

Nervous System



Chapter Outline

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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.

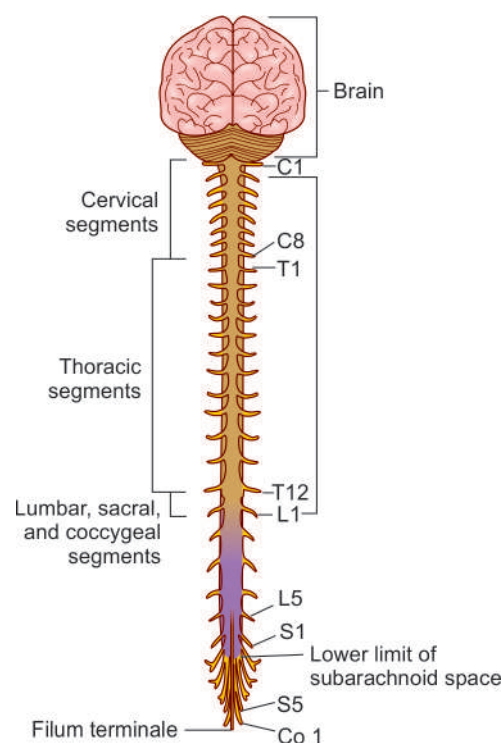


Fig. 1.1: Nervous system—diagrammatic representation

It sends and receives information to and from muscles, glands, organs and other systems in the body through the peripheral nervous system.

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 gastro-intestinal 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

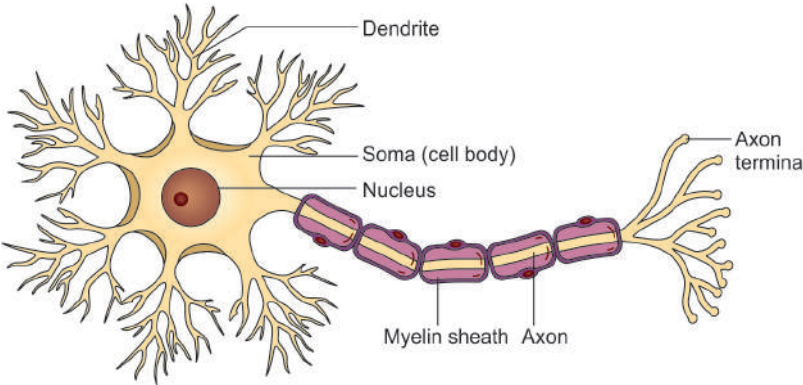


Fig. 1.2: Structure of neuron

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.

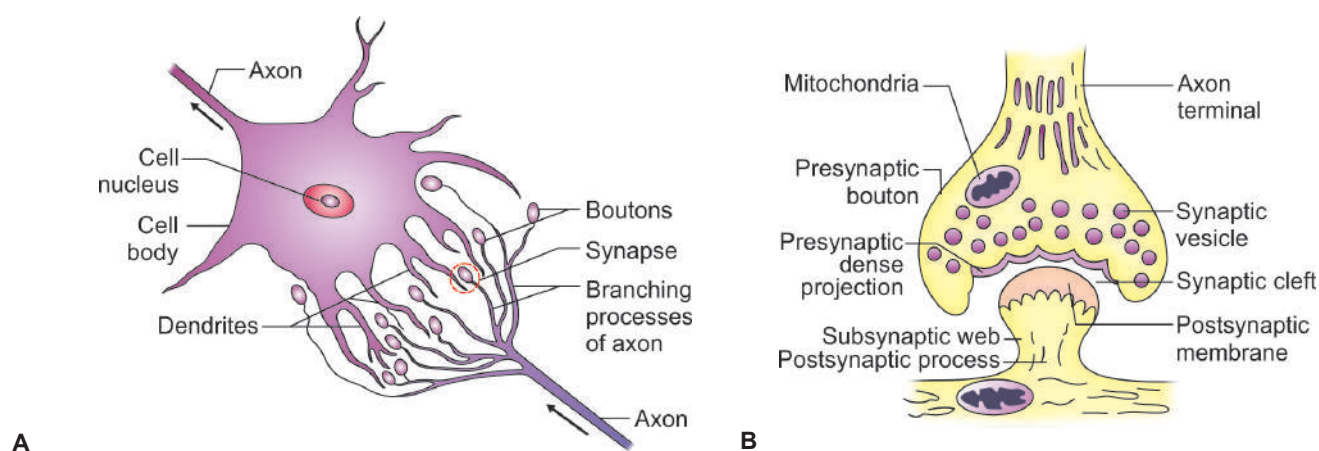
Neuron Communication

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 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.

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
• 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

OTHER NERVOUS TISSUES

Neuroglial Cells

Various types of neuroglial (Greek word that means ‘nerve glue’) cells are shown in Fig. 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. These remove dead cells.
- Ependymal cells are columnar cells lining the cavities of the CNS. These secrete CSF.
- Schwann cells lay myelin sheath in PNS.

