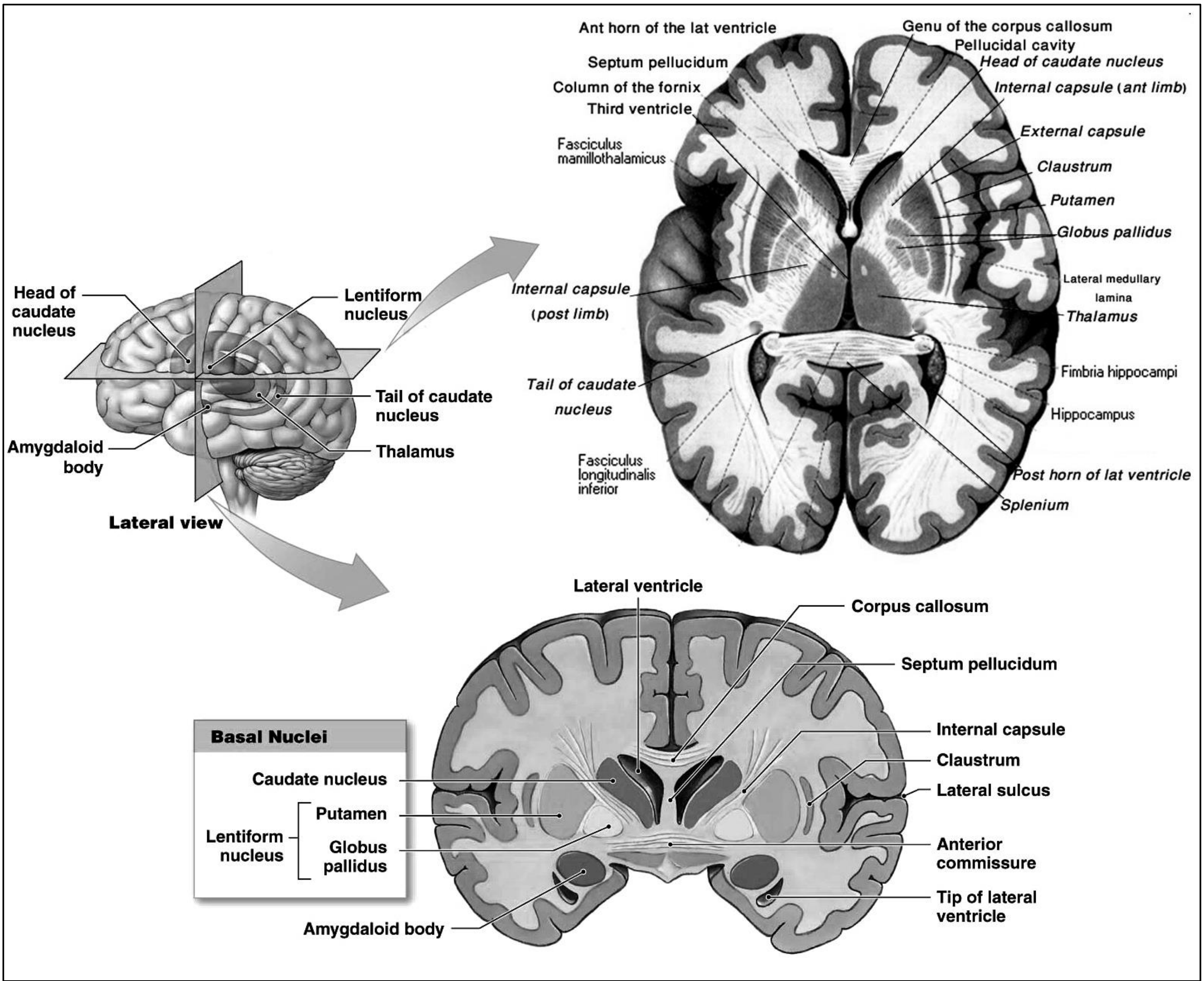


Figure 12: The basal nuclei in coronal (lower right) and horizontal (upper right) sections. The inset to the upper left shows the position of the nuclei in the hemisphere.

The Caudate Nucleus

This nucleus has the shape of a highly curved comma (**C-shaped**). It is closely related to the concavity of the **lateral ventricle** and curves around the lateral side of the **thalamus**. It consists of a head, a body and a tail.

The **head** is large and bulbous and tapers from front backwards toward the body. The **body** curves posteriorly around the lateral part of the thalamus and then bends sharply forwards into the long anteriorly tapering thin **tail**. The end of the tail joins the amygdaloid body.

The concavity of the caudate nucleus is curled snugly around the fibers of the internal capsule like a hand holding a bunch of flowers. The whole length of the convexity projects into the lateral ventricle so that the head lies in the lateral wall of the anterior horn of the ventricle, the body runs in the lateral part of the floor of the body of the ventricle and the tail runs in the roof of the inferior horn.

The Lentiform Nucleus

The lentiform nucleus has the shape of a biconvex lens with an inferior base. The **lateral surface** is smooth and slightly convex and is separated from the **claustrum** by the **external capsule**. The **medial surface** is more sharply convex and has an **apex** opposite the **interventricular foramen** between the head of the caudate nucleus anteriorly and the thalamus posteriorly.

Two vertical sheets of white matter called the **medial** and **lateral medullary laminae** divide the lentiform nucleus into three parts. The **medial** two **pale parts** form the **globus pallidus** and the **lateral dark part** forms the **putamen**.

The Claustrum

This is a thin sheet of grey matter, which is **circular** in outline but appears curved into a **saucer-shape** in cross sections. It is located between the putamen medially and the insular cortex laterally. It is separated from the grey matter of the **insular cortex** by a sheet of white matter called the **extreme capsule**. The exact function of the claustrum is unknown.

The Amygdaloid Body

This is a nuclear complex found in the dorsomedial part of the **temporal pole** (near the **uncus**), close to (and may be fused with) the **tail of the caudate nucleus**. It forms the ventral, superior and medial walls of the tip of the inferior horn of the lateral ventricle. It is **functionally** part of the **limbic system**, being concerned with the neural mechanisms underlying emotional behavior.

The substantia nigra of the midbrain and the subthalamic nuclei of the diencephalon are two grey matter areas that are functionally related to the activities of the basal nuclei. The neurons of the substantia nigra are dopaminergic and inhibitory and have many connections to the corpus striatum. The neurons of the subthalamic nuclei are glutaminergic and excitatory and have many connections to the globus pallidus and substantia nigra.

Function of the basal nuclei

The basal nuclei exert a **supraspinal control** over skeletal muscle movements by influencing their **rate**, **range** and **coordination**. *They do not initiate muscle contraction but modify it.*

The activity of the basal nuclei is initiated by information received from the premotor and supplemental areas of the motor cortex, the primary sensory cortex, the thalamus, and the brainstem. The outflow from the basal nuclei is channeled through the globus pallidus, which then influences the activities of the motor areas of the cerebral cortex or other motor centers in the brainstem. In this way, the basal nuclei assist in the regulation of voluntary movement and the learning of motor skills.

The basal nuclei not only influence the execution of a particular movement, but also help prepare for the movements. This important preparatory function enables the trunk and limbs to be placed in appropriate positions before the primary motor part of the cerebral cortex activates discrete movements in the hands and feet.

Because the basal nuclei exert their effect without descending to the spinal cord and lower centers, they are distinguished from the motor fibers that do descend (The corticonuclear and corticospinal fibers).

Disorders of the basal nuclei

Disorders of the basal nuclei are of two types. Hyperkinetic disorders are those in which there are excessive and abnormal movements, such as seen with chorea and hemiballismus. Hypokinetic disorders include those in which there is a lack or slowness of movement like athetosis. Parkinson disease includes both types of motor disturbances.

WHITE MATTER OF THE CEREBRAL HEMISPHERE

The white matter of the cerebral hemispheres is made up of three groups of fibers **[figure 13].**

- **Association (arcuate) fibers** connect one part of the cerebral cortex to another part in the same hemisphere.
- **Commissural fibers** cross the midline and connect one part of a hemisphere to the corresponding (reciprocal) part of the opposite hemisphere.
- **Projection fibers** connect the cerebral cortex to the subcortical nuclei in the cerebral hemispheres and with nuclei in the diencephalon, brainstem and spinal cord.

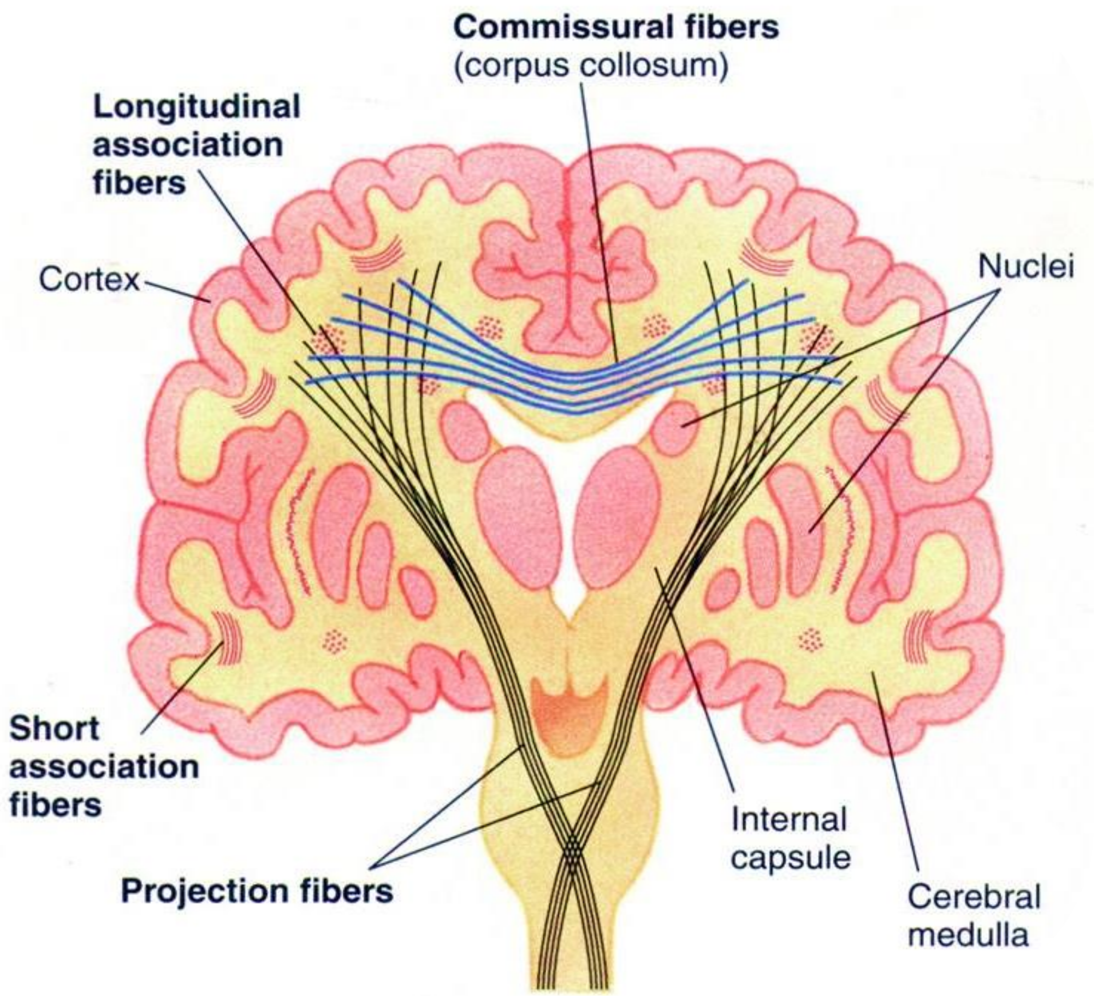


Figure 13: Types of white matter fibers of the cerebral hemispheres.

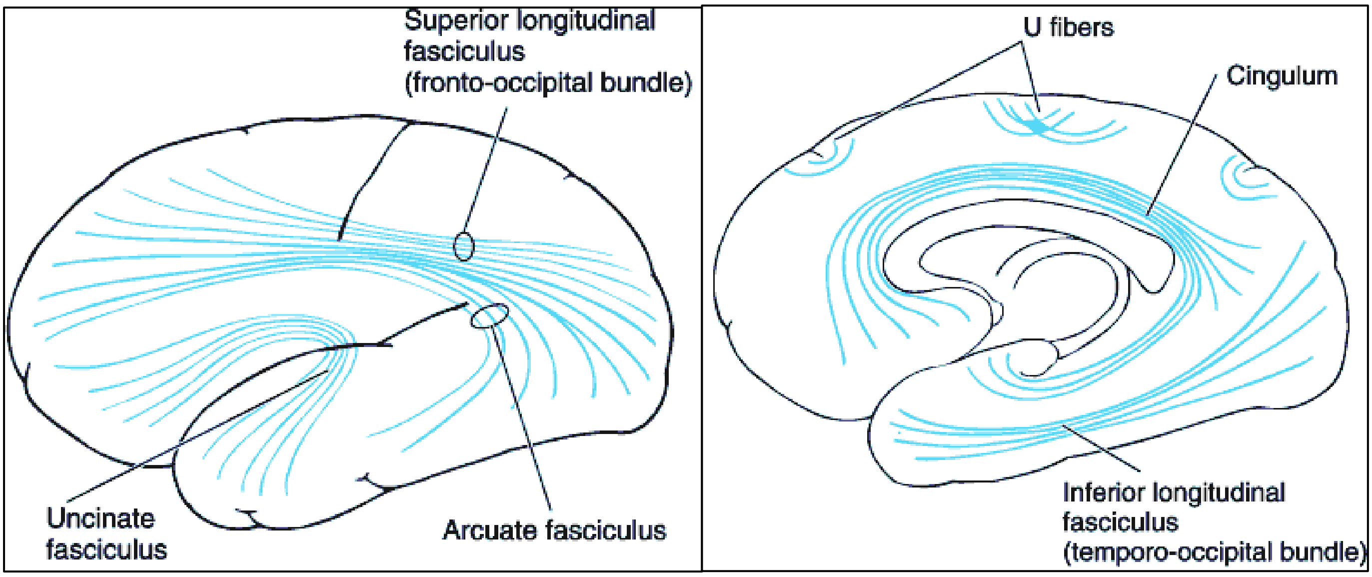


Figure 14: Association fibers seen in lateral (left) and media (right) dissection of the cerebral hemisphere.

Association fibers

According to their length, these fibers are classified into two types;

A. Short association fibers are U-shaped short fibers that pass from one part of a gyrus to another part of the same gyrus or they may arch around a sulcus to the adjacent gyrus.

B. Long association fibers run long distances between cortical areas of different lobes forming visible nerve bundles. Six bundles of long association fibers are recognized; **[figure 14]**

- The **cingulum** is a long, curved fasciculus lying within the white matter of the cingulate gyrus. It connects the frontal and parietal lobes with the parahippocampal gyrus.
- The **uncinate fasciculus** connects the inferior frontal lobe gyri with the anterior temporal lobe.
- The **superior longitudinal fasciculus** is the largest bundle of nerve fibers. It connects the anterior part of the frontal lobe to the occipital and temporal lobes.
  - The **fronto-occipital (occipitofrontal) fasciculus** represents the upper part of the superior longitudinal fasciculuc. It connects the frontal lobe to the occipital and temporal lobes. It is related to the lateral border of the caudate nucleus.

- The **arcuate fasciculus** represents the lower part of the superior longitudinal fasciculus. It sweeps around the insula and connects the motor speech area (frontal lobe) with the sensory speech area (temporoparietal lobe).

- The **inferior longitudinal fasciculus** runs anteriorly from the occipital lobe, passing lateral to the optic radiation, and is distributed to the temporal lobe.

Commissural fibers

Most of the commissural fibers are grouped together in the corpus callosum. The remaining fibers are distributed in five other commissures; anterior commissure, optic chiasma, posterior commissure, habenular commissure and commissure of the fornix (hippocampal commissure).

A. The Corpus Callosum

The corpus callosum lies at the bottom of the longitudinal cerebral fissure. It consists of a mass of 100 million commissural fibers, each of which extends from cortex to cortex between symmetrical parts of the two hemispheres. Viewed cut in a sagittal section, the corpus begins at the upper end of the lamina terminalis of the diencephalon. From here it curves up and backwards increasing in thickness. It consists of four parts:

- The **rostrum** is the tapered anterior end passing anterosuperiorly from the anterior commissure. Its fibers connect the orbital cortices.
- The **genu** is the sharp backward bend from the rostrum. Its fibers connect the frontal cortices.
- The **body (trunk)** is the gently convex upwards part. Its fibers connect the parietotemporal cortices.
- The **splenium** is the thick rounded posterior end connecting the occipital cortices.

In a horizontal section, the fibers of the genu appear arching forwards in a narrow arch from one frontal cortex to another and they are called the **forceps minor**. The fibers of the splenium are seen arching backwards in a wide arch from one occipital cortex to another forming the **forceps major.** Between the forceps minor and major, the fibers of the trunk spread out to the cortex on the lateral surface of the hemisphere (parietal and temporal cortices). These fibers pass over the anterior horn and body of the lateral ventricle forming their roofs. Then they descend into the temporal lobe forming the lateral walls of the inferior and posterior horns of the lateral ventricle where they are called the **tapetum**.

