CHAPTER

1

Nervous System

Chapter Outline

- Organisation (overview) of the nervous system
- Cellular components of the nervous system
- Neuron communication
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ORGANISATION (OVERVIEW) OF THE NERVOUS SYSTEM

Nervous system is the chief controlling and coordinating system of the body. It is responsible for judgment, intelligence and memory. Nervous system is highly evolved at the cost of regeneration. It is the most complex system of the body.

It adjusts the body to the surroundings and regulates all bodily activities both voluntary and involuntary. The sensory part of the nervous system collects information from the surroundings and helps in gaining knowledge and experience, whereas the motor part is responsible for responses of the body.

With more than 100 trillion connections, the human brain is the core organ of the nervous system. Messages are conveyed to the brain via the spinal cord, which runs in middle of the back and contains thread-like nerves that branch out to every organ and body part (Fig. 1.1).

Central nervous system (CNS) comprises brain and spinal cord. It is responsible for integrating, coordinating the sensory information and ordering appropriate motor actions. CNS is the seat of learning, memory, intelligence and emotions. It is made of delicate tissue but is well protected by the skull and vertebrae. The blood–brain barrier also prevents many toxins from entering the brain. The CNS acts as the control center. It sends and receives information to and from muscles, glands, organs and other systems in the body through the peripheral nervous system.

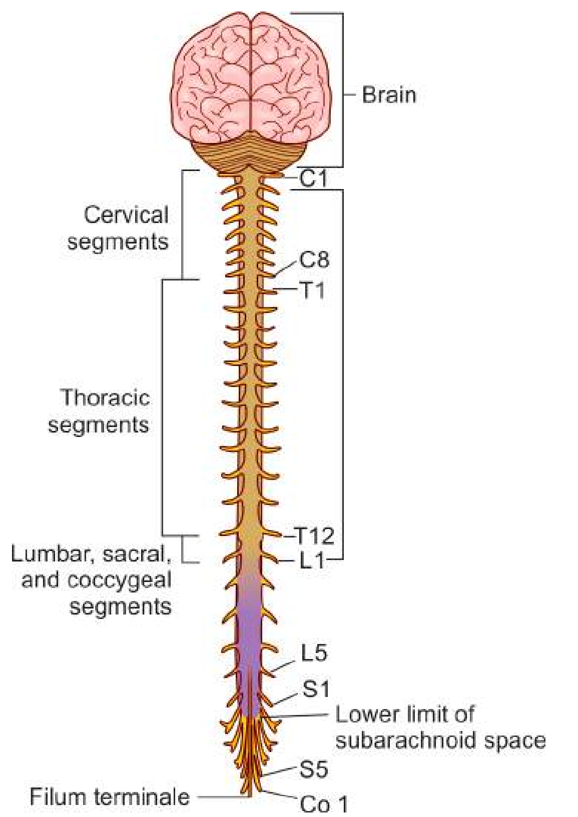


Fig. 1.1: Nervous system—diagrammatic representation

Peripheral nervous system (PNS) acts as a relay center and transmits information between the CNS and the rest of the body. PNS is not protected by the vertebral column and skull, or by the blood–brain barrier, therefore it remains exposed to toxins and mechanical injuries. *Peripheral nervous system (PNS)* includes 12 pairs of cranial nerves and 31 pairs of spinal nerves. These pairs provide afferent impulses to CNS and carry efferent impulses to muscles, glands and blood vessels.

The PNS includes a sensory division and a motor division.

The sensory and motor divisions each includes a part of the somatic system and an autonomic system.

Somatic Nervous System

In Greek, 'Soma means body', therefore, somatic means related to the body. The somatic sensory receptors receive information from the senses and send it to the CNS while the somatic motor division sends information from the CNS to control the actions of the skeletal muscles.

Autonomic Nervous System

The autonomic nervous system primarily regulates involuntary or unconscious activities of body such as heart rate, breathing and pupil dilation. It also helps in regulating glands and internal organs, blood pressure, digestion, and many chemical processes that keep our body functioning.

The autonomic motor division is divided into two complimentary subsystems: The sympathetic and the parasympathetic systems. These systems constantly work to shift the body to more prepared and more relaxed states. The constant shifting of control between these two systems keeps the body ready for any situation. The comparison between sympathetic, parasympathetic and enteric nervous systems has been presented in Table 1.1.

CELLULAR COMPONENTS OF THE NERVOUS SYSTEM

Neurons

Neurons are the cells that form a framework for communication throughout the nervous system (Fig. 1.2).

Neurons are the main functional units of the nervous system. They can generate electrical signals to quickly transmit information over long distances and pass them onto many other neurons. They can be in several shapes and sizes depending on their specialized functions but all neurons have axons and dendrites that protrude from the cell body. Each neuron is made-up of the dendrites and axons.

Dendrites

Dendrites (Greek word that means 'branch of a tree') are many, short or long, richly branched and specialized extensions that resemble the branch of a tree, often varicose. Dendrites help to increase the surface area required for connections with the adjacent neurons and receive incoming signals from them.

Table 1.1: Comparison of sympathetic, parasympathetic and enteric nervous systems

	Sympathetic nervous system (SNS)	*Parasympathetic nervous system*	*Enteric nervous system*
How it works	Prepares the body to react and spend energy during stress	Helps in conserving energy and maintaining functions under ordinary conditions	Known as the 'second brain' or the brain in the gut because it can operate independently of the brain and spinal cord, (the central nervous system)
Reaction	Reacts with the 'fight-or-flight' or fright phenomenon	Helps the body by 'rest-and-digest'	Includes a number of neural circuits—a mesh-like system of neurons that governs the function of the gastrointestinal tract
Actions	Quickens the heart rate and fastens the breathing to increase oxygen, further dilates pupils for better vision, reduces digestion so as to conserve energy	Acts slowly as compared to SNS and may take longer time to get the body back to a normal relaxed state after some stressful situations	Controls motor functions, local blood flow, mucosal transport and secretions, and modulates immune and endocrine functions

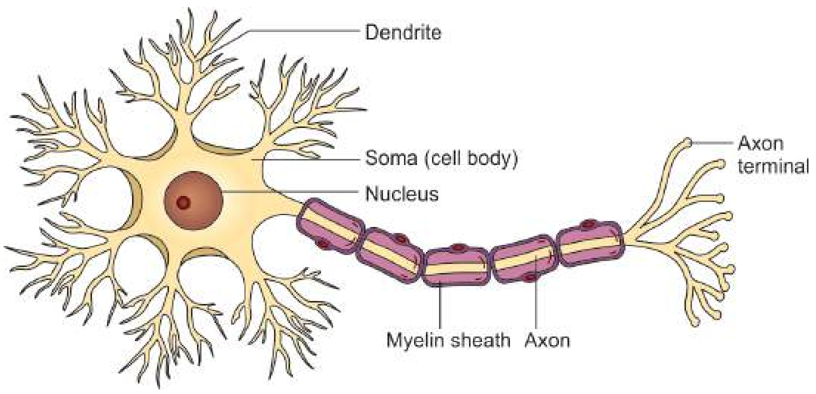


Fig. 1.2: Structure of neuron

Functions

- Acquiring chemical impulses from neurons and other cells
- Converting the chemical signals into electrical impulses
- Further carrying electrical impulses toward the next part of the neuron, the cell body.

Cell Body or Soma

It is the central part of the neuron, which is similar to a cell and contains the nucleus along with other cell organelles. The cell body is the largest part of a neuron and is enclosed by a cell membrane, which protects the cell from the immediate surroundings and allows interaction with the outside environment. They attach to all the dendrites and, therefore integrate all the signals. All metabolic activities of the cell happen in the cell body. It also contains DNA, the genetic material of the neuron.

Functions

- Supports and organizes the functions of the whole neuron.
- Joins the signals received by the dendrites and pass them to the axons, the next part of the neuron.

Axons

Most neurons have a single axon that generally sends electrical impulses outward that is away from the cell body. The axon is a single elongated fiber-like extension of the nerve cell membrane. Axons run from the cell body of one neuron until the terminal of the next neuron. The larger the diameter of the axon, the faster is the rate of transmission of nerve signals.

The branches of axons often arise at right angles and are called the collaterals. Axons are the longest part of the neuron that varies widely in length from extremely short to more than 3 feet, for example, to reach from the base of the spine to ankle. Collectively, the axons form tracts (white matter) in the CNS, and nerves in the peripheral nervous system.

Parts of an Axon

- **Axon hillock:** The part of the axon that remains attached to the cell body or soma.
- **Myelin sheath:** The layer of fatty acid produced from specialized cells called Schwann cells that are wrapped around the axon.
- **Nodes of Ranvier:** The gaps between the discontinuous myelin sheath that is running along the axon.

Functions

- Axons receive signals from other neurons and transmit flow of the messages to the adjacent connected neurons and to glands and other muscles by changing the electrical potential of the cell membrane called the action potential.
- Myelin sheath insulates the axon, therefore, preventing the shock—it is similar to an insulated electric wire.
- Myelin sheath also increases the speed of the flow of signals through the axon.
- Nodes of Ranvier allow diffusion of ions in and out of the neuron. They maintain the electrical potential of the neuron.

Types of Neurons

The different types of neurons are tabulated in Table 1.2.

NEURON COMMUNICATION

Neurotransmitters

Neurotransmitters are the biochemical messengers, or carriers of information between cells. Neurotransmitters may be excitatory or inhibitory. Excitation makes it more likely that an action potential will be triggered and the inhibition makes it less likely that an action potential will occur. Neurotransmitters and their receptors influence learning, behavior, emotions, and sleep (Figs 1.3A and B).

A summarized list of neurotransmitters that are involved in many functions of our bodies is mentioned in Table 1.3.

Neuroreceptors

Neuroreceptors are structures on the surfaces or inside the cells. These recognize and bind to hormones, specific neurotransmitters, or psychotropic drugs. The bond created by neuroreceptors, acts with either inhibitory or excitatory action potential. After this, the receptor generally changes shape. This causes a chemical cascade of cellular actions. These further make the cells to release their own neurotransmitters. Each type of neurotransmitters has multiple receptors; each has a different function. The functional classification of neuroreceptors is given in Table 1.4.

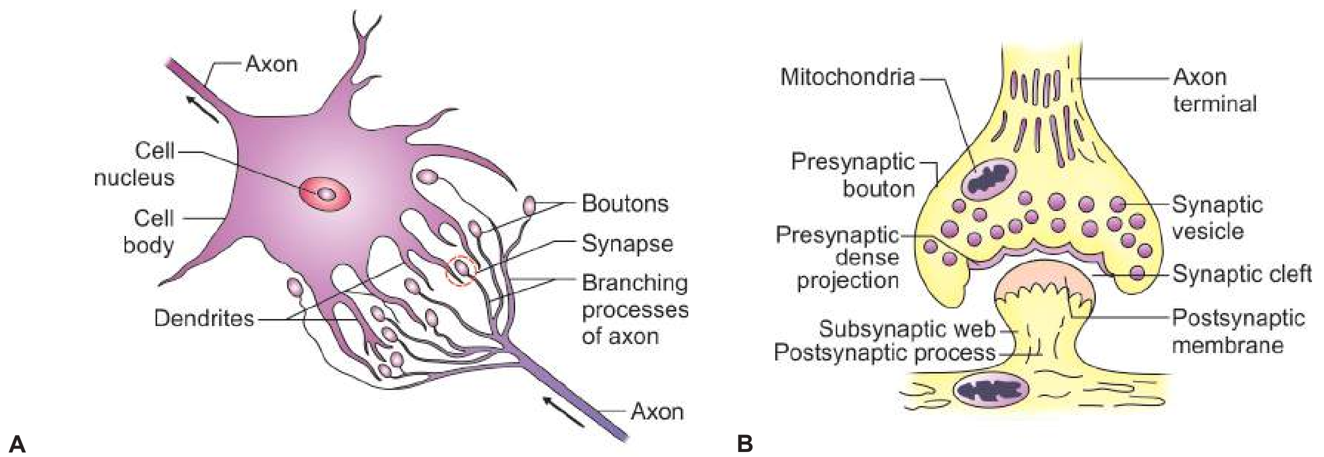
Neuron Communication

Neurons communicate electrochemically. An electrical signal from axon of one neuron triggers a release of neurotransmitters, which bind to channels on another neuron's dendrite. This causes the channels to open and receive positively charged ions from the synapse. If this increases enough charge, it can trigger an action potential, causing neuron to send an electrical signal (positive charge) down its own axon.

Nervous system is formed from a large assemblage of connected neurons. A nerve impulse may be transmitted

Table 1.2: Types of neurons

Type of neuron	*Present in*
According to the number of their processes	
Multipolar neurons	All motor and internuncial neurons
Bipolar neurons	Confined to the first neuron of the retina, ganglia of eighth cranial nerve, and the olfactory mucosa
Pseudounipolar neurons—actually unipolar to begin with but become bipolar functionally	Found in dorsal nerve root ganglia and sensory ganglia of the cranial nerves
Unipolar neurons—common in lower vertebrates	Mesencephalic nucleus of trigeminal nerve, and also occur during fetal life
Functional classification	
Sensory neurons	
• Primary or 1st order sensory neurons	• In the dorsal root ganglion of spinal nerves
• Secondary or 2nd order sensory neurons	• In the grey matter of spinal cord and in medulla
• Tertiary or 3rd order sensory neurons	• Seen in thalamus
Motor neurons	
• Upper motor neurons	• In motor area of brain and synapse with cranial nerve nuclei and anterior horn cells of spinal cord
• Lower motor neurons	• In cranial nerve nuclei and anterior horn cells of spinal cord
Parasympathetic neurons—'craniosacral outflow'	
• Preganglionic neurons	• Located in cranial nerves III, VII, IX and X, also in sacral 2–4 segments of the spinal cord
• Postganglionic neurons	• Located close to the wall or within the wall of the viscera
Sympathetic neurons—'thoracolumbar outflow'	
• Preganglionic neurons	• Are located in the lateral horn of thoracic one to lumbar two segments of the spinal cord
• Postganglionic neurons	• Situated in the ganglia of the sympathetic trunk away from the viscera



Figs 1.3A and B: Neurotransmitters and neuroreceptors: A. Low power magnification; B. high power magnification

from a sensory receptor cell to a neuron. It can be from a neuron to a set of muscles or to an endocrine gland. Any cell that receives a synaptic signal from a neuron may be modulated, excited, or inhibited.

OTHER NERVOUS TISSUES

Neuroglial Cells

Various types of neuroglial (Greek word that means 'nerve glue') cells are shown in Figure 1.4:

- Astrocytes concerned with nutrition of the nervous tissue are star-shaped cells. These form blood–brain barrier. These are of two types—protoplasmic and fibrous. Astrocytes are absent in pineal gland and posterior pituitary.
- Oligodendrocytes (Greek word for 'few processes') are counterparts of the Schwann cells. Schwann cells myelinate the peripheral nerves. Oligodendrocytes myelinate the tracts.
- Microglia (Greek word that means 'small glue') behave like macrophages of the CNS. They develop from mesoderm.
- Ependymal cells are columnar cells lining the cavities of the CNS.
- Schwann cells.

Unit I

Human Anatomy and Physiology II

Table 1.3: Summarized list of neurotransmitters

Neurotransmitter	*Role*
Acetylcholine	Acetylcholine is a very widely distributed excitatory neurotransmitter that triggers voluntary muscle contraction and stimulates the secretion of certain hormones. It is involved in wakefulness, attentiveness, learning, memory, sleep, anger, aggression, sexuality, and thirst
Dopamine	Dopamine correlates with movement, attention, and learning. Dopamine is involved in controlling movement and posture. It also modulates mood and plays a central role in positive reinforcement and dependency
Norepinephrine	Norepinephrine is associated with alertness. This neurotransmitter is important for attentiveness, emotions, sleeping, dreaming, and learning. Norepinephrine is also associated with the 'fight, flight or fright' response
Serotonin	Serotonin plays a role in mood, sleep, appetite, and impulsive and aggressive behavior
Gamma-aminobutyric acid (GABA)	GABA is the major inhibitory neurotransmitter in the CNS, contributing to motor control, anxiety regulation, vision, and many other cortical functions
Endorphins	Involved in pain relief and feelings of pleasure and contentedness

Table 1.4: Functional classification of neuroreceptors

Functional classification	
Exteroceptors	These respond to stimuli from external environment, i.e. pain, temperature, touch and pressure
Proprioceptors	These respond to stimuli in deeper tissues, i.e. contraction of muscles, movements, position and pressure
Interoceptors/ enteroceptors	These include receptor end-organs in the walls of viscera, glands, blood vessels and specialized structures in the carotid sinus, carotid bodies and osmoreceptors
Special sense receptors	These are concerned with vision, hearing, balance, smell and taste

Various features of these cells are shown in Table 1.5. Proliferation of glial cells is called the 'gliosis'. A CNS lesion heals by gliosis. A spontaneous gliosis is an indication of a degenerative change in the nervous tissue. Since the glial cells are capable of dividing, they can form the CNS tumors.

NERVE IMPULSE

A neuron is excitable with the proper stimulus to fire off a nerve impulse. The chemical make-up of extracellular fluid makes the region electrically positive, while the intracellular fluid has negative charge this chemical

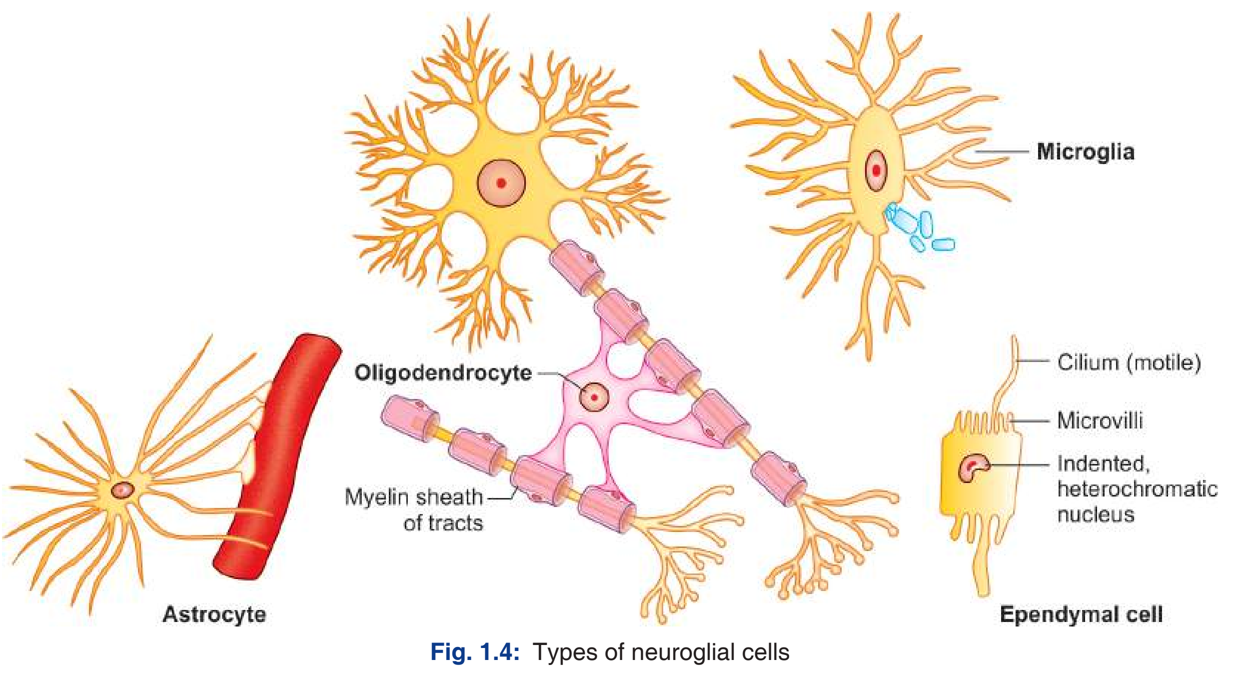


Fig. 1.4: Types of neuroglial cells

imbalance is called 'resting potential'. If the electrical charges reverse briefly, resting potential changes into 'action potential', i.e. a nerve impulse. The impulse travels down the axon till its tip.

Synapse

The neurons are connected to one another by their processes, forming long chains along which the impulses are conducted. The site of contact (contiguity without continuity) between the nerve cells, is known as synapse (Greek together) (Fig. 1.5). One cell may establish such contacts through its dendrites with as many as 1000 axonal terminals. However, it must be remembered that each neuron is an independent unit and the contact between neurons is by contiguity and not by continuity ('neuron theory' of Waldeyer, 1891).

Table 1.5: Characteristics of neuroglial cells

Criteria	Protoplasmic astrocyte	Fibrous astrocyte	Oligodendrocyte	Microglia
Cell size	Large	Large	Medium	Small, elongated
Shapes of nucleus	Oval, light-stained	Oval, light-stained	Small, spherical, dark-stained	Small, elongated, dark-stained
Cytoplasmic processes	Many, short and thick	Many, long slender	Few, short, beaded	Short, thin, spinous
Cytoplasm	Granular	Fibrillar	—	—
Situation	Grey matter	White matter	White matter	Grey and white matters
Function	Blood–brain barrier (BBB)	BBB	Myelination	Phagocytosis
Embryological origin	Neural crest	Neural crest	Neural crest	Mesoderm

Neurons communicate through axon–dendrite and sometimes dendrite–dendrite connections although these protrusions do not actually touch.

A small gap exists at the membrane-to-membrane junction point called synapse. It contains molecular structures that control energy by allowing electrical or chemical signals to be rapidly transmitted through biochemical neurotransmitters (acetylcholine).

Functionally, each neuron is specialized for sensitivity and conductivity. The impulses can flow in them with great rapidity, in some cases about 125 m/sec. A neuron shows dynamic polarity in its processes. The impulse flows toward the cell body in the dendrites, and away from the cell body in the axon.

SENSORY AFFERENT RECEPTORS

The peripheral endings of afferent fibers which receive impulses are known as receptors.

Free Nerve Endings

Sensory nerve endings which repeatedly form plexus or terminate with fewer branches constitute free nerve endings. Such types of endings are found in connective tissue, dermis of skin, fasciae, tendons, ligaments, joints, capsules, peritoneum, perichondrium and sheaths of blood vessels. These are particularly numerous in relation to hair follicles.

These endings respond to temperature, touch and stretch. So these are thermoreceptors and mechanoreceptors. They respond to pain also (Fig. 1.6).

Merkel (Disc-Shaped) Endings

The nerve fibers of these structures expand into a disc applied closely to the base of a specialized non-nervous cell (the Merkel cell) which is inserted into the basal cells of epithelium of the epidermis. These are also found around apical ends of certain hair follicles. These are responsive to pressure sensations.

Encapsulated Nerve Endings

These are special end organs. These have one feature in common, that is, the termination of nerve is enveloped by a capsule. These may be in dermis, joints, muscles and tendons.

Dermis

- **Tactile corpuscles of Meissner:** These are found in the dermal papillae of skin of hand, feet, front of forearm, lips and mucous membrane of tip of tongue. They are cylindrical in shape with long axis perpendicular to deep surface of epidermis and are about 80 µm long and 30 µm broad. Each corpuscle consists of a capsule with central core. The core of corpuscle is supplied by several myelinated nerve fibers and a few unmyelinated nerve fibers. These are responsible for touch such as lamellated, Ruffini's, and Krause's end bulb.

Joints, Muscles and Tendons

The afferent endings are proprioceptors and furnish the central nervous system with information required for the performance of properly coordinated movements.

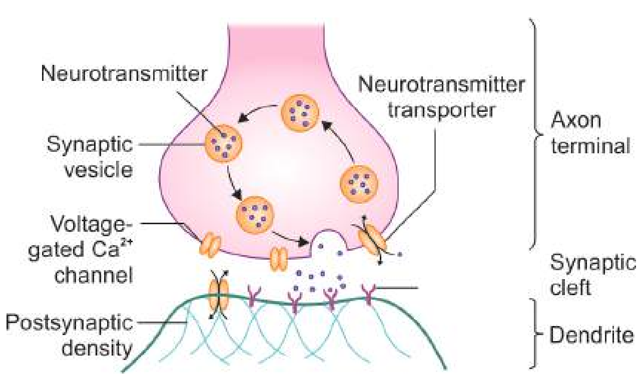


Fig. 1.5: Synapse

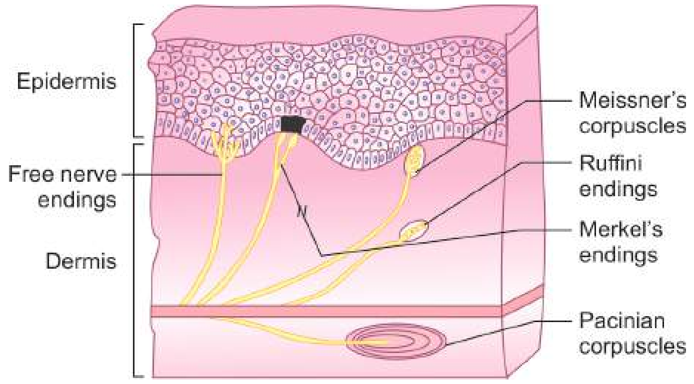


Fig. 1.6: Sensory endings in relation to skin (schematic)

The receptors in tendons and muscles are:

- Neurotendinous spindle of Golgi: These are found at musculotendinous junctions. Each consists of small tendon fibers enclosed in delicate capsule (Fig. 1.7).
- Neuromuscular spindles: The proprioceptive organs contained in the skeletal muscles are neuromuscular spindles (Fig. 1.8).

They lie in the long axes of muscles and their collagenous capsules are continuous with the fibrous septa that separate muscle fibers. They are numerous in muscles that perform highly-skilled movements. These are bounded by fusiform connective tissue capsule within which are a few muscle fibers of a special kind. These fibers are called intrafusal fibers in contrast to extrafusal fibers that constitute the bulk of the muscle.

Each neuromuscular spindle is supplied by two afferent nerve fibers. One of these is group Ia (12–20 μm) fiber. These are called primary sensory endings or anulospiral endings. The second smaller afferent fiber branches terminally, and ends in varicosities on the intrafusal muscle fiber at some distance from mid-region. The latter terminals are called flower-spray endings.

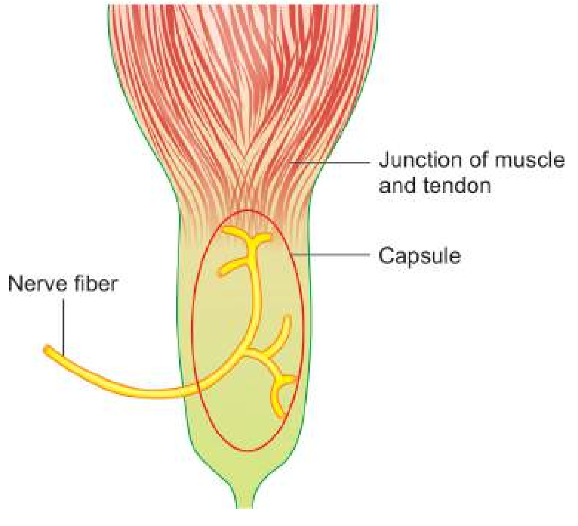


Fig. 1.7: Neurotendinous spindle of Golgi

The neuromuscular spindle has also an efferent or motor innervation. Small motor end plates are present at both ends of intrafusal fibers. During muscular activity, intrafusal fibers get stretched, increasing rate of passage of nerve impulse to brain or spinal cord. By informing CNS about rate of change of length of muscle, neuromuscular spindle influences control of voluntary muscles.

MOTOR EFFERENT ENDINGS

Skeletal Muscle

The myoneural junctions or motor end plates on extrafusal and intrafusal fibers of skeletal/striated muscles are synapse-like structure with two components, i.e. the ending of a motor nerve fiber and subjacent part of the muscle (Fig. 1.9).

Each branch of nerve fiber gives up its myelin sheath on approaching a muscle fiber and ends as several branchlets that constitute the neural component of end plate.

In the majority of muscles, the terminals of the nerve end in a small localized area of muscle fiber forming a so-called motor end plate. The sarcolemma of muscle fiber has a wavy outline where they oppose the nerve terminal, with irregularities being known as junctional folds. Axon terminal in this region is rich in mitochondria and contains vesicles similar to those seen in the region of synapse. There is no protoplasmic continuity between the axoplasm and sarcoplasm.

The vesicles in axoplasm contain the neurotransmitter acetylcholine that is released when nervous impulse reaches myoneural junction. Acetylcholine creates a wave of depolarization in the sarcolemma resulting in contraction of muscle fibers. Thereafter, acetylcholine is quickly destroyed by an enzyme called cholinesterase.