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.

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

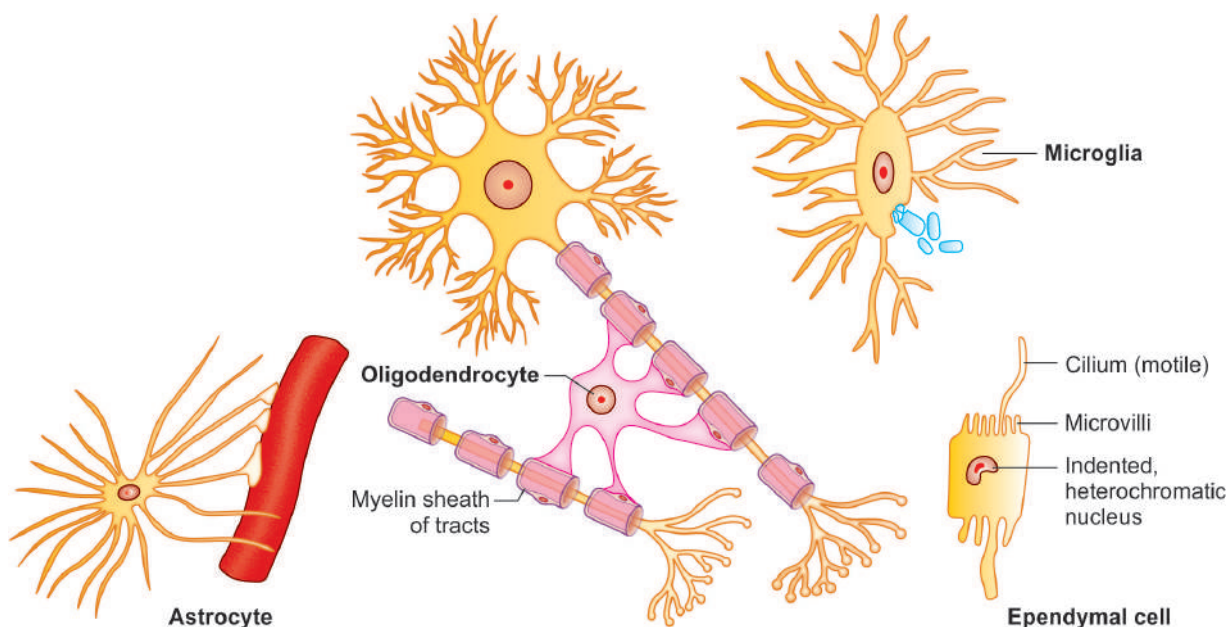


Fig. 1.4: Types of neuroglial cells

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 thus chemical 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

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

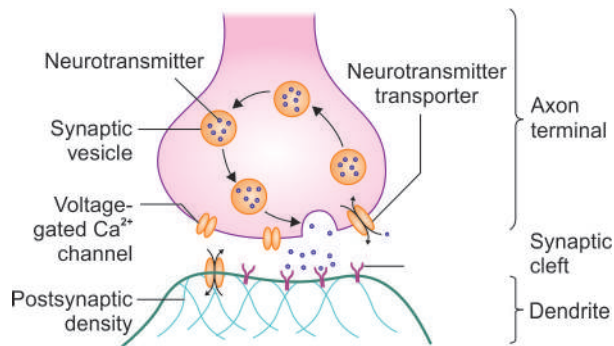


Fig. 1.5: Synapse

and the contact between neurons is by contiguity and not by continuity (‘neuron theory’ of Waldeyer, 1891). 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).

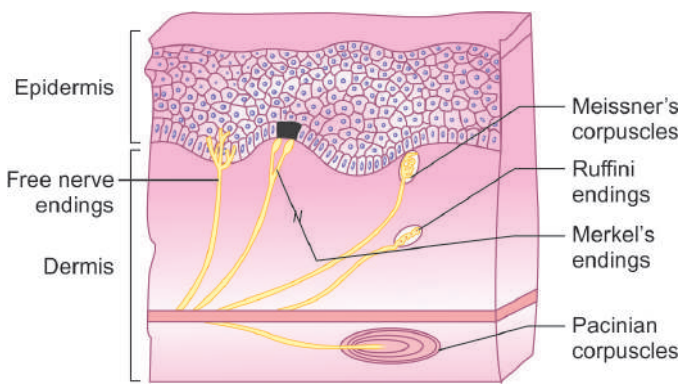


Fig. 1.6: Sensory endings in relation to skin (schematic)

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 μ m long and 30 μ m 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. 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 annulospiral 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.