A thin layer of grey matter lies in contact with the dorsal surface of the corpus callosum and is continuous laterally with the grey matter of the cingulate gyrus. This layer is called the **supracallosal gyrus** or **indusium griseum**. It contains two longitudinally directed strands of fibers termed respectively the medial and lateral longitudinal striae (of Lancisi).

B. The anterior commissure

The anterior commissure is situated in the anterior wall of the third ventricle at the upper end of the lamina terminalis. A few fibers passing through the commissure interconnect the olfactory bulbs of the two cerebral hemisphere. Most fibers interconnect the parahippocampal gyri and other parts of the temporal lobe.

C. The posterior commissure

This commissure lies in the inferior lamina of the stalk of the pineal gland immediately above the opening of the cerebral aqueduct into the third ventricle. The destinations and functional significance of many of the nerve fibers are not known. However, the fibers from the pretectal nuclei involved in the pupillary light reflex are believed to cross in this commissure.

D. The habenular commissure

This is a small bundle of nerve fibers that cross the midline in the superior stalk of the pineal gland. It connects the habenular nuclei , which are situated on either side of the midline in this region.

E. Commissure of the fornix (Hippocampal commissure)

This is situated below the splenium of the corpus and contains fibers which connect one hippocampal formation to another (explained in details with the limbic system).

Projection fibers

These fibers connect the cerebral cortex with lower part of the brain or brainstem and the spinal cord, in both directions (ascending and descending):

- The corticopetal (afferent/ascending) fibers include
  - The geniculocalcarine (optic) radiation from the lateral geniculate body to the calcarine cortex,
  - The auditory radiation from the medial geniculate body to the auditory cortex.
  - The thalamic radiations from the thalamic nuclei to specific cerebrocortical areas
- The corticofugal (efferent/descedning) fibers proceed from the cerebral cortex to the thalamus, brain stem, or spinal cord.

Afferent and efferent nerve fibers passing to and from the brainstem to the entire cerebral cortex must travel between large nuclear masses of gray matter within the cerebral hemisphere. At the upper part of the brainstem, these fibers form a compact band known as the **internal capsule**, which is flanked medially by the caudate nucleus and the thalamus and laterally by the lentiform nucleus. Once the nerve fibers have emerged superiorly from between the nuclear masses, they radiate in all directions to the cerebral cortex. These radiating projection fibers are known as the **corona radiata**. Below the internal capsule, the projection fibers pass to the brainstem as the **cerebral peduncles**. Most of the projection fibers lie medial to the association fibers, but they intersect the commissural fibers of the corpus callosum and the anterior commissure.

A. The Internal Capsule

This bundle of projection fibers contains ascending and descending tracts to and from the cerebral cortex. It can be compared to a narrow gate where the fibers are densely crowded. Therefore, even pin-point lesions of the capsule can lead to widespread derangements of the body. The capsule is continuous upwards as the corona radiata. Downwards, most of the fibers enter the brainstem via the cerebral peduncles (crura cerebri) of the midbrain.

In a horizontal section the capsule appears as a band of white matter with a medial convex bend and a lateral concavity and consists of 5 parts **[figure 15]**:

1. The anterior limb lies between caudate nucleus medially and the anterior part of the lentiform nucleus laterally
2. The posterior limb lies between the thalamus medially and the posterior part of the lentiform nucleus laterally.
3. The genu is the narrow bend where the anterior and posterior limbs meet.
4. The retrolentiform part extends behind the lentiform nucleus.
5. The sublentiform part extends below the lentiform nucleus.

The afferent and efferent fibers are arranged in the internal capsule so that:

- The fibers to and from the anterior part of the frontal lobe pass through the anterior limb of the internal capsule.
- The fibers to and from the posterior part of frontal lobe and greater part of parietal lobe occupy genu and posterior limb of the internal capsule.
- Fibers to and from the temporal lobe (and lowest part of parietal lobe) occupy the sublentiform part. Whereas those to and from the occipital lobe occupy the retrolentiform part of the internal capsule.

The table below shows the detais of these fibers and bundles (for reference).

Arrangement of fibers in the Internal Capsule		
Part	**Descending tracts**	**Ascending tracts**
Anterior limb	• Frontopontine fibers	○ Anterior thalamocortical fibers
Genu	• Corticonuclear fibers • Corticospinal fibers (head and neck)	○ Anterior part of the superior thalamocortical fibers
Posterior limb	• Cosrticospinal fibers • (upper and lower limbs and trunk) • Corticopontine fibers • Corticorubral fibers	○ Superior thalamocortical fibers
Retrolentiform	• Some parietopontine and occipitopontine fibers • Occipitocollicular fibers	○ Optic radiation
Sublentiform	• Some parietopontine and temporopontine fibers	○ Auditory radiation

B. The External capsule

This is a thin layer of white matter lying on the lateral surface of the lentiform nucleus, separating it from the claustrum. It contains fibers passing from the cerebral cortex to the claustrum.

C. The Extreme Capsule

This is the thin layer of white matter lying between the claustrum and the cortex of the insula.

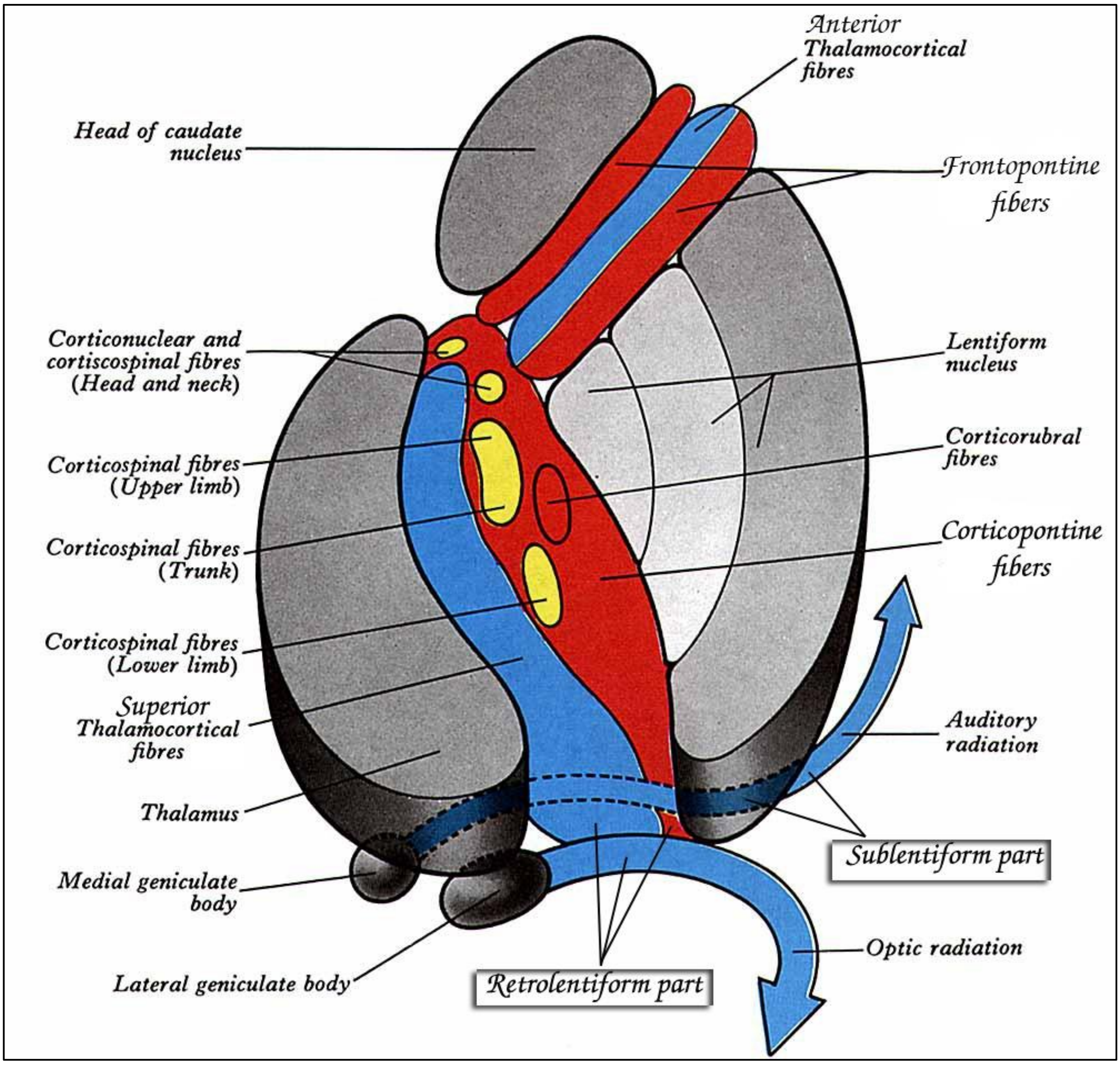
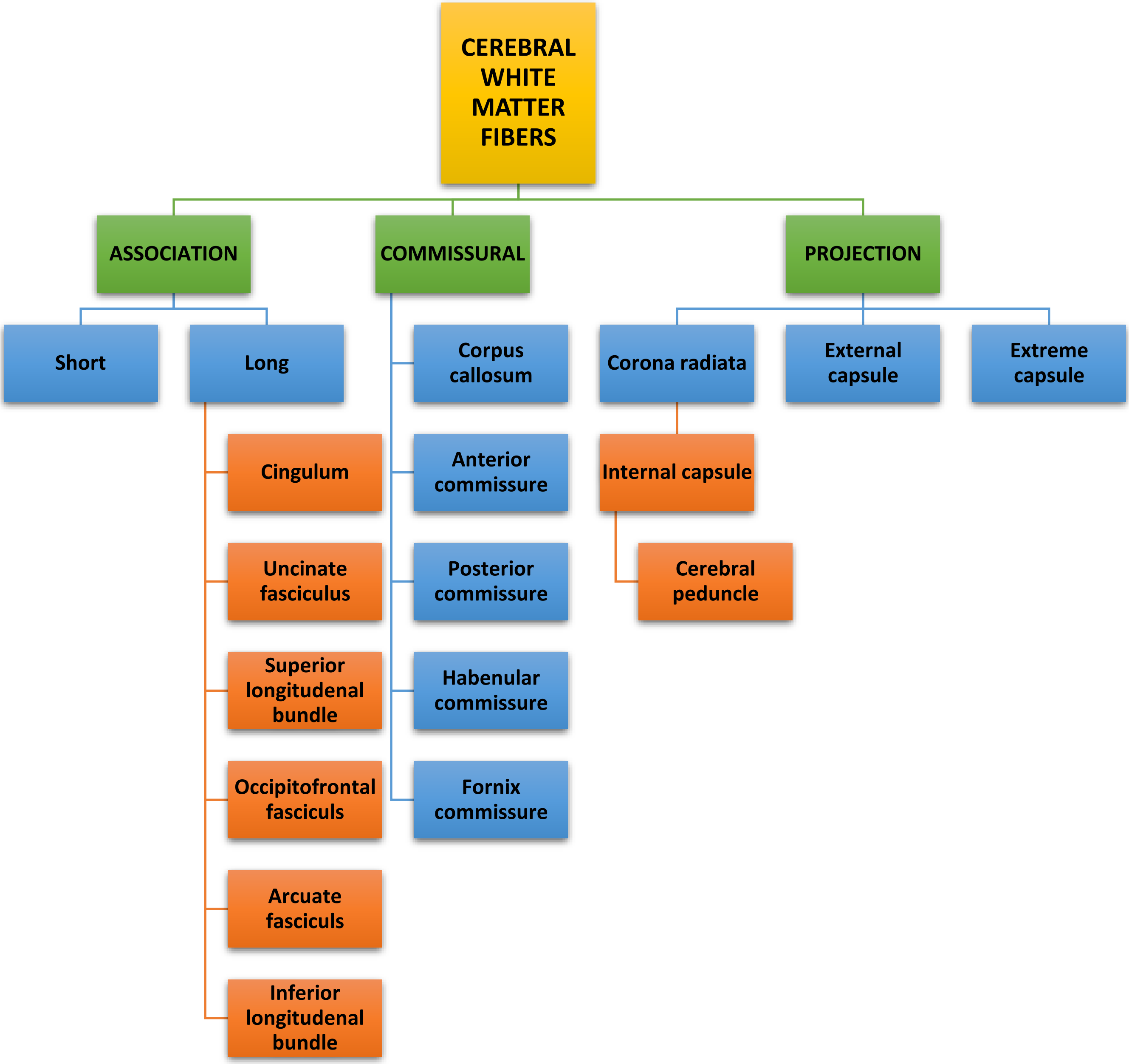


Figure 15: Parts and fibers of the right internal capsule as they appear in a horizontal section.



SUMMARY OF CEREBRAL WHITE MATTER FIBERS

The Limbic System

The word limbic means border or margin, and the term limbic system is loosely used to include a group of structures that lie in the border zone between the cerebral cortex and the hypothalamus **[figure 16]**. These structures surround the corpus callosum and diencephalon and are concerned with regulating behaviors related to the objectives of primitive life (food, shelter and sex). They represent parts of the primitive brain controlling such behaviors as seeking and procuring food, courtship, mating, housing, rearing of young, rage, aggression and emotions. The system also affects and is affected by mood and memory.

Areas that are typically included in the limbic system fall into two categories. Many of these areas are portions of the cerebral cortex, while some are subcortical structures.

- **Cortical regions** that are involved in the limbic system include:
  - The **hippocampal formation** (Memory).
  - The **insular cortex**.
  - **Orbital frontal cortex**.
  - **Subcallosal gyrus**.
  - **Cingulate gyrus**.
  - **Parahippocampal gyrus**.

This cortex has been termed the **"limbic lobe"** because it makes a rim surrounding the corpus callosum, following the lateral ventricle.

- **Subcortical portions** of the limbic system include:
  - The **olfactory bulb**.
  - The **hypothalamus**.
  - The **amygdala** (Rage/Aggression).
  - The **septal nuclei** (Pleasure/Addiction).
  - The **anterior thalamic nucleus**.

The cingulate gyrus, fornix, anterior commissure and mammillary bodies are the connecting pathways of different parts of the limbic system.

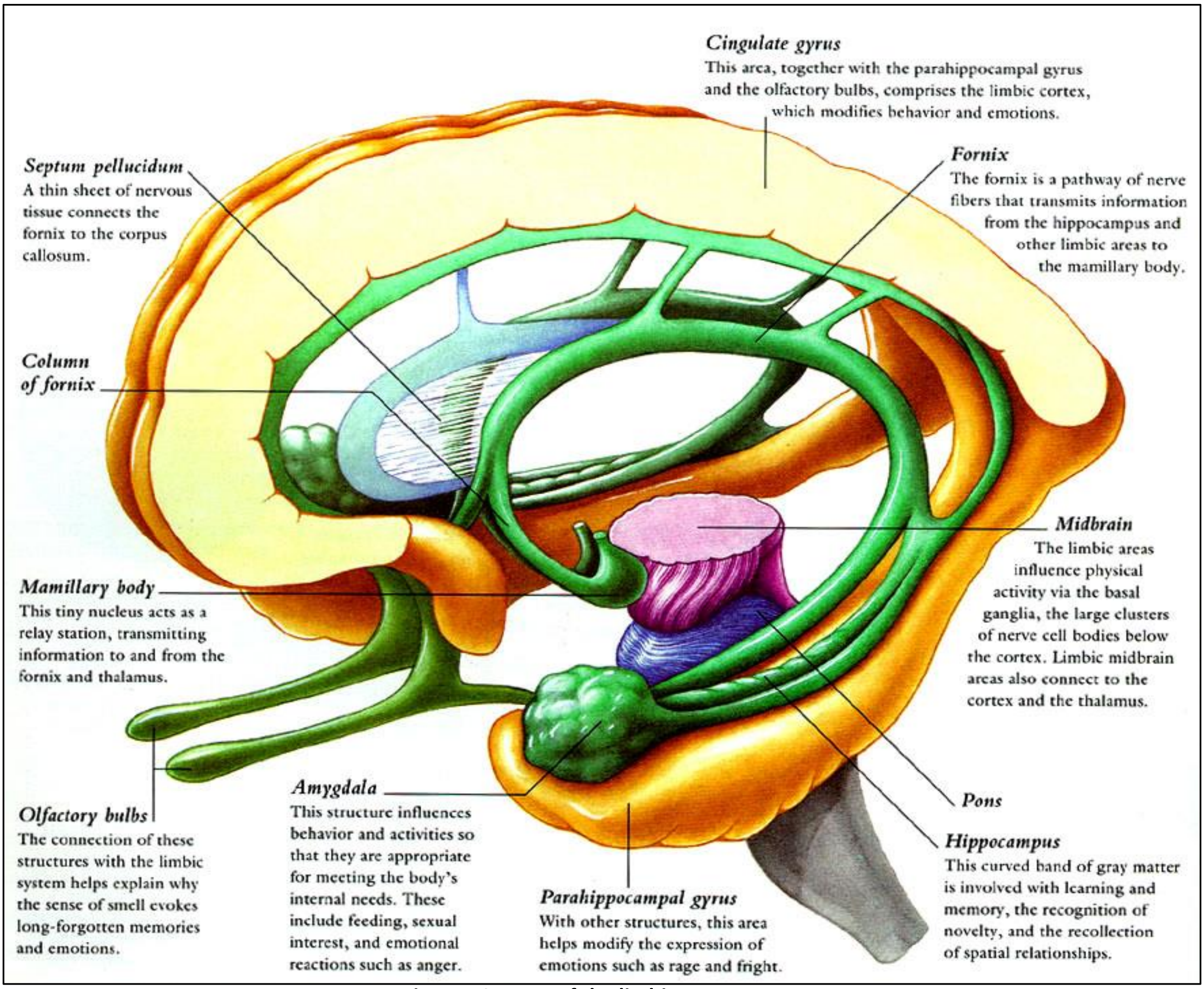


Figure 16: Parts of the limbic system.