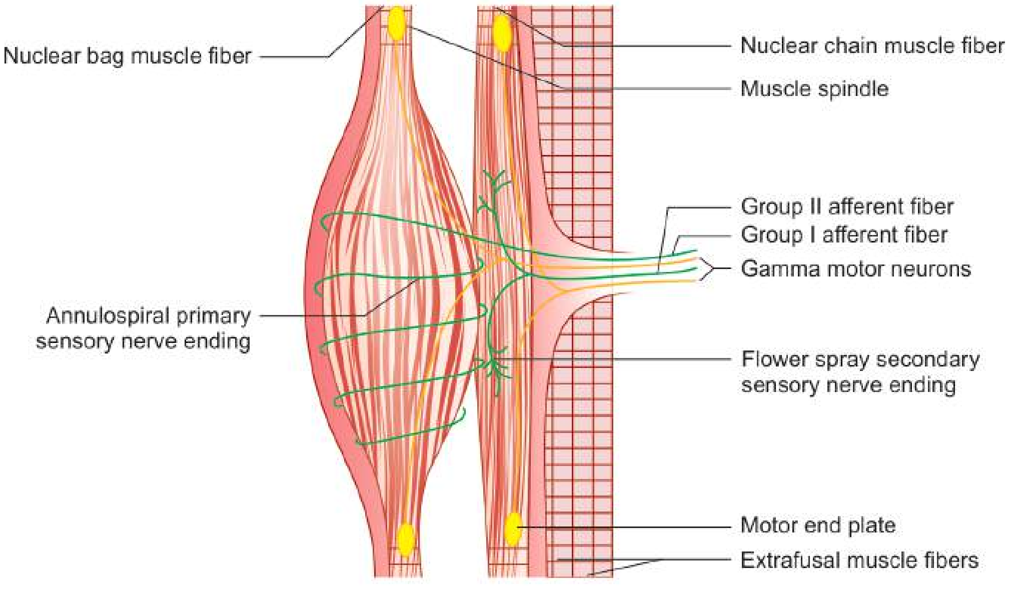


Fig. 1.8: Neuromuscular spindle

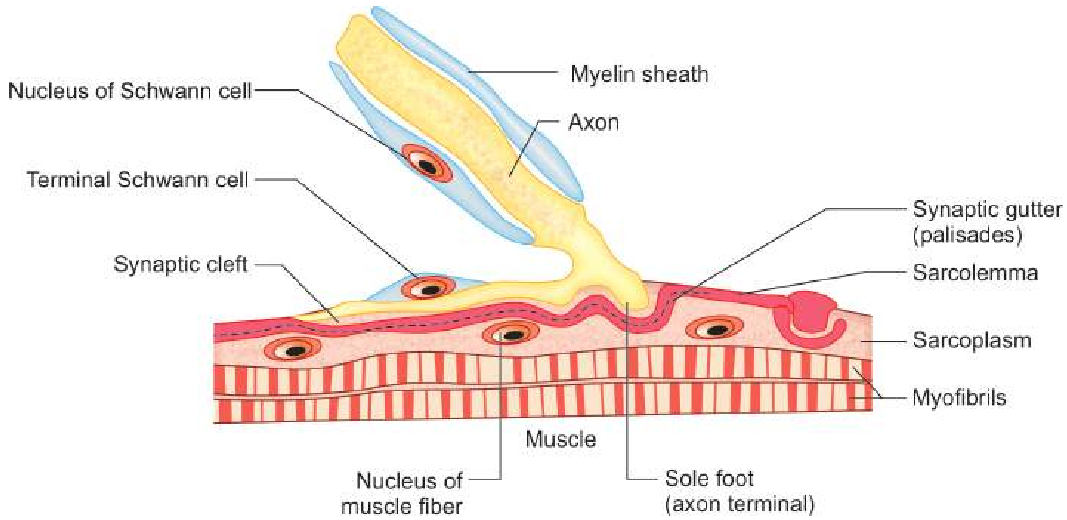


Fig. 1.9: Motor end plate

Motor Unit

The number of muscle fibers in a motor unit (number of muscle fibers supplied by a single alpha motor neuron) varies from one to several hundred depending upon the size and function of a muscle.

A large motor unit in which a single neuron supplies many muscle fibers, is adequate for the function of muscles such as those of trunk and proximal portion of limbs. However, in extraocular and intrinsic muscles of hand which function with precision, the motor unit includes only a few muscle fibers.

CENTRAL NERVOUS SYSTEM

The main components of central nervous system (CNS) are spinal cord and brain.

- Spinal cord: It extends from the base of the skull to the lower border of first lumbar vertebra in an adult. The spinal cord receives sensory information from the skin, joints, and muscles of the trunk, limbs, and contains the motor neurons responsible for both voluntary and reflex movements. It also receives sensory information from the internal organs and controls many visceral functions. Within the spinal cord, there is an orderly arrangement or sensory cell groups that receive input from the periphery and motor cell groups that control specific muscle groups. In addition, the spinal cord contains ascending pathway through which sensory information reaches the brain and descending pathways that relay motor command from the brain to motor neurons. The grey matter is in the center and white matter is at the periphery. Cerebrospinal fluid (CSF) present in central canal lies in the grey matter.
- **Brain:** It includes:
  - **The medulla:** This is the direct rostral extension of the spinal cord. It participates in regulating blood pressure and respiration control. It resembles the spinal cord in both organization and function.
  - **Pons:** It lies rostral to the medulla and contains a large number of neurons that relays information from the cerebral hemispheres to the cerebellum.
  - **Midbrain:** This is the smallest brainstem component, which lies rostral to the pons. The midbrain contains essential relay nuclei of the auditory and visual system. Several regions of this structure play an important role in the direct control of eye movement, whereas others are involved in motor control of skeletal muscles.
  - **Cerebellum:** The cerebellum lies dorsal to the pons and medulla. It has a corrugated surface. The cerebellum receives somatosensory input from the spinal cord, motor information from the cerebral cortex and balance information from the vestibular organs of the inner ear. The cerebellum integrates this information and coordinates the planning, timing and patterning of skeletal muscle contractions during movement. The cerebellum plays a major role in the control of tone, equilibrium and posture, including head and eye movements.
  - **Diencephalon:** It includes the thalamus and hypothalamus. It is present between the cerebral hemispheres and the midbrain. The thalamus receives almost all sensory and motor information going to the cerebral cortex except smell. It regulates levels of awareness and some emotional aspects of sensory experiences. The hypothalamus lies ventral to the thalamus and regulates autonomic activity and the hormonal secretion by the pituitary gland.
  - **Cerebral hemispheres:** This is the largest region of the brain. It consists of the cerebral cortex/grey matter and the fibers which form white matter with deeply located nuclei. The basal ganglia, the hippocampal formation and the amygdala. The cerebral hemispheres are divided by the hemispheric fissure and are thought to be concerned with perception, cognition, emotion, memory and high motor functions. Each hemisphere is comprised

of four lobes, e.g. frontal, parietal, temporal and occipital lobes. Each hemisphere has a flat medial surface, which lies adjacent to each other separated by a longitudinal fissure. In the lower part of the fissure is present a thick band of fibers—the corpus callosum. The hemisphere shows infoldings in the form of sulci and gyri, giving more space for the neurons.

BRAIN

The brain is a very important delicate organ. The brain is an organ that is made-up of a large mass of nerve tissue and is protected within the skull. This has been extensively covered in skeleton system (Fig. 1.10). Here, occipital bone is taken for discussion.

Occipital Bone

Occipital bone is a curved bone and contains the foramen magnum, a large oval hole, which allows the medulla oblongata to travel from the brain and continue as spinal cord in the vertebral canal. In addition to the medulla oblongata, the foramen magnum also gives space to the accessory nerves, these nerves serve the neck and shoulder, the alar ligaments which help to stabilize the head and neck, and the membrana tectoria—a ligament that connects the 2nd cervical vertebra with occipital bone. This collection of nerves and ligaments allows the brain to communicate with the rest of the body through the spine and helps in rotating the head.

As the age increases, the occipital bone fuses with other bones of the cranium. Between the ages of 18 and 25, the sphenoid bone, which is located in the middle of the skull, and sphenoid occipital bone grow together. Between the ages of 26 and 40, the parietal bones at the top of the head and the occipital bone may fuse together.

Brain plays a role in almost every major body system. The functions of brain include:

- Processing sensory information
- Regulating breathing and blood pressure
- Releasing hormones

Meninges of Brain

The brain is covered over by three membranous coverings (meninges): The outer dura mater (pachymeninx), middle arachnoid mater, inner pia mater. The arachnoid and pia mater are together known as the leptomeninges.

These three meninges cover brain and spinal cord with intervening spaces. The outermost is the dura mater, middle layer is delicate cobweb-like arachnoid mater and the inner one is the pia mater. The subdural space is very narrow while the subarachnoid space is big containing very important cerebrospinal fluid.

Lastly, brain and spinal cord with their meninges are securely kept in the bony skull and vertebral canal, respectively.

Dura Mater

The cerebral matter is made-up of two layers, an outer endosteal layer and an inner meningeal layer, enclosing the cranial venous sinuses between the two. The meningeal layer forms four folds, which divides the cranial cavity into intercommunicating compartments for different parts of the brain (Figs 1.11, 1.12 and Table 1.6).

Spinal Dura Mater

Surrounds and protects spinal cord from foramen magnum till sacral 2 vertebra. Then it covers filum terminale to fuse with periosteum of coccyx. Space between vertebrae and spinal cord is the epidural space

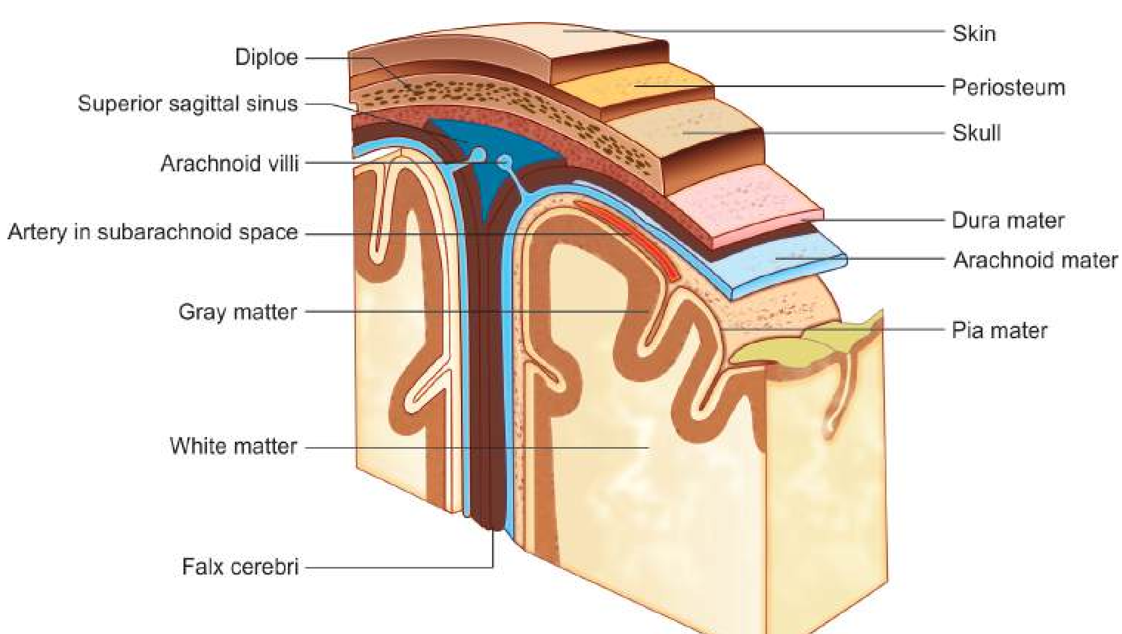


Fig. 1.10: Protective membranes of central nervous system

with veins. The dura mater is attached to margin of foramen magnum and to posterior longitudinal ligament.

Arachnoid Mater

The arachnoid (Latin cobweb like) mater is a thin transparent membrane that loosely surrounds the brain *without* dipping into many of its sulci. Thus, it bridges all irregularities of the brain.

- It surrounds spinal cord and ends at sacral two vertebra.
- Arachnoid granulations are structures filled with CSF which invaginate into the venous sinuses through dura mater. These allow the drainage of CSF from subarachnoid space into the venous sinuses (Fig. 1.13).

Pia Mater

The pia (Latin word that means 'loving mother') mater is a thin vascular membrane that closely invests the brain, dipping into various sulci and other irregularities of its surface. Blood vessels to nourish the brain and spinal cord pierce it. It covers spinal cord until second sacral two vertebra. It pierces arachnoid tube and connects with periosteum of coccyx. Laterally, there are ligamentum denticulate with 21 pairs of teeth-like projections, which fuse with arachnoid mater and dura mater.

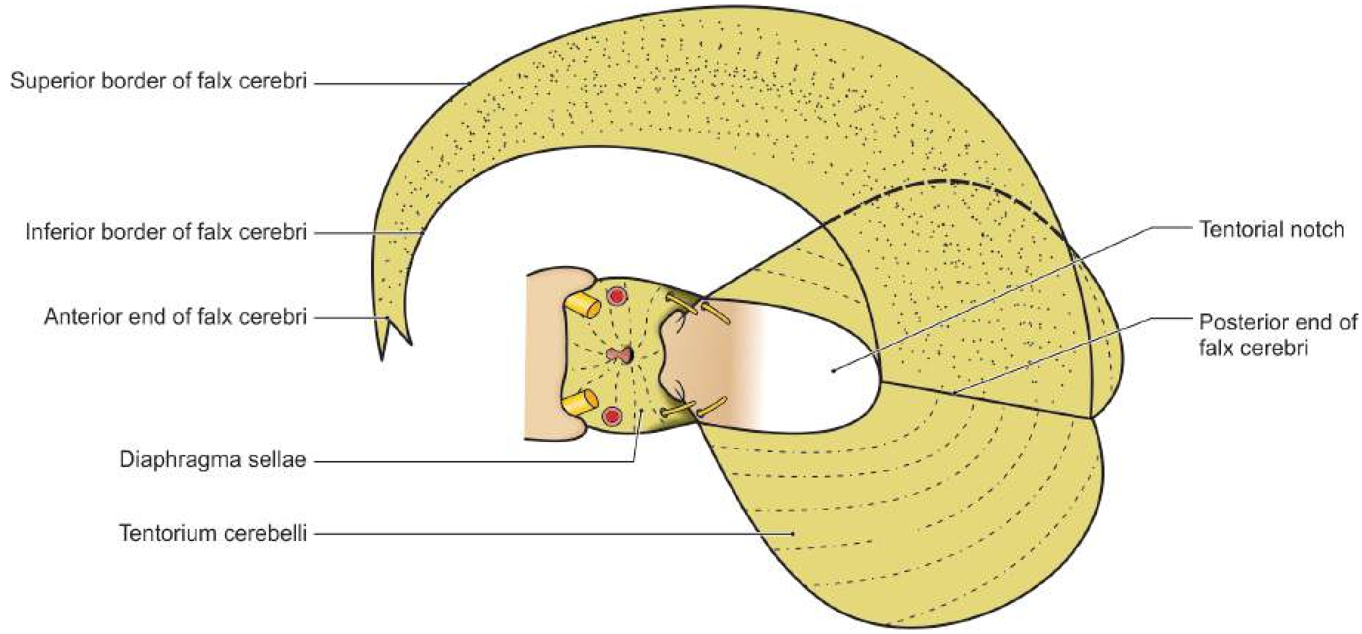


Fig. 1.11: Folds of meningeal layer of dura mater

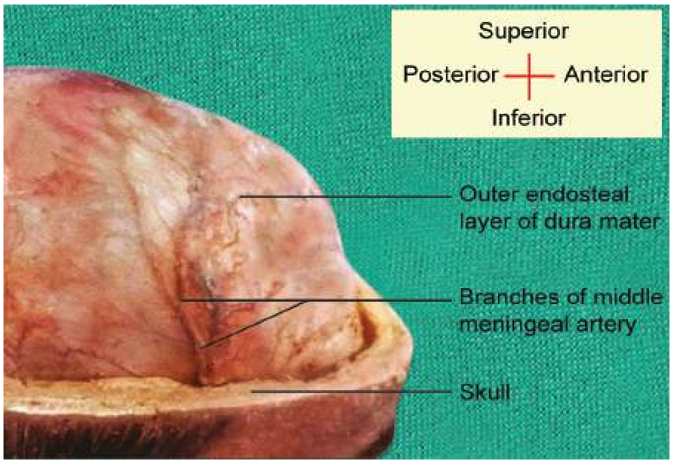


Fig. 1.12: Endosteal layer of dura mater

Table 1.6: Different folds of dura mater due to meningeal layers

Folds	*Shape*	*Venous sinuses enclosed*
Falx cerebri	Is sickle-shaped, separates the right from left cerebral hemisphere	Superior sagittal sinus, inferior sagittal sinus and straight sinus
Tentorium cerebelli	Is tent-shaped, separates the cerebral hemispheres from hindbrain and lower part of midbrain Lifts off the weight of occipital lobes from the cerebellum	Transverse sinuses
Falx cerebelli	Is small sickle-shaped fold partly separating two cerebellar hemispheres	Encloses occipital sinus
Diaphragma sellae	Is small horizontal fold over hypophyseal fossa enclosing the pituitary gland	Encloses anterior and posterior intercavernous sinuses

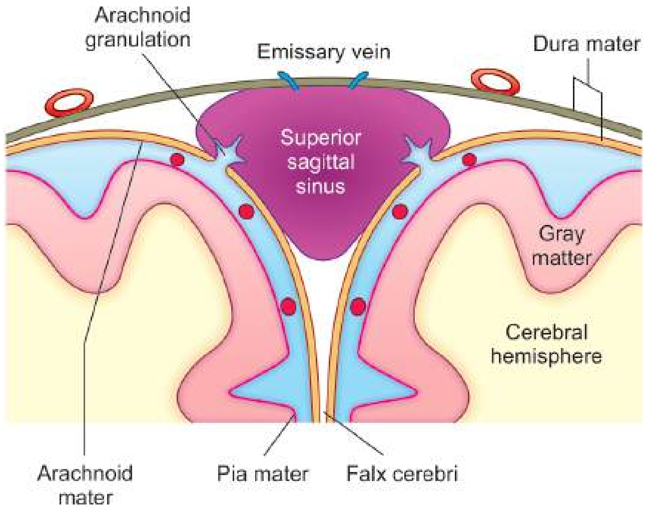


Fig 1.13: Arachnoid granulation

Spaces in Relation to Meninges

Extradural/epidural and subdural spaces: The extradural or epidural space is a potential space between the inner aspect of skull bone and the endosteal layer of duramater. Vertebral epidural space is present between vertebral column and spinal dura mater. The subdural space is traversed by cerebral veins on their path for draining into dural venous sinuses.

Subarachnoid: This is the space between the arachnoid and the pia mater. It surrounds the brain and spinal cord, and ends below at the lower border of the second sacral vertebra. The subarachnoid space contains CSF, and large vessels of the brain. Cranial nerves pass through the space.

The outermost meninx, the dura mater, not only separates the right and left cerebral hemisphere, but also partitions the cerebrum from cerebellum and hypophysis cerebri. In addition, it encloses various venous sinuses.

Ventricles of Brain

Ventricles are continuous cavities in various parts of brain. Lateral ventricle is cavity of each cerebral hemisphere. Third ventricle is present between the two thalami. It continues as aqueduct of midbrain. Fourth ventricle is cavity of hindbrain, i.e. pons, medulla and cerebellum and continues downwards as central canal of spinal cord. CSF circulation in the ventricles and subarachnoid space provides nourishment to the components of brain (Figs 1.14 and 1.15).

Summarized enumeration of cavities and subdivisions of brain is given in Table 1.7.

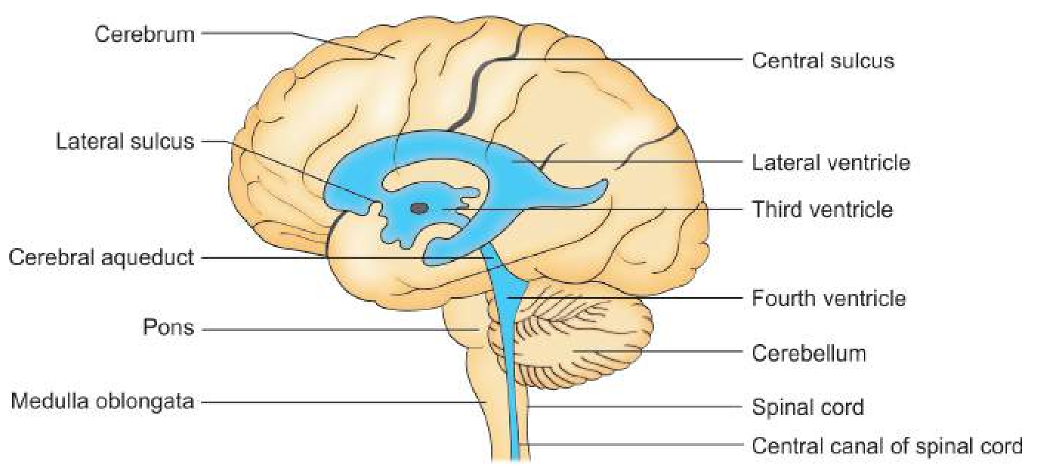


Fig. 1.14: Ventricles of brain

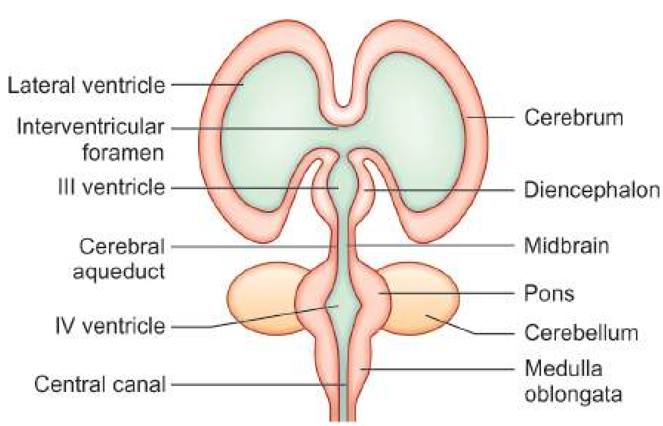


Fig. 1.15: Parts of the brain (diagrammatic)

Cisterns

At the base of the brain and around the brainstem, the subarachnoid space forms intercommunicating pools, called cisterns (Latin 'reservoir'). These reinforce the protective effect of CSF on the vital centers situated in the medulla (Fig. 1.16). The subarachnoid cisterns are as follows.

Cerebellomedullary cistern or cisterna magna: It is the largest cistern lying in the angle between medulla oblongata, cerebellum and occipital bone. The cerebellomedullary cistern contains:

- The vertebral artery and the origin of the posteroinferior cerebellar artery (PICA)

Table 1.7: Cavities and subdivisions of brain

Parts	*Subdivisions*	*Cavity*
• Forebrain (prosencephalon)	• Telencephalon (cerebrum), made-up of two cerebral hemispheres and the median part in front of the interventricular foramen	Lateral ventricle
	• Diencephalon (thalamencephalon), hidden by the cerebrum, consists of: • Thalamus • Hypothalamus • Metathalamus, including the medial and lateral geniculate bodies, and • Epithalamus, including the pineal body, • Subthalamus	Third ventricle
• Midbrain (mesencephalon)	Crus cerebri, substantia nigra, tegmentum, and tectum, from before backwards	Cerebral aqueduct
• Hindbrain (rhombencephalon)	• Metencephalon, made-up of pons and cerebellum • Myelencephalon or medulla oblongata	Fourth ventricle

- The ninth (IX), tenth (X), eleventh (XI) and twelfth (XII) cranial nerves

Cisterna pontis: It is present on the ventral aspect of pons.

- The basilar artery
- The origin of the superior cerebellar arteries

Interpeduncular cistern: This is a large cistern as the arachnoid mater passes across the two temporal lobes. The cistern is continuous with the subarachnoid spaces around anterior, middle and posterior cerebral arteries. It contains:

- The optic chiasma, bifurcation of the basilar artery and circle of Willis.

Cistern of lateral sulcus: It lies in front of each temporal pole and is formed due to bridging of arachnoid mater over the lateral sulcus. This cistern contains middle cerebral artery.

CEREBROSPINAL FLUID

The cerebrospinal fluid is a modified tissue fluid. It is contained in the ventricular system of the brain and in the subarachnoid space around the brain and

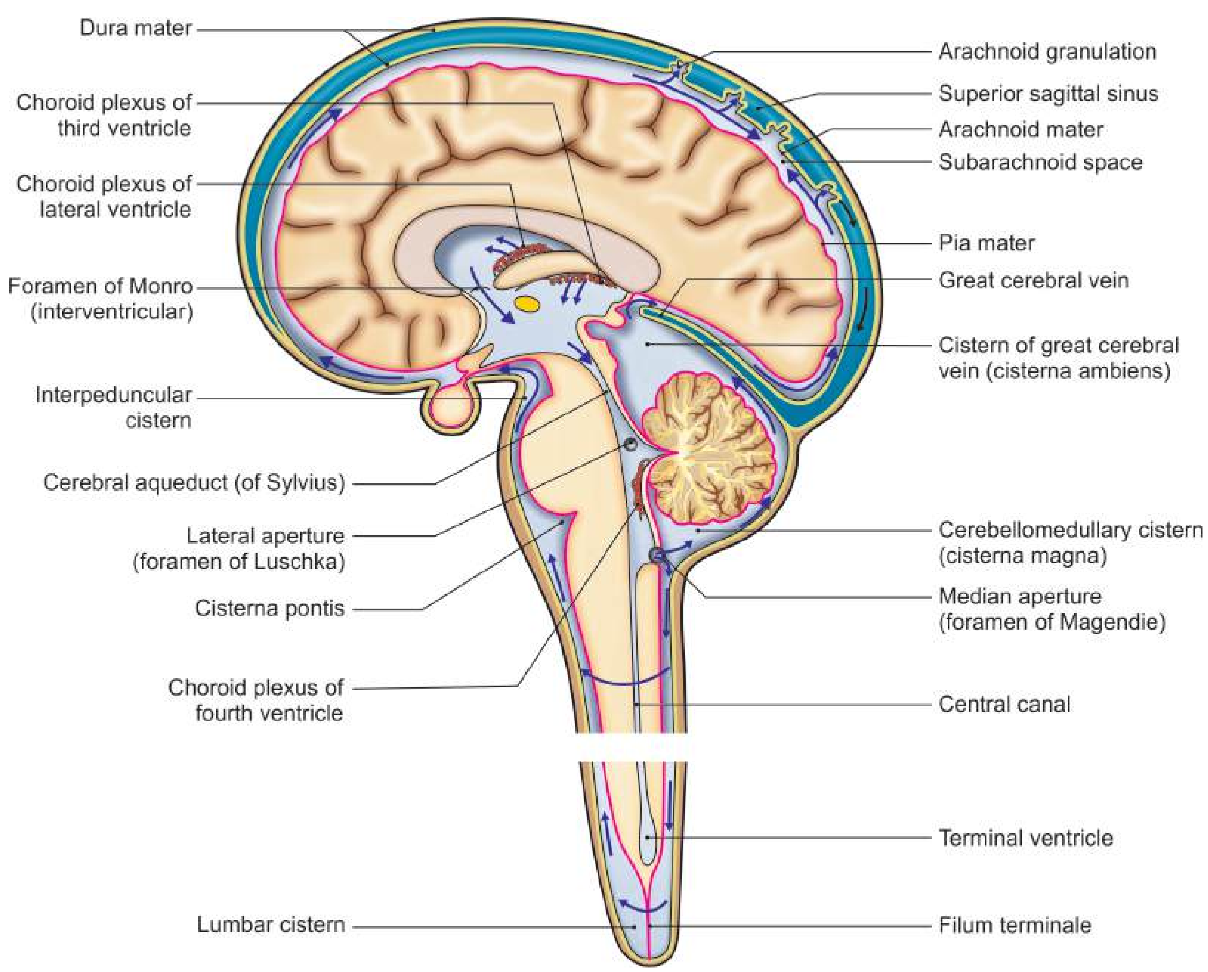


Fig. 1.16: Cisterns of the brain-formation, circulation and absorption of cerebrospinal fluid. Arrows show the direction of flow of cerebrospinal fluid

spinal cord. CSF replaces lymph in the CNS. It fills the space between the arachnoid and the pia maters (subarachnoid space) and acts as a water cushion. The brain almost floats in the cerebrospinal fluid without putting 'its weight' on the neck. The CSF forms watery cushions around the blood vessels of the brain to give them shock-free environment.

Formation

The choroid plexuses of the lateral ventricles and lesser amounts by the choroid plexuses of the third and fourth ventricles form the bulk of the CSF. The rest of the fluid is synthesized by the **ultrafiltration** of blood plasma through **choroidal capillaries**.