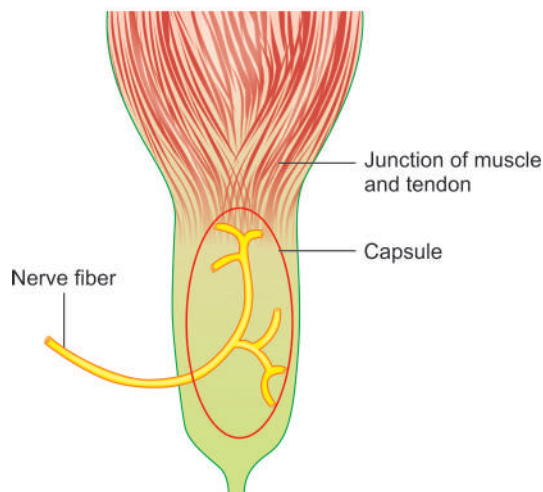


Fig. 1.7: Neurotendinous spindle of Golgi

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.

Motor Unit

The number of muscle fibers in a motor unit (number of muscle fibers supplied by a single alpha motor neuron)

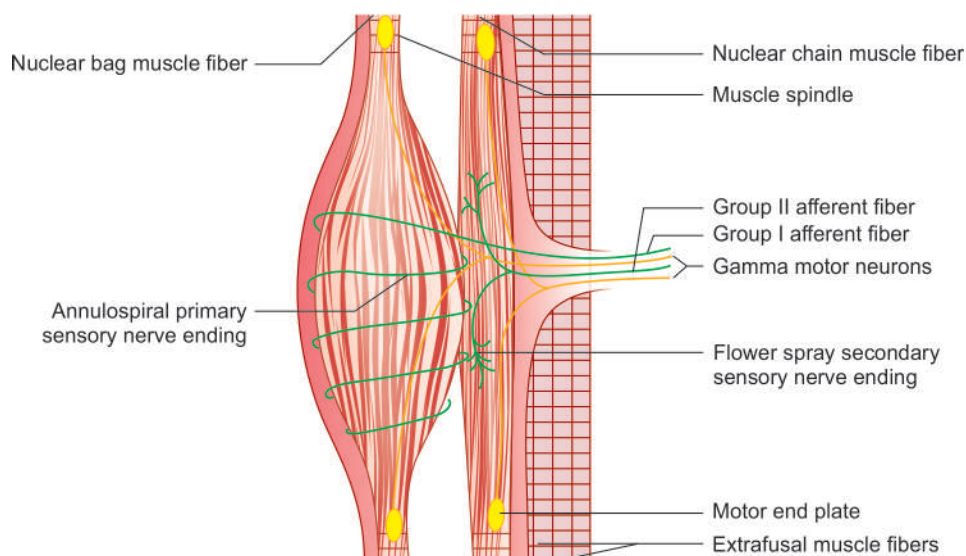


Fig. 1.8: Neuromuscular spindle

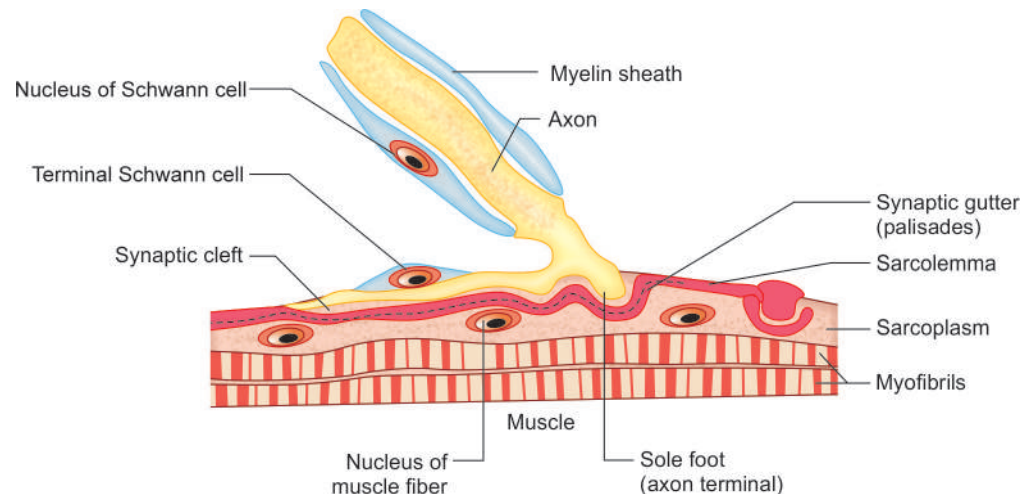


Fig. 1.9: Motor end plate

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 by membranes within the skull (Fig. 1.10).

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 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.