The olfactory pathways

The **olfactory nerve** filaments pass through the cribriform plate of the ethmoid bone and synapse with second order neurons in the **olfactory bulb**. The olfactory bulb is the expanded anterior end of the **olfactory tract**. The tract represents an elongated extension of the white matter of the brain lying in the olfactory sulcus lateral to the gyrus rectus. The second order neurons run posteriorly in the tract to the anterior perforated substance. Here the tract divides into **lateral** and **medial striae**.

The lateral stria runs laterally to the uncus at the front of the parahippocampal gyrus. The medial stria passes in front of the lamina terminalis and connects to the anterior parts of the limbic system.

Unlike other sensory pathways, the olfactory pathway reaches the olfactory cortex (uncus) without relay in the thalamus. However, fibers from the olfactory cortex pass through the thalamus to the orbitofrontal cortex (processing cortex) and brainstem afterwards.

The Amygdaloid body (Amygdaloid nucleus, Amygdala)

The amygdaloid body is an almond shaped collection of nerve cell bodies located at the anterior end of the hippocampus and tip of the tail of the caudate nucleus, in the medial part of the temporal lobe.

The Hippocampal Formation, Fornix and Mammillary Bodies

A hippocampal formation is located in the temporal lobe of each cerebral cortex, medial to the inferior (temporal) horn of the lateral ventricle. The hippocampal formation consists of the **hippocampus**, the **dentate gyrus**, **subiculum** and the **parahippocampal gyrus**. The **Fornix** serves as the major efferent pathway of the hippocampal formation.

The hippocampus represents the projection of the hippocampal sulcus into the floor of the inferior horn of the lateral ventricle *(the hippocampal sulcus lies just above the anterior part of the parahippocampal gyrus of the temporal lobe).*

In the *sagittal plane* it appears to consists of a head, body and tail. The **head** is the anterior part and appears like the knuckles of the clenched fist, hence called the **pes hippocampus**. The **body** is more cylindrical in shape, and the **tail** tapers posteriorly.

In the *coronal plane* the hippocampus and parahippocampal gyrus form an S-shaped configuration that resembles a seahorse. The hippocampus itself consists of two interlocking C-shaped gyri: the hippocampal gyrus or Ammon's horn (cornu ammonis) and the dentate gyrus **[figure 17]**.

The hippocampal gyrus is continuous with the parahippocampal gyrus by a transitional zone called the **subiculum**. Histologically, it is further divided into four sections: CA1 to CA4. The **dentate gyrus** faces backwards from the hippocampal gyrus and envelops the CA3 and CA4 regions of Ammon's horn. The term dentate gyrus comes from the beaded or toothed appearance of this structure resulting from the many small blood vessels from subarachnoid space that penetrate the dentate gyrus.

On the ventricular (upper) surface of the hippocmpual formation is a thin layer of white matter called the **alveus** whose fibers thicken medially to form the **fimbria**.

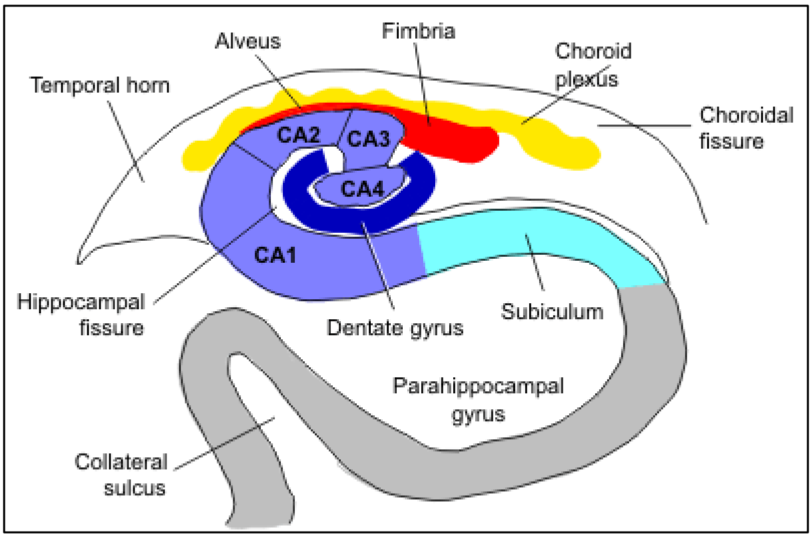


Figure 17: Coronal section of the hippocampal formation.

The **fornix** is a "C" shaped tract (in sagittal section). The fornix begins as the alveus. As the fibers of the alveus travel posteriorly, they aggregate medially to form the **fimbria of the fornix.** The fimbria of each hippocampus thickens as it moves posteriorly and eventually splits off from the hippocampus forming the **crus** or **posterior pillar of the fornix**. The two crua (of right and left) come together and form the **hippocampal commissure**. The hippocampal commissure provides a path whereby the hippocampi communicate with each other. The fibers decussate in the commissure and continue as a conjoined mass beneath the corpus callosum called the **body of the fornix** which reaches the anterior commissure. From the body, two conjoined **columns of the fornix** arch down anterior to the thalami and each divides into anterior and posterior fibers. The anterior fibers run to the septal nuclei near the lamina terminalis while the posterior fibers run to the mamillary body. Some fibers from the fornix also pass through the anterior commissure to the contralateral hippocampus. This is the second of the two major paths by which the hippocampi communicate with each other.

The **mammillary bodies** are a pair of small round bodies, located on the undersurface of the brain, as part of the diencephalon related to the limbic system. They are located at the ends of the anterior arches of the fornix. They consist of two groups of nuclei, the medial mammillary nuclei and the lateral mammillary nuclei.

Neurophysiology of the Limbic System

The limbic system, via the hypothalamus and its connections with the outflow of the autonomic nervous system and its control of the endocrine system, is able to influence many aspects of emotional behavior. These include particularly the reactions of fear and anger and the emotions associated with sexual behavior and pleasure sensation. There is also evidence that the limbic system is concerned with memory and learning.

The following table demonstrates the main functions of the major parts of the limbic system and the disorders that may result from their disruption.

Functions and disorders of the limbic system		
Component	**Main function**	**Related disorders**
Amygdala	Signals the cortex of motivationally significant stimuli (e.g. reward/fear) & social functions (e.g. mating).	Anxiety, autism, depression, post-traumatic stress disorder, phobias
Hippocampus/Dentate gyrus	**Learning (Conversion of short-term memories to long-term memories)**	**Anterograde amnesia, Alzheimer's disease**
Parahippocampal gyrus	Spatial memory formation	Alzheimer's disease, Navigational disability
Septal nuclei	**Reward & pleasure center**	**Neuropsychiatric disorders (Schizophrenia, Bipolar),**
Mammillary bodies	Formation of recognition memory	Prosopagnosia
Insular cortex	**Social emotions**	**Addictive behavior**

THE DIENCEPHALON

The diencephalon is the median part of the forebrain that develops from the cranial end of the neural tube between the two cerebral hemispheres, just cranial to the midbrain. The slit-like cavity of the diencephalon is the third ventricle, continuous laterally with the lateral ventricles via the interventricular foramina and caudally with the cerebral aqueduct. The cranial end of the neural tube forms the anterior wall of the 3rd ventricle by developing into a thin sheet of grey matter called the ***lamina terminalis***.

On a median section, this lamina extends from the rostrum of the corpus callosum and the anterior commissure above to the optic chiasma below. A thin partition is also seen connecting the rostrum, genu and front of the body of the corpus callosum to the anterior column of the fornix. This partition is the ***septum pellucidum***, which is composed of two adherent layers. The two layers may be separated by the small cavity of the septum between them.

The different parts of the diencephalon are seen forming the lateral walls, roof and floor of the 3rd ventricle. The roof and floor converge posteriorly towards the midbrain. The ***hypothalamic sulcus*** is a clear groove seen on the lateral wall curving from the interventricular foramen (just below the thalamus) to the cerebral aqueduct. The sulcus divides the diencephalon into dorsal (upper) and ventral (lower) parts. The following are the components of each part:

1. ***The dorsal diencephalon:***
   a. Thalamus
   b. Metathalamus
   c. Epithalamus

2. ***The ventral diencephalon:***
   a. Hypothalamus
   b. Subthalamus

The Thalamus

The thalamus is a large oval (egg-shaped) mass of grey matter situated in the lateral wall of the 3rd ventricle and the floor of the body of the lateral ventricle. Each thalamus is about 3cm long and 1.5 cm wide, lying obliquely with its long axis directed backwards and laterally. The small anterior ends of the two thalami are nearer to the median plane while the large posterior ends are separated from each other by the pineal body, superior colliculi and habenular triangles. In 60% of brains, the two thalami adhere to each other in the midline; and are gummed together at the ***interthalamic connection***. This connection is not a commissure (i.e. there is no interchange of fibers between the two sides). The thalamus functions as an "executive secretary" to the cortex; a relay center between cortical and subcortical areas.

Parts and Surfaces

- The ***anterior*** *narrow* ***end*** is the ***tubercle*** of the thalamus. It forms the posterior boundary of the interventricular foramen.
- The ***posterior*** *expanded* ***end*** is the ***pulvinar****.* It overlies the geniculate bodies (metathalamus) and superior colliculus (midbrain).
- The ***lateral surface*** is applied to the posterior limb of the internal capsule.
- The ***medial surface*** forms part of the lateral wall of the 3rd ventricle and may be connected to its fellow anteriorly at the interthalamic adhesion.
- The ***inferior surface*** rests on the hypothalamus and subthalamus.
- The ***superior surface*** is applied laterally to the body of the lateral ventricle and medially to the tela choroidea of the 3rd ventricle.

The thalamic white matter and nuclear divisions

There are three groups of white matter fibers that allow the thlamaus to connect to the cortical and subcortical areas.

- The **thalamic radiations** are fiber bundles that emerge from the lateral surface of the thalamus and terminate in cerebral cortex.
- The **exrtemal medullary lamina** is a layer of myelinated fibers on the lateral surface of the thalamus close to the internal capsule that separates the thalamic reticular nucleus from the other thalamic nuclei.
- The **internal medullary lamina** is a vertical sheet of white matter that bifurcates in its anterior portion (like a Y) and divides the gray matter of the thalamus into lateral, medial, and anterior nuclear groups. The anterior group lies between the limbs of the Y, and the medial and lateral parts lie on the sides of the stem of the Y **[figure 18]**.

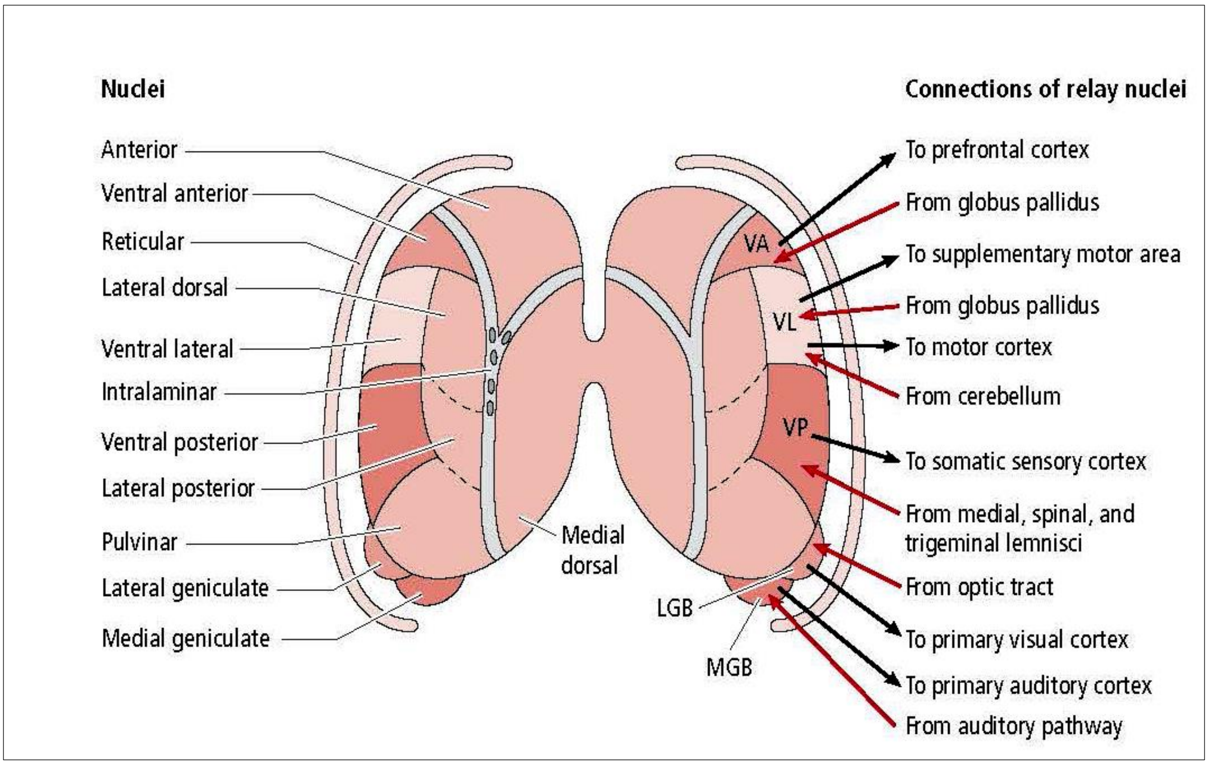


Figure 18: The thalamic nuclei and divisions (LGB; lateral geniculate body, MGB: medial geniculate body).

The thalamic nuclear regions and nuclear group

The **main thalamic nuclei** are arranged in the three thalamic areas as follow:

- The **anterior part** contains the **anterior nucleus (AN)**.
- The **medial part** contains the large **dorsomedial (DM) nucleus**, and the small **midline nuclei** that lie at the interthalamic adhesion.
- The **lateral part** is subdivided into ventral and dorsal parts:
  - The **dorsal part** contains the **lateral dorsal (LD) nucleus**, **lateral posterior (LP) nucleus** and **pulvinar**.
  - The **ventral part** contains the **ventral anterior (VA) nucleus, ventral lateral (VL) nucleus, ventral posterlateral (VPL) nucleus and ventral posteromedial (VPM) nucleus.** The VPL and VPM nuclei form the large **ventral posterior (VP) nucleus.**
- **Additional nuclei** include the **intralaminar (centromedian [CM]) nuclei** inside the internal medullary lamina and the **reticular nucleus** on the lateral surface separated from other nuclei by the external medullary lamina.

According to their function, these nuclei are divided into **motor**, **sensory**, **limbic** and **associational**.

Summary of the thalamic nuclei groups, types and functions			
Nuclear group	**Subnucleus**	**Type**	**Established function**
Anterior	AN	Limbic	Memory formation
Medial	DMN	Limbic	Emotional behavior
	Midline	Sensory	Unknown
Lateral	LD	Associational	Integration of sensory information and emotional behavior
	LP	Associational	
	Pulvinar	Associational	Integration of sensory information and modulation of spatial attention
	VA	Motor	Facilitate movement
	VL	Motor	Facilitate movement
	VPL	Sensory	Somatosensory relay of the body
	VPM	Sensory	Somatosensory relay of face, taste relay
Additional	Intralaminar	Associational	Relay of pain
	Reticular	Associational	Regulate flow of information from thalamus to cortex, modulation of arousal and sleep

Lesions of the Thalamus

Since the thalamus is such an important relay and integrative center, it follows that disease of this area of the central nervous system will have profound effects. The thalamus may be invaded by tumor, undergo degeneration following disease of its arterial supply, or be damaged by hemorrhage.

- ***Sensory Loss***

These lesions usually result from thrombosis or hemorrhage of one of the arteries supplying the thalamus. Damage to the ventral posteromedial nucleus and the ventral posterolateral nucleus will result in the loss of all forms of sensation, including light touch, tactile localization and discrimination, and muscle joint sense from the opposite side of the body.

- ***Thalamic Pain***

Thalamic pain may occur as the patient is recovering from a thalamic infarct. Spontaneous pain, which is often excessive (thalamic overreaction), occurs on the opposite side of the body. The painful sensation may be aroused by light touch or by cold and may fail to respond to powerful analgesic drugs.