The total quantity of CSF is about 150 ml. It is produced at a rate of 20 ml/hour (thus replacing itself three times a day). The normal pressure of CSF is 60–100 mm H_2O (Table 1.8).

Circulation

The CSF passes from each lateral ventricle to the third ventricle through the interventricular foramina of Monro into the third ventricle. From the third ventricle, it passes to the fourth ventricle through the cerebral aqueduct. Mesencephalic duct (aqueduct of Sylvius) connects the third and fourth ventricles and the liquor flows further into the subarachnoid space by means of three foramina: Single median aperture (foramen of Magendie) and a pair of lateral apertures (foramen of Luschka).

From the fourth ventricle, the CSF passes to the subarachnoid spaces of the cerebrum and the vertebral canal through the median and lateral apertures of the fourth ventricle (Flowchart 1.1). A part of CSF passes down the central canal of spinal cord. The resorption of liquor takes place in the arachnoid granulations (arachnoid villi—Pacchioni's granulations).

Absorption

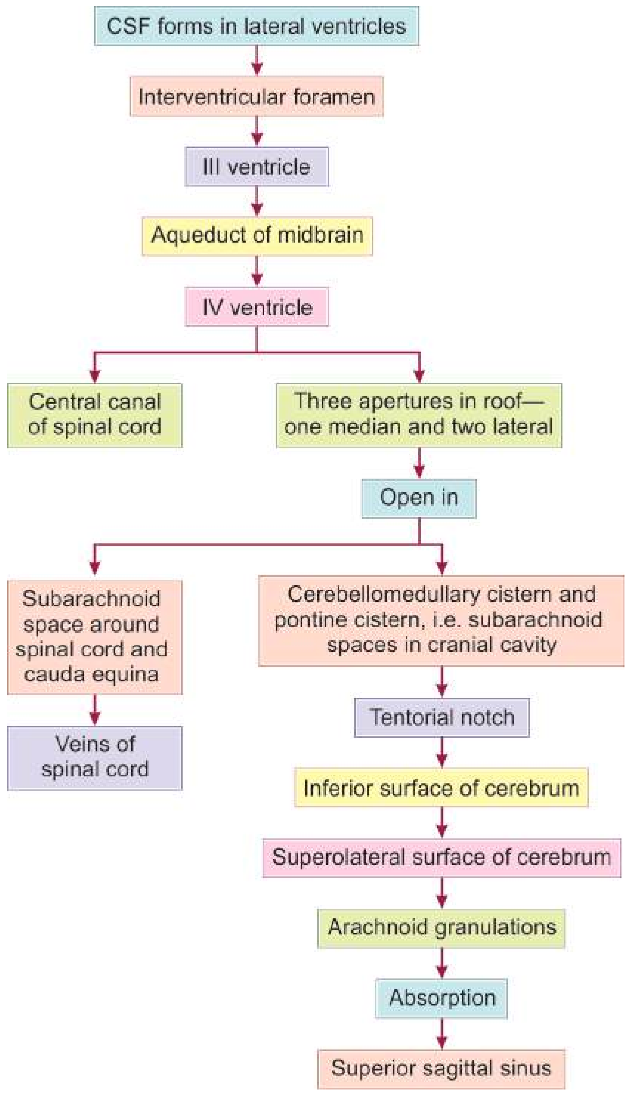
The CSF is absorbed chiefly through the arachnoid villi and granulations, and is thus drained into the cranial venous sinuses. It is also absorbed by veins related to spinal nerves.

Functions of CSF

- CSF decreases the sudden pressure or forces on delicate nervous tissue.

Table 1.8: Composition of normal CSF	
Component	***Quantity***
Protein	15–14 mg/dl
Glucose	50–80 mg/dl
Urea	6.0–16 mg/dl
Uric acid	0.5–3.0 mg/dl
Creatinine	0.6–1.2 mg/dl
Cholesterol	0.2–0.6 mg/dl
Ammonia	10–35 μg/dl

Flowchart 1.1: Circulation of cerebrospinal fluid



- CSF nourishes nervous tissue. Only CSF comes in contact with neurons. Even blood cannot directly come in contact with neurons. It provides nourishment and returns products of metabolism to the venous sinuses.
- Neurons cannot live without glucose and oxygen for more than 3–5 minutes. These are constantly provided by CSF.
- Pineal gland secretions reach pituitary gland via CSF.
- A major function of CSF is to cushion the brain within its solid vault. The brain and CSF have approximately the same specific gravity, so that the brain simply floats in the fluid.

SPINAL CORD

The spinal cord is surrounded by three meninges. The outermost is the dura mater, the middle one is arachnoid mater and the innermost is the pia mater. The space between dura mater and arachnoid mater is called subdural space. The arachnoid and pia maters are separated by subarachnoid space which contains cerebrospinal fluid.

The medical procedure known as a lumbar puncture or spinal tap involves use of a needle to withdraw cerebrospinal fluid from the subarachnoid space, usually from the lumbar region of the spine.

The spinal cord extends in the lower part of 1st lumbar vertebra as conus medullaris. Below the level of conus medullaris only pia mater is continued as a thin fibrous cord, the filum terminale.

The **filum terminale** is 20 cm long and after leaving through sacral hiatus ends by getting attached to the periosteum of dorsal surface of first segment of coccyx.

Enlargements

Limbs form the appendages of the trunk. Their muscles have to be supplied by neurons of spinal cord. Neurons at appropriate levels form enlargements to be able to supply increased musculature. It presents:

- **Cervical enlargement for supply of upper limb muscles:** This extends from C4 to T1 spinal segments with maximum diameter of 38 mm at level of C6 segment (Fig. 1.17).
- **Lumbar enlargement for supply of muscles of lower limb:** It extends from level of L2 to S3 segments. Its maximum diameter is 35 mm at level of S1 segment.

Cauda Equina

Dorsal and ventral nerve roots of right and left sides of L2 to L5, S1 to S5 and Co1 nerves lie almost vertically around filum terminale. These are called cauda equina as these resemble a horse's tail.

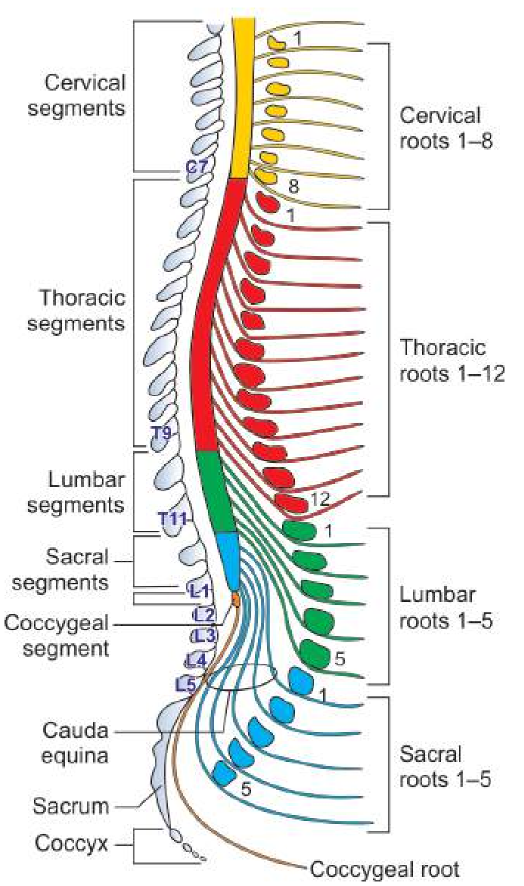


Fig. 1.17: Spinal cord with 31 pairs of spinal nerves

The ventral horn comprises motor neurons that innervate skeletal muscle. Nerve cells in the grey substance are multipolar, varying much in their morphology.

Shape and size of the horns differ in different segments due to functional reasons and are shown in Table 1.9.

Spinal Nerves

Spinal nerves arise in pairs. There are 31 pairs of spinal nerves as 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal (Fig. 1.18).

Each spinal nerve arises by a series of six to eight dorsal and ventral nerve rootlets. These rootlets unite in or near the intervertebral foramen to form the spinal nerve.

Spinal Segment

Segment or part of spinal cord to which a pair of dorsal nerve roots (right and left) and a pair of ventral nerve roots is attached, is called a spinal segment.

Nuclei in Anterior Grey Column or Anterior Horn

The nuclei in anterior horn innervate the skeletal muscles. Most prominent neurons are alpha neurons. Their axons leave the spinal cord through ventral nerve roots to innervate skeletal muscles. Smaller neurons are gamma neurons. These supply intrafusal fibers of muscle spindles. The cells in the anterior horn are arranged in the following three main groups.

Medial group: It is present throughout the extent of spinal cord and innervates the axial muscles of the body.

Lateral group: It is present only in the cervical and lumbar enlargements and supplies musculature of limbs.

- Anterolateral supplying proximal muscles of limbs (shoulder and arm/gluteal region and thigh).
- Posterolateral supplying intermediate muscles of limbs (forearm/leg).

Table 1.9: Shape of horns in different segments of spinal cord

Segments of spinal cord	*Posterior horn*	*Lateral horn*	*Anterior horn*
Cervical, oval shaped	Slender	Absent	Narrow in 1–3 segments Broad in C4 to C8 segments for supply of upper limbs
Thoracic, circular shaped	Slender	Present for thoracolumbar outflow	Slender in T2–T12 segments, broad in T1 segment
Lumbar, circular shaped	Bulbous	Present only in lumbar 1 and 2 segments	Bulbous for supply of lower limbs
Sacral, circular but smaller	Thick	Group of cells in sacral 2–4 segments for sacral outflow	Bulbous for supply of lower limbs

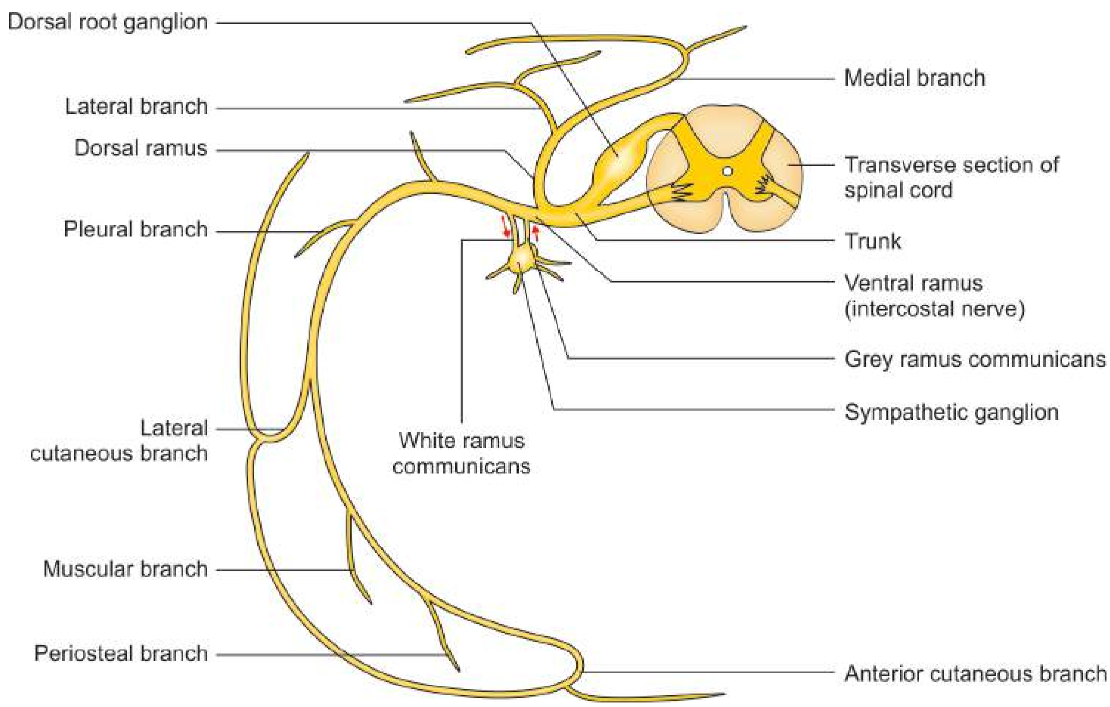


Fig. 1.18: Typical spinal nerve

- Postposterolateral innervating the distal segment (hand/foot).

Central group: Only in upper cervical segments as phrenic nerve nucleus and nucleus of spinal root of accessory nerve.

Nuclei in Lateral Grey Column or Horn

Nuclei in lateral horn are as follows:

Intermediolateral nucleus: This acts as both efferent and afferent nuclear columns. This nucleus is seen at two levels.

- From T1 to L2 segments, giving rise to preganglionic sympathetic fibers (thoracolumbar outflow).
- From S2 to S4 segments, giving rise to preganglionic parasympathetic fibers chiefly for the pelvic viscera.

Tracts of the Spinal Cord

A collection of nerve fibers that connects two masses of grey matter within the central nervous system is called a tract. Tracts may be ascending or descending. They are usually named after the masses of grey matter connected by them. Some tracts are called fasciculi or lemnisci.

The pyramidal or corticospinal tract is formed by the axons of pyramidal cells predominantly lying in the motor area of cerebral cortex. There is some contributions to it from axon of cells in premotor and sensory areas. From here, the fibers course through the posterior limb of internal capsule, midbrain, pons and medulla oblongata. At the lower level of medulla oblongata, 80% of fibers cross to the opposite side. This is known as pyramidal decussation. The fibers that have crossed enter lateral column of white matter of spinal cord and descend as lateral corticospinal tract. Most of these fibers terminate by synapsing through the internuncial neurons at the anterior horn cells.

The 15% of fibers that do not cross enter anterior white column of spinal cord to form anterior corticospinal tract. The fibers of this tract also cross at appropriate levels to reach grey matter of the opposite half of spinal cord. Only 5% corticospinal fibers supply muscles of the same side, chiefly the neck muscles. Thus, neck muscles have bilateral controls.

Thus, the cerebral cortex through lateral and anterior corticospinal tracts controls anterior horn cells of opposite half of spinal cord (Table 1.10).

Functional Significance

- The cerebral cortex controls gross and fine skilled voluntary movements of opposite half of body through anterior horn cells.
- Influence of this tract is supposed to be facilitatory for flexors and inhibitory for extensors.
- Anterior corticospinal tract controls voluntary gross movement like walking and running.
- Corticospinal tract facilitates superficial reflexes and muscle tone.
- Actions of basal ganglia and cerebellum are mediated by corticospinal tracts.

Extrapyramidal Tracts (Table 1.10)

Rubrospinal tract: This tract is formed by the axons of red nucleus, situated in the midbrain. The fibers cross with the fibers of the opposite side in the tegmentum of midbrain; thus constituting the ventral tegmental decussation. The tract descends through the pons and medulla oblongata. The fibers terminate by synapsing through internuncial neurons with anterior horn cells.

Table 1.10: The descending tracts				
Name	***Function***	***Crossed and uncrossed***	***Beginning***	***Termination***
Pyramidal tracts 1. Lateral corticospinal 2. Anterior corticospinal	• Main motor tract for skillful voluntary movements, facilitates flexors	• Crosses in medulla • Crosses in corresponding spinal segment	• Motor area of cortex (areas 4, 6) • Motor area of cortex (areas 4, 6)	• Anterior grey column cells (alpha motor neurons) • Anterior grey column cells (alpha motor neurons)
Extrapyramidal tracts 1. Rubrospinal	• Efferent pathway for cerebellum and corpus striatum	• Crossed	• Red nucleus of midbrain	• Alpha and gamma motor neurons of anterior grey column cells
2. Medial reticulospinal	• Extrapyramidal tract • Facilitates extensors	• Uncrossed	• Reticular formation of grey matter of pons	• Alpha and gamma motor neurons of anterior grey column cells
3. Lateral reticulospinal	• Extrapyramidal tract • Facilitates flexors	• Uncrossed and crossed	• Reticular formation of grey matter of medulla oblongata	• Alpha and gamma motor neurons of anterior grey column cells
4. Olivospinal	• Extrapyramidal tract	• Uncrossed	• Inferior olivary nucleus	• Alpha and gamma motor neurons of anterior grey column cells
5. Lateral vestibulospinal	• Efferent pathway for equilibratory control	• Uncrossed	• Lateral vestibular nucleus	• Alpha and gamma motor neurons of anterior grey column cells
6. Tectospinal	• Efferent pathway for visual reflexes	• Crossed	• Superior colliculus	• Alpha and gamma motor neurons of anterior grey column cells
7. Descending autonomic fibers	• Control parasympathetic and sympathetic systems		• Cerebral cortex hypothalamus reticular formation	• Parasympathetic and sympathetic outflows

Medial reticulospinal tract: The medial reticulospinal tract is formed by the fibers from reticular formation in pons and descends to the cervical segments only. It lies in the anterior white column of spinal cord. It has uncrossed fibers (Fig. 1.19). It influences voluntary movement, reflex activity and muscle tone by controlling the activity of both alpha and gamma neurons.

Lateral reticulospinal tract: The lateral reticulospinal tract originates from reticular formation in brainstem. Its action is similar to that of medial reticulospinal tract.

Olivospinal tract: Its fibers originate from the inferior olivary nucleus in medulla oblongata, descend to spinal cord, lie in the anterolateral column of white matter and synapse with the anterior horn cells. It controls activity of motor neurons in spinal cord.

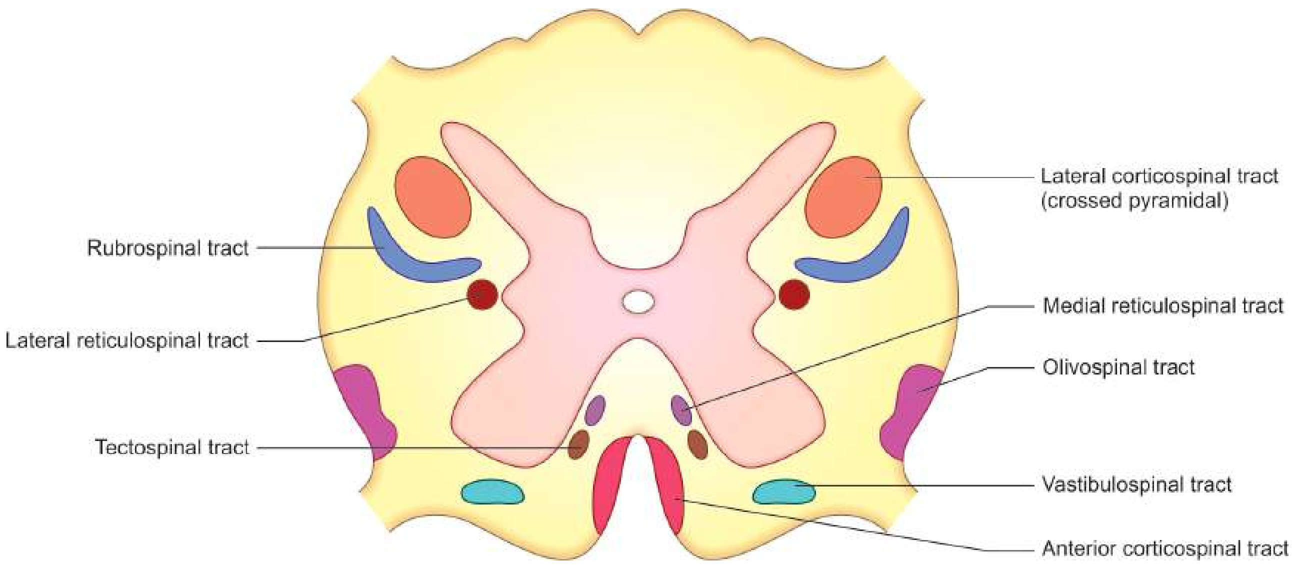


Fig. 1.19: Location of descending tracts in spinal cord

Vestibulospinal tract (Fig. 1.20): The fibers arise from lateral vestibular nucleus lying at pontomedullary junction. The fibers descend uncrossed to spinal cord. This tract is situated in the anterior white column of spinal cord. These fibers synapse with anterior horn cells. It has two types:

Lateral—controls extensors muscle tone and medial—for movement of head.

Tectospinal tract: The tract is formed by the axons of neurons lying in the superior colliculus of the midbrain. The tract descends through pons, medulla and anterior white column of spinal cord. It mediates reflex movements of head and neck in response to visual stimulus.

Ascending tracts of the spinal cord are given in Table 1.11 and Figure 1.21.

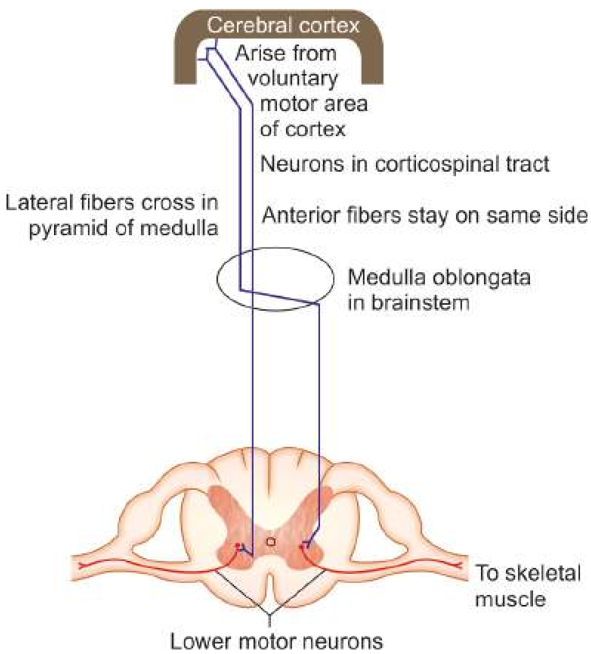


Fig. 1.20: Pyramidal/corticospinal tracts—course of corticospinal fibers

Blood Supply of Spinal Cord

The spinal cord receives its blood supply from three longitudinal arterial channels that extend along the length of the cord. The anterior spinal artery is present in relation to the anterior median sulcus. Two posterior spinal arteries (one on each side) run along the posterolateral sulcus (i.e. along the line of attachment of the dorsal nerve roots) (Fig. 1.25).

The main source of blood to the spinal arteries is from the vertebral arteries (from which the anterior and posterior spinal arteries take origin). However, the blood from the vertebral arteries reaches only up to the cervical segments of the cord. The spinal arteries also receive blood through radicular arteries that reach the cord along the roots of spinal nerves. These radicular arteries arise from spinal branches of the vertebral, ascending cervical, deep cervical, intercostal, lumbar and sacral arteries.

The veins draining the spinal cord are arranged in the form of six longitudinal channels. These are anteromedian and posteromedian channels that lie in the midline; also anterolateral and posterolateral channels that are paired. These channels are interconnected by a plexus of veins that form a venous vasocorona. The blood from these veins is drained by radicular veins that open into a venous plexus lying between the dura and the vertebral canal (epidural or internal vertebral plexus) and through it into various segmental veins.

MEDULLA OBLONGATA

The medulla is the lowest part of brainstem, extending from the lower border of pons to a plane just above which the first cervical nerve arises where it is continuous with the spinal cord (Fig. 1.26).

External Features

The medulla is divided into right and left halves by the anterior and posterior median fissures. The anterior

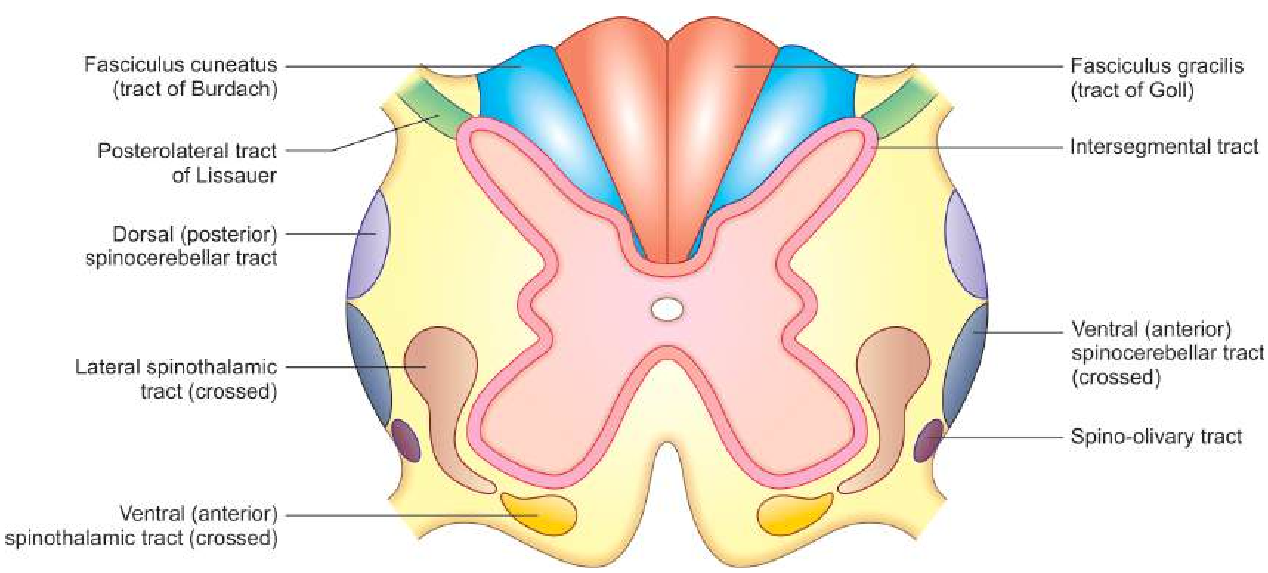


Fig. 1.21: Location of ascending tracts in spinal cord

Table 1.11: The ascending tracts of the spinal cord (Fig. 1.21)

Name	*Function*	*Crossed and uncrossed*	*Beginning*	*Termination*
1. Lateral spinothalamic (axons of 2nd order neurons) (Figs 1.22 and 1.23)	Pain and temperature from opposite half of body	Crosses to opposite side in the same spinal segment	Laminae I–IV of posterior grey column (substantia gelatinosa)	Forms spinal lemniscus in medulla, reaches posterolateral ventral nucleus of thalamus for another relay and ends in areas 3, 1, 2
2. Anterior spinothalamic (axons of 2nd order neurons)	Touch (crude) and pressure from opposite half of body	Ascends to 2–3 spinal segments to cross to opposite side	Laminae I–IV of posterior grey column	Joins medial lemniscus in brainstem, reaches posterolateral ventral nucleus of thalamus for another relay and ends in areas 3, 1, 2
3. Fasciculus gracilis (axons of 1st order sensory neurons) (lower limb)	• Conscious proprioception • Discriminatory touch • Vibratory sense • Stereognosis	• Uncrossed	Dorsal root ganglion cells	Relays in nucleus gracilis, 2nd order fibers form medial lemniscus which reaches posterolateral ventral nucleus of thalamus for another relay and ends in areas 3, 1, 2
4. Fasciculus cuneatus (axons of 1st order sensory neurons) (upper limb)	Same as above	Same as above	Same as above	Relays in nucleus cuneatus, rest is same as above
5. Posterior spinocerebellar (axons of 2nd order neurons) (Fig. 1.24)	Unconscious proprioception from individual muscles of lower limb	Uncrossed	Laminae V, VI of posterior grey column	Vermis of cerebellum (via inferior cerebellar peduncle)
6. Anterior spinocerebellar (axons of 2nd order neurons)	Unconscious proprioception from lower limb as a whole	Crosses twice, once in spinal cord and recrosses in midbrain	Laminae V, VI of posterior grey column	Vermis of cerebellum (via superior cerebellar peduncle) via recrossing

median fissure ends in foramen caecum at its junction with pons. Each half is further divided into anterior, lateral and posterior regions by the anterolateral and posterolateral sulci (Fig. 1.27).

The anterior region on either side of the fissure is formed of a longitudinal elevation called the pyramid.