Spaces in Relation to Meninges

Extradural/epidural and subdural spaces: The extradural or epidural space is a potential space between the

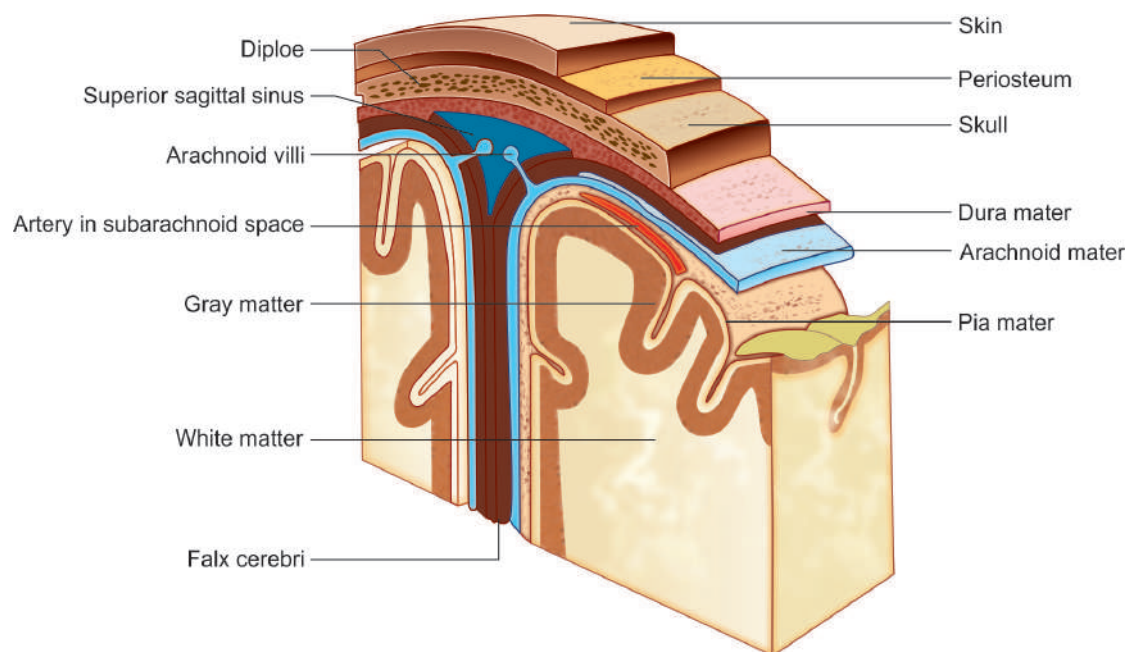


Fig. 1.10: Protective membranes of central nervous system

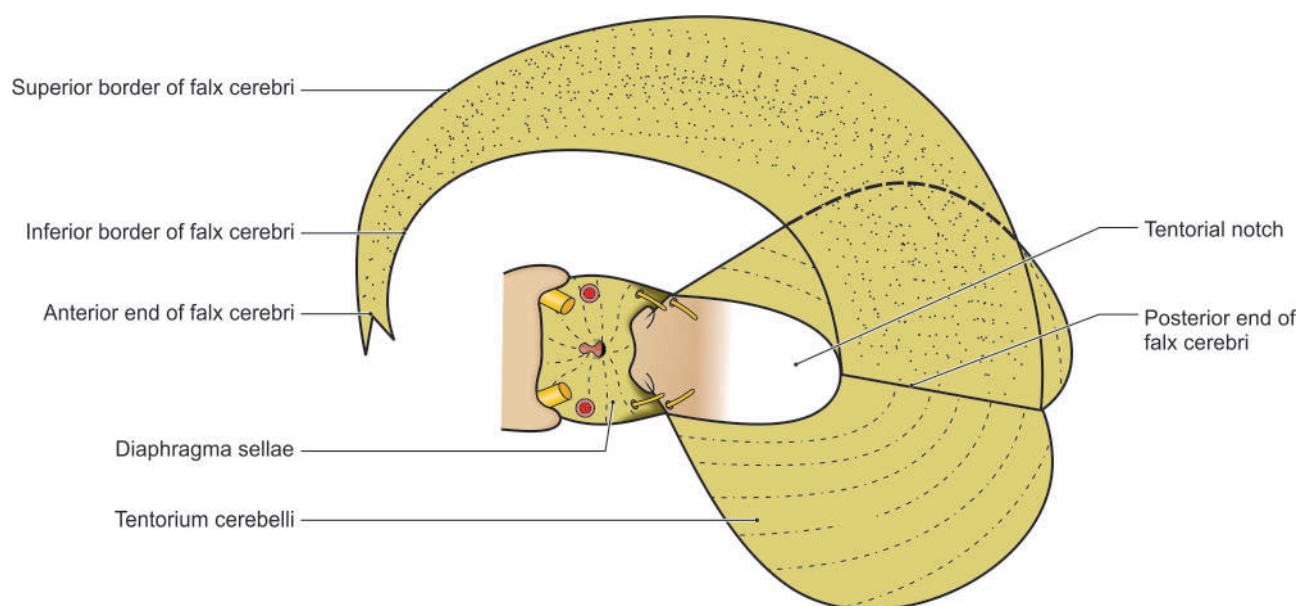


Fig. 1.11: Folds of meningeal layer of dura mater

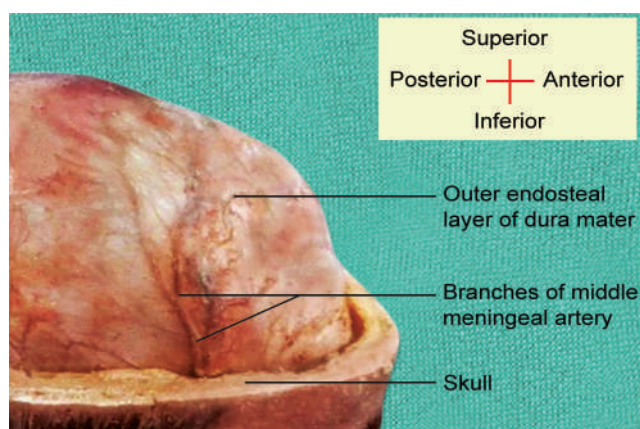


Fig. 1.12: Endosteal layer of dura mater

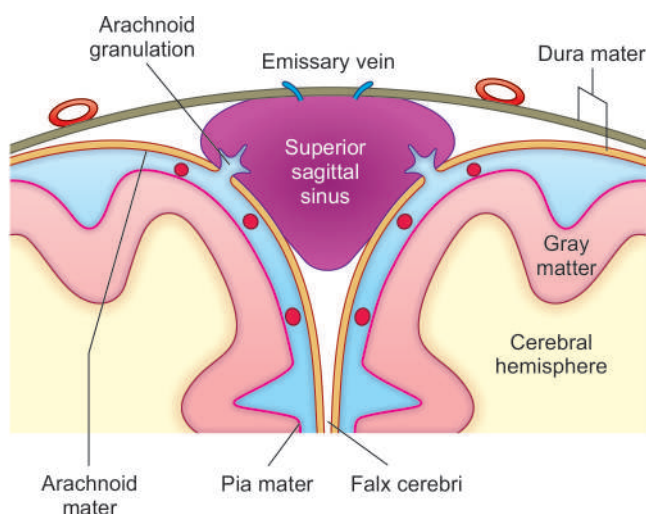


Fig 1.13: Arachnoid granulation

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.