- ***Abnormal Involuntary Movements***

Choreoathetosis with ataxia may follow vascular lesions of the thalamus. It is not certain whether these signs in all cases are due to the loss of function of the thalamus or to involvement of the neighboring caudate and lentiform nuclei. The ataxia may arise as the result of the loss of appreciation of muscle and joint movement caused by a thalamic lesion.

Surgical Relief of Pain by Thalamic Cauterization

The intralaminar nuclei of the thalamus are known to take part in the relay of pain to the cerebral cortex. Cauterization of these nuclei has been shown to relieve severe and intractable pain associated with terminal cancer.

The Metathalamus

The metathalamus consists of the medial and lateral geniculate bodies which are situated on each side of the dorsal surface of the thalamus.

The medial geniculate body and auditory pathway

The medial geniculate body (MGB) forms part of the auditory pathway and is a swelling on the posterior surface of the thalamus beneath the pulvinar. Afferent (cochlear) fibers to the medial geniculate body form the inferior brachium and arise from the inferior colliculus of the midbrain. The medial geniculate body receives auditory information from both ears but predominantly from the opposite ear (i.e. hearing is bilaterally presented on the cerebral cortex). The efferent fibers leave the medial geniculate body to form the auditory radiation, which passes to the auditory cortex of the superior temporal gyrus. ***Because the auditory pathway above the cochlear nuclei represents parts of the sound input to both ears, a unilateral lesion in the lateral lemniscus, medial geniculate body, or auditory cortex does not result in marked loss of hearing on the ipsilateral side.*** The auditory pathway is summarized in the diagram below.

Ear	• Organ of corti cells axons form the afferent (cochlear) fibers of the vestibulocochlear nerve
Medulla oblongata	• Cochlear fibers end in the cochlear nuclei and 2 sets of fibers arise. • Dorsal fibers cross the pontine tegmentum to the contralateral lateral lemniscus, Ventral fibers synapse bilaterally in superior olivary nucleus complex to the bilateral lateral lemnisci.
Midbrain	• The lateral lemniscus ends at the inferior colliculus of the midbrain
Metathalamus	• The medial geniculate body (MGB) receives the inferior brachium from the inferior colliculus of the midbrain.
Cerberal Hemisphere	• The auditory radiation arises from the MGB, passes through the sublentiform part of the internal capsule to reach the auditory cortex (temoral lobe).

The lateral geniculate body and the visual pathways

The lateral geniculate body (LGB) forms part of the visual pathway and is a swelling on the undersurface of the pulvinar of the thalamus, just anterolateral to the MGB. The nucleus consists of six layers of nerve cells and is the terminus of all but a few fibers of the optic tract (except the fibers passing to the pretectal nucleus). The fibers are the axons of the ganglion cell layer of the retina and come from the temporal half of the ipsilateral eye and from the nasal half of the contralateral eye, the latter fibers crossing the midline in the optic chiasma. Each lateral geniculate body, therefore, receives visual information from the opposite field of vision. The efferent fibers leave the lateral geniculate body to form the visual radiation, which passes to the visual cortex of the occipital lobe

- *The visual pathway* ***[figure 19]*** *begins at the optic nerve which is composed of the axons of the ganglionic cells of the retina. At the optic foramen the dura and arachnoid leave it and the nerve, still sheathed in pia, passes up to meet its fellow at the optic chiasma at the anterior part of the floor of the 3rd ventricle.*
- *In the chiasma, the nasal fibers of each optic nerve decussate and pass into the optic tract of the opposite side while the temporal fibers continue in the tract of the same side. Therefore, each optic tract contains fibers from the ipsilateral sides of the 2 retinae (i.e. contralateral sides of the visual fields) e.g. the right optic tract has fibers from the temporal side (right retinal half) of the right eye and fibers from the nasal side (right retinal side) of the left eye, both carry information about the left half of the visual field.*
- *The optic tract passes from the chiasma around the cerebral peduncle (crus cerebri) to reach the side of the thalamus where it divides into 2 roots:*

  - *The lateral root is the larger branch which carries visual fibers that enter the lateral geniculate body to synapse. From the lateral geniculate body, the optic radiation passes through the retrolentiform part of the internal capsule and spreads in the parietal and temporal lobes.* The *Parietal radiations carry fibers from the superior retinal quadrants that detect information from the inferior visual fields, they end in the lower lip of the calcarine sulcus. The Temporal radiations (Meyer's loop) carry fibers from inferior retinal quadrants that detect information from the superior visual fields, they end in the upper lip of the calcarine sulcus.*
  - *The medial smaller root is the superior brachium which passes from the optic tract to the midbrain and synapse in the superior colliculus and pretectal nucleus of the midbrain. The fibers of the superior brachium are concerned with mediating the light reflex. Fibers which synapse in the superior colliculus continue as tectobulbar and tectospinal tracts to the motor nuclei of the general light reflex (e.g. reflex blinking or turning away from a flash or bright light). Fibers which synapse in the pretectal nucleus continue to the Edinger-*

Westphal nucleus (accessory oculomotor nucleus) and then via the oculomotor nerve to supply the sphincter papillae and ciliary body and mediate the pupillary light reflex.

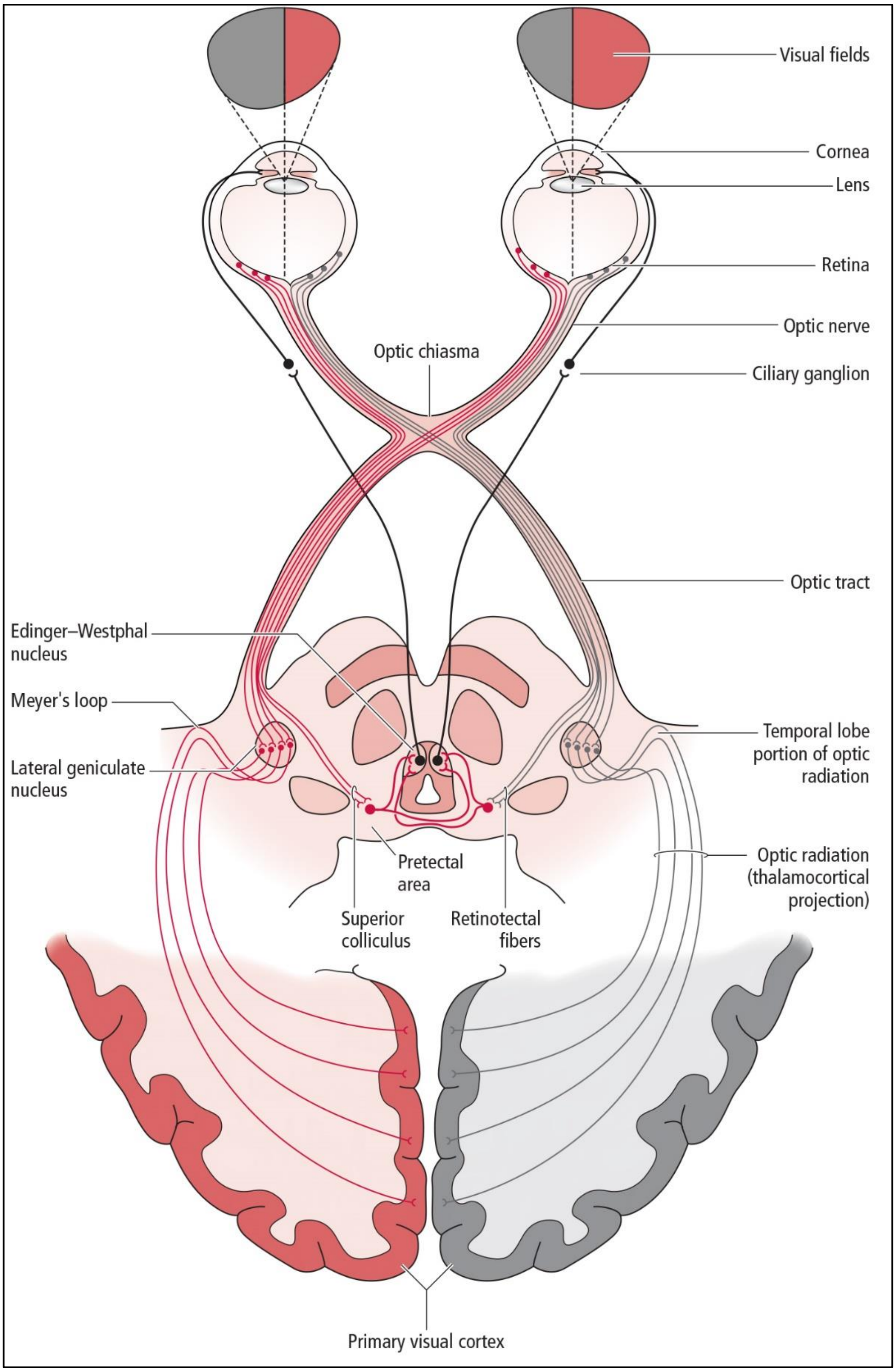


Figure 19: The visual pathway.

Lesions of the visual pathway [figure 20]

1. Complete damage to the optic nerve leads to complete blindness in the corresponding eye.
2. Compression of the optic chiasma at the midline (e.g. pituitary tumors) causes blindness in the temporal half of both visual fields (Bipolar (hetronymous) hemianopia).
3. Compression of the optic chiasma at its angle with the optic tract results in loss of vision in the ipsilateral nasal half of the visual field only (Ipsiltaeral nasal hemianopia)
4. Lesions to an optic tract cause blindness of the contralateral halves of both visual fields (Contralateral homonymous hemianopia).
5. Damage to the lower fibers of the optic radiation causes a contralateral lower quadrantic homonymous hemianopia.
6. Damage to the upper fibers of the optic radiation (rare) causes contralateral upper quadrantic homonymous hemianopia.
7. Damage to the anterior part of the visual cortex (e.g. from occlusion of the posterior cerebral artery) causes contralateral homonymous hemianopia similar to lesions of the optic tract but the macular (central) vision is usually spared.
8. Damage to the occipital pole tip causes contralateral homonymous macular defect.

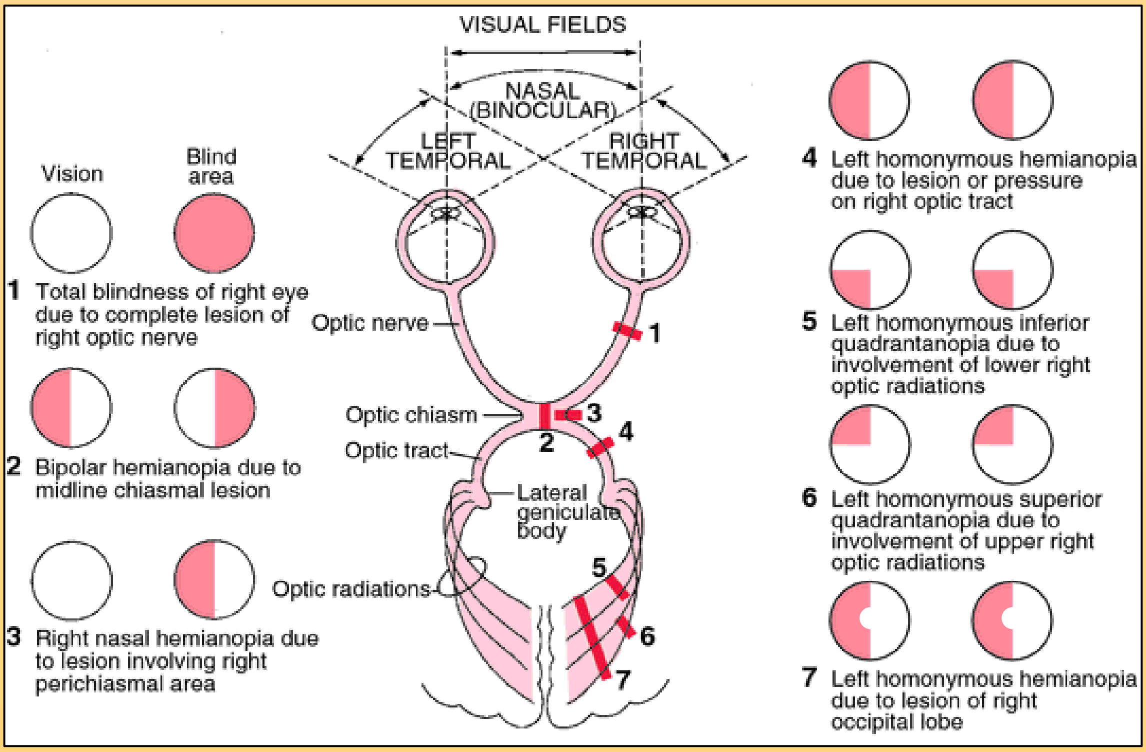


Figure 20: Lesions of the visual pathway.

The Epithalamus

The epithalamus occupies the caudal part of the roof of the diencephalon. It consists of the pineal body, the habenular nuclei and related commissures; the habenular commissure and the posterior commissure.

The Habenular Nuclei

Each habenular nucleus is situated beneath the floor of the *habenular trigone* which is a small depressed triangular area situated medial to the pulvinar. The habenular nucleus receives afferent fibers from the olfactory centers (some of which cross via the habenular commissure to the nucleus of the opposite side) and sends efferent fibers to the interpeduncular nucleus. It functions with the limbic system in *regulating mood and behavior*.

The Pineal Body (gland)

The pineal body (epiphysis cerebri) is a small conical body (<0.5 cm long) projecting posteroinferiorly below the splenium and between the superior colliculi of the midbrain. It consists of a small conical body and a peduncle (stalk) which divides anteriorly into two laminae. The superior lamina contains the habenualr commissure while the inferior lamina contains the posterior commissure. The hollow between the two laminae is the pineal recess of the 3^{rd} ventricle.

The pineal body is characterized by the absence of the blood-brain barrier and the presence of *corpora arenacea* (calcareous concretions or *brain sand*) which calcify with increasing age. The gland secretes melatonin and other substances which have an inhibitory effect on other endocrine glands and gonads. Its function is affected by the light-dark cycle of the day.

The Hypothalamus and Pituitary gland

The hypothalamus is the part of the diencephalon that extends from the region of the optic chiasma to the caudal border of the mammillary bodies, below the hypothalamic sulcus and thalamus. It forms the floor and the inferior part of the lateral walls of the third ventricle. Caudally, the hypothalamus merges into the tegmentum of the midbrain. The lateral boundary of the hypothalamus is formed by the internal capsule.

When observed from below, the hypothalamus is seen to be related to the following structures, from anterior to posterior: (1) the optic chiasma, (2) the tuber cinereum and the infundibulum, and (3) the mammillary bodies.

The hypothalamus is composed of **grey matter nuclei [figure 21]** arranged in three **zones** by parasagittal planes that contain the columns of the fornix and the mammilothalamic tract. These zones are **periventricular**, **medial** and **lateral**. They also aggregate in three **regions** anteroposteriorly: **anterior**, **middle** and **posterior**. According to which part they overlie, the regions and zones consist of four main regional groups: **preoptic** (just behind the lamina terminalis), **supra**-optic (above the optic chiasma and tract), **tuberal** (above the tber cinereum and infundibulum) and **mammillary** (above the mammillary bodies and anterior to the midbrain).

	Anterior region		Middle region	Posterior region
Zone	Preoptic region	Supraoptic (chiasmatic) region	Infundibular (tuberal) region	Mammillary region
Periventricular	Preoptic nucleus Periventricular nuclei	Suprachiasmatic nucleus Periventricular nuclei	Arcuate nucleus	
Medial	Medial preoptic nucleus	Anterior hypothalamic nucleus Paraventricular nucleus Supraoptic nucleus	Dorsomedial nucleus Ventromedial nucleus	Mammillary nuclei Posterior hypothalamic nuclei
Lateral	Lateral preoptic nucleus	Lateral hypothalamic nucleus	Lateral tuberal nuclei Lateral hypothalamic nucleus	Lateral hypothalamic nucleus

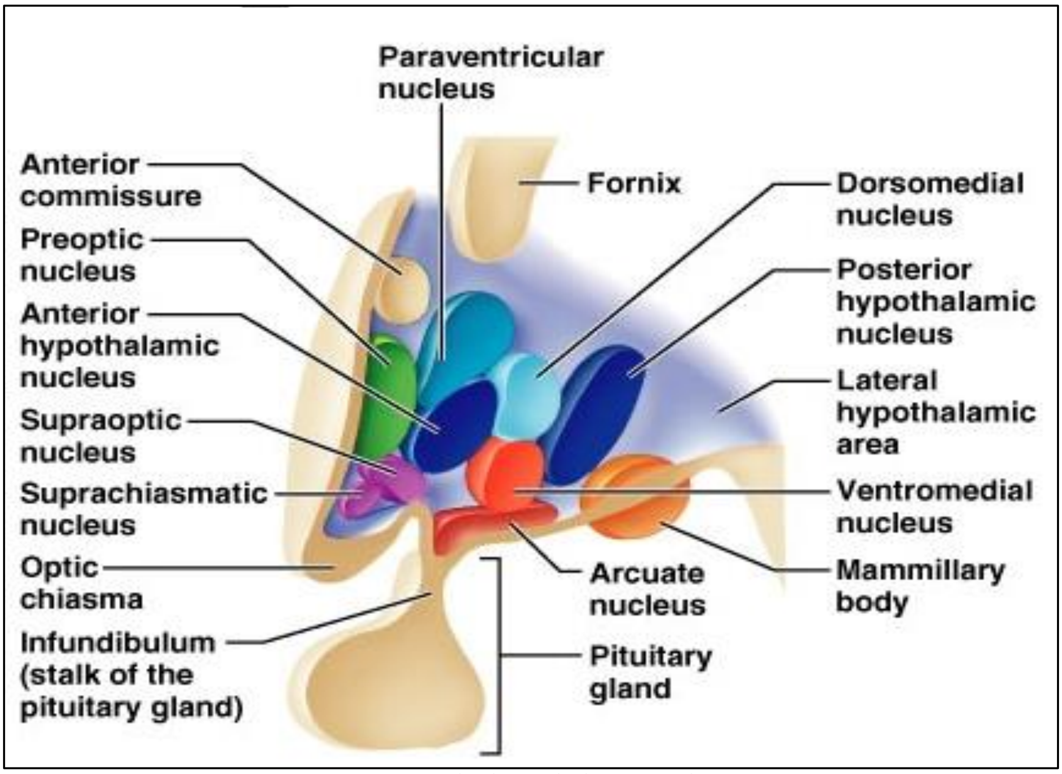


Figure 21: The hypothalamic nuclei.