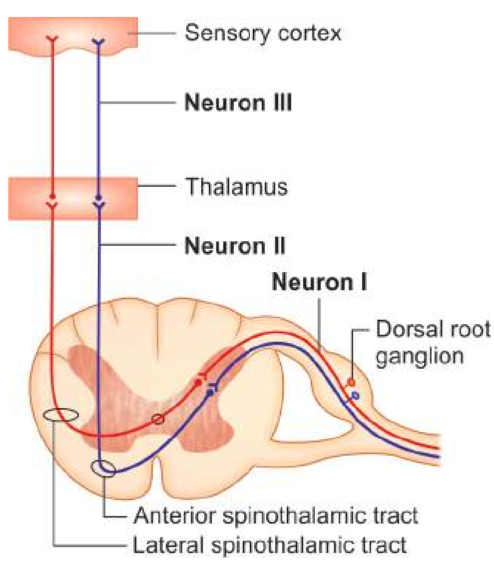


Fig. 1.22: Spinothalamic pathways

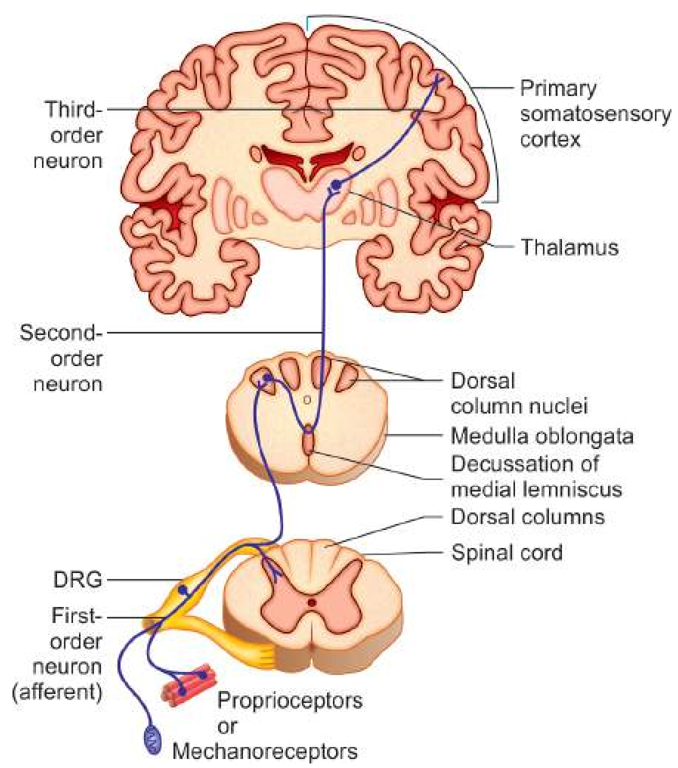


Fig. 1.23: Tracts of dorsal columns

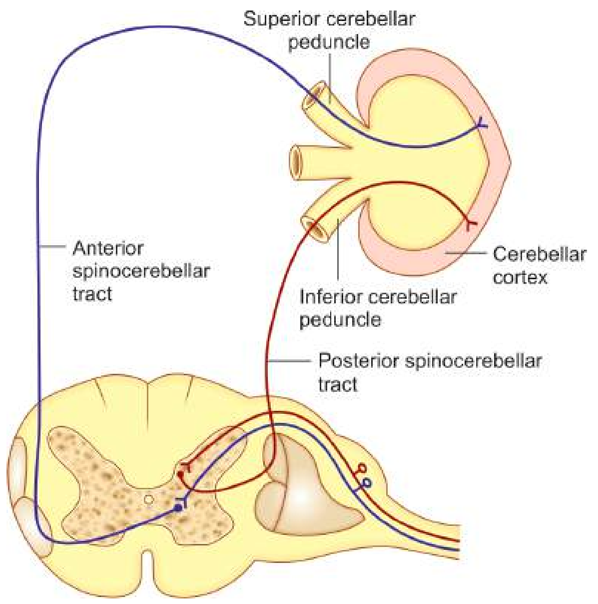


Fig. 1.24: Pathway of posterior and anterior spinocerebellar tract

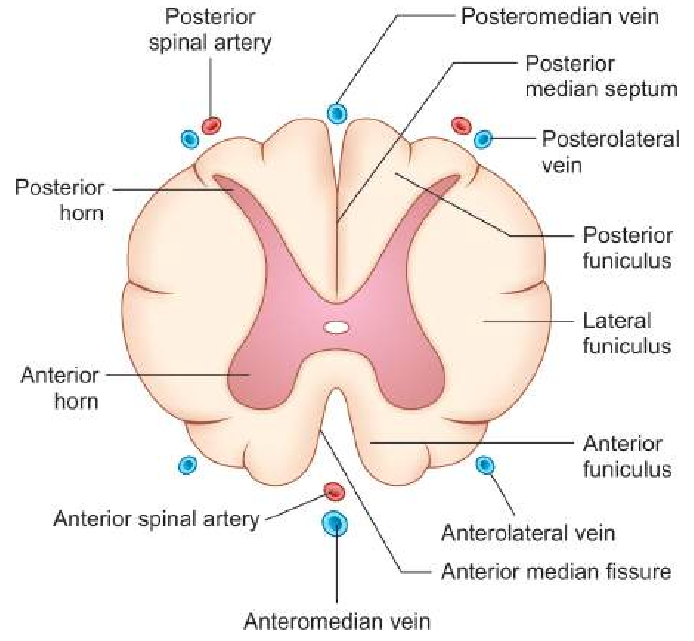


Fig. 1.25: Blood supply of spinal cord

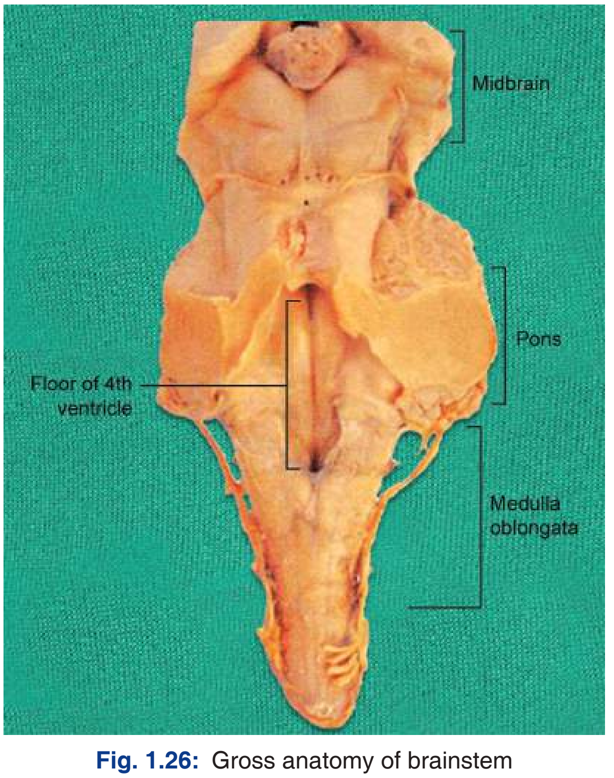


Fig. 1.26: Gross anatomy of brainstem

The pyramid is made-up of corticospinal tract and corticobulbar fibers. In the lower part of the medulla, many fibers of the right and left pyramids cross in the midline forming the pyramidal decussation.

The upper part of the lateral region shows an oval elevation—the olive. It is produced by an underlying mass of grey matter, called the inferior olivary nucleus.

The rootlets of the hypoglossal nerve emerge from the anterolateral sulcus between the pyramid and the olive.

The rootlets of the cranial nerves IX and X and cranial part of the accessory nerve emerge through the posterolateral fissure, behind the olive.

The posterior region lies between the posterolateral sulcus and the posterior median fissure. The upper part of this region is marked by a V-shaped depression which is the lower part of the floor of the fourth ventricle. Below the floor, we see three longitudinal elevations. From medial to lateral side, these are the fasciculus gracilis, the fasciculus cuneatus and the inferior cerebellar peduncle. The upper ends of fasciculus gracilis and fasciculus cuneatus end in their respective nuclei. Fibers from these two nuclei decussate with the opposite side fibers to form sensory decussation (Fig. 1.28).

Transverse section (TS) through the lower part of the medulla passing through the pyramidal decussation. It resembles a transverse section of the spinal cord in having the same three funiculi and the same tracts.

Grey matter: The decussating pyramidal fibers separate the anterior horn from the central grey matter.

Transverse section through the middle of medulla passing through the sensory decussation is as seen in Figure 1.29.

White matter: The nucleus gracilis and cuneatus give rise to the internal arcuate fibers. These fibers cross to the opposite side where they form a paramedian band of fibers, called the medial lemniscus. Placed deeply are:

- Respiratory center, cardiac center for regulation of heart rate, reflex centers for vomiting, coughing, sneezing, hiccupping and swallowing.

PONS

The pons (Latin bridge) is also called metencephalon, 2.5 cm long and extends from cranial end of medulla oblongata to the cerebral peduncles of midbrain (Fig. 1.26). Cranial nerves V, VI, VII, and VIII are attached here (Fig. 1.27).

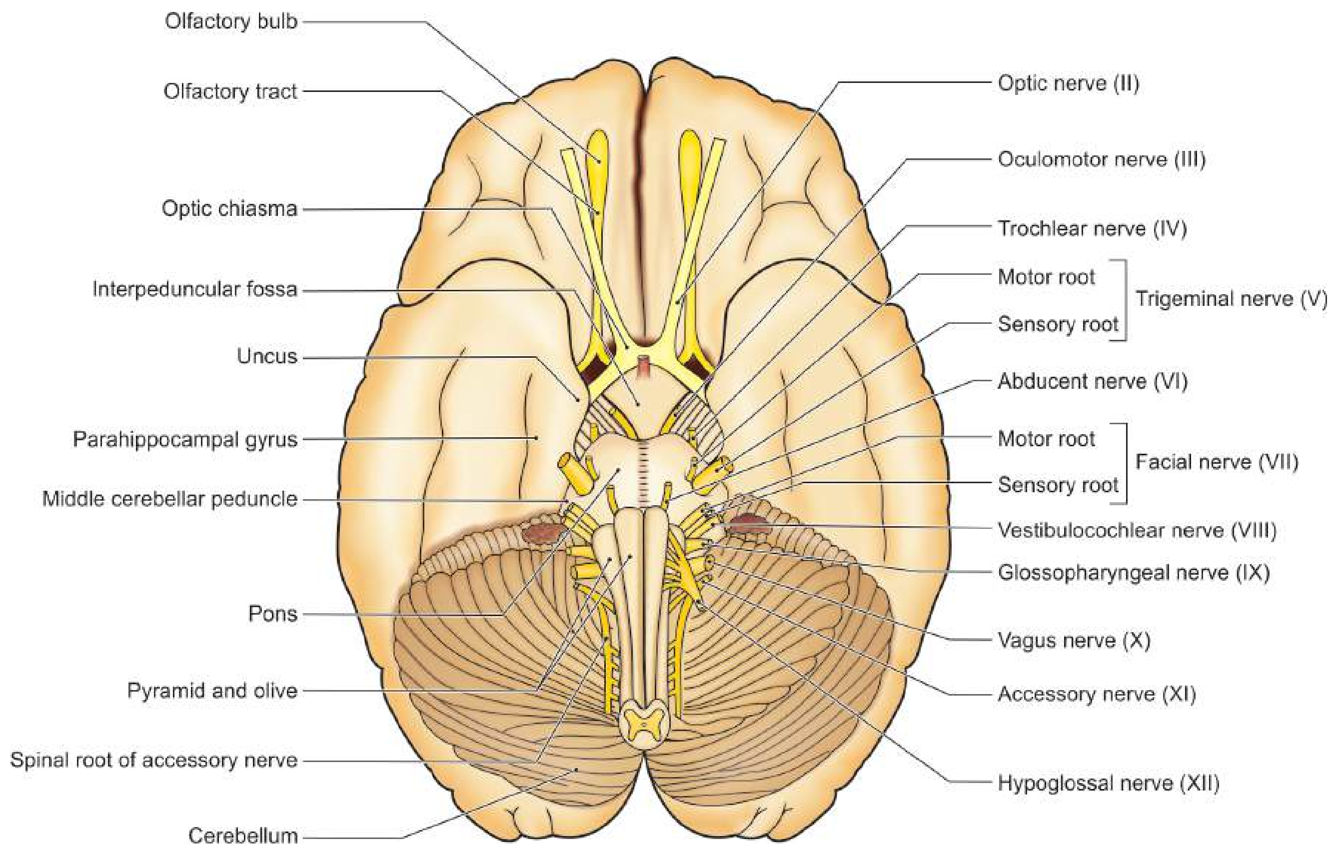


Fig. 1.27: Attachment of cranial nerves to the ventral surface of brainstem with external features of medulla oblongata, pons and midbrain

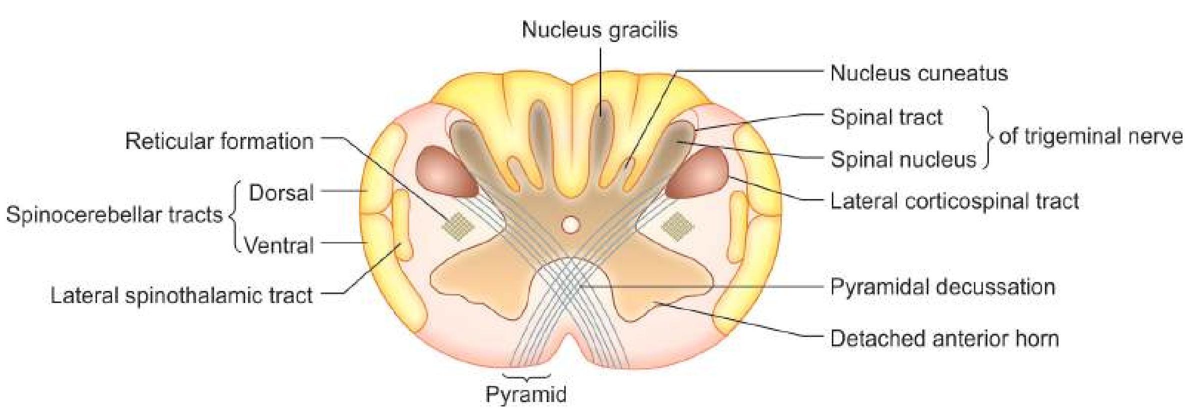


Fig. 1.28: Transverse section of medulla oblongata at the level of pyramidal decussation

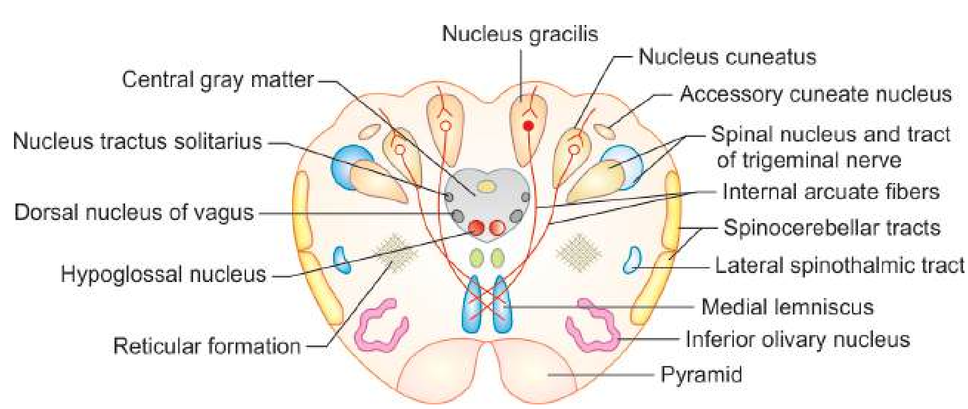


Fig. 1.29: Transverse section of medulla oblongata at the level of sensory decussation

Unit

I

Nervous System

The pons has two surfaces—ventral and dorsal.

The ventral or anterior surface is convex in both directions and is transversely striated. In the median plane, it shows a vertical basilar sulcus which lodges the basilar artery. Laterally, the surface is continuous with the middle cerebellar peduncle. The dorsal or posterior surface is hidden by the cerebellum, and forms the upper half of the floor of the fourth ventricle.

Pons has two borders—superior and inferior.

- **Superior border:** Crus cerebri are attached here. III and IV nerves are also seen.
- **Inferior border:** Lies at the junction of pons and medulla. VI, VII and VIII nerves lie at this border.

Internal Structure

Grey matter: It is represented by the nuclei pontis which are scattered among longitudinal and transverse fibers. The pontine nuclei form an important part of the cortico-ponto-cerebellar pathway. Fibers from all these nuclei go to the opposite half of the cerebellum. The dorsal and ventral cochlear nuclei are situated dorsal and ventral to the inferior cerebellar peduncle.

White matter: It consists of longitudinal and transverse fibers.

- The longitudinal fibers include:
  - The corticospinal and corticonuclear (pyramidal) tracts.
  - The corticopontine fibers ending in the pontine nuclei.
- The transverse fibers are pontocerebellar fibers beginning from the pontine nuclei and going to the opposite half of the cerebellum, through the middle cerebellar peduncle.

Grey Matter

- The sixth nerve nucleus lies beneath the facial colliculus.
- The seventh nerve nucleus lies in the reticular formation of the pons.
- The vestibular and cochlear nuclei lie in relation to the inferior cerebellar peduncle. The vestibular nuclei lie deep to the vestibular area in the floor of the fourth ventricle.

The dorsal and ventral cochlear nuclei are situated dorsal and ventral to the inferior cerebellar peduncle (Fig. 1.30).

Upper part of pons: The special features are the motor, and superior sensory nuclei of the trigeminal nerve. The motor nucleus is medial to the superior sensory nucleus (Fig. 1.31).

Pneumotaxic center and apneustic centers are present in pons. These control respiration.

MIDBRAIN

The midbrain is also called the mesencephalon. It is 2 cm long and connects the hindbrain with the forebrain. Its cavity is known as the cerebral aqueduct of Sylvius (French anatomist, 1478–1555). It connects the third ventricle with the fourth ventricle (Figs 1.32A and B).

The major subdivisions of midbrain are as follows:

- The tectum is the part posterior to aqueduct. It is made up of the right and left superior and inferior colliculi (Fig. 1.33).
- Each half of the midbrain anterior to the aqueduct is called the cerebral peduncle. Each cerebral peduncle is subdivided into:
  - Crus cerebri, anteriorly
  - Substantia nigra, in the middle
  - Tegmentum, posteriorly

External Features

Ventral surface presents crus cerebri. On the dorsal aspects, superior and inferior colliculi are present. The superior colliculus is connected to the lateral geniculate body by the superior brachium.

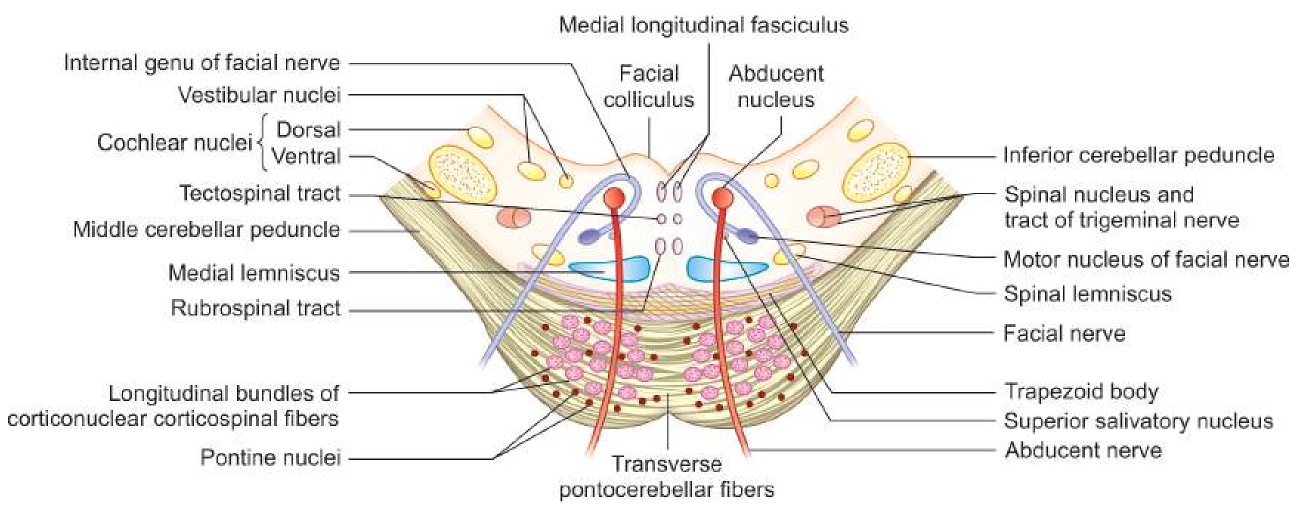


Fig. 1.30: Transverse section of lower part of pons at the level of facial colliculus

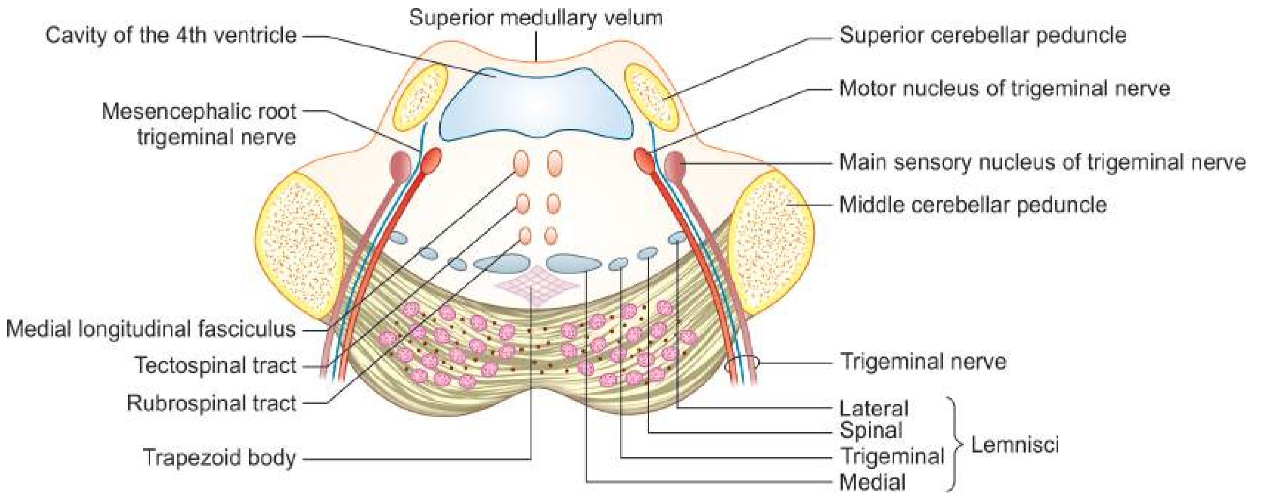
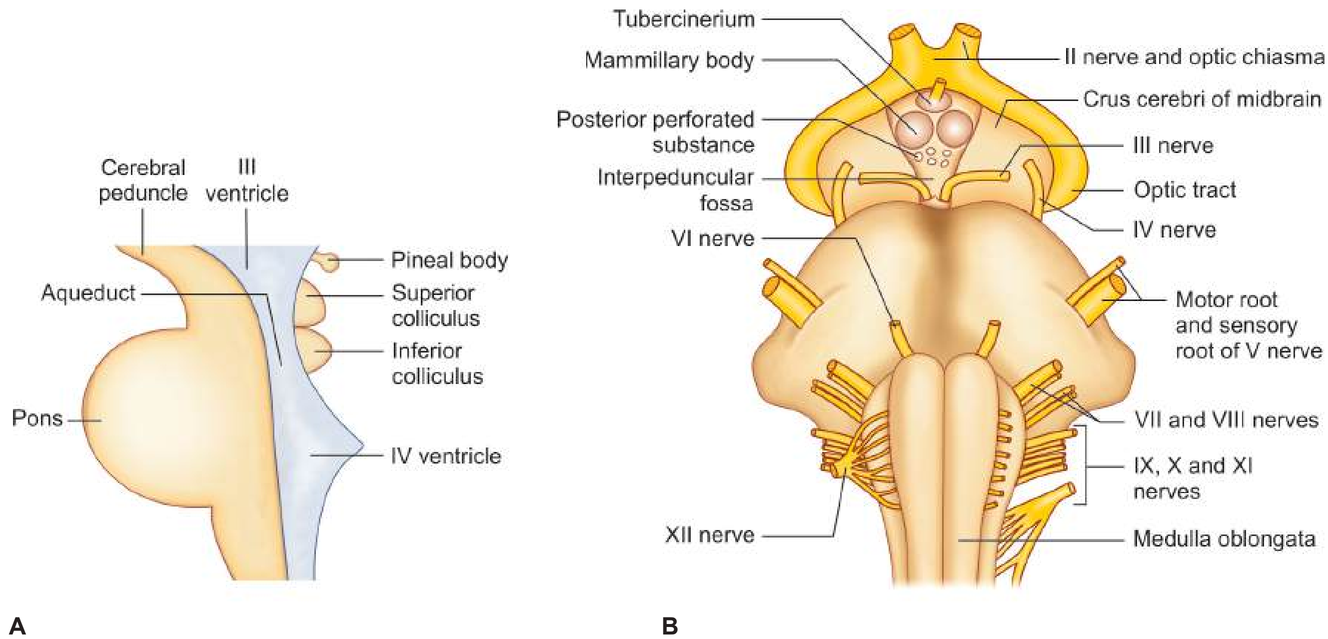


Fig. 1.31: Transverse section of upper pons



Figs 1.32A and B: A. Sagittal section of midbrain with pons; B. ventral aspect of midbrain

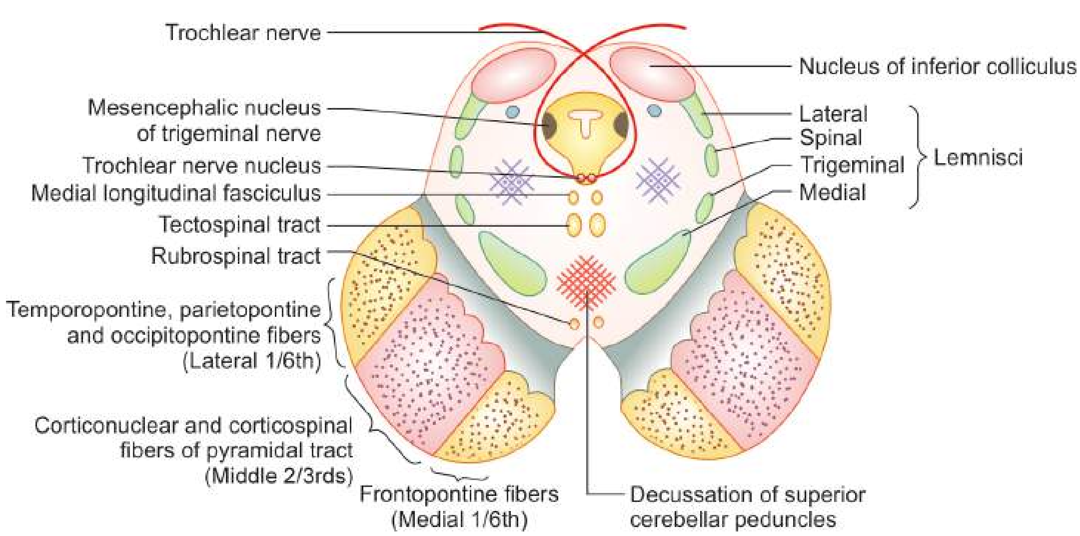


Fig. 1.33: Parts of midbrain and transverse section at the level of inferior colliculus

Likewise, the inferior colliculus is connected to the medial geniculate body by the inferior brachium. III and IV cranial nerves are attached to midbrain.

Level of Inferior Colliculi

Grey matter: The central (periaqueductal) grey matter contains:

- The nucleus of the trochlear nerve in the ventromedial part.
- The mesencephalic nucleus of the trigeminal nerve in the lateral part. The mesencephalic nucleus is made-up of unipolar cells (first neuron) and receives proprioceptive impulses from the muscles of mastication, the facial and ocular muscles, the teeth and temporomandibular joint.
- The inferior colliculus receives afferents from the lateral lemniscus, and gives efferents to the medial geniculate body. In the past, it has been considered as the center for auditory reflexes, but the available evidence indicates that, it helps in localizing the source of sounds.

White matter: The tegmentum contains ascending tracts as follows.

- The *lemnisci* (medial, trigeminal, spinal and lateral) are arranged in the form of a band in which they lie in the order mentioned (from medial to lateral side) like a necklace.
- The trochlear nerve passes laterally and dorsally round the central grey matter.

The transverse section of midbrain at the level of superior colliculi is shown in Fig. 1.34.

Grey matter: The central grey matter contains:

- Nucleus of oculomotor nerve with Edinger-Westphal nucleus in the ventromedial part.
- Mesencephalic nucleus of the trigeminal nerve in the lateral part. The oculomotor nuclei of the two sides are very close to each other (Fig. 1.34).

Superior colliculus receives afferents from the retina (visual), and various other centers. It gives efferent to the spinal cord (tectospinal tract). It controls reflex movements of the eyes, and of the head and neck in response to visual stimuli.

Red nucleus is about 0.5 cm in diameter. It receives afferents from the superior cerebellar peduncle, globus pallidus, subthalamic nucleus and cerebral cortex. It gives efferents to the spinal cord (rubrospinal tract), reticular formation, thalamus, olivary nucleus subthalamic nucleus, etc. It has an inhibitory influence on muscle tone.

CEREBELLUM

Cerebellum (Latin small brain), though small in size (weighs about 150 g), subserves important functions for maintaining tone, posture, and equilibrium of the body. It is the largest part of the hindbrain and the second largest part of the brain. Cerebellum controls the same side of the body directly or indirectly. The cerebellum does not initiate movement, but it contributes to coordination, precision and accurate timing. The grey matter is highly folded to accommodate millions of neurons in a small area and the arrangement is called 'arbor vitae' (vital tree of life). The structure of cerebellum is uniform throughout, i.e. homotypical.