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

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

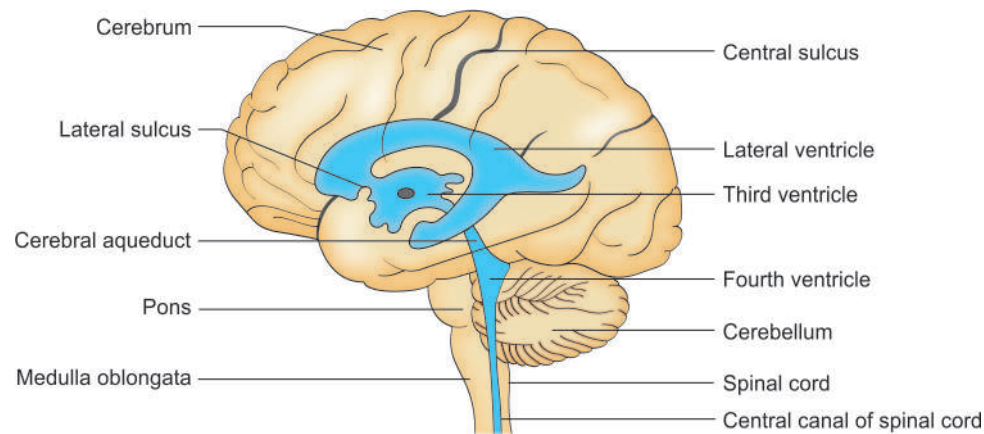


Fig. 1.14: Ventricles of brain

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.

Cisterns

At the base of the brain and around the brainstem, the subarachnoid space forms intercommunicating pools,

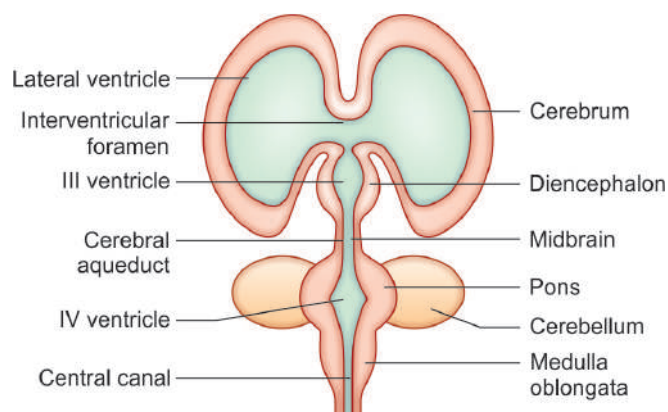


Fig. 1.15: Parts of the brain (diagrammatic)

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)
- 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.