The hypothalamus is considered the head ganglion that controls the autonomic nervous system and a complex neuroglandular structure concerned with the regulation hormonal release. Functionally, the hypothalamus may be divided into five parts:

- The anterior part controls the parasympathetic system.
- The posterior part controls the sympathetic system.
- The paraventricular (paramedian) part controls the endocrine system
- The medial part is concerned with enteric activities related to hunger and satiety.
- The lateral part is concerned with thermoregulation and control of cardiovascular functions.

The hypothalamus is also concerned with regulation of sexual behavior and reproduction; and control of the biological clocks and circadian rhythm.

Nucleus	Function(s)
Preoptic	Controls the release of reproductive hormones from the adenohypophysis
Suprachiasmatic	Regulates circadian rhythms; "master clock"
Arcuate	Produces hypothalamic releasing and inhibiting hormones
Periventricular	Produces hypothalamic releasing and inhibiting hormones
Medial preoptic	Regulates the release of reproductive hormones from the adenohypophysis
Anterior	Regulates parasympathetic nervous system activity Regulates body temperature; involved in body heat loss
Dorsomedial	Stimulation of this nucleus causes savage behavior in animals
Ventromedial	Involved in eating behavior; "satiety center"
Mammillary	Processes information related to emotional expression
Posterior	Regulates sympathetic nervous system activity Regulates body temperature Involved in heat conservation and heat production; "thermostat"
Lateral preoptic	Unknown
Lateral	Regulates sympathetic nervous system Involved in eating behavior; "feeding center"
Paraventricular	Produces ADH and oxytocin
Supraoptic	Produces ADH and oxytocin

ADH, antidiuretic hormone.

The pituitary gland and the hypothalamohypophyseal connections [figure 22]

The pituitary gland (**hypophysis cerebri**) is a pea-sized, compound endocrine gland that weighs 0.5 g in males and 1.5 g in multiparous women. It is centrally located at the base of the brain, where it lies in a saddle-shaped depression of the sphenoid bone called the **sella turcica** (hypophyseal fossa). A short **stalk**, the **infundibulum**, and a vascular network connect the pituitary gland to the hypothalamus. The pituitary gland has two functional components: **anterior lobe** (**adenohypophysis**) is the glandular **epithelial tissue**, the **posterior lobe** (**neurohypophysis**) is the **neural secretory tissue**.

These two portions are of different embryologic origin. The anterior lobe of the pituitary gland is derived from an evagination of the **ectoderm** of the **oropharynx** toward the brain (**Rathke's pouch**). The posterior lobe of the pituitary gland is derived from a downgrowth (the future infundibulum) of neuroectoderm of the floor of the third ventricle of the developing brain.

The anterior lobe of the pituitary gland consists of three derivatives of Rathke's pouch:

- **Pars distalis** comprises the bulk of the anterior lobe of the pituitary gland and arises from the thickened anterior wall of the pouch
- **Pars intermedia** is a thin remnant of the posterior wall of the pouch that abuts the pars distalis
- **Pars tuberalis** develops from the thickened lateral walls of the pouch and forms a collar or sheath around the infundibulum

The embryonic infundibulum gives rise to the posterior lobe of the pituitary gland. The posterior lobe of the pituitary gland consists of the following:

- **Pars nervosa**, which contains neurosecretory axons and their endings.
- **Infundibulum**, which is continuous with the median eminence and contains the neurosecretory axons forming the hypothalamohypophyseal tracts.

The hypothalamus is connected to the pituitary gland by two pathways: the hypothalamohypophyseal tracts and the hypophyseal portal system.

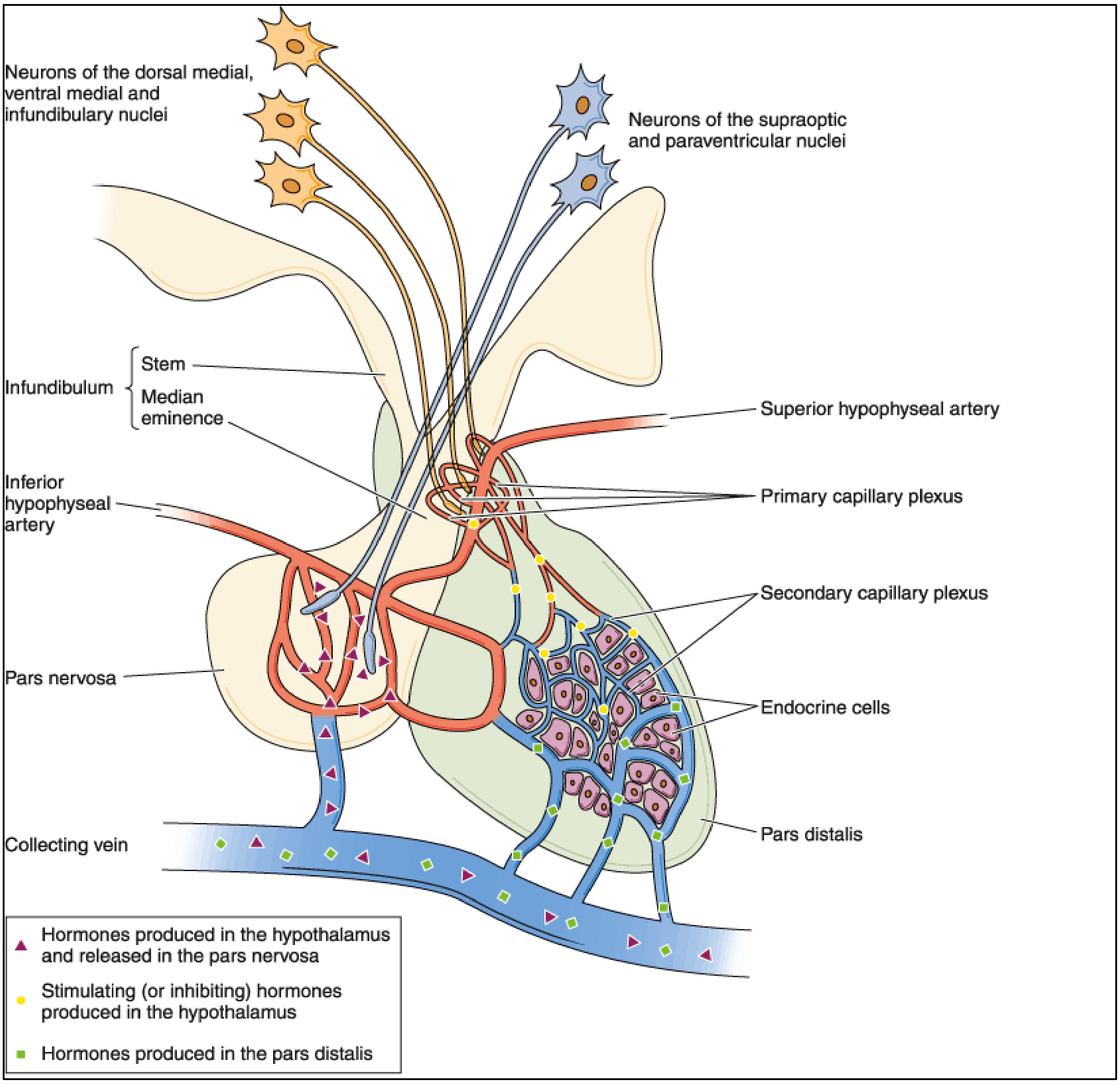


Figure 22: The pituitary gland and its connections to the hypothalamus.

- The **hypothalamohypophyseal tracts** are nerve fibers that travel from the supraoptic and paraventricular nuclei to the posterior lobe of the hypophysis. The hormones vasopressin (ADH) and oxytocin are synthesized in the nerve cells of the supraoptic and paraventricular nuclei. The hormones are passed along the axons together with carrier proteins called neurophysins and are released at the axon terminals. Here, the hormones are absorbed into the bloodstream in fenestrated capillaries of the posterior lobe of the hypophysis.
- The **hypophyseal portal system** is formed on each side mainly from the **superior hypophyseal artery**, which is a branch of the internal carotid artery. The artery

enters the median eminence and divides into tufts of capillaries. These capillaries drain into long and short descending vessels that end in the anterior lobe of the hypophysis by dividing into vascular sinusoids that pass between the secretory cells of the anterior lobe. The portal system carries the releasing hormones and the release-inhibiting hormones from the hypothalamic nuclei to the secretory cells of the anterior lobe of the hypophysis. The neurons of the hypothalamus that are responsible for the production of the releasing hormones and the release-inhibiting hormones are influenced by the afferent fibers passing to the hypothalamus. They also are influenced by the level of the hormone produced by the target organ controlled by the hypophysis. The **inferior hypohyseal artery** provides blood supply to the neurohypophysis and does not participate in the hypophyseal portal system.

The Subthalamus

The subthalamus is the smallest area of the diencephalon lying between the midbrain and the thalamus, medial to the internal capsule. Its grey matter consists of the subthalamic nucleus, zona incerta and the cranial ends of the red nucleus and substantia nigra of the midbrain.

The subthalamic nucleus appears to have inhibitory control on the globus pallidus and motor cortex. The zona incerta is a thin lamina of grey matter lying dorsal to the subthalamic nucleus with unknown function.

ARTERIAL SUPPLY OF THE BRAIN

The blood supply of the brain is derived from two pairs of arteries: a pair of **internal carotid arteries** that form the **carotid system** and a pair of **vertebral arteries**. The two vertebral arteries unite at the lower border of the pons to form the **basilar artery** (**vertebrobasilar system**). The cerebral arterial supply is peculiar in four aspects:

- The arterial supply is **directed mainly to the grey matter**, which needs more blood than the white matter. There are two types of cerebral arteries supplying the grey matter. The **superficial** or **cortical arteries** supply the grey matter of the **cortex**. **Perforating** or **central arteries** (through the anterior and posterior perforated substances) supply the **subcortical grey matter** (basal nuclei, thalamus, cranial nerve nuclei…etc.). Both types of arteries send branches to the adjacent white matter.
- The cerebral arteries anastomose freely with each other in the subarachnoid space, but once they perforate the surface of the brain, they become **end arteries**. Cerebral arteries invaginate a tubular sheath of pia and arachnoid matter around them forming a **perivascular space** that extends to the fine branches of the vessels.
- There is a free anastomotic circle (**arterial circle of Willis**) between the carotid and basilar system of arteries in the interpeduncular cistern. The circle allows equalization of blood pressure and flow between the two sides of the brain.
- The brain vasculature is characterized by the presence of the **blood-brain barrier** that permits selective passage of substances to the brain tissue.

The carotid arterial system of the brain

The **intracranial part** of the internal carotid artery may be divided into **three segments**. As it enters the skull through the carotid canal within the petrous bone it forms the **petrous segment**. The **cavernous segment**, usually called the **carotid siphon** because of its shape, is the portion of the artery within the cavernous sinus and provides minor branches supplying the posterior pituitary (meningohypophyseal artery) and the abducens nerve. The ophthalmic artery arises from this segment just as it pierces the dura and emerges from the cavernous sinus to pass through the optic canal into the orbit with the optic nerve. The **supraclinoid segment** is the last portion of the internal carotid artery. It begins when this segment penetrates the dura. The *posterior communicating artery* and the *anterior choroidal artery and the small striate arteries are* given at this level. The internal carotid artery then ends by bifurcating into *the anterior cerebral artery* and *middle cerebral artery*.

Cerebral branches of the internal carotid artery

- The **posterior communicating artery** is usually a slender branch that passes backwards across the crus cerebri to join the posterior cerebral artery.
- The **anterior choroidal artery** arises above the posterior communicating artery and passes posterolaterally close to the optic tract and above the uncus to enter the **choroid plexus of the inferior horn of the lateral ventricle.**
- The **striate arteries** enter the **anterior perforated substance** and supply the internal capsule, thalamus and basal nuclei. Anatomically, they are divided into lateral (large) and medial (small) groups.
- The **anterior cerebral artery** leaves the internal carotid at the anterior perforated substance and passes forwards above the optic nerve where it connects to its fellow of the opposite side by the **anterior communicating artery.** From here it curves upwards and backwards running on the superior surface of the corpus callosum in the cingulate sulcus. Its branches ramify to be distributed to the medial surface of the hemisphere as far backwards as the splenium of the corpus. They also extend to a gyrus breadth of the upper part of the superolateral surface of the hemisphere.
- The **middle cerebral artery** is the largest branch and represents the direct continuation of the internal carotid (thus most susceptible for embolism). It runs deep in the lateral sulcus (over the insula) and its branches emerge from the lateral sulcus to supply all the superolateral surface of the hemisphere to a level that falls one gyrus breadth short from the border of the superolateral surface.

The vertebrobasilar arterial system of the brain

The 4th part of the vertebral artery

The **4th part** of each **vertebral artery** passes from the **suboccipital triangle** to enter the **posterior cranial fossa** through the **foramen magnum**. It gives meningeal branches and the posterior spinal artery and then it pierces the dura and arachnoid to give the *posterior inferior cerebellar artery* (PICA) and anterior spinal artery. Each vertebral artery then runs anterosuperiorly towards the midline on the ventral surface of the medulla oblongata giving off its medullary branches. The two vertebral arteries unite in the midline at the lower border of the pons to form the **basilar artery**.

Branches of the 4th part of the vertebral artery

- The **meningeal branches** supply the meninges of the posterior cranial fossa.
- The **posterior spinal artery** arises just before the vertebral artery pierces the meninges. It descends to the spinal cord.
- The **posterior inferior cerebellar artery (PICA)** arises just after the vertebral artery pierces the meninges. It curves around the side of the medulla oblongata to reach its posterior surface where it turns to the lower surface of the cerebellum.
- The **anterior spinal artery** is a **single median artery** formed by the union of a branch from each vertebral artery. It descends supplying the medulla and continues anterior to the spinal cord.
- The **medullary arteries** are numerous small branches distributed to the medulla oblongata.

The basilar artery

The basilar artery is a **single median artery** formed by the union of the two vertebral arteries at the lower border of the pons. Here it gives two anterior inferior cerebellar arteries and two labyrinthine arteries above them. It then ascends on the pons giving multiple pontine arteries. Near the upper border of the pons it gives two superior cerebellar arteries and ends by dividing into two posterior cerebral arteries.

Branches of the basilar artery (all in pairs)

- The **anterior inferior cerebellar artery** runs laterally and loops around the flocculus of the cerebellum to supply its anteroinferior surface.
- The **labyrinthine artery** accompanies the VIII nerve to the internal ear and supplies part of the VII nerve.
- The **pontine arteries** supply the pons.
- The **superior cerebellar artery** winds backwards around the upper border of the pons and the middle cerebellar peduncle supplying both and the upper part of the cerebellum and lower part of the midbrain.
- The **posterior cerebral arteries** diverge at the upper border of the pons, give central branches into the interpeduncular fossa and then each curves posteriorly on the inferomedial surface of the corresponding hemisphere towards the occipital pole. Each posterior cerebral artery is joined at this curve by the posterior communicating branch of the middle cerebral artery

The Cerebral Arterial Circle of Willis

This anastomotic circle lies at the base of the brain in the interpeduncular cistern. It is formed anteriorly by the anterior communicating artery connecting the two anterior cerebral arteries. Posteriorly, it is formed by the basilar artery as it divides into the posterior cerebral arteries. On the sides, it is formed by posterior communicating arteries connecting the middle to the posterior cerebral arteries.