Location

The cerebellum (little brain) is the largest part of the hindbrain. It is situated in the posterior cranial fossa behind the pons and medulla. It is an infratentorial structure that coordinates voluntary movements of the body (Fig. 1.35).

Relations

- Anteriorly: Fourth ventricle, pons and medulla.
- Posteroinferiorly: Squamous occipital bone.
- Superiorly: Tentorium cerebelli.

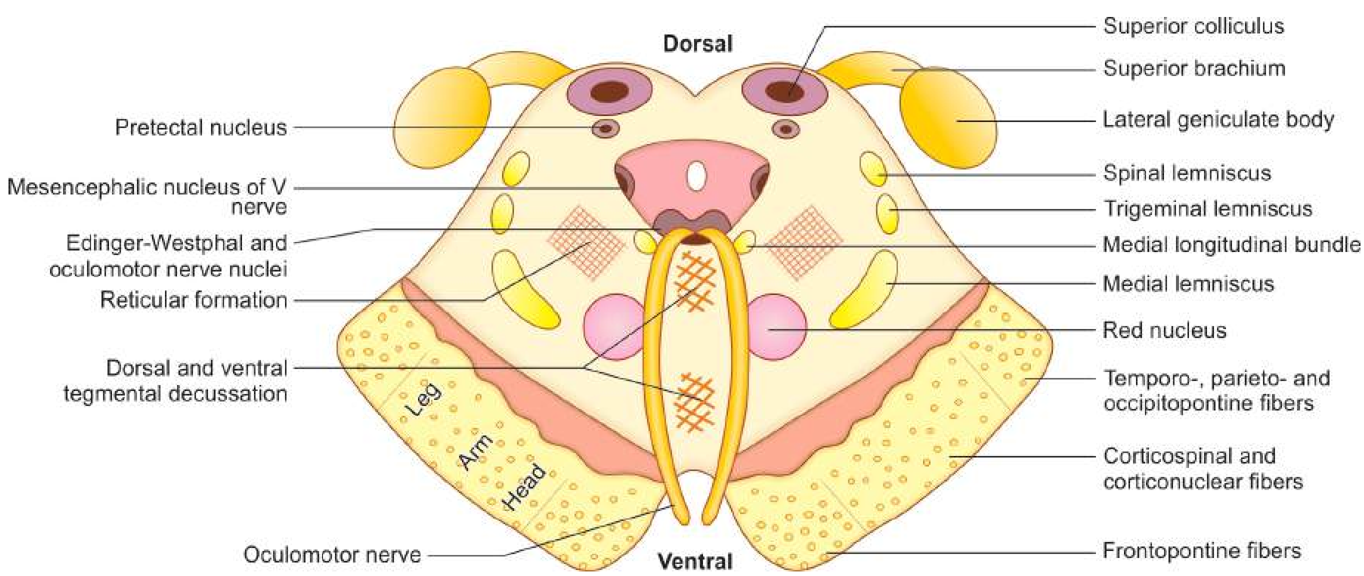


Fig. 1.34: Transverse section of midbrain at the level of superior colliculus

Characteristic Features

The cerebellum consists of two cerebellar hemispheres that are united to each other through a median vermis. It has two surfaces—superior and inferior. The superior surface is slightly convex. The two hemispheres are continuous with each other on this surface.

The inferior surface shows a deep median notch called the vallecula which separates the right and left convex hemispheres. The anterior aspect of the cerebellum is marked by a wide and deep notch in which the pons and medulla are lodged.

Posteriorly, there is a narrow and deep notch in which the falx cerebelli lies (Fig. 1.36).

Each hemisphere is divided into three lobes:

- The anterior lobe lies on the anterior part of the superior surface. It is separated from the middle lobe by the fissura prima.
- The middle lobe is the largest of three lobes situated on both its surfaces. It is limited in front by the fissura prima (on the superior surface), and by the posterolateral fissure (on the inferior surface).
- The flocculonodular lobe is the smallest lobe of the cerebellum. It lies on the inferior surface, in front of the posterolateral fissure.

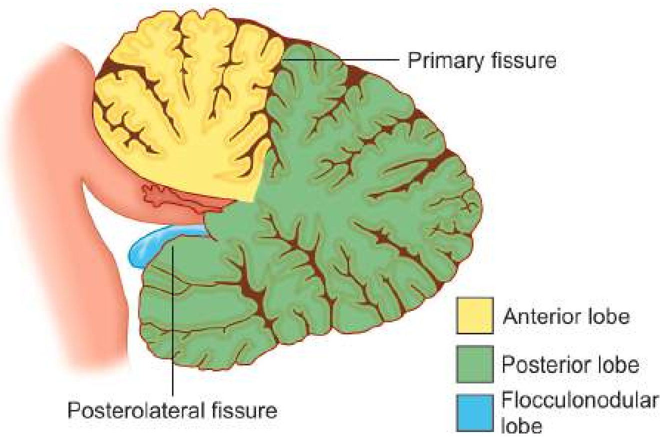


Fig. 1.35: Anatomical lobes of the cerebellum

Histological Structure

The structure of cerebellum is uniform throughout, i.e. homotypical. In contrast, the structure of cerebral cortex varies in different areas, i.e. it is heterotypical.

Grey matter contains basket cells which inhibit body of Purkinje cells.

It also has stellate cells which inhibit dendrites of Purkinje cell (Figs 1.37A and B).

Purkinje cell: It is the characteristic cell of cerebellum. It is a large cell with flask shape.

Morphological Divisions of Cerebellum

The archicerebellum phylogenetically is the oldest part of the cerebellum to appear in evolution in aquatic vertebrates. It includes the flocculonodular lobe and the lingula. It is chiefly vestibular in its connections. It controls the axial musculature and the bilateral movements used for locomotion and maintenance of equilibrium.

The paleocerebellum is the next part of the cerebellum to appear in terrestrial vertebrates with the appearance of limbs. It is made-up of the anterior lobe (except lingula), and the pyramid and uvula of the inferior vermis. Its connections are chiefly spinocerebellar. It controls tone, posture and crude movements of the limbs.

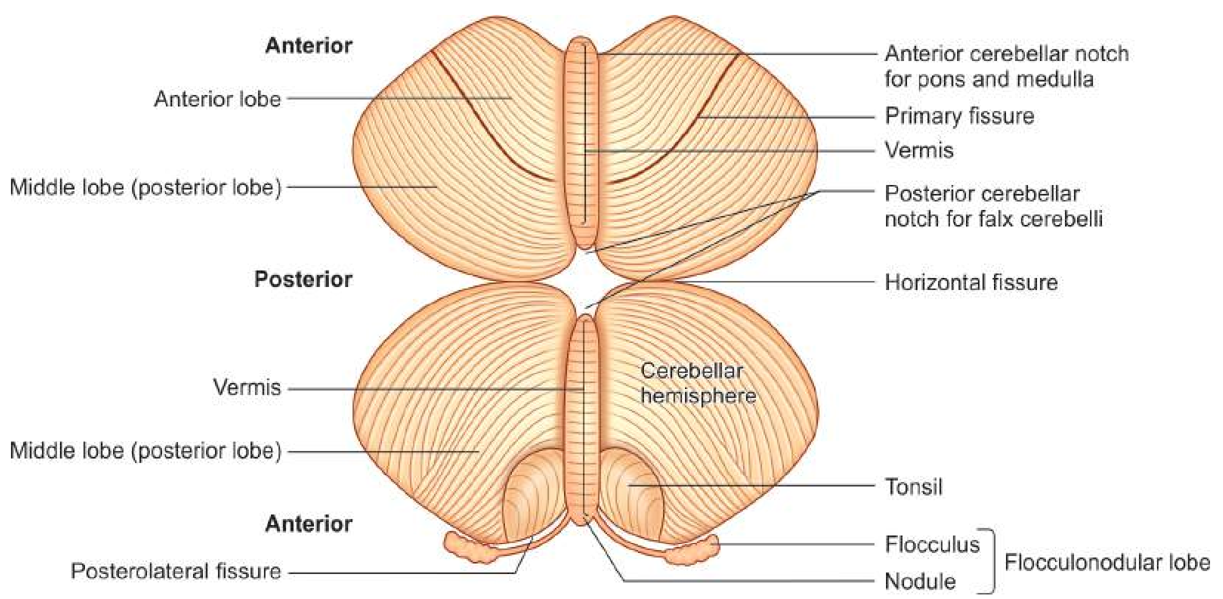
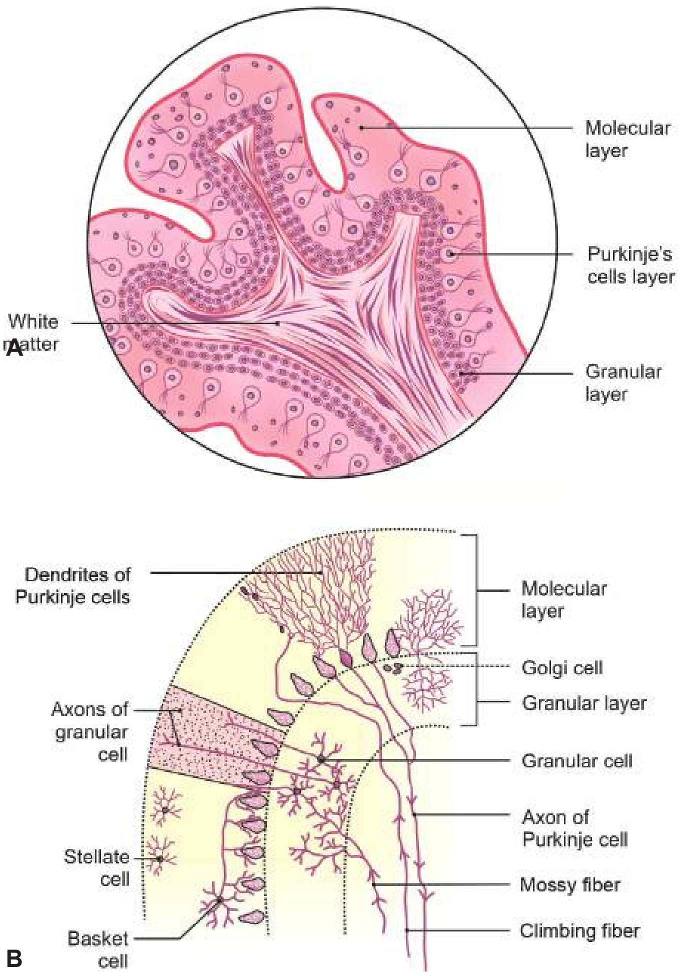


Fig. 1.36: Lobes and morphological subdivisions of cerebellum. Area above horizontal fissure represents superior surface and area below the fissure shows inferior surface



Figs 1.37A and B: A. Histology of cerebellum; B. histological connections of cerebellar neurons

The neocerebellum is the newest part of the cerebellum to develop. It is made-up of the posterior/ middle lobe (the largest part of the cerebellum) except the pyramid and uvula of the inferior vermis. It is primarily concerned with the regulation of fine movements of the body.

Functional Divisions of Cerebellum

The anterior and posterior lobes are organized into three longitudinal zones—lateral, intermediate and vermis (Figs 1.38A and B).

Connections of Cerebellum

The constituent fibers in them are given in Table 1.12. It is clear from Table 1.13 that the middle and inferior peduncles are chiefly afferent to the cerebellum and that the superior cerebellar peduncle is chiefly efferent in nature.

Grey matter of cerebellum: It consists of the cerebellar cortex and the cerebellar nuclei. Most important is nucleus dentatus, others are emboliformis, fastigii and globose.

Functional division of cerebellum	*Function*
Lateral zone	Connected with association areas of the brain and is involved in planning, programming and coordination of muscular activities of the entire body
Intermediate zone	Concerned with control of muscles of distal parts of limbs like hands and feet
Median zone/vermis	Concerned with control of muscles of trunk, neck, shoulders and hips through vestibulospinal and reticulospinal tracts
Flocculonodular lobe	This is an extra lobe. This lobe functions with vestibular system in controlling equilibrium

Blood Supply

Cerebellum is supplied by two superior cerebellar arteries, two anterior inferior cerebellar arteries and two posterior inferior cerebellar arteries. Veins drain into neighbouring sinuses.

Functions of Cerebellum

Cerebellum controls the same side of the body. Its influence is ipsilateral. This is in marked contrast to cerebrum which controls the opposite half of the body. It coordinates voluntary movements so that they are smooth, balanced and accurate.

Cerebellum controls tone, posture and equilibrium. This is chiefly done by the archicerebellum and paleocerebellum.

Cerebellum controls movements of eyeballs. It controls and coordinates these movements by affecting agonists, antagonists and synergists. It also helps in learning of special motor skills. It plays a role in cognition.

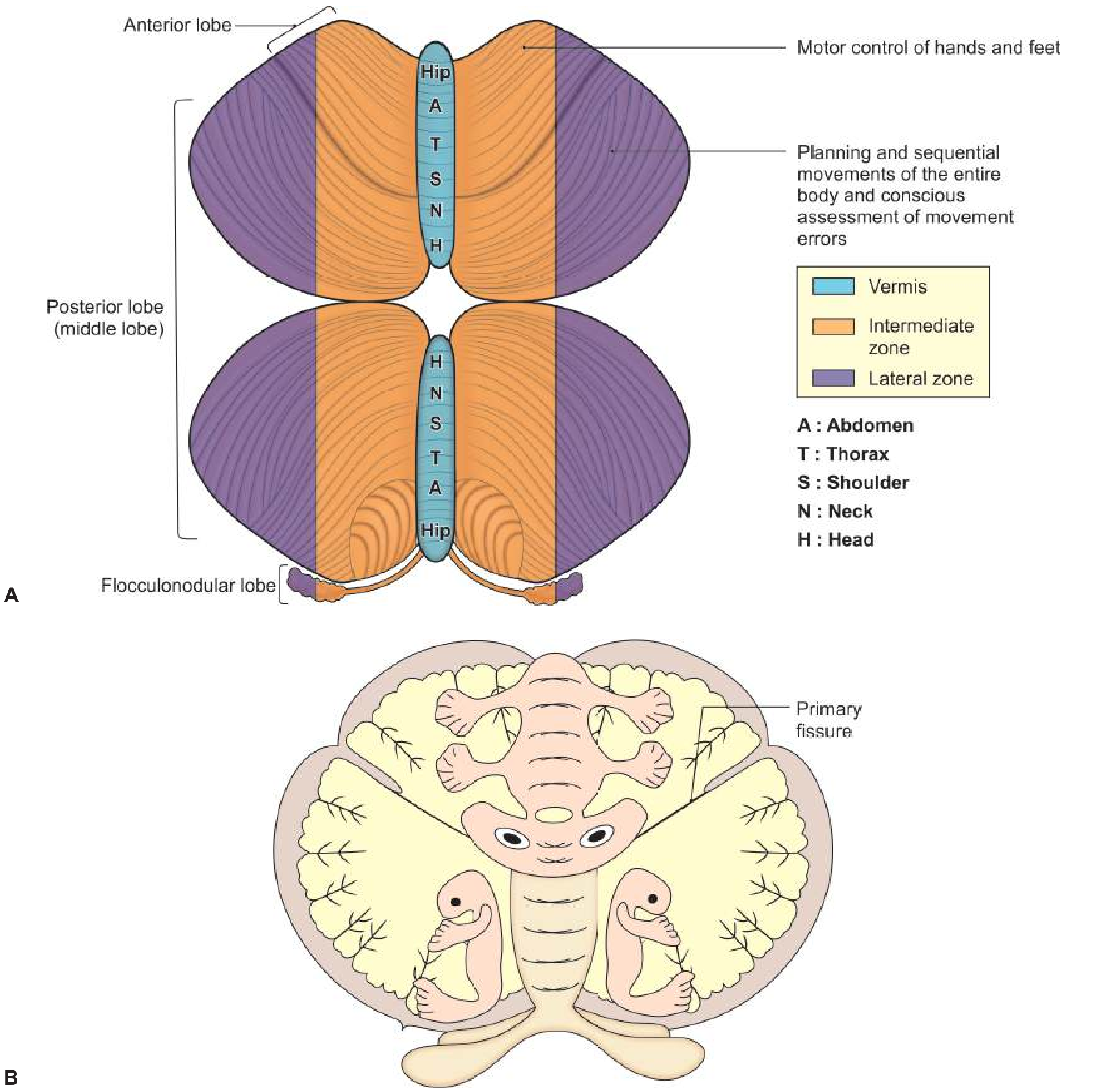
Flocculonodular lobe is connected to vestibular nuclei. It is involved in maintenance of muscle tone and posture. Spinocerebellum, vermis and intermediate regions receive afferents from motor cortex via corticopontocerebellar fibers. All sensory information of muscles, joints, cutaneous, auditory and visual parts are relayed here.

Vermis controls axial muscles, and thus maintains posture. Paramedian areas are involved in control of distal group of muscles to bring smooth coordinated activity (Fig. 1.39).

Cerebellum functions as 'comparator'. It receives information from cerebrum and spinal cord. It corrects and modifies ongoing movements.

Neocerebellum is responsible for fine tuning of motor performance for precise movements. It helps in planning and production of skilled movements along with cerebrum.

It has been seen by functional magnetic resonance imaging (fMRI) that if fingers of right hand are moved



Figs 1.38A and B: A. Functions of cerebellum according to the zones; B. cerebellar cortex showing somatosensory projection areas

Table 1.12: Morphological and functional divisions of cerebellum

	Afferents	*Efferents*	*Functions*
Vestibulocerebellum	• Vestibulocerebellar tract	• Cerebellovestibular • Fastigiobulbar	• Fixes position of body during skilled movements • Maintains equilibrium of body • Controls eyeball movements
Spinocerebellum	• Dorsal spinocerebellar • Ventral spinocerebellar • Cuneocerebellar tract • Reticulocerebellar • Trigeminocerebellar	• Cerebelloreticular • Cerebello-olivary	• Receives tactile, proprioceptive, auditory and visual impulses control synergistic activity of agonistic and antagonistic muscles. Concerned with skilled movements
Neocerebellum	• Pontocerebellar tract • Olivocerebellar	• Dentatothalamic • Dentatorubral	• Smooth transition of motor activity from proximal to distal muscle groups. • Planning and programming of purposeful and rapid movements including their duration and termination. • Acts as a feedback center between cerebral cortex and peripheral motor movements.

Table 1.13: Constituents of the cerebellar peduncles		
Peduncle	***Afferent tracts***	***Efferent tracts***
• Superior cerebellar peduncle (connects cerebellum to midbrain)	• Anterior spinocerebellar • Tectocerebellar	• Globorubral • Dentatothalamic • Dentato-olivary • Fastigioreticular
• Middle cerebellar peduncle (connects cerebellum to pons)	• Pontocerebellar (part of the corticopontocerebellar pathway)	
• Inferior cerebellar peduncle (connects cerebellum to medulla oblongata)	• Posterior spinocerebellar • Cuneo cerebellar (posterior external arcuate fibers) • Olivocerebellar • Parolivocerebellar • Reticulocerebellar • Vestibulocerebellar • Anterior external arcuate fibers • Striae medullaris • Trigeminocerebellar	• Fastigiovestibular • Cerebello-olivary • Fastigioreticular

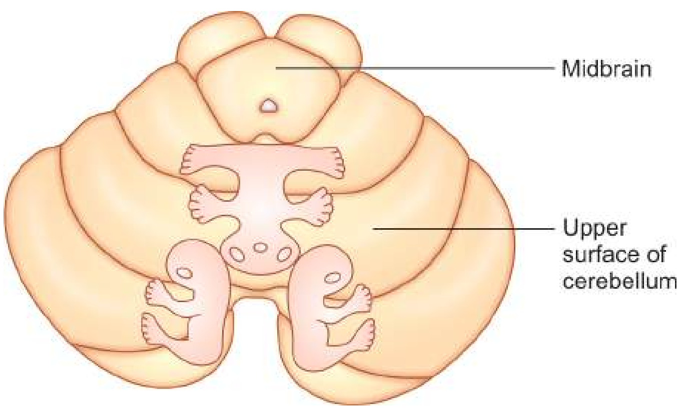


Fig. 1.39: Somatotopic representation of the body

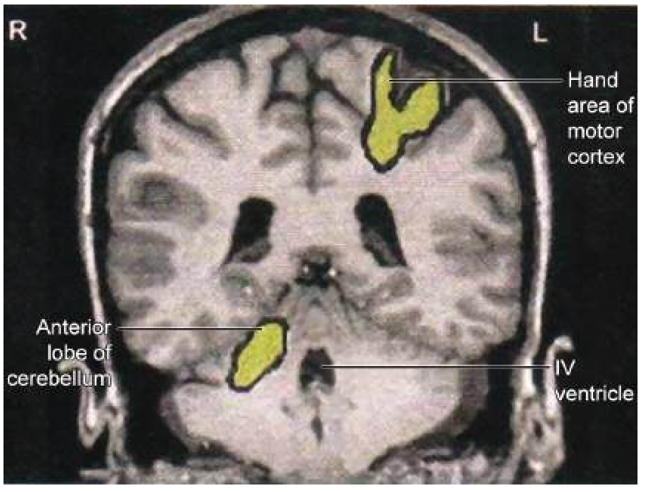


Fig. 1.40: fMRI showing activity in left cerebral cortex and right cerebellum on moving the fingers of right hand

repetitively, the activity is seen in precentral gyrus of left cerebral cortex and in anterior quadrangular lobule of right cerebellar hemisphere (Fig. 1.40).

CEREBRUM

The cerebrum (Latin 'brain') is the largest part of the brain. It is also known as pallium. It occupies anterior, middle cranial fossae and the supratentorial part of the posterior cranial fossa. It is made-up of outer grey matter and inner white matter and some neuronal masses called basal ganglia nuclei within the white matter. Besides this, each hemisphere contains a middle structure called diencephalon and a cavity called lateral ventricle.

There is free flow of information in the central nervous system; between two hemispheres through the commissural fibers; between various parts of one hemisphere through the association fibers and between upper and lower parts through the projection fibers. Internal capsule contains lots of fibers packed in its 'limbs'. It is supplied by the 'end artery'. The haemorrhage or thrombosis of 'end artery' may cause the 'end' of the human being concerned, if not treated properly.

Characteristic Features

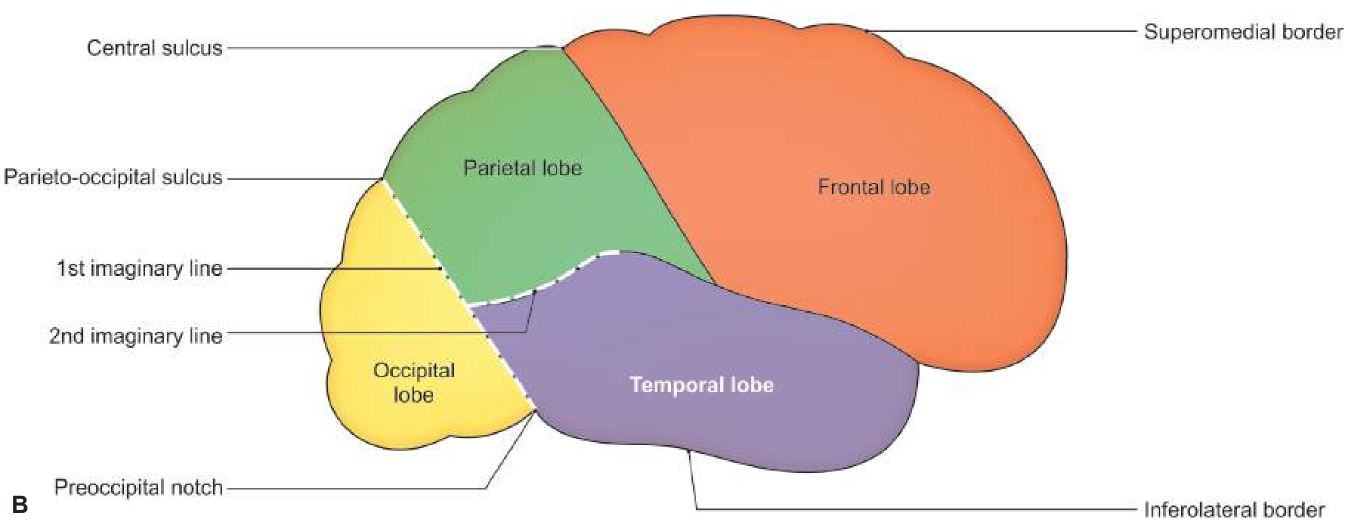
The cerebrum is made-up of two cerebral hemispheres which are incompletely separated from each other by the median longitudinal fissure. The two hemispheres are connected to each other across the median plane by the corpus callosum. Each hemisphere contains a cavity, called the lateral ventricle. The surface area of cerebrum is 2000 cm^2.

CEREBRAL HEMISPHERE

Characteristic Features

Each hemisphere has the following features:

- **Three surfaces:**
  - The superolateral surface is convex and is related to the cranial vault (Figs 1.41A, B and 1.42).



Figs 1.41A and B: Superolateral surface of cerebral hemisphere: A. Original; B. suggestive parts

- The medial surface is flat and vertical. It is separated from the corresponding surface of the opposite hemisphere by the falx cerebri and the longitudinal fissure (Fig. 1.43).
- The inferior surface is irregular. It is divided into an anterior part—the orbital surface, and a posterior part—the tentorial surface. The two parts are separated by a deep cleft called the stem of the lateral sulcus (Fig. 1.44).

- **Four borders:**
  - Superomedial border separates the superolateral surface from the medial surface.
  - Inferolateral border separates the superolateral surface from the inferior surface. The anterior part of this border is called the superciliary border. There is a depression on the inferolateral border situated about 5 cm in front of the occipital pole, it is called the preoccipital notch.
  - Medial orbital border separates the medial surface from the orbital surface (Fig. 1.43).
  - Medial occipital border separates the medial surface from the tentorial surface (Fig. 1.43).
- **Three poles:**
  - Frontal pole, at the anterior end.
  - Occipital pole, at the posterior end.
  - Temporal pole, at the anterior end of the temporal lobe (Fig. 1.44).

Functional or Cortical Areas of Cerebral Cortex

Motor Areas

Primary Motor Area

It is located in the precentral gyrus, including the anterior wall of central sulcus, and in the anterior part of paracentral lobule on the medial surface of cerebral hemispheres. This corresponds to area 4 of Brodmann.