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, • 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

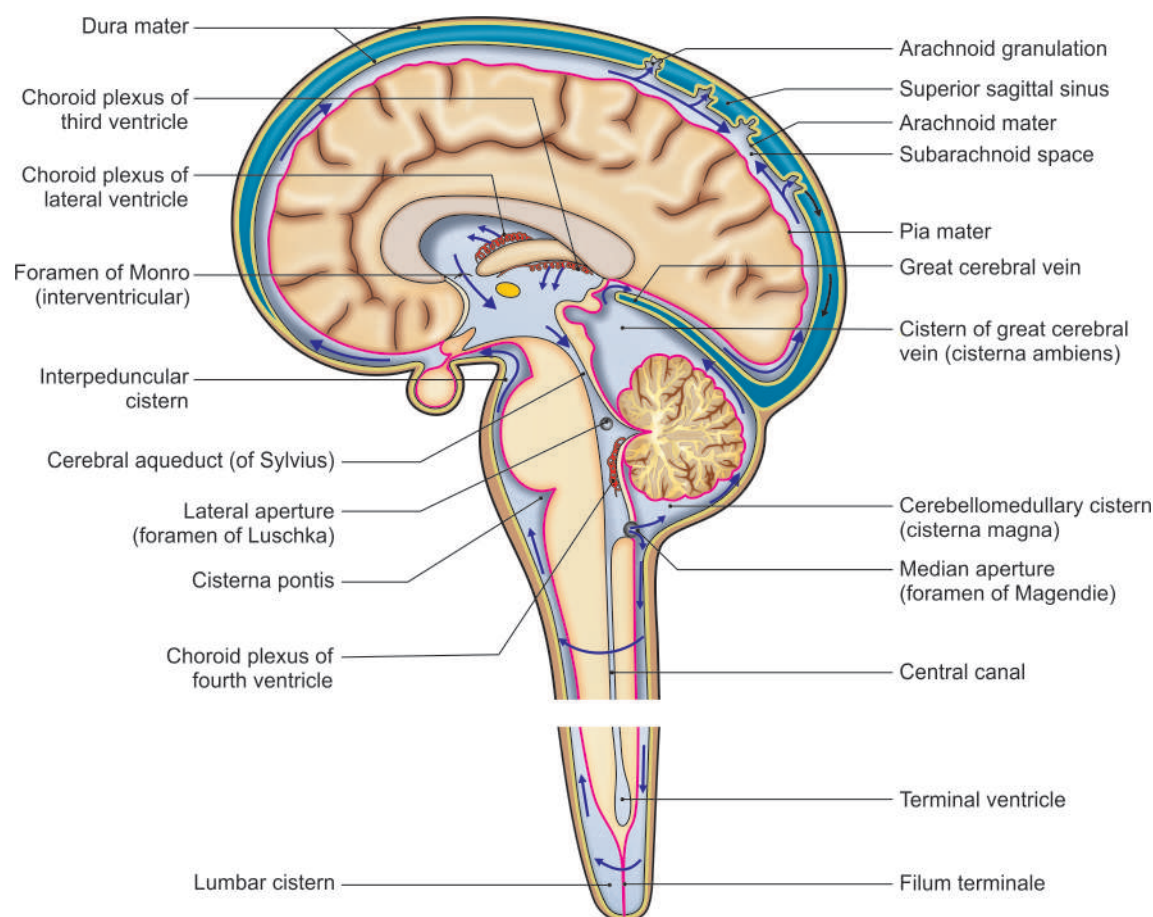


Fig. 1.16: Cisterns of the brain—formation, circulation and absorption of cerebrospinal fluid. Arrows show the direction of flow of cerebrospinal fluid

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 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 H₂O (Table 1.8).

Circulation

The CSF passes from each lateral ventricle to the third ventricle through the interventricular foramina of Monro