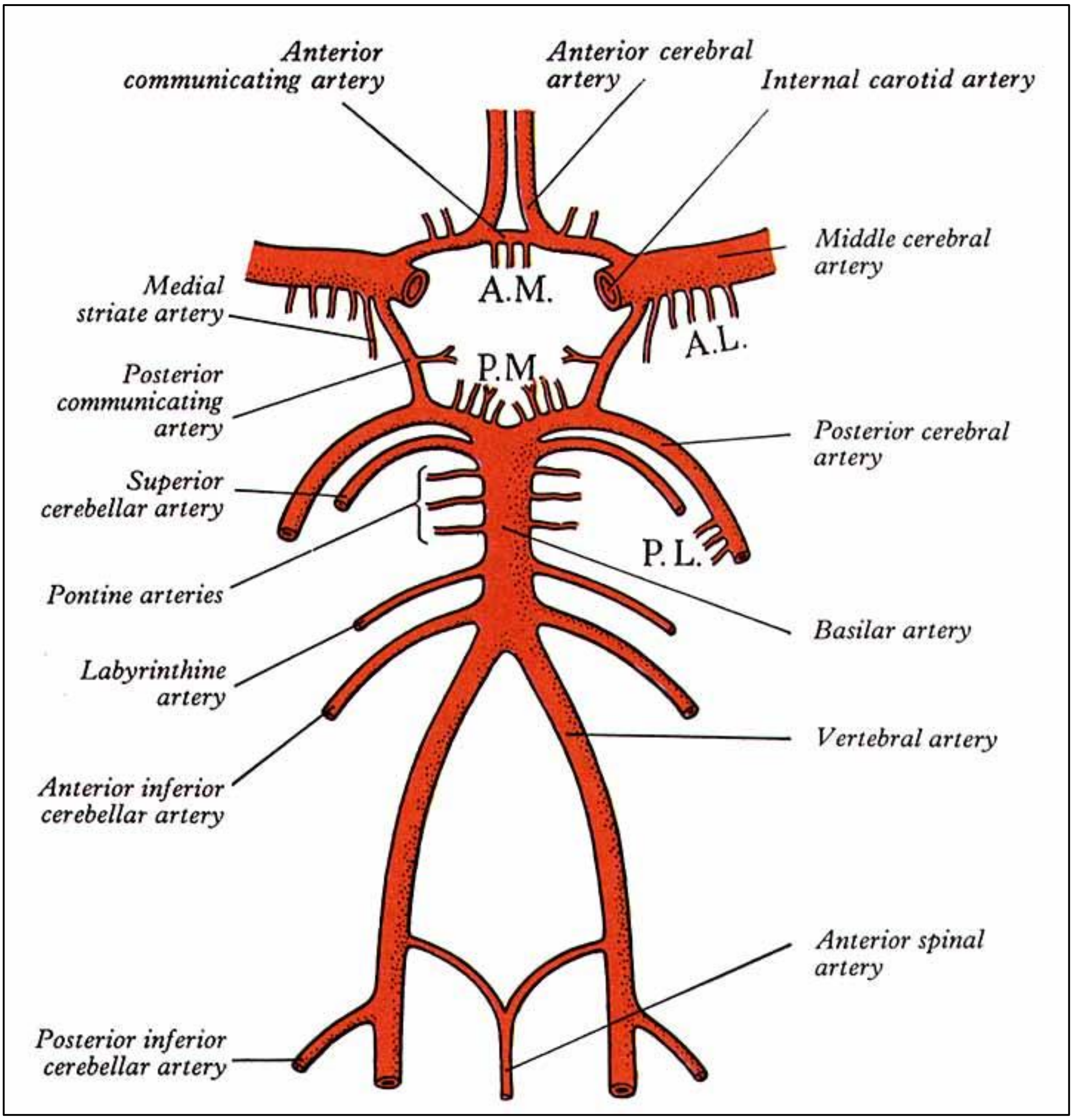


Figure 23: the arterial circle of Willis and the main cerebral bracnhes of the carotid and vertebrobasillar systems. (The striate arteries are indicated by the letters: AL: anterior lateral, AM: anterior medial, Pl: posterior lateral, PM: posterior medial)

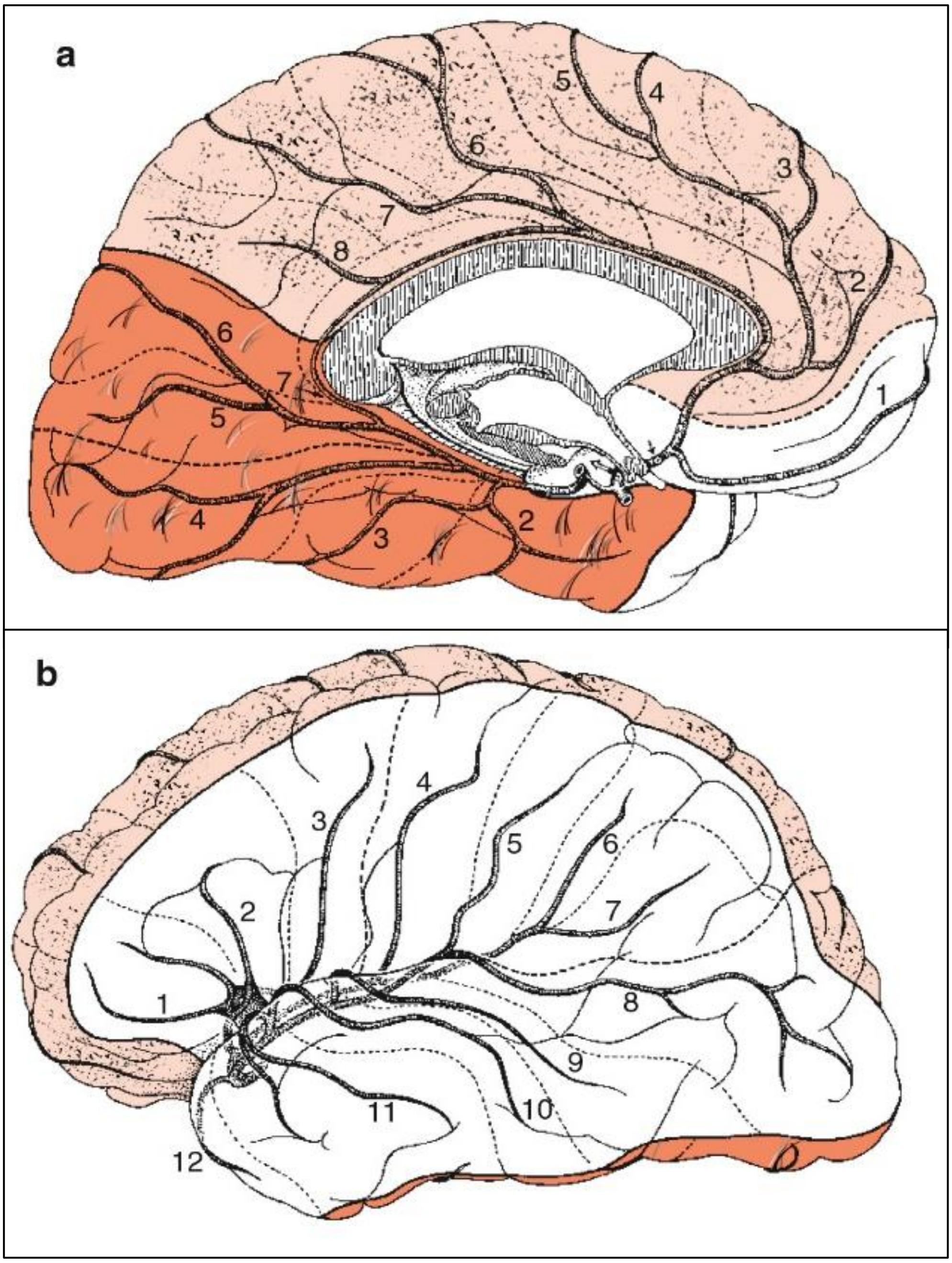


Figure 24: vascularization of the cerebral cortex.

(**a**) Vascularization of the medial surface of the cerebral cortex by the anterior (ACA in *light dotted color*) and posterior (PCA in *dark color*) cerebral arteries. The vascular territory of the middle cerebral artery (MCA) is uncoloured. The ACA gives off the following branches: *1* orbitofrontal artery; *2* frontopolar artery; *3–5* anterior, middle and posterior frontal arteries; *6* paracentral artery; *7*, *8* superior and inferior parietal arteries. The PCA divides into: *1* hippocampal arteries (not shown); *2–4* anterior, middle and posterior temporal arteries; *5* calcarine artery; *6* parieto-occipital artery; *7* splenial artery.

(**b**): Vascularization of the lateral surface of the cerebral cortex, largely by the middle cerebral artery (MCA; uncoloured). The MCA gives off the following branches: *1* orbitofrontal artery; *2* prefrontal artery; *3* precentral artery; *4* central artery; *5*, *6* anterior and posterior parietal arteries; *7* angular artery; *8* temporo-occipital artery; *9–11* posterior, middle and anterior temporal arteries; *12* temporopolar artery.

The following table summarizes the territorial supply of the main cerebral arteries and the resulting clinical syndromes of their damage.

Artery	Brain area supplied	Clinical effect of arterial damage
Anterior Cerebral	Medial upper frontal and parietal lobes, paramedian cortex, rostral corpus callosum, anterior limb of internal capsule, rostral putamen and caudate nucleus	Contralateral weakness of the foot and leg (lower monoplegia), abulia (lack of initiative), urinary incontinence
Middle Cerebral	Cortical areas: Lateral frontoparietal and temporal areas including the angular gyrus (Wernick's area) Subcortical areas: corona radiata, striatum, posterior limb of internal capsule	Contralateral hemiplegia and hemianastheisa (face and arm > leg), aphasia (dominant hemisphere), variable visuospatial neglect (non-dominant hemisphere), contralateral gaze paresis
Posterior Cerebral	Mediobasal temporal lobe, occipital lobe Midbrain, thalamus	Contralateral homonymous hemianopia with macular sparing (if purely cortical), Memory disturbance, colour dysnomia, agitated delirium, hemisensory deficits with thalamic stroke
Vertebral/PICA	Inferior/posterior aspects of cerebellar hemisphere, inferior vermis, inferior cerebellar peduncle, lateral medulla (spinothalamic tract and descending sympathetic tract)	Ipsilateral Horner, vertigo, nystagmus, ataxia, dysphagia, dysarthria, gaze paresis, pain/temperature deficits face (ipsilateral), trunk/extremities (contralateral)

VENOUS DRAINAGE OF THE BRAIN

Unlike other arteries of the body, which have corresponding veins, the cerebral arteries do not have venous counterparts. The **cerebral venous system** comprises the superficial and deep cerebral venous systems which are very richly anastomosed. The **superficial cerebral veins** drain the blood from the cerebral cortex and the subcortical white matter to the superior longitudinal sinus or the sinuses at the base of the brain. The **deep cerebral veins** drain the diencephalon, the basal ganglia, the deep white matter and the choroid plexuses into the internal cerebral veins and the great cerebral vein. The **dural venous sinuses** drain all the cerebral venous blood to the internal jugular vein. They are summarized in the following table.

Dural sinus	Location	Receives
Superior sagittal (single)	Superior border of falx cerebri	Superior cerebral, diploic, and emissary veins and CSF
Inferior sagittal (single)	Inferior margin of falx cerebri	A few cerebral veins and veins from the falx cerebri
Straight (single)	Junction of falx cerebri and tentorium cerebelli	Inferior sagittal sinus, great cerebral vein, posterior cerebral veins, superior cerebellar veins, and veins from the falx cerebri
Occipital (single)	In falx cerebelli against occipital bone	Communicates inferiorly with vertebral plexus of veins
Transverse (paired)	Horizontal extensions from the confluence of sinuses along the posterior and lateral attachments of the tentorium cerebelli	Drainage from confluence of sinuses (right-transverse and usually superior sagittal sinuses; left-transverse and usually straight sinuses); also superior petrosal sinus, and inferior cerebral, cerebellar, diploic, and emissary veins
Sigmoid (paired)	Continuation of transverse sinuses to internal jugular vein; groove parietal, temporal, and occipital bones	Transverse sinuses, and cerebral, cerebellar, diploic, and emissary veins
Cavernous (paired)	Lateral aspect of body of sphenoid	Cerebral and ophthalmic veins, and emissary veins from pterygoid plexus of veins and sphenoparietal sinuses
Sphenoparietal (paired)	Inferior surface of lesser wings of sphenoid	Diploic and meningeal veins
Superior petrosal (paired)	Superior margin of petrous part of temporal bone	Cavernous sinus, and cerebral and cerebellar veins
Inferior petrosal (paired)	Groove between petrous part of temporal bone and occipital bone ending in internal jugular vein	Cavernous sinus, cerebellar veins, and veins from the internal ear and brainstem

Intracranial Hemorrhage

There are four types of intracranial hemorrhage according to their location and source of bleeding:

- **Epidural hemorrhage**: blood collects between the dura and bone due to tearing of arteries, mainly the middle meningeal artery (e.g. after a skull fracture).
- **Subdural hemorrhage** results from tearing the bridging veins that connect the brain and dural sinuses.
- **Subarachnoid hemorrhage** blood collects in the subarachnoid space from a torn (cortical) cerebral artery, usually the result of leakage from an aneurysm in the region of Willis.
- **Intracerebral hemorrhage** results from rupture of a perforating (subcortical) cerebral artery within the brain substance.

THE VENTRICULAR SYSTEM & CSF CIRCULATION

The Lateral Ventricle (Cavity of the Cerebral Hemisphere)

The rapid growth & curling of the telencephalic dilatations of the brain vesicle causes them to draw the neural tube cavity within. The cavity of the hemispheres is therefore curved into a C-shaped lateral ventricle.

Each hemisphere contains a lateral ventricle lined with *ependyma*. The cerebrospinal fluid (CSF) filling the lateral ventricles flows through the interventricular foramina (of Monro) to the third ventricle (slit-like cavity of the diencephalon). Each interventricular foramen lies on the medial aspect of the hemisphere between the anterior column of the fornix (anteriorly) and the anterior pole of the thalamus (posteriorly) **(figure 25,26)**.

From the 3rd ventricle, the CSF runs down the cerebral aqueduct of Sylvius (cavity of the midbrain) to the fourth ventricle (cavity of the hindbrain). The fourth ventricle contains three foramina: 1 median (Foramen of Magendie) & two lateral (Foramina of Luschka) through which the CSF escapes the ventricle to the subarachnoid space of the brain & spinal cord. The circulating CSF is drained from the subarachnoid space to the intracranial venous sinuses via the arachnoid villi.

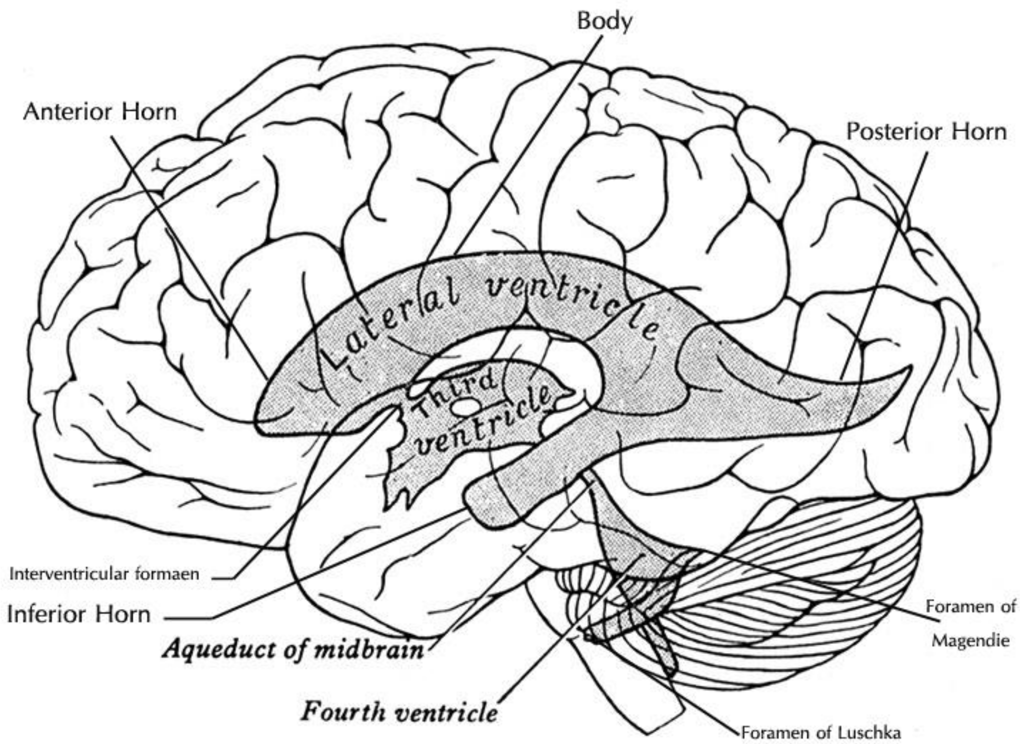


Figure 25: Lateral view of the ventricular system in situ & the foramina leading from one ventricle to another

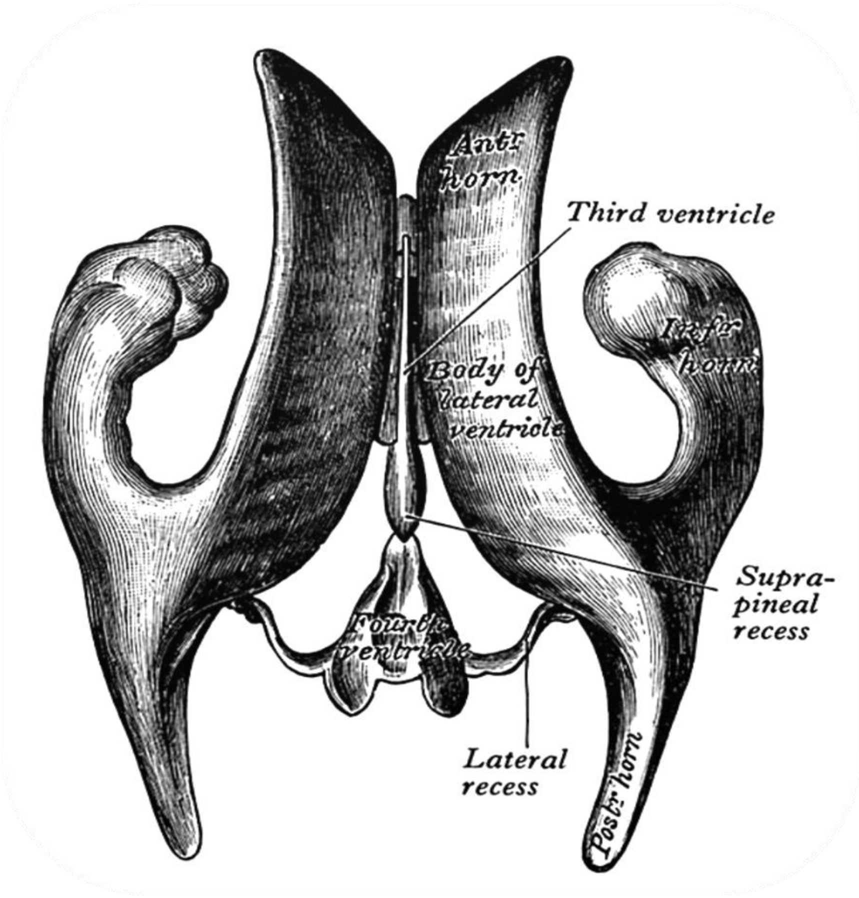


Figure 26: Superior View of the Ventricular System

About 5000 ml of CSF is produced daily but only 150 ml circulate around the central nervous system at any given time. This is efficiently achieved by the fact that the arachnoid villi act as one way valves allowing the drainage of the CSF from the subarachnoid space to the venous sinuses whenever the CSF pressure exceeds the blood pressure inside the sinuses.