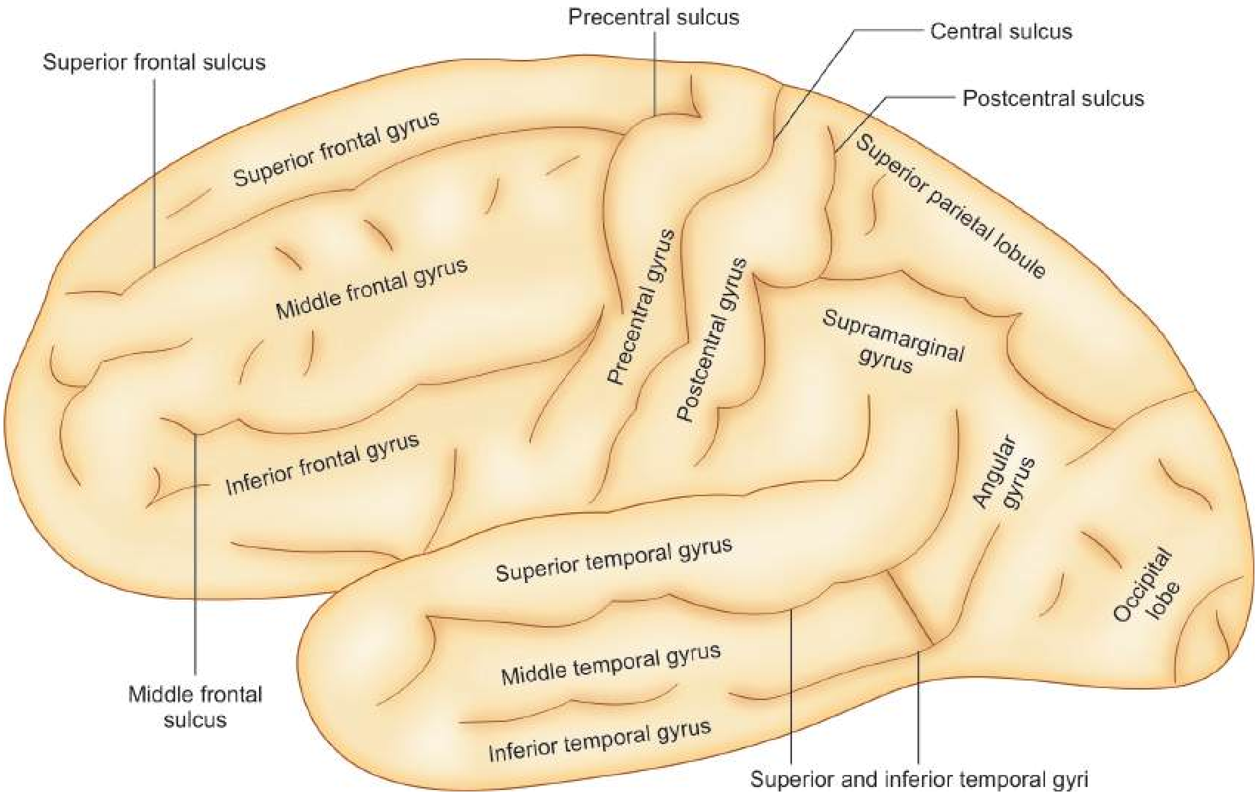


Fig. 1.42: Sulci and gyri on superolateral surface of left cerebral hemisphere

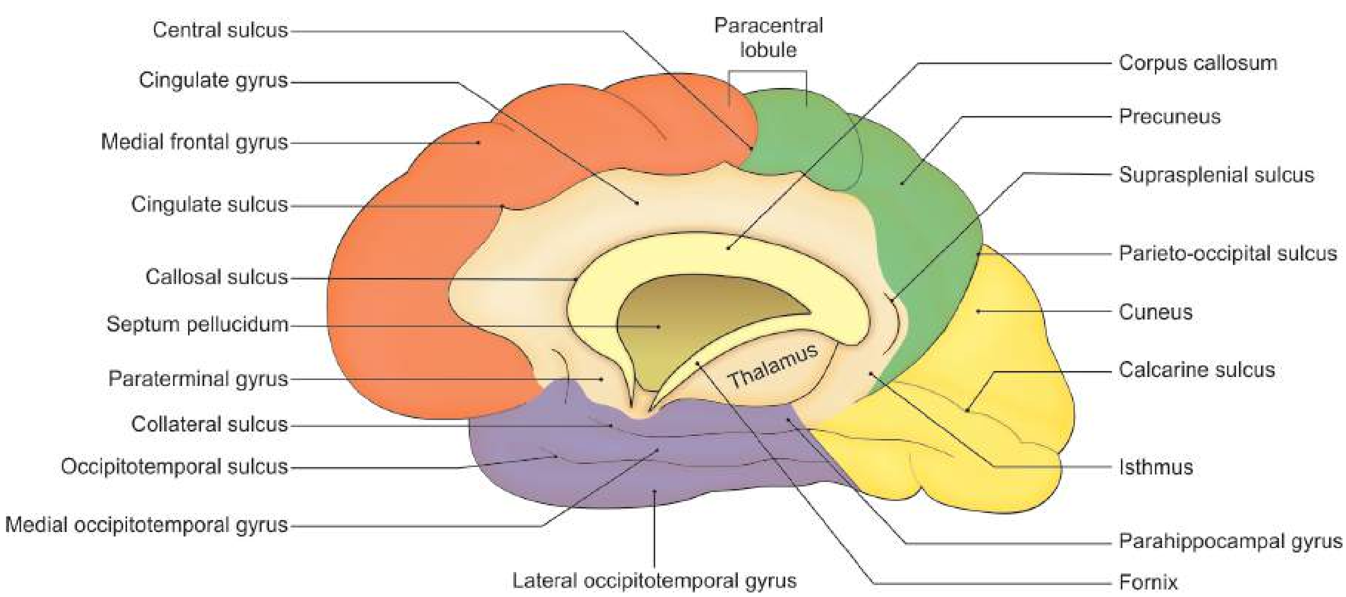


Fig. 1.43: Sulci and gyri on the medial surface of right cerebral hemisphere

Electrical stimulation of primary motor area elicits contraction of muscles that are mainly on the opposite side of body. Although cortical control of musculature is mainly contralateral, there is significant ipsilateral control of most of the muscles of the head and axial muscles of the body. The contralateral half of the body is represented as upside down, except the face (Fig. 1.45).

The area for the face, especially the larynx and lips, is, therefore, disproportionately large and a large area is also assigned to the hand particularly the thumb and index finger. Movements of joints are represented rather than individual muscles (Table 1.14).

Premotor Area

This area coincides with the Brodmann's area 6 and is situated anterior to motor area in the superolateral and medial surfaces of the hemisphere. The premotor area contributes to motor function by its direct contribution to the pyramidal and other descending motor pathways and by its influence on the primary motor cortex (Figs 1.46A and B).

In contrast, the premotor area programs skilled motor activity and thus, directs the primary motor area in its execution. The premotor and primary motor areas

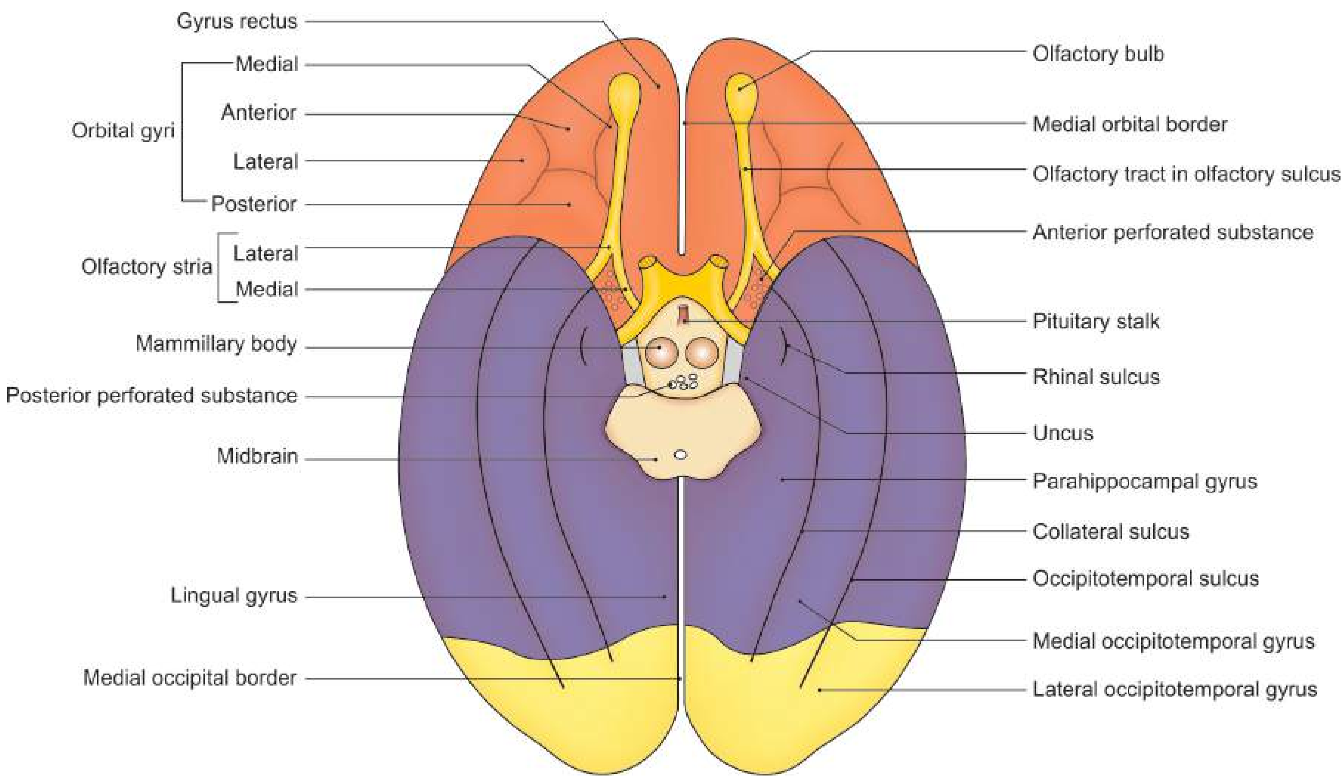


Fig. 1.44: Sulci and gyri on the inferior aspect of cerebral hemisphere

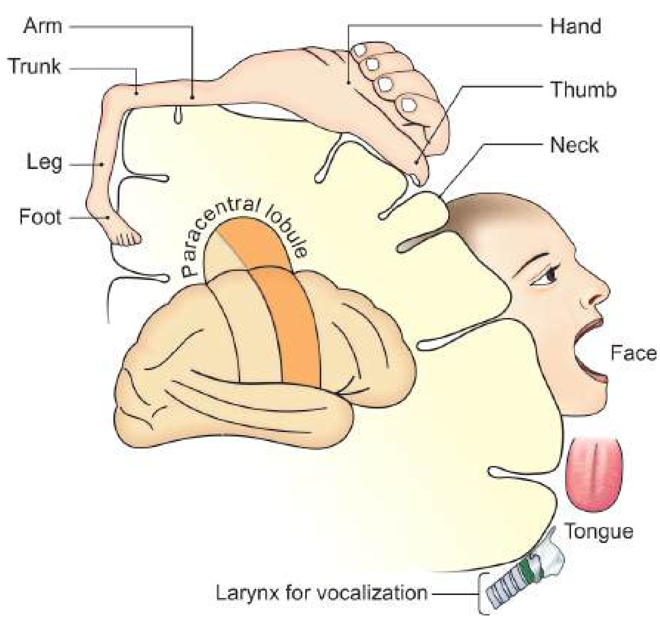


Fig. 1.45: Motor homunculus on the precentral gyrus

are together referred to as the primary somatomotor area (Ms I).

Supplementary Motor Area (Ms II)

It is predominantly motor in function. This motor area is in the part of area 6 that lies on the medial surface of the hemisphere anterior to the paracentral lobule.

Motor Speech Area of Broca (French Neurologist, 1824–80)

This area occupies the opercular and triangular portions of the inferior frontal gyrus corresponding to the areas 44 and 45 of Brodmann. This is present on the left side in 98% of right-handed persons. In 70% of left handers, it is again present in left hemisphere. Only in 15%, it is situated in right hemisphere. In remaining 15%, it may be on either side.

Frontal Eye Field

It lies in the middle frontal gyrus just anterior to precentral gyrus. It is the lower part of area 8 of Brodmann on the lateral surface of cerebral hemisphere, extending slightly beyond that area. Electrical stimulation of this area causes deviation of both the eyes to the opposite side. This is called conjugate movements of eyes. Movements of the head and dilatation of pupil may also occur. This area is connected to the cortex of occipital lobe which is concerned with vision.

Prefrontal Cortex

Prefrontal cortex is a large area lying anterior to the precentral area. It includes the superior, middle, and inferior frontal gyri, medial frontal gyms, orbital gyri and anterior half of the cingulate gyrus. These include Brodmann's areas 9, 10, 11 and 12. This area is connected to other areas of the cerebral cortex, corpus striatum, thalamus and hypothalamus. It is also connected to cerebellum through the pontine nuclei. It controls emotions, concentration, attention, initiative and judgment. It has reciprocal connections with thalamic dorsomedial nucleus, hypothalamus, and limbic system.

Sensory Areas

First Somesthetic Area

First somesthetic (general sensory) area is also called first somatosensory area (Sm I). It occupies postcentral

Table 1.14: Functional areas of the cerebral cortex

Lobe	*Area*	*Area no.*	*Location*	*Representation of body parts*	*Function*	*Effect of lesion*
Frontal	Motor	4	Precentral gyrus and paracentral lobule	Upside down except face	Controls voluntary activities of the opposite half of body	Contralateral paralysis and Jacksonian fits
	Premotor	6	Posterior parts of superior, middle and inferior frontal gyri	—	Controls extrapyramidal system	Often mixed with pyramidal effect
	Frontal eye field	6, 8	Posterior part of middle frontal gyrus	—	Controls horizontal conjugate movements of the eyes	Horizontal conjugate movements are lost
	Motor speech (Broca's area)	44, 45	Pars triangularis and pars opercularis	—	Controls the spoken speech	Aphasia (motor)
	Prefrontal	9, 10, 11, 12	The remaining large, anterior part of frontal lobe	—	Controls emotions, concentration, attention initiative and judgment intelligence	Loss of orientation
Parietal	Sensory (somesthetic)	3, 1, 2	Postcentral gyrus and paracentral lobule	Upside down except face	Perception of exteroceptive (touch, pain and temperature) and proprioceptive impulses	Loss of appreciation of the impulses received
	Sensory association	5, 7	Between sensory and visual areas	—	Stereognosis and sensory speech	Astereognosis and sensory aphasia
	(Wernicke's area)	40	Inferior part of parietal lobule	—	Sensory speech	Sensory aphasia
Occipital	Visuosensory area or striate	17	In and around the postcalcarine sulcus	Macular area has largest representation	Reception and perception of the isolated visual impressions of color size, form, motion, illumination and transparency	Homonymous hemianopia with macular sparing
	Visuopsychic area, para striate and peristriate	18, 19	Surround the striate area	—	Correlation of visual impulses with past memory and recognition of objects seen, and also the depth	Visual agnosia
Temporal	Auditosensory	41, 42	Posterior part of superior temporal gyrus and anterior transverse temporal gyrus	—	Reception and perception of isolated auditory impressions of loudness, quality and pitch	Impaired hearing
	Auditopsychic	22	Rest of the superior temporal gyrus	—	Correlation of auditory impressions with past memory and identification (interpretation) of the sounds heard	Auditory agnosia

gyrus on the superolateral surface of the cerebral hemisphere and posterior part of paracentral lobule, the medial surface. It corresponds to areas 3, 1 and 2 of Brodmann (Fig. 1.47).

The representation of the body in this area corresponds to that in the motor area that is contralateral half of body is represented upside down except the face.

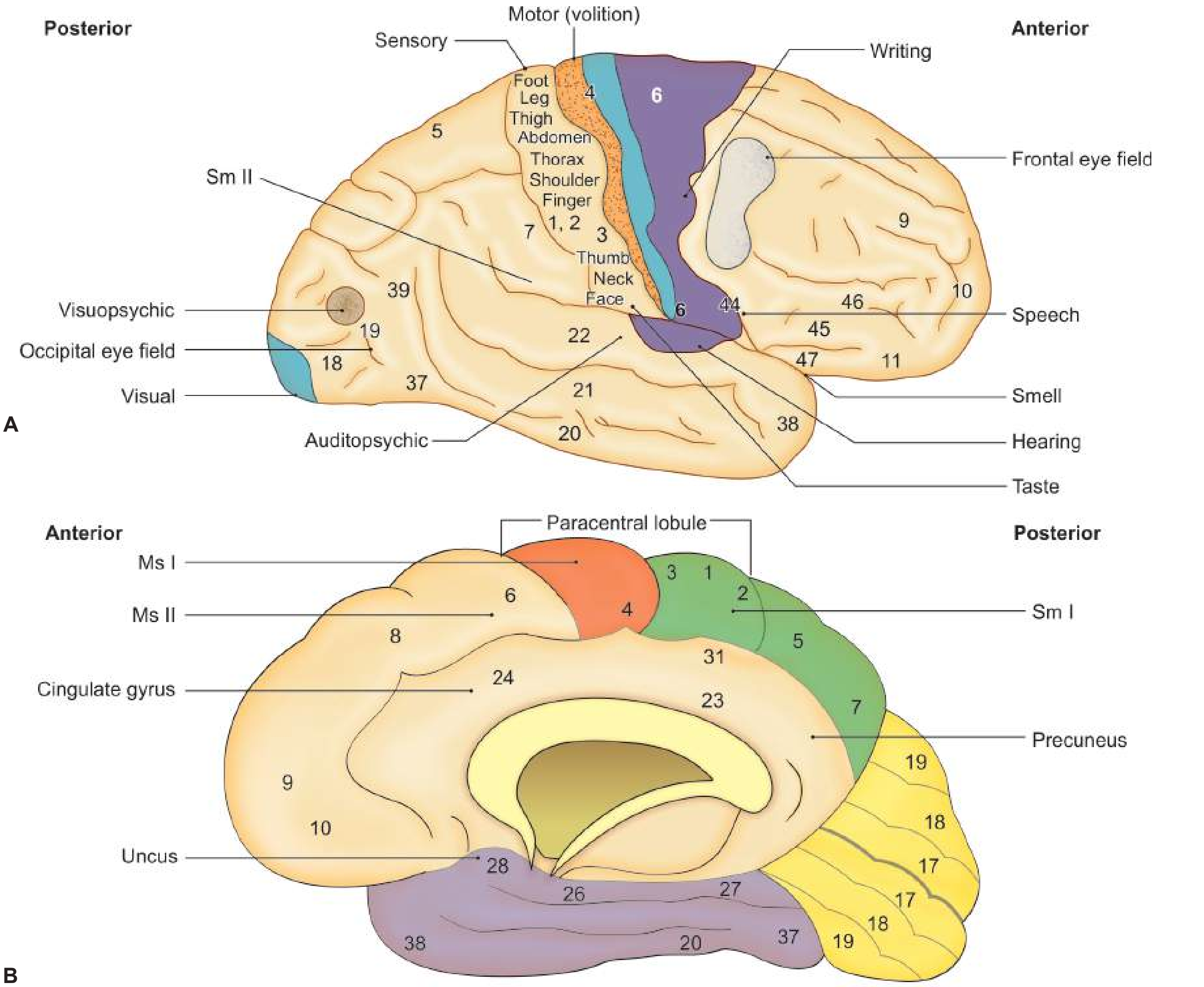
Thus, the thumb, fingers, lips and tongue have a disproportionately large representation.

Second Somesthetic Area

Second somesthetic area, also known as second somatosensory area (Sm II), has been demonstrated in primates including humans. This is situated in the superior lip of the posterior ramus of lateral sulcus with postcentral gyrus. The parts of body are represented, bilaterally.

Somesthetic Association Cortex

Somesthetic association cortex is mainly in the superior parietal lobule on the superolateral surface of the



Figs 1.46A and B: Functional areas of cerebral hemispheres: A. Superolateral surface; B. medial surface of cerebral hemisphere

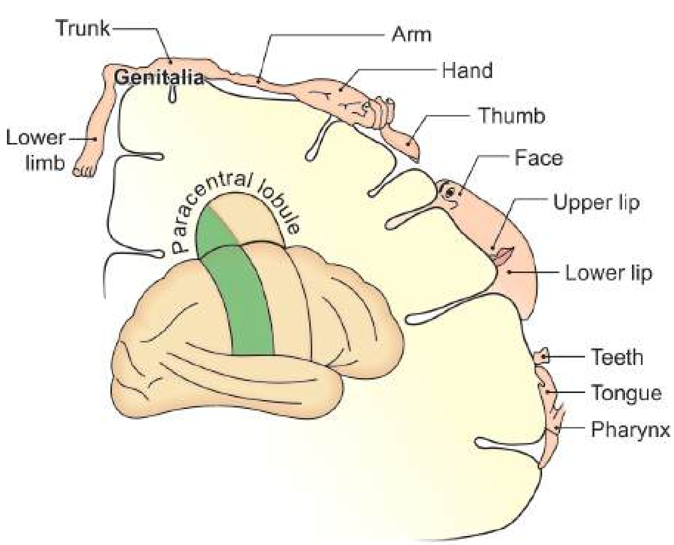


Fig. 1.47: Sensory homunculus of the postcentral gyrus

hemisphere and in the precuneus on the medial surface. It coincides with areas 5 and 7 of Brodmann. This receives afferents from first sensory area and has reciprocal connection with dorsal tier of nuclei of lateral mass of thalamus. Data pertaining to the general senses are integrated, permitting a comprehensive assessment of the characteristic of an object held in hand and its identification without visual aid.

Receptive Speech Area of Wernicke

(German Neurologist, 1848–1903)

This is also known as sensory language area. It consists of auditory association cortex and of adjacent parts of the inferior parietal lobule.

Areas of Special Sensations

Vision

The visual area is located above and below the calcarine sulcus on the medial surface of occipital lobe. It corresponds to area 17 of Brodmann.

It is continuous both above and below with area 18 and beyond this with area 19 of Brodmann which are also known as visual association or psychovisual areas.

The role of the second and third visual areas includes the relating of present to past visual experience, with recognition or what is seen, and appreciation of its significance.

Hearing

The auditory (acoustic) area lies in the temporal lobe. Most of it is concealed as it lies in that part of superior temporal gyrus which forms inferior wall of the posterior ramus of lateral sulcus. It corresponds with areas 41 and 42 of Brodmann.

The auditory radiation does not only end in first auditory area but extends to neighboring area as well, that is known as auditory association area or second auditory area. This area lies behind the first auditory area in superior temporal gyrus. It corresponds to area 22 of Brodmann on the lateral surface of superior temporal gyrus.

Taste

The taste area (gustatory area) is located in dorsal wall of posterior ramus of lateral sulcus, with extension into insula and corresponds to area 43 of Brodmann.

Smell

Ends in pyriform lobe.

Vestibular Area

Vestibular area is situated close to the part of postcentral gyrus concerned with sensations of face.

DIENCEPHALON

(Dorsal part of diencephalon)

Thalamus

The thalamus (Greek inner chamber) is a large mass of Grey matter, 4 cm each in transverse, vertical and anteroposterior diameters situated in the lateral wall of the third ventricle and in the floor of the central part of the lateral ventricle. It measures:

- Anteroposterior—4 cm
- Vertical—4 cm
- Transverse—4 cm

The anterior end with anterior nucleus is narrow and forms the posterior boundary of the interventricular foramen (Figs 1.48A and B).

The posterior end is expanded, and is known as the pulvinar. It overhangs the lateral and medial geniculate bodies and the superior colliculus with its brachium (Fig. 1.49).

The superior surface is divided into a lateral ventricular part which forms the floor of the central part of the lateral ventricle, and a medial extraventricular part which is covered by the tela choroidea of the third ventricle.

The inferior surface rests on the subthalamus and the hypothalamus.

The medial surface forms the posterosuperior part of the lateral wall of the third ventricle.

The lateral surface forms the medial boundary of the posterior limb of the internal capsule.

Grey Matter

It comprises:

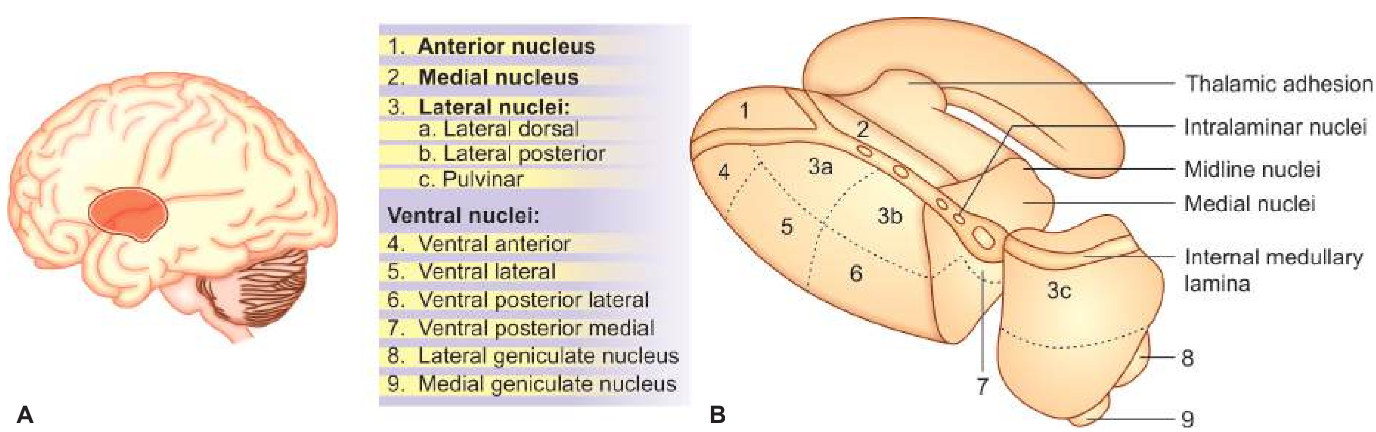
- Anterior nucleus in the anterior part.
- Medial nucleus in the medial part.
- The lateral part of the thalamus is largest and represents the neothalamus. It is divided into the lateral 3a, 3b, 3c nucleus in the dorsolateral part, and the ventral nucleus in the ventromedial part. The ventral nucleus is subdivided into anterior, intermediate and posterior. groups. The posterior group is further subdivided into the posterolateral and posteromedial groups.

Connections and Functions of Thalamus

Afferent impulses from a large number of subcortical centers converge on the thalamus. Exteroceptive and proprioceptive impulses ascend to it through the medial lemniscus through spinothalamic tracts and trigeminothalamic tracts.

Visual and auditory impulses reach the medial and lateral geniculate bodies.

Sensations of taste are conveyed to it through solitariothalamic fibers. Although the thalamus does not receive direct olfactory impulses, they probably reach it through the amygdaloid complex.



Figs 1.48A and B: A. Location of thalamus in the cerebral hemisphere; B. Three-dimensional view of thalamus

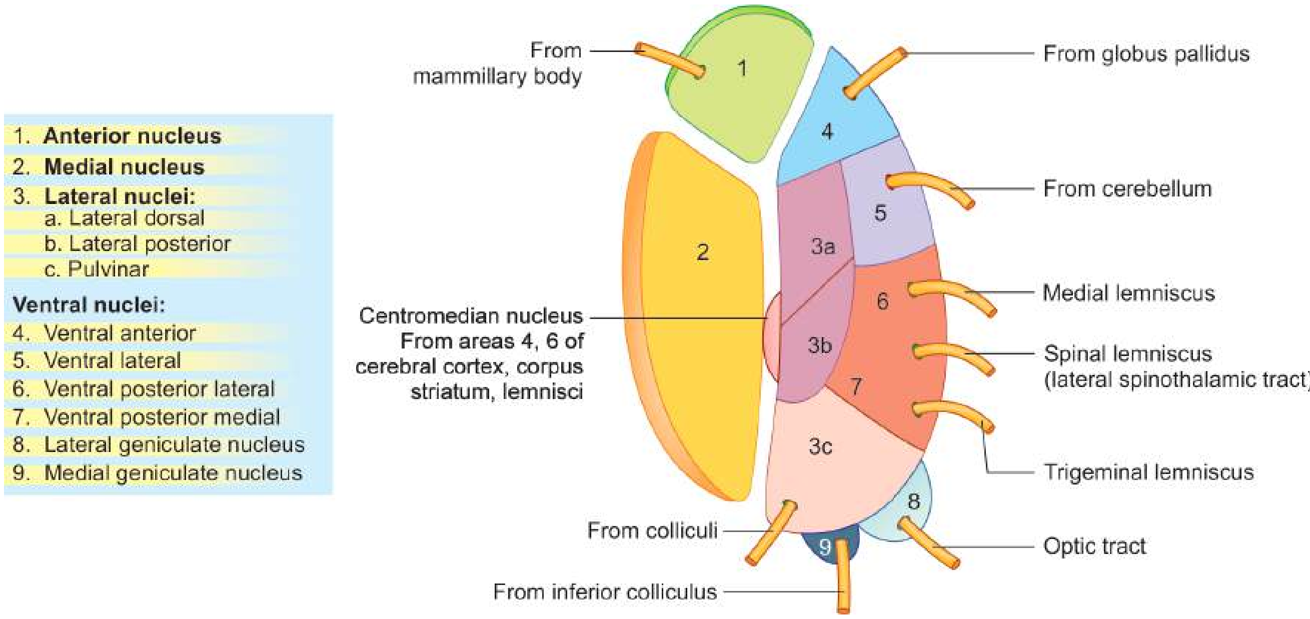


Fig. 1.49: Parts of the thalamus. The afferents to the nuclei of thalamus are also indicated

Visceral information is conveyed from the hypothalamus and probably through the reticular formation. In addition to these afferents, the thalamus receives profuse connections from all parts of the cerebral cortex, the cerebellum and the corpus striatum.

The thalamus is, therefore, regarded as a great integrating center where information from all these sources is brought together. This information is projected to almost the whole of the cerebral cortex through profuse thalamocortical projections. Efferent projections also reach the corpus striatum, the hypothalamus and the reticular formation.

Besides its integrating function, the thalamus has some degree of ability to perceive exteroceptive sensations, especially pain.

The connections and functions of nuclei of thalamus are shown in Table 1.15.

Medial Geniculate Body

It is an oval elevation situated just below the pulvinar of the thalamus and lateral to the superior colliculus. The inferior brachium connects the medial geniculate body to the inferior colliculus. The connections of the medial geniculate body are as follows:

- **Afferent:** Lateral lemniscus
- **Efferents:** It gives rise to the acoustic (auditory) radiation going to the auditory area of the cortex (in the temporal lobe) through the sublentiform part of the internal capsule.

Lateral Geniculate Body

It is a small oval elevation situated anterolateral to the medial geniculate body, below the thalamus. It is overlapped by the medial part of the temporal lobe, and is connected to the superior colliculus by the superior brachium.