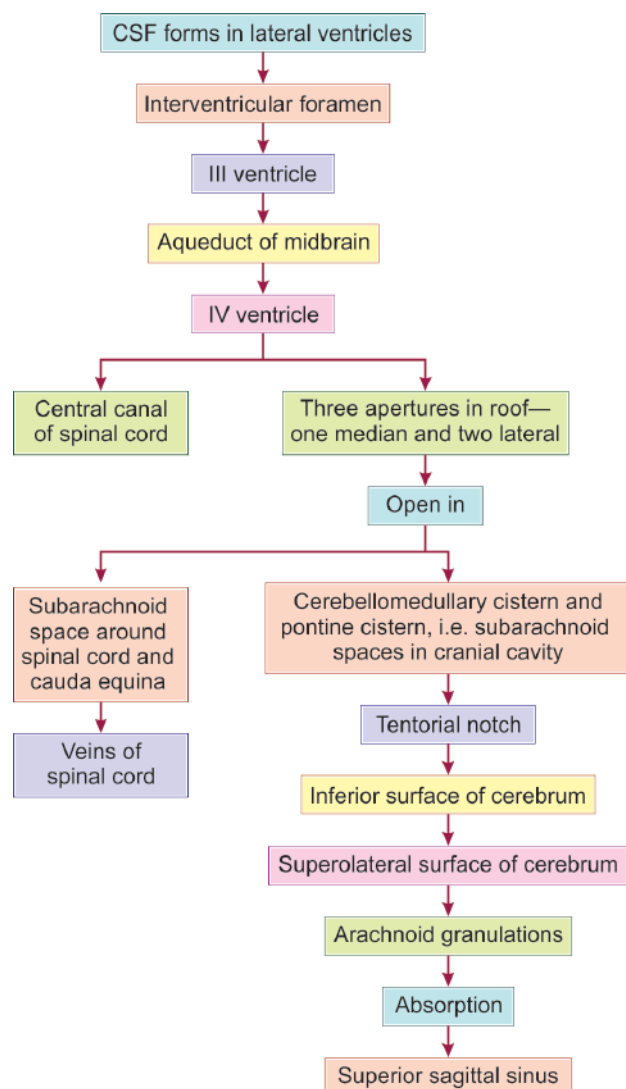
Table 1.8: Composition of normal CSF

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 g/dl

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).

Flowchart 1.1: Circulation of cerebrospinal fluid



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.
- 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).

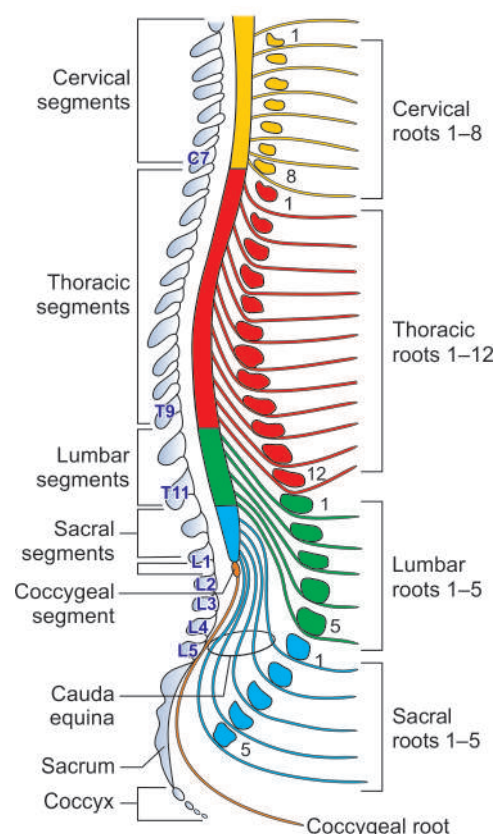


Fig. 1.17: Spinal cord with 31 pairs of spinal nerves

- **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.