Most of the CSF (80%) is formed by the choroid plexus of the lateral ventricle. The rest is formed by the choroid plexuses of the 3^{rd} & 4^{th} ventricles and possibly by the capillaries on the surface of the brain & spinal cord. On the medial side of the lateral ventricle, the pia matter (*tela choroidea*) & the ependyma come into contact with each other at a narrow line. The line curves around the top of the thalamus and the tail of the caudate nucleus, forming a C-shaped slit on the medial aspect of the hemisphere called the *choroid fissure*. A mass of blood capillaries enters the fissure invaginating the pia matter & ependyma before it. The combination of capillaries, pia & ependyma form the *choroid plexus* which secretes the CSF (**figure 27)**. The choroid plexus of the lateral ventricle lies in the floor of its body & the medial wall of its inferior horn & extends through the interventricular foramen to be continuous with the plexus of the 3^{rd} ventricle (it doesn't extend into the anterior horn). The choroid plexuses of the 3^{rd} & 4th ventricles lie in their roofs.

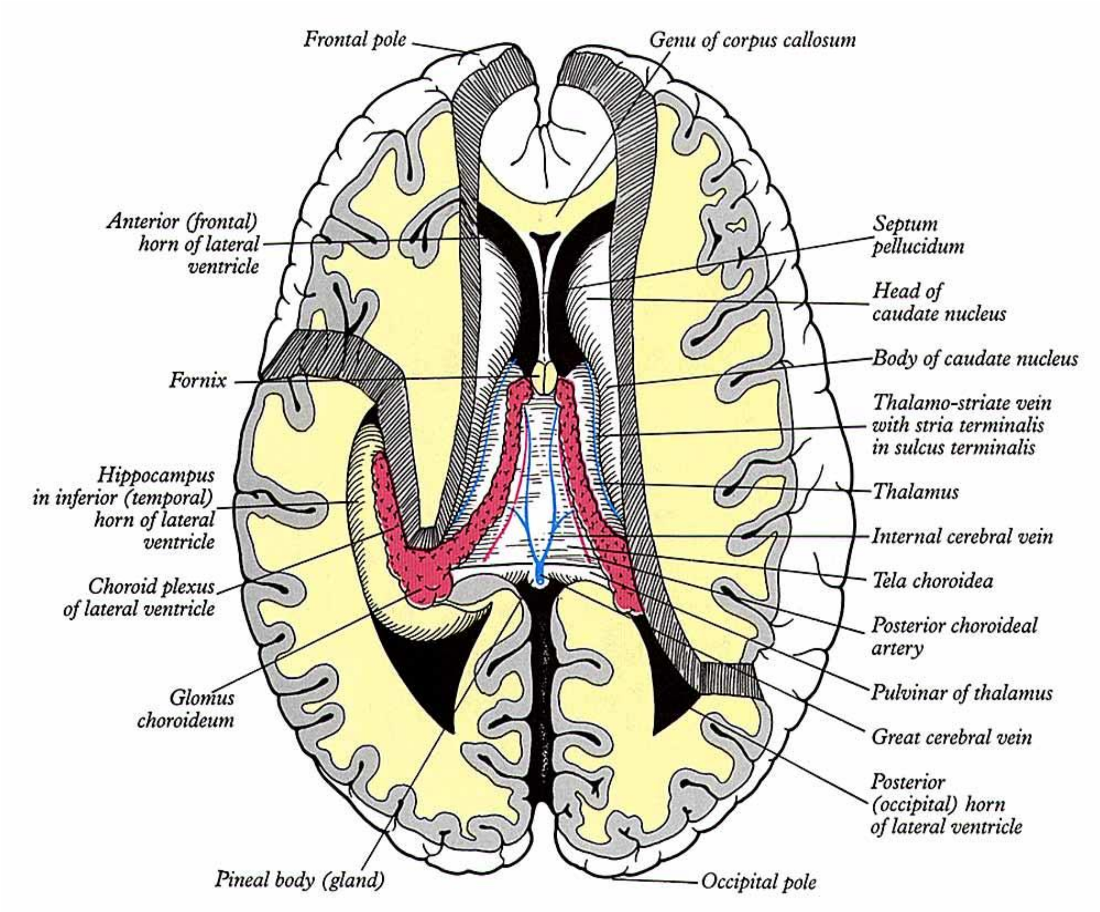


Figure 27: ***Exposure of the lateral ventricles from above to view the choroid plexus***

Parts & Relations of the Lateral Ventricle

Each lateral ventricle is composed of four parts: a body & 3 horns (cornu).

1. ***The anterior horn***: projects anterolaterally downwards into the frontal lobe. Its anterior end is closed by the genu & rostrum of the corpus callosum. In coronal section it appears triangular with a roof (above), floor (laterally) and a medial wall.

2. ***The body***: is the central part which lies behind the level of the interventricular foramen. In coronal sections it appears triangular anteriorly & rectangular posteriorly.

3. ***The posterior horn***: projects posteromedially into the occipital lobe. It's very variable in length and may be absent. It appears as a narrow triangular slit in coronal sections.

4. ***The inferior horn***: is the largest horn of the lateral ventricle projection into the temporal lobe from the junction of the body & posterior horn. It appears as a curved rectangle on coronal sections with the choroid plexus running on its medial wall.

It’s more applicable to know the main structures that lie in proximity of the lateral ventricle rather than knowing the details of the structures which form the walls of each part. The main structures adjoining the ventricle are the first to be affected if the CSF circulation is blocked & the ventricle is dilated applying pressure on the adjacent parts of the brain. Structures which adhere to and project into the cavity of the lateral ventricle include:

a. *Grey matter*: the hippocampal sulcus, calcarine sulcus, collateral sulcus, caudate nucleus & thalamus.

b. *White matter*: corpus callosum, fimbria, fornix, optic radiation & inferior longitudinal bundle.

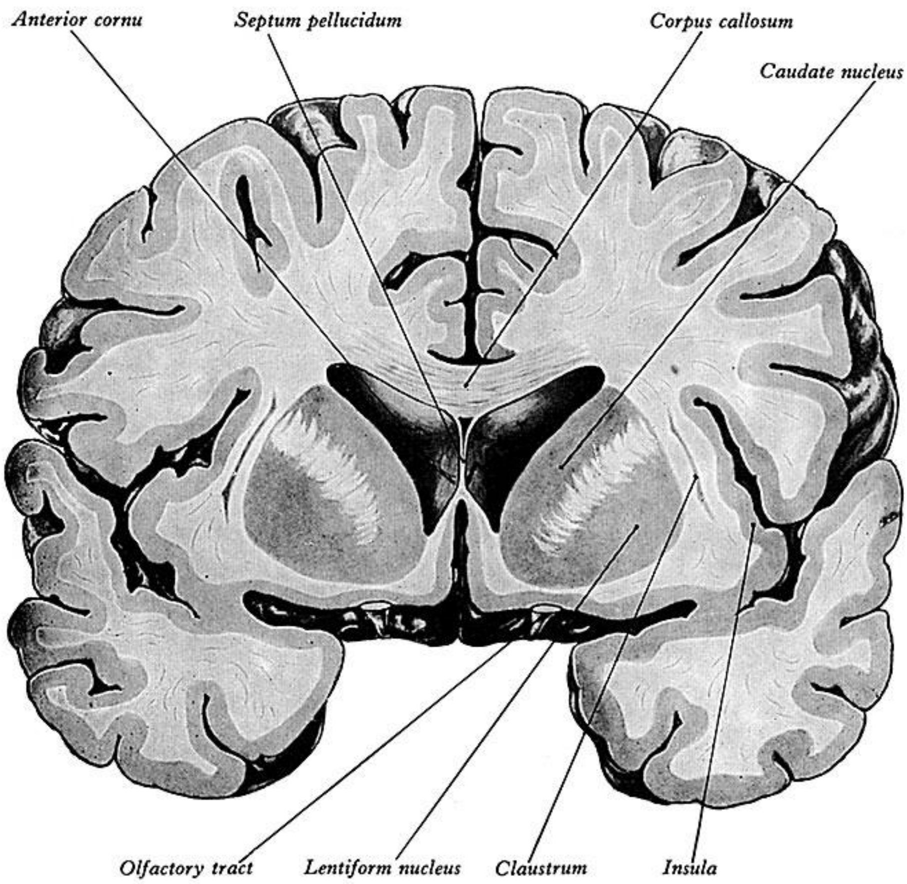
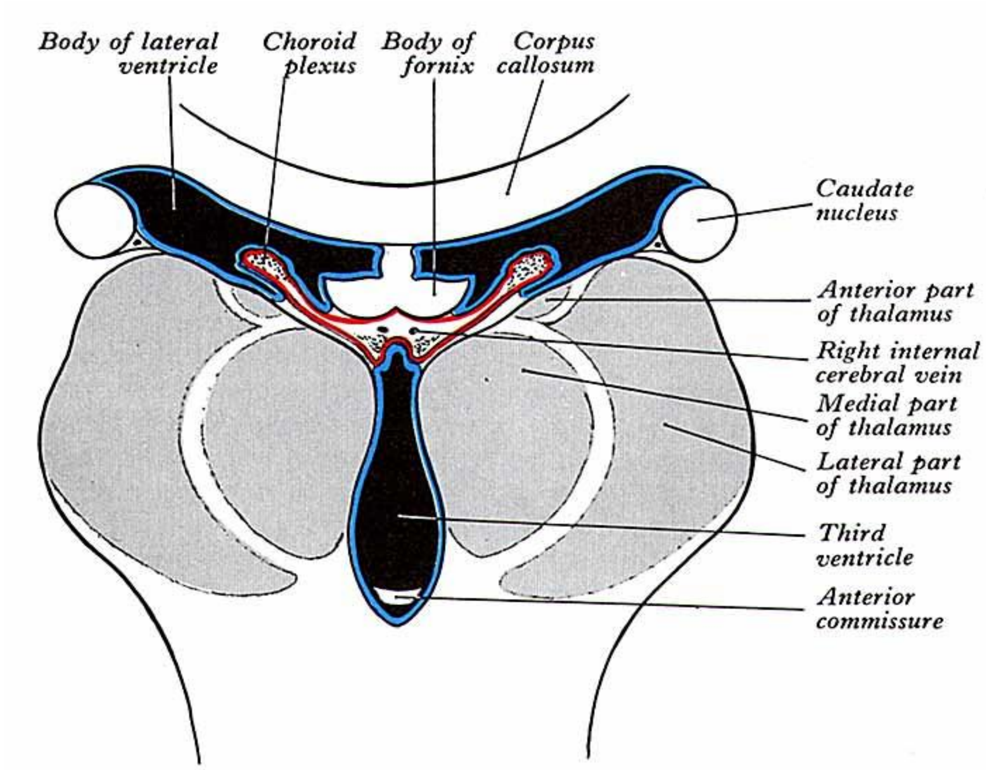
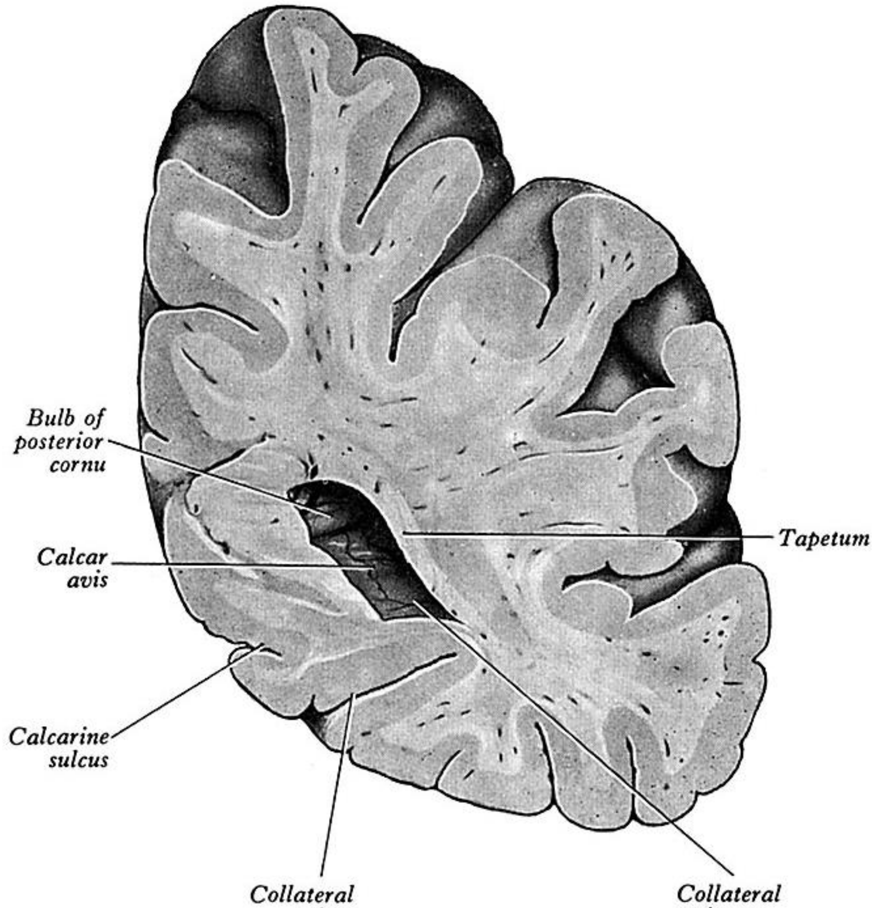


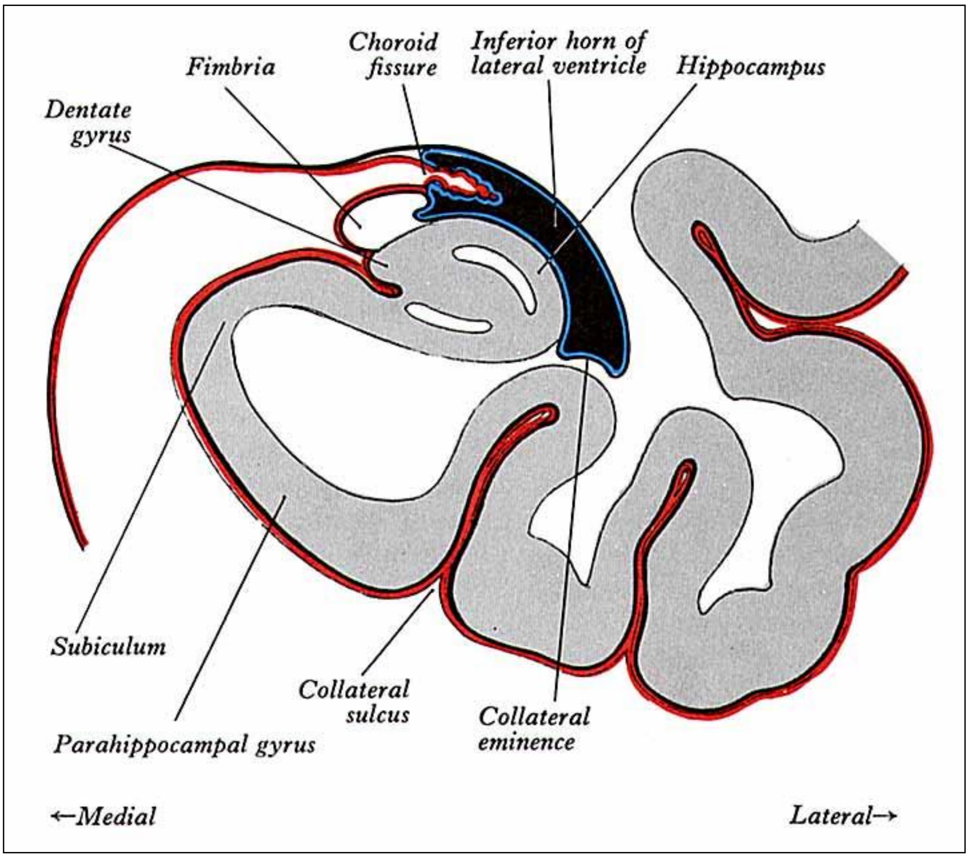
Figure 28: A. Coronal sections through the anterior horn of the lateral ventricle.