It is a six-layered structure. Layers 1 , 4 and 6 receive contralateral optic fibers, and layers 2, 3 and 5 receive ipsilateral optic fibers.

Connections

Afferents: Optic tract (lateral root).

Efferents: It gives rise to optic radiations going to the visual area of cortex.

Function

Lateral geniculate body is the last relay station on the visual pathway to the occipital cortex.

Pineal Body/Pineal Gland

(Discussed in Endocrine System) (Ventral Part of Diencephalon)

Hypothalamus

The hypothalamus is a part of the diencephalon (Fig. 1.50). It lies in the floor and lateral wall of the third ventricle. The hypothalamus is subdivided into optic, tuberal and mammillary parts.

Functions of Hypothalamus

Endocrine Control

By forming releasing hormones or release inhibiting hormones, the hypothalamus regulates secretion of thyrotropin (TSH), corticotropin (ACTH), somatotropin (STH), prolactin, luteinizing hormone (LH), follicle-stimulating hormone (FSH) and melanocyte-stimulating hormone, by the pars anterior of the hypophysis cerebri.

Neurosecretion

Oxytocin and vasopressin (antidiuretic hormone, ADH) are secreted by the hypothalamus and transported to the infundibulum and the posterior lobe of the hypophysis cerebri.

Table 1.15: Connections and functions of thalamus

Name	*Afferents*	*Efferents*	*Functions*
• Anterior nucleus	• Mammillothalamic tract	• To cingulate gyrus	• Relay station for emotions and recent memory
• Medial nucleus	• From hypothalamus, frontal lobe and other thalamic nuclei	• To same parts from which the afferents are received	• Relay station for visceral impulses, integration of visceral somatic, olfactory impulses, related to emotions
• Lateral nuclei: Lateral dorsal, lateral posterior and pulvinar	• From precuneus and superior parietal lobule	• To precuneus and superior parietal lobule	• Correlative in function
• Ventral nuclei: Ventral • Anterior	• From globus pallidus	• To areas 6 and 8 of cortex	• Relay station for activity of motor cortex
• Ventral lateral	• From cerebellum (dentatothalamic fibers) and red nucleus	• To motor areas 4 and 6	• Relay station for cerebellar impulses, activity of motor cortex
• Ventral posterolateral	• Spinal and medial lemnisci	• To postcentral gyrus (areas 3, 1, 2)	• Relay station for exteroceptive (touch, pain, temperature) and pressure and proprioceptive impulses
• Ventral posteromedial	• Trigeminal and solitariothalamic lemnisci (taste)	• To postcentral gyrus (areas 3, 1, 2)	• Relay station for impulses from the face, head and taste impulses
• Intralaminar, midline, and reticular nuclei	• Reticular formation of brainstem	• To all parts of cerebral cortex	• Participate in arousal reactions/ascending reticular activating system (ARAS)
• Centromedian nucleus	• From parts of corpus striatum; spinal, medial, trigeminal lemnisci, from areas 4, 6 of cerebral cortex	• Not connected to cerebral cortex, connected to other thalamic nuclei, corpus striatum	• Receive pain fibers
• Medial geniculate body	• Auditory fibers from inferior colliculus	• Primary auditory areas 41, 42	• Relay station for auditory impulses
• Lateral geniculate body	• Optic tract	• Primary visual cortex area 17	• Relay station for visual impulses

General Autonomic Effect

The anterior parts of the hypothalamus chiefly mediate parasympathetic activity; and the posterior parts, chiefly mediate sympathetic activity.

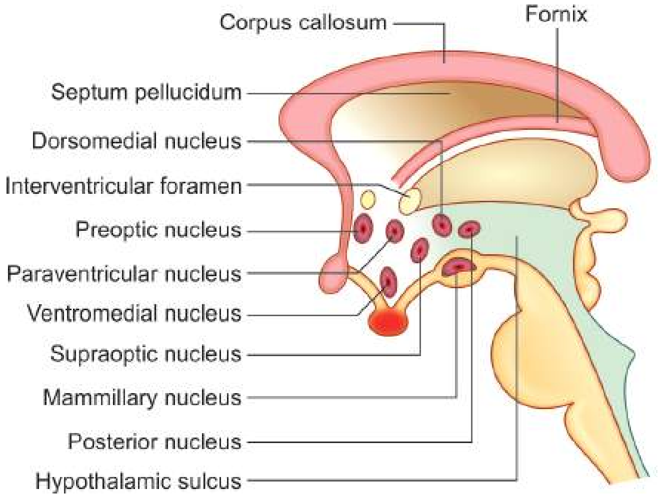


Fig. 1.50: Nuclei of medial zone of hypothalamus

Temperature Regulation

The hypothalamus maintains a balance between heat production and heat loss of the body.

Regulation of Food and Water Intake

The hunger or feeding center is placed laterally, the satiety center, medially. Stimulation of the feeding center or damage of the satiety center causes hyperphagia (overeating) leading to obesity. Stimulation of the satiety center or damage of the feeding center causes hypophagia or even aphagia and death from starvation. The thirst or drinking center is situated in the lateral part of the hypothalamus. Its stimulation causes copious drinking and overhydration.

Sexual Behavior and Reproduction

Through its control of the anterior pituitary, the hypothalamus controls gametogenesis, various reproductive cycles (uterine, ovarian, etc.) and the maturation and maintenance of secondary sexual characteristics. Through its connections with the limbic system, it participates in the elementary drives associated with food (hunger and thirst) and sex.

Biological Clocks

Many tissues and organ systems of the body show a cyclic variation in their functional activity during the 24 hours of a day (circadian rhythm). Sleep and wakefulness is an outstanding example of a circadian rhythm. Wakefulness is maintained by the reticular activating system. Lesions of the anterior hypothalamus seriously disturb the rhythm of sleep and wakefulness.

Emotion, Fear, Rage, Aversion, Pleasure and Reward

These faculties are controlled by the hypothalamus, the limbic system and the prefrontal cortex.

BASAL NUCLEI

The basal nuclei are subcortical and, intracerebral masses of grey matter forming important parts of the extrapyramidal system. They include the following:

- The corpus striatum (Fig. 1.51), which is, partially divided by the internal capsule into two nuclei:
  - (i) The caudate nucleus.
  - (ii) The lentiform nucleus.
- The amygdaloid body forms a part of the limbic system.

Corpus Striatum

Corpus striatum (Latin striped body) comprises the caudate nucleus and lentiform nucleus.

Caudate Nucleus

It is a C-shaped or comma-shaped nucleus which is surrounded by the lateral ventricle. The concavity of 'C' encloses the thalamus and the internal capsule). The nucleus has a head, a body, and a tail.

Lentiform Nucleus

This is a large, lens-shaped (biconvex) nucleus, forming the lateral boundary of the internal capsule.

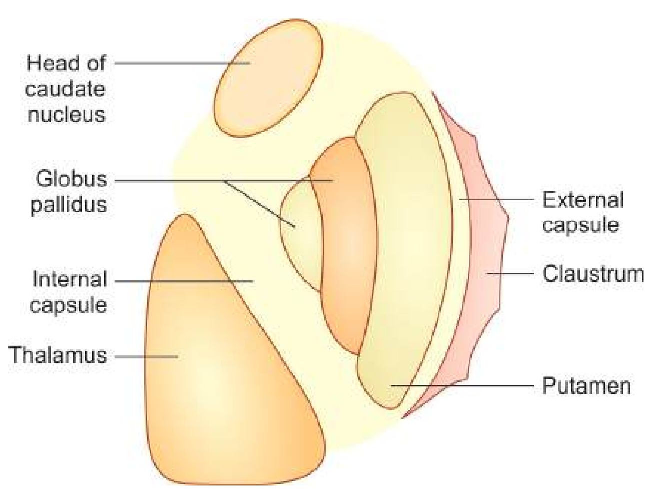


Fig. 1.51: Horizontal section through corpus striatum, thalamus and internal capsule

Connections of Corpus Striatum

The caudate nucleus and putamen are afferent nuclei, while the globus pallidus is the efferent nucleus, of the corpus striatum. Receives impulses from cerebral cortex and give efferent which indirectly affects the anterior horn cells.

Functions of Corpus Striatum

- The corpus striatum regulates muscle tone and thus helps in smoothening voluntary movements.
- It controls automatic-associated movements, like the swinging of arms during walking. Similarly, it controls the coordinated movements of different parts of the body for emotional expression.
- Basal ganglia contribute to cognitive function of the brain. These help cortex in execution of learned patterns of movements subconsciously.
- Corpus striatum, cerebellum and motor areas of cerebrum jointly are responsible for planning, execution and control of movements.
- Corpus striatum and cerebellum without sending fibers to spinal cord modify the effect on spinal cord through projections to motor cortex and extra-pyramidal fibers.
- Basal ganglia and cerebellum do not initiate movements but are able to adjust motor commands.

Amygdaloid Body

This is a nuclear mass in the temporal lobe, lying antero-superior to the inferior horn of the lateral ventricle. Topographically, it is continuous with the tail of the caudate nucleus, but functionally, it is related to the stria terminalis. It is a part of the limbic system.

It is continuous with the cortex of the uncus, the limen insulae and the anterior perforated substance.

Afferents: From the olfactory tract.

Efferents: It gives rise to the stria terminalis which ends in lie anterior commissure, the anterior perforated substance and in hypothalamic nuclei.

Functions: Emotional control.

White Matter of Cerebrum

The white matter of the cerebrum consists chiefly of myelinated fibers which connect various parts of the cortex to one another and also to the other parts of the CNS. The fibers are classified into three groups—association fibers, and commissural fibers and projection fibers.

Association (Arcuate) Fibers

These are the fibers which connect different cortical areas of the same hemisphere to one another. These are subdivided into the following two types.

Short association fibers: These fibers connect adjacent gyri to one another.

Long association fibers: These fibers connect more widely separated gyri to one another. Some examples are:

- The uncinate fasciculus, connecting the temporal pole to the motor speech area and to the orbital cortex.
- The cingulum, connecting the cingulate gyrus to the parahippocampal gyrus seen on the medial surface.
- The superior longitudinal fasciculus, connecting the frontal lobe to occipital and temporal lobes.
- The inferior longitudinal fasciculus, connecting the occipital and temporal lobes (Fig. 1.52).

Commissural Fibers

The corpus callosum connecting the cerebral cortex of the two sides (Fig. 1.53).

Corpus callosum

The corpus callosum is the largest commissure of the brain. It connects the two cerebral hemispheres.

- The genu is the anterior end. It lies 4 cm behind the frontal role.

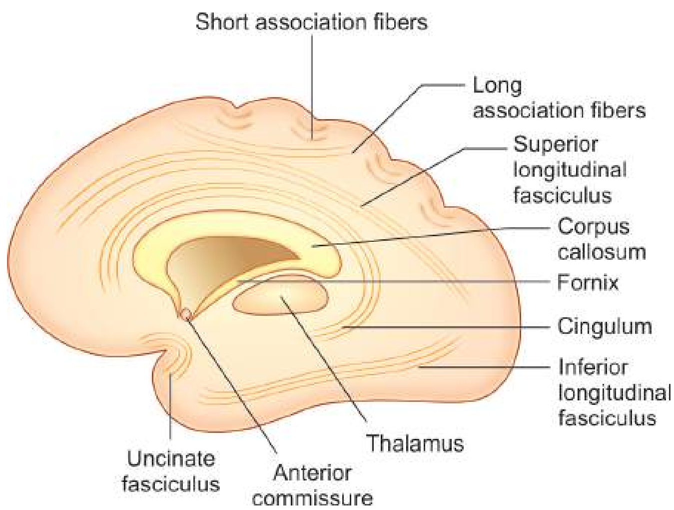


Fig. 1.52: Association fibers of cerebrum

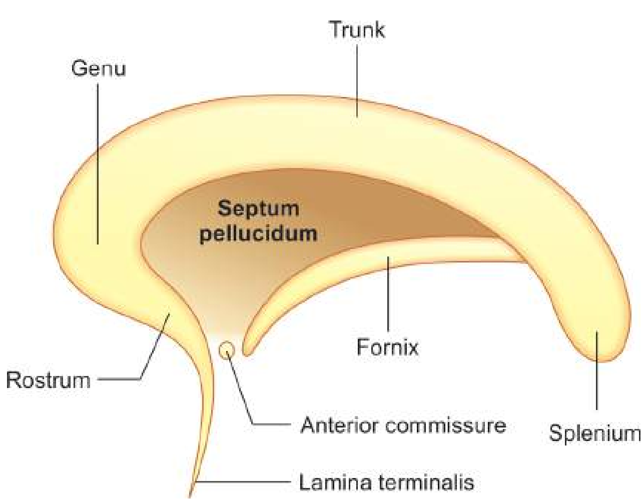


Fig. 1.53: Parts of corpus callosum

- The rostrum is directed downwards and backwards from the genu, and ends by joining the lamina terminalis, in front of the anterior commissure.
- The trunk or body is the middle part, between the genu arid the splenium.
- The splenium is the posterior end forming the thickest part of the corpus callosum. It lies 6 cm in front of the occipital pole.

Functional significance

The corpus callosum helps in coordinating activities of the two hemispheres.

Projection Fibers

These are fibers which connect the cerebral cortex to other parts of the CNS, e.g. the brainstem and spinal cord. Many important tracts, e.g. corticospinal and corticopontine, are made-up of projection fibers. Examples: (a) Corona radiata and (b) internal capsule.

Corona radiata

Descending fibers of the lobes of cerebrum converge to form the 'corona radiata' and continue as internal capsule.

Internal Capsule

Gross Anatomy

The internal capsule is a large band of fibers, situated in the inferomedial part of each cerebral hemisphere. In horizontal sections of the brain, it appears V-shaped with its concavity directed laterally. The concavity is occupied by the lentiform nucleus (Fig. 1.54).

The internal capsule is divided into the following parts.

- The anterior limb lies between the head of the caudate nucleus and the lentiform nucleus.
- The genu is the bend between the anterior and posterior limbs.
- The posterior limb lies between the thalamus and the lentiform nucleus.
- The sublentiform part lies below the lentiform nucleus. It can be seen in a coronal section, whereas the rest of the parts are seen in a horizontal section.
- The retrolentiform part lies behind the lentiform nucleus.

Constituent fibers

The fibers of internal capsule are shown in Figure 1.54 and presented in Table 1.16.

Arteries supplying internal capsule are shown in Figure 1.55.

RETICULAR FORMATION

The reticular formation is a diffuse network of fine nerve fibers intermingled with numerous poorly defined nuclei. Phylogenetically, it is very old. In primitive vertebrates, it represents the largest part of the CNS. In man, it is best developed in the brainstem although it can be traced to all levels of the CNS.

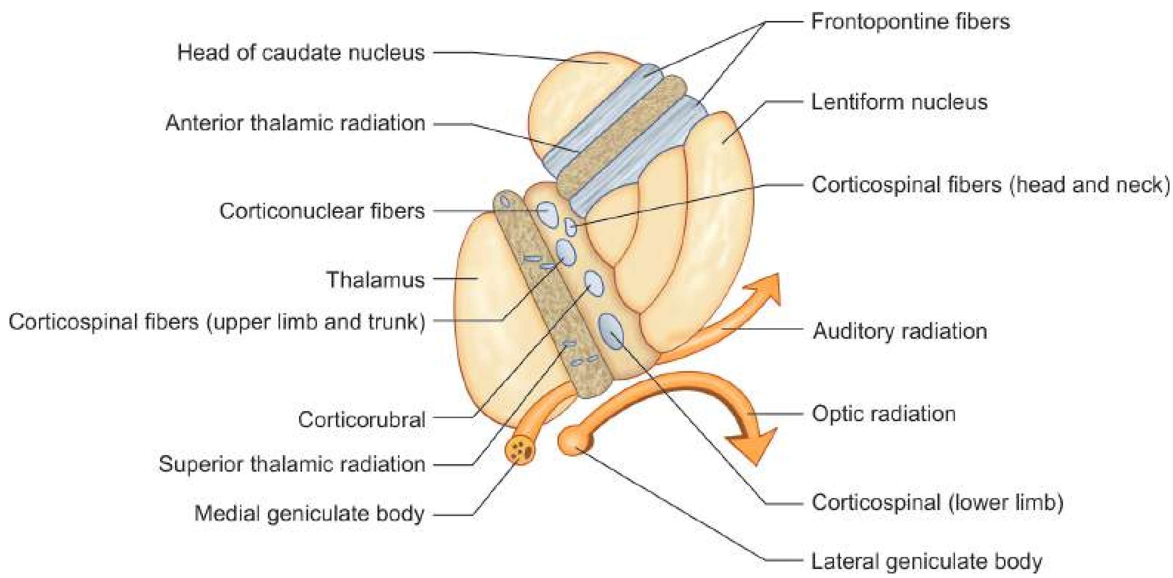


Fig. 1.54: Boundaries and parts of internal capsule

Table 1.16: Fibers in the internal capsule

Part	*Descending tracts*	*Ascending tracts*	*Arterial supply*
Anterior limb	• Frontopontine fibers (a part of the corticopontocerebellar pathway)	Anterior thalamic radiation (fibers from anterior and medial nuclei of thalamus)	Direct branches from anterior cerebral
Genu	• Corticonuclear fibers going to motor nuclei of cranial nerves	Anterior part of the superior thalamic radiation (fibers from posterior ventral nucleus of thalamus)	Direct branches from internal carotid
Posterior limb	• Corticospinal tract (pyramidal tract for the upper limb, trunk and lower limb) • Corticopontine fibers	Superior thalamic radiation	Lateral striate branches of middle cerebral
Sublentiform part	• Parietopontine and temporopontine fibers • Fibers between temporal lobe and thalamus	Auditory radiation	Branches of posterior cerebral
Retrolentiform part	• Parietopontine and occipitopontine fibers • Fibers from occipital cortex to superior colliculus and pretectal region	Posterior thalamic radiation made-up of mainly optic radiation	Branches of posterior cerebral

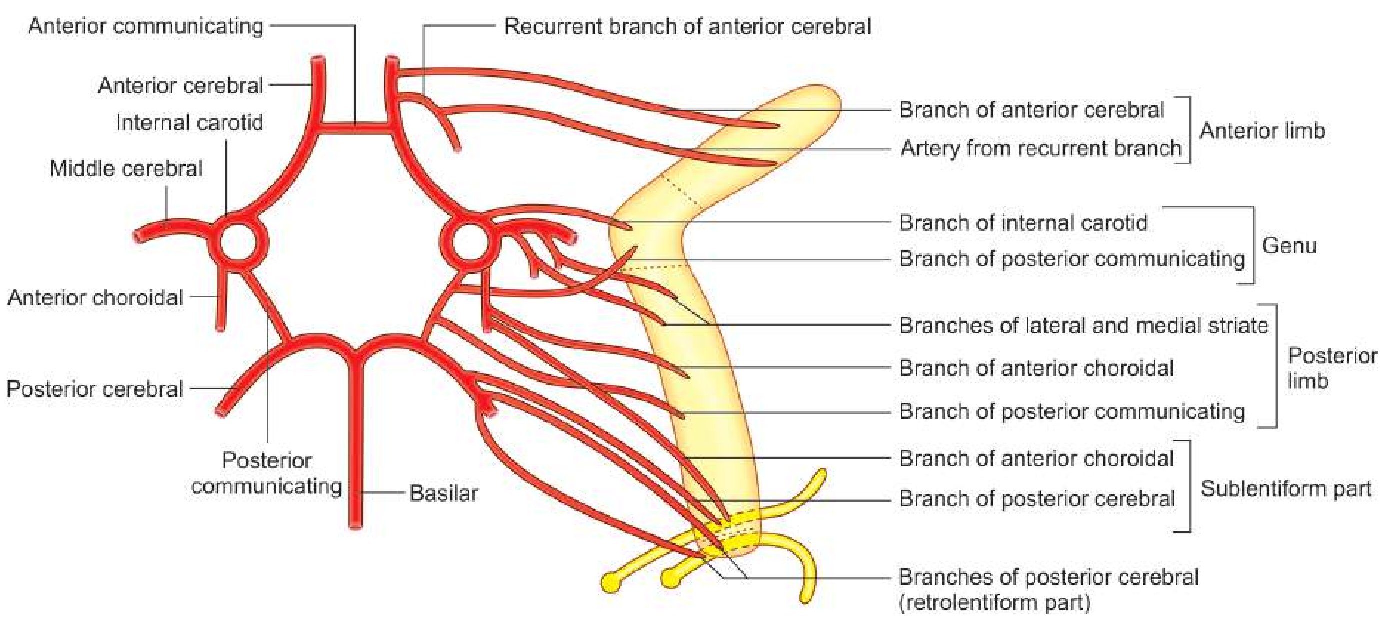


Fig. 1.55: Arteries supplying the internal capsule

Unit I Nervous System

Location and Identity

- The reticular formation, in general, is placed in the deep and dorsal parts of the neural axis.
- It is very diffused in its distribution, and has ill-defined boundaries.
- It is better defined physiologically than anatomically.

Connections

The reticular formation is connected to all the principal parts of the nervous system, including the motor, sensory and autonomic pathways with their centers. The connections are reciprocal (to-and-fro), providing feedback mechanisms. Thus, the reticular formation is connected to:

- The motor neurons of the cerebral cortex, the basal ganglia, the cerebellum, various masses of grey matter in the brainstem including the nuclei of cranial and spinal nerves.
- The sensory neurons of the somesthetic pathway (cortex, thalamus and spinal cord), visual pathway, auditory pathway, and equilibratory pathways. In this group, the ascending reticular activating system (ARAS) is of prime importance. It is formed by a great number of collaterals from the spinothalamic, trigeminal and auditory pathways to the lateral parts of the reticular formation, which themselves project to the reticular and intralaminar nuclei of the thalamus. These nuclei, in turn, project to widespread area of cerebral cortex.
- The autonomic neurons of the hypothalamus, limbic system and the general visceral efferent colunms.

Functions

Inhibitory and Facilitatory Influences

Through its connections with the motor areas of the nervous system, certain areas of the reticular formation inhibit voluntary and reflex activities of the body, while certain other area facilitate them. It coordinates skeletal activity with balance management.

State of Arousal, General Awareness and Alertness

The ascending reticular activating system (ARAS) is responsible for maintaining the state of wakefulness and alertness, by its connections with a great number of collaterals from sensory tracts. Thus, sensory perception of any type is quickly and acutely appreciated, so that an appropriate motor response by the body may be synthesized and actuated.

Sleep is a normal, periodic inhibition of the reticular formation. Hypnotics and general anesthetics produce their effects by acting on this system.

Autonomic Influences

Through its autonomic connections and certain specific centers, the reticular formation influences respiratory and vasomotor activities. They are stimulated or suppressed according to the needs.

Through its connections with the limbic system, it participates in regulating emotional, behavioral and visceral activities. It also takes part in neuroendocrine regulation and the development of conditioned and learned reflexes.

BLOOD SUPPLY OF BRAIN

Two vertebral and two internal carotid arteries carry the total arterial supply to the brain.

Vertebral Arteries

Vertebral artery courses through neck, through foramen tranfersarium of C6–C1 vertebrae, lies on posterior arch of atlas. Finally, it enters cranial cavity through foramen magnum.

In the cranial cavity it gives branches to spinal cord, medulla oblongata and cerebellum (Fig. 1.56).

Basilar Artery

It is formed by the union of two vertebral arteries at the lower border of pons. It lies in the median groove of pons in cisterna pontis and at the upper border of pons ends by dividing into two posterior cerebral arteries.

Branches

- Anterior inferior cerebellar artery, labyrinthine artery, pontine branches, superior cerebellar artery
- Two terminal posterior cerebral branches diverge at upper border of pons

Internal Carotid Artery

Each internal carotid artery (ICA) enters the cranial cavity after traversing the carotid canal and superior aspect of foramen lacerum. It then courses through the cavernous sinus, pierces the dural roof of sinus and ends immediately lateral to optic chiasma and inferior to anterior perforated substance and gives four branches and continues as middle cerebral artery (Fig. 1.57).

Branches

Ophthalmic artery for the contents of orbit, posterior communicating artery, anterior choroidal artery, anterior cerebral artery, middle cerebral artery—continuation of ICA.

Circulus Arteriosus or Circle of Willis

It is a hexagonal arterial circle, situated at the base of brain in the interpeduncular fossa. It is formed by the anterior cerebral branches and terminal parts of internal carotid arteries with its posterior communicating branches and the posterior cerebral branches of basilar artery.

The two anterior cerebral arteries are connected by anterior communicating artery. The internal carotids and posterior cerebral arteries of same side are united by the posterior communicating artery.

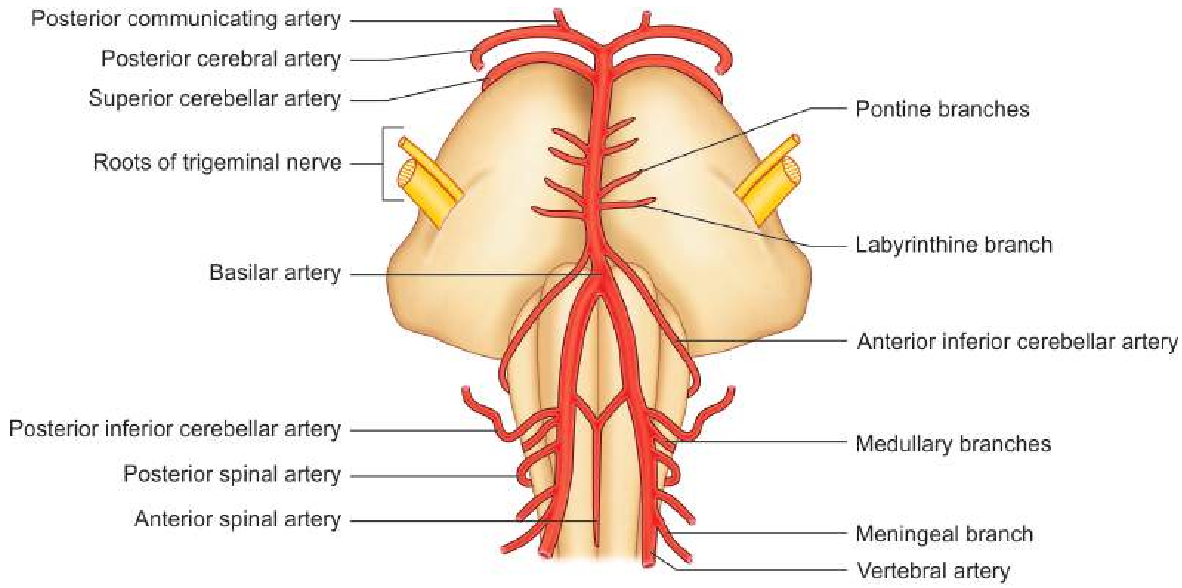


Fig. 1.56: Arteries related to brainstem

Formation

Anteriorly: Anterior communicating artery joining the two anterior cerebral arteries.

- **Anterolaterally:** Anterior cerebral arteries.
- **Laterally:** Internal carotid arteries.
- **Posterolaterally:** Posterior communicating arteries
- **Posteriorly:** Posterior cerebral arteries

The circulus arteriosus attempts to equalize the flow of blood to different parts of brain and provides a collateral circulation in the event of obstruction to one of its components. There is hardly any mixing of bloodstreams on right and left sides of the circulus arteriosus. Middle cerebral artery is not a forming part of the circle of Willis (Fig. 1.57).

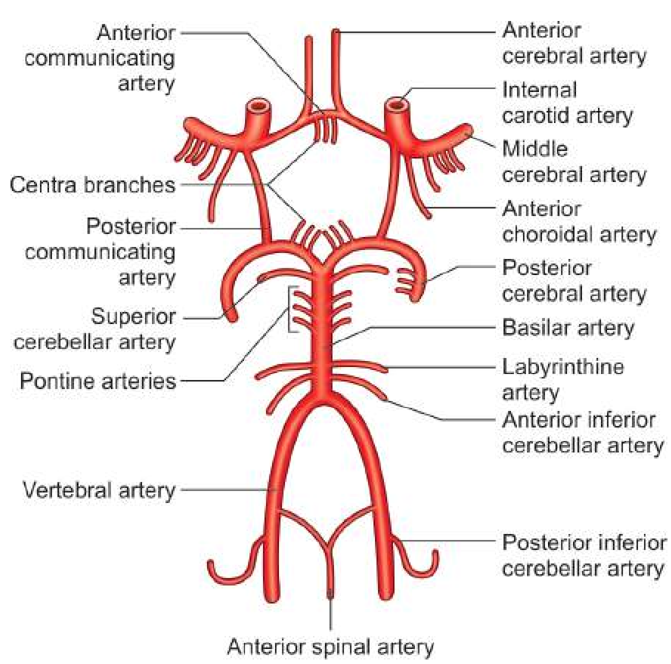


Fig. 1.57: Circle of Willis and the branches of arteries supplying the brain

Branches

The branches of the circulus arteriosus are cortical, central and choroidal. Cortical or external branches run on the surface of the cerebrum, anastomose freely and if these get blocked, they give rise to small infarcts.

The central branches perforate the white matter to supply the thalamus, the corpus striatum, and the internal capsule. These do not anastomose and if these get blocked, they give rise to large infarcts. Choroidal branches supply the choroid plexuses of the various ventricles.

Cortical Branches

These branches arise from all three cerebral arteries, i.e. anterior cerebral, middle cerebral and posterior cerebral. Their origin, course, and branches are given in Table 1.17.

Central Branches

These arteries are thin, numerous end arteries. These arise in groups.

- Anteromedial (AM) group arises from both anterior cerebral and anterior communicating arteries for part of hypothalamic regin.
- Anterolateral (AL) group arises from each middle cerebral artery. These are lateral striate arteries. The lateral striate artery supplies important 'internal capsule'. It is also called Charcot's artery of cerebral hemorrhage.
- The posteromedial (PM) group arises from posterior communicating and posterior cerebral arteries. These supply tuberoinfundibular and mammillary regions of hypothalamus, subthalamus, anterior and medial parts of thalamus, and crus cerebri of midbrain.
- Posterolateral (PL) group arises from the lateral parts of each posterior cerebral artery. These supply caudal part of thalamus.

Table 1.17: Important arteries of brain

Artery	Origin	Course	Cortical branches
Middle cerebral (Fig. 1.58)	Largest and direct continuation of ICA	In the lateral sulcus and on the insula	• Orbital • Frontal • Parietal • Temporal
Anterior cerebral (Fig. 1.59)	Smaller terminal branch of ICA	Coextensive with corpus callosum. Two arteries are connected by the anterior communicating artery	• Orbital • Frontal • Parietal, including paracentral artery
Posterior cerebral (Fig. 1.60}	Terminal branch of basilar artery	Winds round cerebral peduncle to reach the tentorial surface of cerebrum	• Temporal • Occipital • Parieto-occipital

Arterial Supply to Three Surfaces of Cerebral Cortex

The three surfaces of cerebral cortex are supplied by branches from all three arteries.

1. Superolateral surface: This surface is mostly supplied by middle cerebral. Areas not supplied by this artery are as under:
   - A strip of about 2 cm wide along the superomedial border extending from frontal pole to the parieto-occipital sulcus is supplied by anterior cerebral artery (Fig. 1.58).
   - Area of occipital lobe is supplied by posterior cerebral artery.
   - Inferior temporal gyrus excluding the part of the temporal pole is also supplied by posterior cerebral artery.
   - Rest of the big area is supplied by middle cerebral artery.
2. Medial and tentorial surfaces: The main artery here is the anterior cerebral. The medial aspects of the occipital lobe, temporal lobe except area around temporal pole is supplied by posterior cerebral artery. Temporal pole area gets nourished by middle cerebral artery (Fig. 1.59).
3. Inferior surface: Medial one-third of orbital surface is supplied by anterior cerebral, while lateral two-thirds, including the temporal pole area and the anteriormost part of temporal surface is vascularized by middle cerebral. Rest of the tentorial surface is supplied by the posterior cerebral artery (Fig. 1.60).

Cerebral Cortex

Cerebral cortex is supplied by branches of all three cerebral arteries. All the three surfaces receive branches from all three arteries.

- Middle cerebral is main artery on superolateral surface (Fig. 1.58).
- Anterior cerebral artery is chief artery on medial surface (Fig. 1.59).
- Posterior cerebral is principal artery on inferior surface (Fig. 1.60).

Cerebellum

The little brain is supplied by the following arteries:

- Superior cerebellar—2
- Anterior inferior cerebellar—2
- Posterior inferior cerebellar—2

Veins of the Brain

Characteristics of the Veins

- The walls are devoid of muscle.
- The veins have no valves.
- To maintain patency, some of them open into the cranial venous sinuses against the direction of blood flow in the sinus, e.g. the superior cerebral veins draining into the superior sagittal sinus.

Groups of Veins

External Cerebral Veins

Superior cerebral veins: These are 6–12 in number. They drain the superolateral surface of the hemisphere. They terminate in the superior sagittal sinus (Figs 1.61A and B).

Superficial middle cerebral vein: This drains the area round the posterior ramus of the lateral sulcus. It terminates in the cavernous sinus.

Deep middle cerebral vein: This drains the surface of the insula and terminates in the basal vein.

Inferior cerebral veins: These are several in number. They are divided into orbital and tentorial veins. The orbital veins terminate in the superior sagittal sinus. The tentorial veins terminate in the cavernous sinus.

Anterior cerebral veins: These are small veins which drain the corpus callosum and the anterior part of the medial surface of the hemisphere. They terminate in the basal vein.

Internal Cerebral Veins

There is one vein on each side. It is formed by the union of the thalamostriate and choroidal veins at the apex of the tela choroidea of the third ventricle. The right and left veins together form the great cerebral vein below the splenium of the corpus callosum (Fig. 1.62).

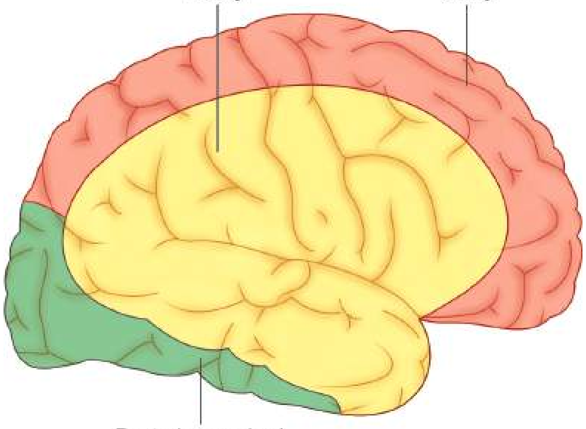


Fig. 1.58: Arterial supply of superolateral surface of right cerebral hemisphere

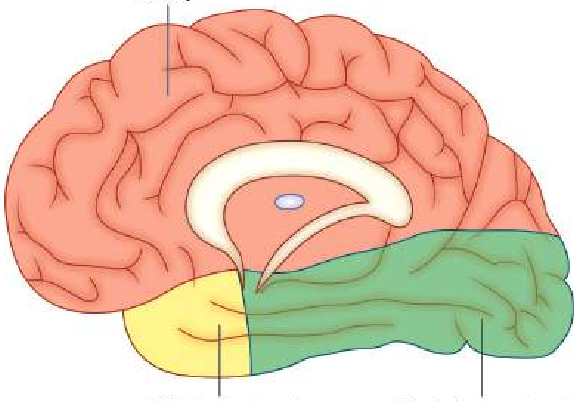


Fig. 1.59: Arterial supply of medial surface of right cerebral hemisphere

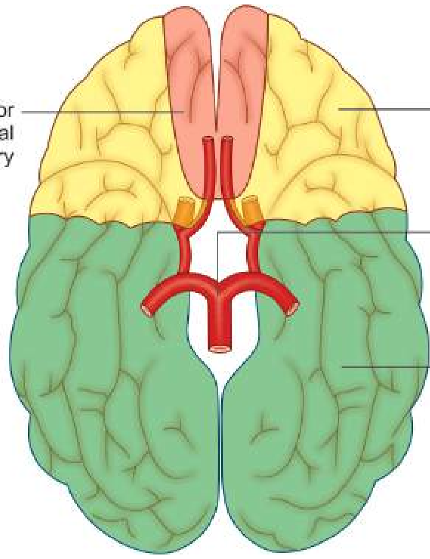
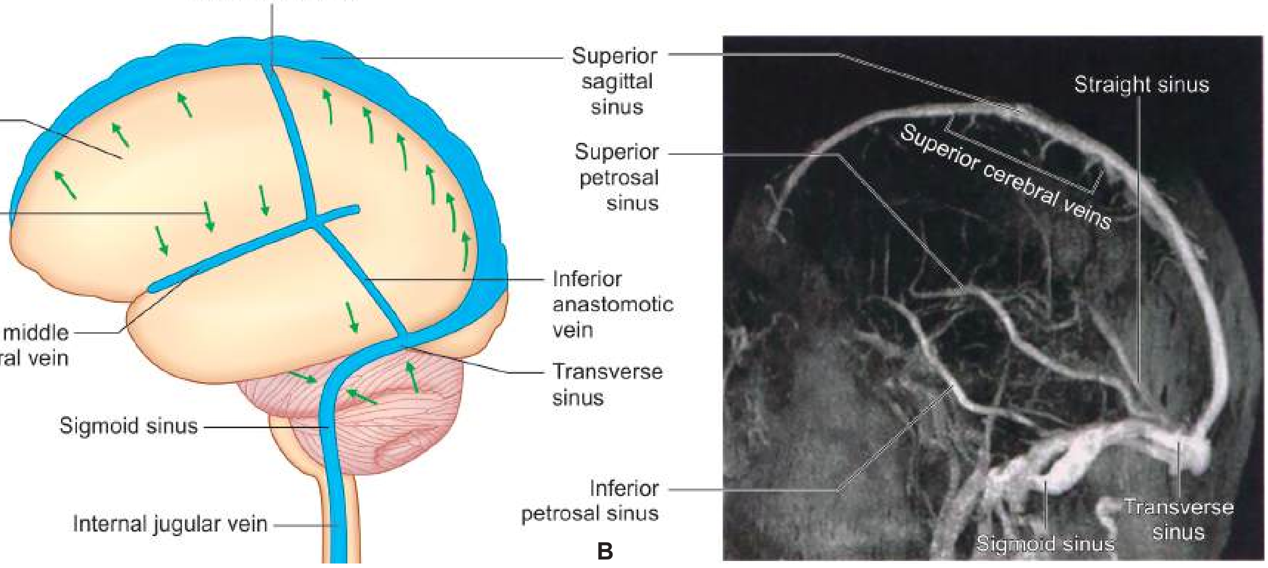


Fig. 1.60: Arterial supply of inferior surface of cerebral hemisphere



Figs 1.61A and B: A. Veins on the superolateral surface of cerebral hemisphere; B. MRI of veins

Unit I Nervous System

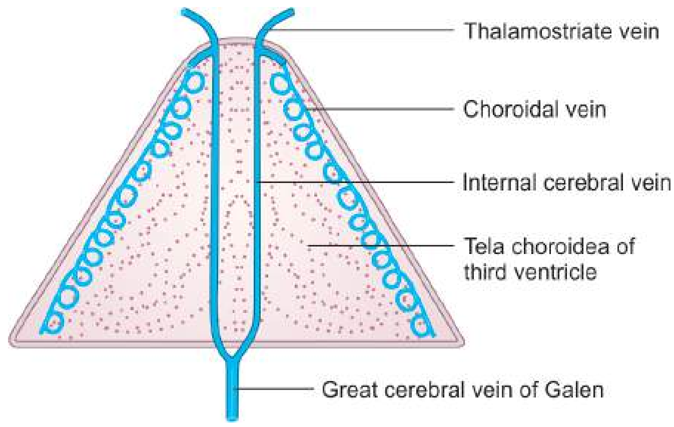


Fig. 1.62: Internal cerebral veins

Great cerebral vein joins with inferior sagittal sinus to form straight sinus which forms left transverse sinus it continues as left sigmoid sinus to continue as internal jugular vein on left side.

SUMMARY OF THE VENTRICLES OF THE BRAIN

Lateral Ventricle

The lateral ventricle comprises a central body and three horns—anterior, posterior and inferior.

Body lies in the parietal lobe:

- Anterior horn extends into the frontal lobe
- Posterior horn extends into the occipital lobe
- Inferior horn extends into the temporal lobe

Third Ventricle

The third ventricle lies between the two thalami. The boundaries are enumerated as:

- Anterior wall
- Posterior wall
- Floor
- Roof
- Lateral walls

Fourth Ventricle

The cavity of fourth ventricle is situated dorsal to pons and upper part of medulla oblongata and ventral to the cerebellum. Its boundaries, recesses, apertures and continuations are mentioned here:

Lateral boundaries: Gracile tubercle, cuneate tubercle, inferior cerebellar peduncles and superior cerebellar peduncles.

Floor

- Upper part: Facial colliculus on the dorsal surface of pons.
- Intermediate part: Vestibular nuclei, medullary striae.
- Lower part: Upper part of medulla oblongata containing hypoglossal and vagal triangles.
- Roof: Superior medullary velum thin sheet of pia mater and ependyma with median aperture, inferior medullary velum.
- Recesses in roof: One median dorsal, two lateral dorsal and two lateral
- Apertures: One median—foramen of Magendie, two lateral—foramina of Luschka (left and right).
- Continuity: Above with cerebral aqueduct
- Below with central canal of spinal cord.

HIGHER MENTAL FUNCTIONS

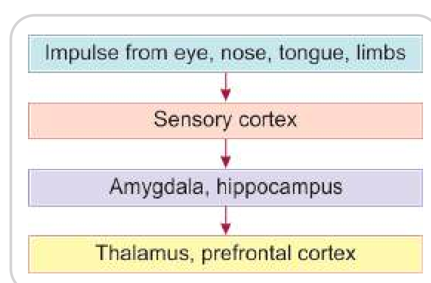
Memory is the capacity of brain to store and retrieve information which is a basic fact for learning numerous skills and facts throughout life. No single part of brain manages these processes. Memories form as sensory processing areas of cerebral cortex interact in simple and complex ways with deeper brain structures including limbic system. Some memories are short term or temporary as the house number of a visiting friend; others are long lasting as wedding ceremony, accident scene.

Prefrontal cortex is the 'mind', where understanding, planning, making judgments, worrying, etc. are done. Here, the information from other regions is processed and integrated. Many parts of brain are involved in these complex processes. So 'mind' is the sum total of activities in many parts of the brain.

New neurons are formed in hippocampus and olfactory bulb only.

Making Memories

When signals enter a repeating pathway that lies between hippocampus, thalamus, basal ganglia and the sensory cortex to form circuits. These circuits cause memories:



Explicit: Repetition memory is fact memory 2 + 2 = 4 name, age, etc. Information with emotions is stored as long-term memory. Part of limbic system and Papez circuit are important for long-term permanent memory.

Implicit memory is skill memory, e.g. dance steps. Parts involved are basal ganglia and cerebellum.

- **Language:** Left hemisphere in right-handed persons contains the center for speech and is called dominant/categorical hemisphere. Right hemisphere in right-handed persons is called non-dominant/

representational hemisphere. In left-handed persons also, left hemisphere is dominant for language (Broca's area).

- In 70% LH, speech area is in left brain.
- In 15% LH, speech area is in right brain.
- In 15% LH, speech area may be in either brain.

- Handedness becomes definite by 4 year of life. Injury/lesion in dominant hemisphere causes language disorders. Lesion in non-dominant hemisphere causes agnosia, i.e. inability to recognize objects by using sensation, lesions are in parietal lobe.
- **Intelligence**: To be able to do calculations is intelligence. It is enhanced by doing oral calculations; first is addition followed by subtraction lastly is multiplication and division. The center is in left angular gyrus. Intelligence is to coordinate various activities and do them in shorter time. Intelligence is knowing, reasoning, thinking and understanding.

Abstract thinking is also intelligence, exist in theory not practicals; exist in thought not matter.

Neurotransmitters and Mental Functioning

Neurotransmitters (NTs) either excite or inhibit the firing of a nerve impulse. If NTs are too much or too little the mental functioning gets disturbed. Low levels of serotonin, norepinephrine and GABA are related to 'clinical depression'. Antidepressant drugs increase their levels.

Golden Points

- Central nervous system (CNS) comprises brain and spinal cord.
- CNS is the seat of learning, memory, intelligence and emotions.
- The autonomic nervous system primarily regulates involuntary or unconscious activities of body such as heart rate, breathing and pupil dilation.
- The autonomic motor division is divided into two complimentary subsystems: The sympathetic and the parasympathetic systems.
- The central part of the neuron contains the nucleus along with other cell organelles.
- All metabolic activities of the cell happen in the cell body.

Types of neurons

- Multipolar neurons—all motor and internuncial neurons.
- Bipolar neurons—first neuron of the retina, ganglia of eighth cranial nerve, and the olfactory mucosa.
- Pseudounipolar neurons are found in dorsal nerve root ganglia and sensory ganglia of the cranial nerves.
- Unipolar neurons are present in the mesencephalic nucleus of trigeminal nerve, and also occur during fetal life.

Various neurotransmitters are:

- Acetylcholine, dopamine, norepinephrine, serotonin, GABA (gamma-amino butyric acid), endorphins.

Synapse:

- The site of contact (contiguity without continuity) between the nerve cells or their processes is known as synapse.

Neuroglia:

- Astrocytes concerned with nutrition of the nervous tissue are star-shaped cells. These form blood–brain barrier.
- Oligodendrocytes myelinate the tracts.
- Microglia behave like macrophages of the CNS.
- Ependymal cells are columnar cells lining the cavities of the CNS.
- Grey matter is the part of nervous tissue containing the cell body (soma), neuroglial cells and abundance of blood vessels.
- White matter comprises only the fibers, i.e. axons, dendrites, neuroglial cells and fewer blood vessels.
- Motor unit is the number of muscle fibres supplied by a single alpha motor neuron.

Meninges around Brain

- The dura mater
- Arachnoid mater
- Pia mater

Spinal segment

- Segment or part of spinal cord to which a pair of dorsal nerve roots (right and left) and a pair of ventral nerve roots is attached, is called a spinal segment.

Descending tracts

- Pyramidal tracts
  1. Lateral corticospinal
  2. Anterior corticospinal
- Extrapyramidal tracts
  1. Rubrospinal
  2. Medial reticulospinal

Ascending tracts

- Lateral spinothalamic tract: Carries pain and temp. sensations
- Anterior spinothalamic tract: Carries touch and pressure sensations to cerebrum of opposite side.
- Fasciculus gracilis, fasciculus cuneatus: Carry conscious sensation of movement, position, fine touch, pressure to cerebrum of opposite side.
- Dorsal or posterior spinocerebellar tract: Ventral or anterior spinocerebellar tract: Carry unconscious sensation of position, movement to cerebellum of same side.

- Transverse section through the lower part of the medulla shows the pyramidal decussation.
- Transverse section through the middle of medulla shows the sensory decussation.

PONS

- The ventral or anterior surface is convex in both directions and is transversely striated. In the median plane, it shows a vertical basilar sulcus which lodges the basilar artery.

MIDBRAIN

- It is 2 cm long and connects the hindbrain with the forebrain.

CEREBELLUM

- Cerebellum though small in size, sub serves important functions for maintaining tone, posture, and equilibrium of the body.
- The cerebellum does not initiate movement, but it contributes to coordination, precision and accurate timing.
- Functions:
  - Cerebellum coordinates voluntary movements so that they are smooth, balanced and accurate.
  - It also helps in learning of special motor skills. It plays a role in cognition.
  - Vermis controls axial muscles, and thus maintains posture.
  - Neocerebellum is responsible for precise movements.

- Purkinje cell: It is the characteristic cell of cerebellum. It is a large flask-shaped cell.

CEREBRAL HEMISPHERE

- The superolateral surface is convex; the medial surface is flat; the inferior surface is irregular.
- Four borders: Superomedial border, Inferolateral border, medial orbital border, medial occipital border.
- Three poles: Frontal pole, occipital pole ,temporal pole
- Medial geniculate body gives rise to the acoustic (auditory) radiation going to the auditory area of the cortex in the temporal lobe.
- Lateral geniculate body gives rise to optic radiations going to the visual area of cortex in the occipital lobe.
- Functions of hypothalamus are: Endocrine control, neurosecretion, temperature regulation, regulation of Food and water intake, sexual behaviour and reproduction, biological clocks.
- Short association fibres connect adjacent gyri to one another, e.g. the uncinate fasciculus, the cingulum, the superior longitudinal fasciculus, the inferior longitudinal fasciculus.

COMMISSURAL FIBERS

- The corpus callosum is the largest commissure of the brain.
- The internal capsule is divided into five parts: The anterior limb, the genu, the posterior limb, the sublentiform part, the retrolentiform.

EEG

- EEG is a record of electrical potentials of the brain obtained from leads of the scalp. EEG displays wave like patterns.
- Alpha waves
- Beta waves
- Theta waves
- Delta waves

CIRCLE OF WILLIS

- It is a hexagonal arterial circle, situated at the base of the brain in the interpeduncular fossa. It is formed by the anterior cerebral branches and terminal parts of internal carotid arteries with its posterior communicating branches and the posterior cerebral branches of basilar artery.
- The circulus arteriosus attempts to equalize the flow of blood to different parts of brain.
- Internal carotid artery continues as middle cerebral artery.
- The branches of the circulus arteriosus and middle cerebral artery are cortical, central and choroidal.
- Middle cerebral is main artery on superolateral surface.
- Anterior cerebral artery is chief artery on medial surface.
- Posterior cerebral is principal artery on inferior surface.
- Prefrontal cortex is the 'mind', where understanding, planning, making judgments, worrying, etc. are done.
- Language: Left hemisphere in right-handed persons contains the centre for speech and is called dominant/categorical hemisphere. Even in left handed persons, centre for speech mostly lies in left hemisphere. Handedness becomes definite by 4 years of life.

Clinical Aspects

Electroencephalograph (EEG)

The EEG is a record of electrical potentials of the brain obtained from leads of the scalp. EEG displays wave-like patterns. These are:

Alpha waves are present in all normal people when they are awake and resting with closed eyes. These waves disappear diving sleep (Fig. 1.63).

- Beta waves appear when a person is alert.
- Theta waves occur when person is experiencing emotional stress. These occur in disorders of brain.
- Delta waves are seen in adults during deep sleep. EEG helps to localize intracranial lesions and brain tumors. It can distinguish diffuse and focal brain lesions in epilepsy. Can diagnose brain death.

Diseases that can be Diagnosed by EEG

Seizures disorders, sleep disorders, attention disorders, brain tumors, brain injury, brain infections, dementia, stroke, Bovine spongiform encephalopathy (mad cow disease).

Applied Aspects

Microcephaly

In this condition, the child's head is very small. The sutures of skull bones fuse prematurely making the skull small. The brain is also small because it cannot grow inside the skull. Such children are usually mentally retarded.

Increased Intracranial Pressure

The cranial cavity encloses brain, CSF, cerebral blood vessels and blood within the rigid cavity. An increase in the volume of any of these raises the intracranial pressure (ICP). Rise in ICP is associated with a reduction in blood flow leading to hypoxia and neuronal damage. Rise in ICP also leads to hypertension and bradycardia. Rise in ICP also leads to herniation (displacement of part of brain from its usual compartment) of any part of brain.

Hydrocephalus

There is blockage to the flow of CSF leading to dilatation of ventricles and increased ICP. It leads to destruction of neural tissue.

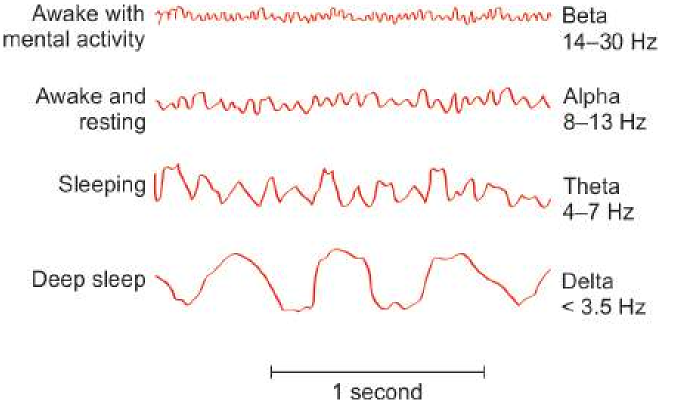


Fig. 1.63: Electroencephalograph

Cerebral Edema

It results from excessive accumulation of fluid in brain cells and/or in interstitial space leading to increased ICP. It is due to injury, hemorrhage, infections, ischemia, hypoxia or tumors.

Degenerative Nervous System Disorders

Parkinson's Disease

It results from gradual degeneration of dopamine releasing neurons in extrapyramidal system. Clinical features are due to lack of control and coordination of muscle movement. It results in muscle tremors, expressionless face, stiff shuffling gait and stooping posture.

Dementia

There is gradual impairment of short-term memory, reasoning, thinking with personality changes due to mental deterioration. It is usually due to progressive, irreversible degeneration and atrophy of cerebral cortex.

Alzheimer's disease (presenile dementia) is the commonest type of dementia. It is commoner in females and affects those over 60 years. Dementia also occurs in stroke, encephalitis, AIDS, head injury, vitamin B deficiency, renal failure and alcohol abuse.

Stroke

It occurs when a vascular disease suddenly interrupts flow of blood to the brain causing hypoxia (cerebrovascular disease). It occurs due to cerebral infarction (85%) and spontaneous intracranial hemorrhage (15%). Cerebral infarction results from either thrombosis (due to atheroma) or embolism or hemorrhage (due to uncontrolled hypertension) of a cerebral artery. It may lead to paralysis of a limb or one side of body and disturbances of speech and vision.

Head Injury

The brain may be injured by a blow to the head or movement of the brain during sudden acceleration or deceleration of the head. It causes intracranial hemorrhage increasing the ICP leading to damage to the brain. It may be:

- **Extradural hemorrhage**: There is collection of blood between inner table of skull and dura mater.
- **Subdural hemorrhage**: There is collection of blood between layers of dura mater. It occurs from veins in dura mater.
- **Intracerebral hemorrhage**: There are diffuse or localized hemorrhage inside the brain.

Epilepsy

It is usually idiopathic but may develop after head injury. It is characterized by seizures (fits), i.e. short, recurrent attacks of motor, sensory or psychological malfunction. The attacks are initiated by abnormal electrical discharge from neurons in the brain. It can be treated by antiepileptic drugs.

Meningitis

The inflammation of meninges of brain is called meningitis. This occurs by blood–borne infection or an injury to skull bones causing leakage of CSF. It can occur due to bacterial or viral agents. The bacterial meningitis is a serious condition and leads to high mortality while the viral meningitis is a relatively a mild infection followed by complete recovery.

Clinical features of bacterial meningitis are severe headache, neck stiffness, fever and skin rash.

Aphasia

It is the inability to use or comprehend words. It results from injury to language areas of the cerebral cortex.

Diseases of Spinal Cord

Spinal Cord Injury

The spinal cord may be damaged by trauma, tumors or herniated intervertebral discs. Depending on the location and extent of spinal cord damage, paralysis may occur.

- Monoplegia is paralysis of one limb only.
- Diplegia is paralysis of both upper limbs or both lower limbs.
- Paraplegia is paralysis of both lower limbs.
- Quadriplegia is paralysis of all four limbs.
- Hemiplegia is paralysis of upper limb, trunk and lower limb on one side of the body.

Aging Changes

After 60–70 years, there are changes in the brain:

- Prominence of sulci due to cortical shrinkage
- Gyri get narrow and sulci get broad
- Subarachnoid space becomes wider
- There is enlargement of ventricles.

Assess Yourself

Long Answer Questions

1. Name the parts of functional areas of cerebrum cortex. Discuss the cerebrum.
2. Discuss the CSF in detail.

Short Answer Questions

1. Name the descending tracts of spinal cord.
2. Name the parts and functions of hindbrain.

Multiple Choice Questions

Tick (✓) the correct option in the following:

1. Myelin sheath is produced by:
   a. Neuron
   b. Axon
   c. Dendrite
   d. Schwann's cells/oligodendrocyte
2. The three regions of brainstem are:
   a. Cerebrum, diencephalon, midbrain
   b. Pons, cerebellum, midbrain
   c. Diencephalon, midbrain, cerebrum
   d. Midbrain, pons, medulla oblongata
3. Which sequence lists cranial meninges in order from superficial to deep?
   a. Pia, arachnoid, dura
   b. Dura, pia, arachnoid
   c. Dura, arachnoid, pia
   d. Arachnoid, dura, pia
4. The three divisions of trigeminal nerve include:
   a. Oculomotor, palatine and lingual
   b. Ophthalmic, maxillary and mandibular
   c. Ophthalmic, palatine and lingual
   d. Frontal, maxillary and mandibular
5. The cranial nerve that arises from both brain as well as spinal cord:
   a. Hypoglossal
   b. Accessory
   c. Vagus
   d. Glossopharyngeal
6. The ratio of cerebellum to cerebrum in an adult is:
   a. 1 : 8
   b. 1 : 16
   c. 1 : 4
   d. 1 : 20
7. Broca's area is located in which lobe?
   a. Parietal
   b. Frontal
   c. Temporal
   d. Occipital
8. Which of the following arteries supply visual fibers?
   a. Anterior and middle cerebral
   b. Middle cerebral
   c. Middle and posterior cerebral
   d. Posterior cerebral

Answer Key

1. d 2. d 3. c 4. b 5. b 6. a 7. b 8. c