B. Coronal section through the body of the lateral ventricle & 3rd ventricle.



C. Coronal section through the posterior horn of the lateral ventricle.



D. Coronal section through the inferior horn of the lateral ventricle.

The Third Ventricle (Cavity of the Diencephalon)

The 3rd ventricle is the median cleft between the two thalami. It communicates with the lateral ventricle of each hemisphere anterosuperiorly through the interventricular foramen of Monro. Posteroinferiorly, in the median plane, it communicates with the 4th ventricle via the cerebral aqueduct of Sylvius. The cavity extends into small **recesses** in 4 areas :

i. ***Suprapineal recess*** above the pineal body **(figure 29)**:
ii. ***Pineal recess*** between the 2 laminae of the stalk of the pineal body
iii. ***Infundibular recess*** above the root of the pituitary infundibulum
iv. ***Optic recess*** above the optic chiasma

The choroid plexus lies in its roof & is continuous with the plexus of the body of the lateral ventricle through the interventricular foramen.

Boundaries of the 3rd ventricle

- ***Anterior wall***: lamina terminalis (below) & the columns of the fornix (above).
- ***Posterior wall***: pineal body, posterior commissure & cerebral aqueduct.
- ***Roof*** is the ependyma lining the under surface of the choroid plexus.
- ***Floor*** is formed by the optic chaisma, tuber cinereum, infundibulum, mamillary bodies, posterior perforated substance and the tegmentum of the midbrain. It leads via the cerebral aqueduct to the fourth ventricle.
- ***Lateral wall*** is formed by the medial surface of the thalamus (posterosuperiorly), the hypothalamus (anteroinferiorly) and the hypothalamic sulcus in between.

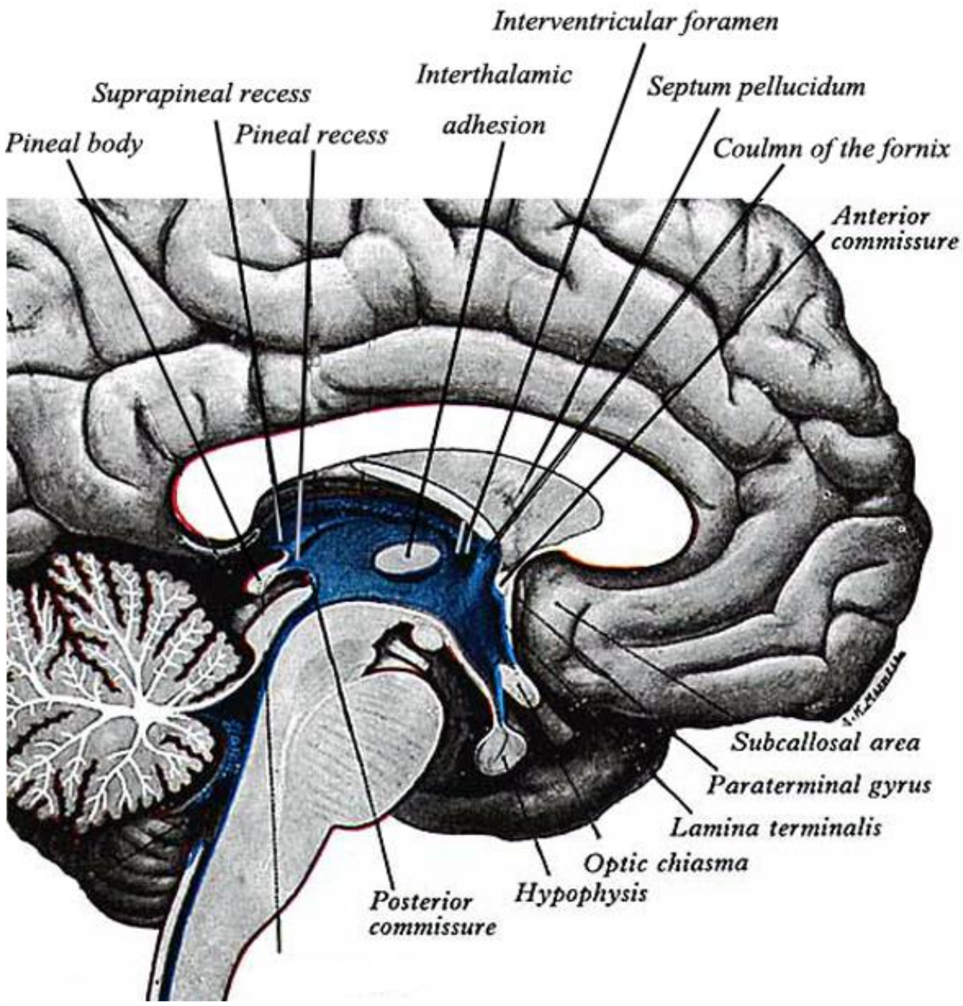


Figure 29: Median sagittal section of the diencephalon showing the boundaries & recesses of the lateral ventricle

The Fourth Ventricle (cavity of the hindbrain)

The 4th ventricle is the cavity of the hindbrain related anteriorly by the pons & open medulla & posteriorly by the cerebellum. It communicates with the 3rd ventricle rostrally via the aqueduct & with the central canal of the spinal cord caudally via the closed medulla. It also opens into the subarachnoid space via *1 median & 2 lateral foramina*. On sagittal section, the roof appears lifted upwards & backwards like a tent and gives the ventricle a triangular shape **(figure 30)**.

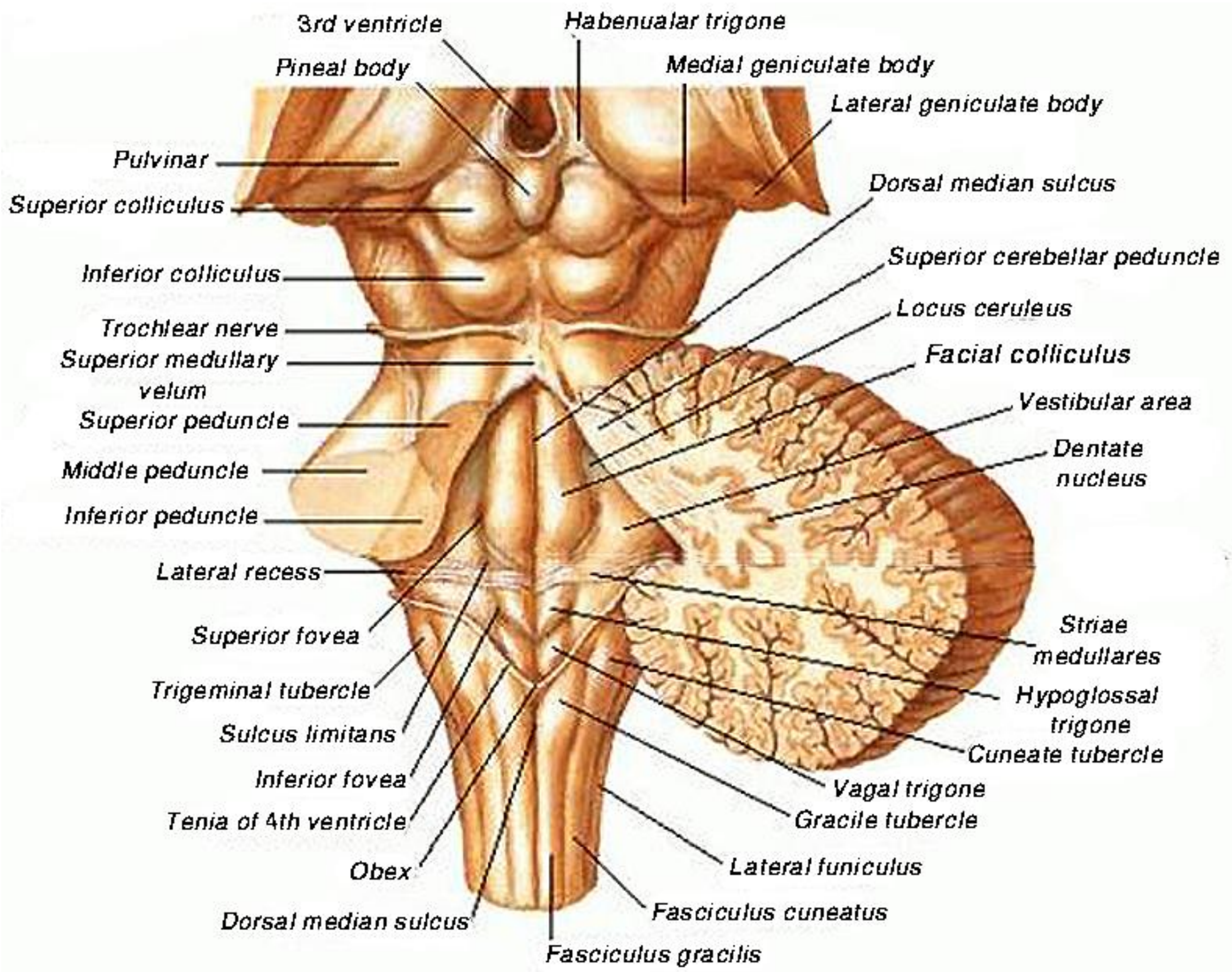


Figure 30: The 4th Ventricle, Cerebellum & Dorsal Surface of the Brainstem

The Floor

- The floor is formed by the dorsal surface of the lower pons & upper (open) medulla. It is called the ***rhomboid fossa*** due to its rhomboidal shape.
- The **dorsal *median sulcus*** extends along the midline of the floor dividing it into 2 equal halves.

- The ***pontine part*** of the floor has the ***facial colliculus*** on each side of the median sulcus and lateral to it a small triangular depression (with the apex downwards) called the ***superior fovea***. The ***vestibular area*** lies lateral to the superior fovea, towards the lateral angles of the floor.

- The ***medullary part*** of the floor consists of the ***hypoglossal & vagal trigones***. The depression just above the vagal triangle is called the ***inferior fovea***.

- The ***striae medullares*** run transversely across the floor from one lateral angle to another.

- The cavity of the ventricle extends laterally on each side over the vestibular area. This extension is the ***lateral recess*** of the 4th ventricle which opens at its end (just behind CN VIII) through the ***foramen of Luschka*** into the **pontine cistern.**

The Roof

- Shaped like a tent lying on its side, the roof has cranial & caudal parts.

- The *cranial part* is formed by the *superior medullary velum* (sheet of white matter stretched between the superior cerebellar peduncles).

- The *caudal part* is devoid of neural tissue and is formed only by *ependyma & pia* matter. The upper ependyma stretching down from the nodule & stalk of the flocculus is called the ***inferior cerebellar velum*.** The pia that extends down from the flocculus itself (laterally) forms the ***tela choroidea*** of the choroid plexus of the 4th ventricle. At the lower angle of the rhomboid the roof is formed by white ependymal ridge called the ***obex*.**

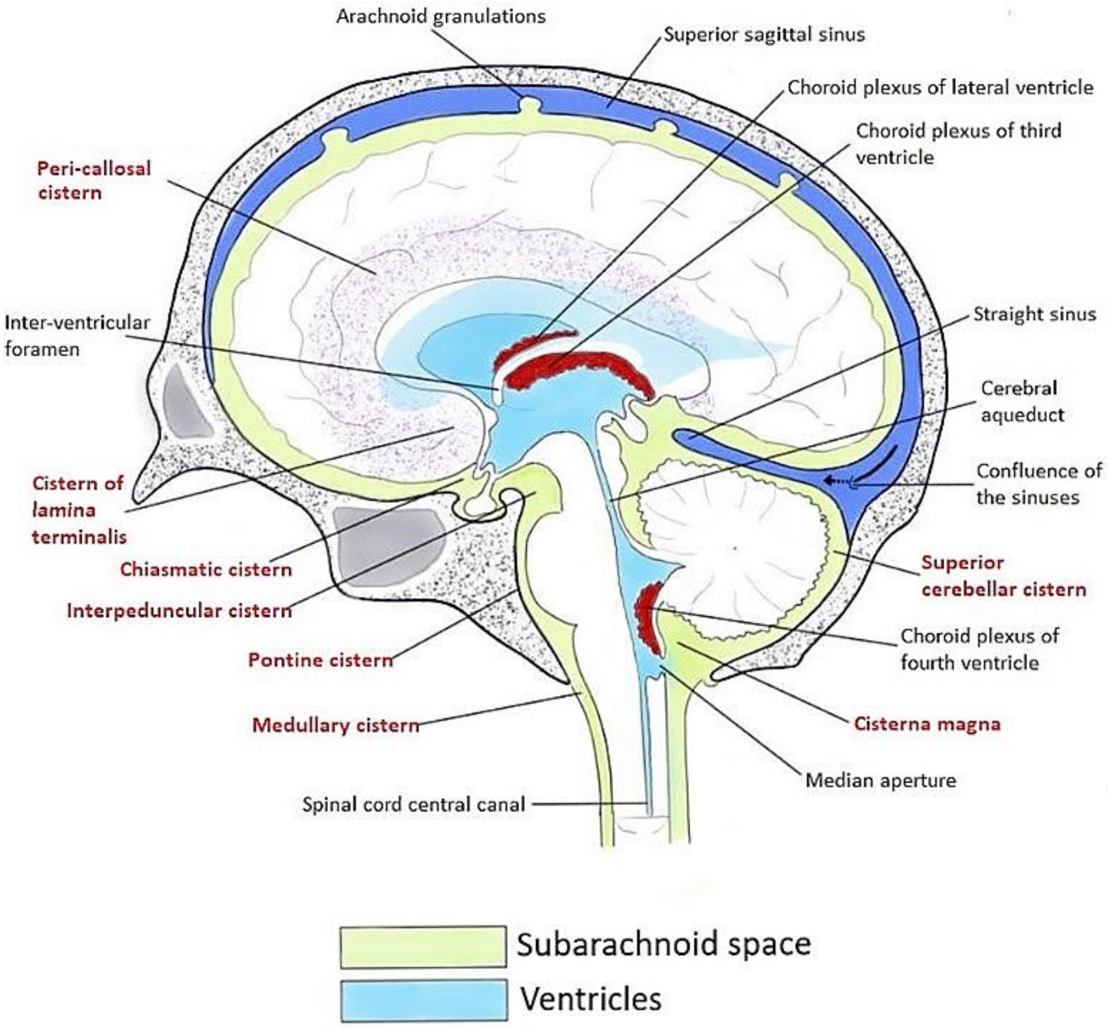
- The caudal part of the roof is perforated by a V-shaped midline slit which is the ***median foramen of Magendie*** that opens into the **cerebellomedulary cistern.**

The Choroid Plexus

The choroid plexus of the 4th ventricle is a small T-shaped structure lying in the medullary part of the roof. It receives its blood supply from a branch of the PICA, which enters through the foramen of Luschka and runs through the lateral recess towards the midline where it meets its fellow and the two run down; side by side; towards the foramen of Magendie.

The Subarachnoid (Basal) Cisterns

The subarachnoid cisterns, or basal cisterns, are compartments within the subarachnoid space where the pia mater and arachnoid membrane are not in close approximation and cerebrospinal fluid (CSF) forms pools or pockets (Latin: “cistern” = "box"). As they are interconnected, their patency is essential for CSF circulation. Cisterns may have vessels and/or cranial nerves passing through them.



The important named cisterns are shown in figure 31 above:

1. The **chiasmatic cistern** lies anteroinferior the optic chiasma.

2. The **interpeduncular cistern** lies between the cerebral crura.

3. The **pontine & medullary cisterns** lie anterior to the pons & medulla, respectively

4. **Cisterna magna** is the largest of the subarachnoid cisterns & lies posterior to the medulla.