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

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

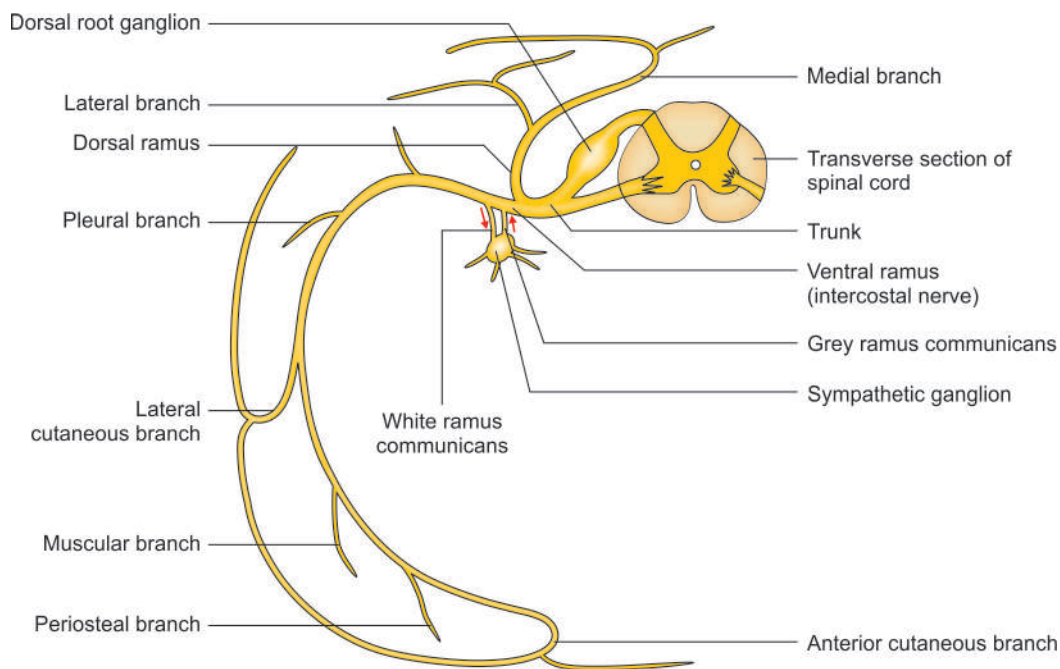


Fig. 1.18: Typical spinal nerve

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

<i>Name</i>	<i>Function</i>	<i>Crossed and uncrossed</i>	<i>Beginning</i>	<i>Termination</i>
Pyramidal tracts	• Main motor tract for skillful voluntary movements, facilitates flexors	• Crosses in medulla	• Motor area of cortex (areas 4, 6)	• Anterior grey column cells (alpha motor neurons)
1. Lateral corticospinal		• Crosses in corresponding spinal segment	• Motor area of cortex (areas 4, 6)	• Anterior grey column cells (alpha motor neurons)
2. Anterior corticospinal				
Extrapyramidal tracts	• Efferent pathway for cerebellum and corpus striatum	• Crossed	• Red nucleus of midbrain	• Alpha and gamma motor neurons of anterior grey column cells
1. Rubrospinal				
2. Medial reticulospinal	• Extrapyramidal tract	• Uncrossed	• Reticular formation of grey matter of pons	• Alpha and gamma motor neurons of anterior grey column cells
	• Facilitates extensors			
3. Lateral reticulospinal	• Extrapyramidal tract	• Uncrossed and crossed	• Reticular formation of grey matter of medulla oblongata	• Alpha and gamma motor neurons of anterior grey column cells
	• Facilitates flexors			
4. Olivospinal	• Extrapyramidal tract	• Uncrossed	• Inferior olivary nucleus	• Alpha and gamma motor neurons of anterior grey column cells

Table 1.10: The descending tracts (*Contd...*)

Name	Function	Crossed and uncrossed	Beginning	Termination
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

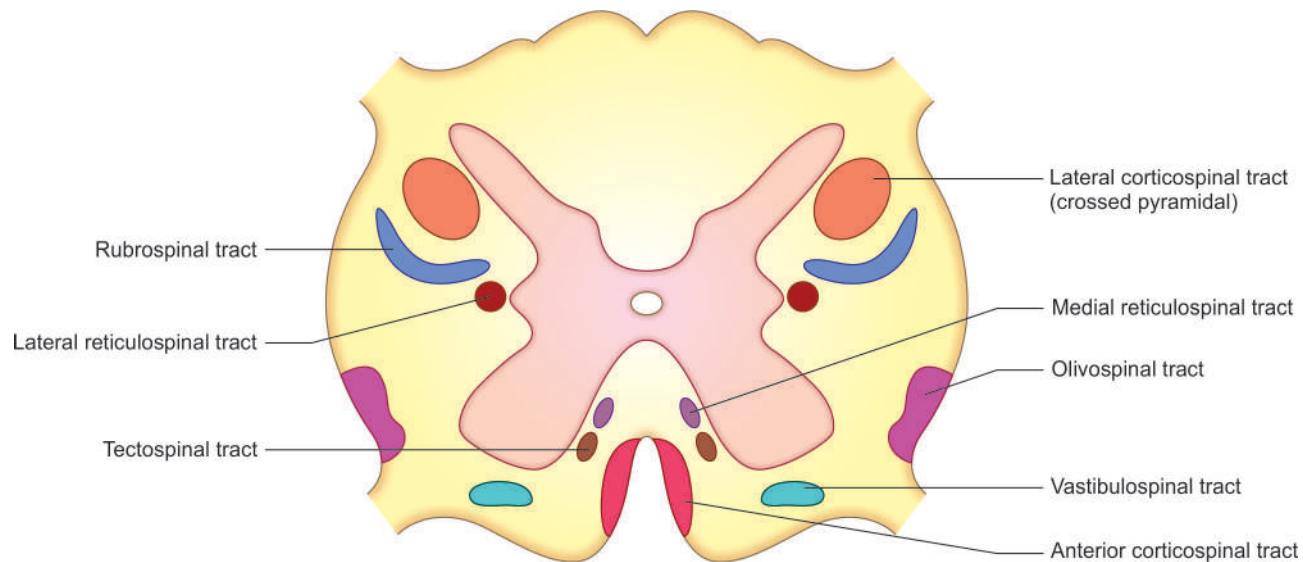


Fig. 1.19: Location of descending tracts in spinal cord

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.

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.

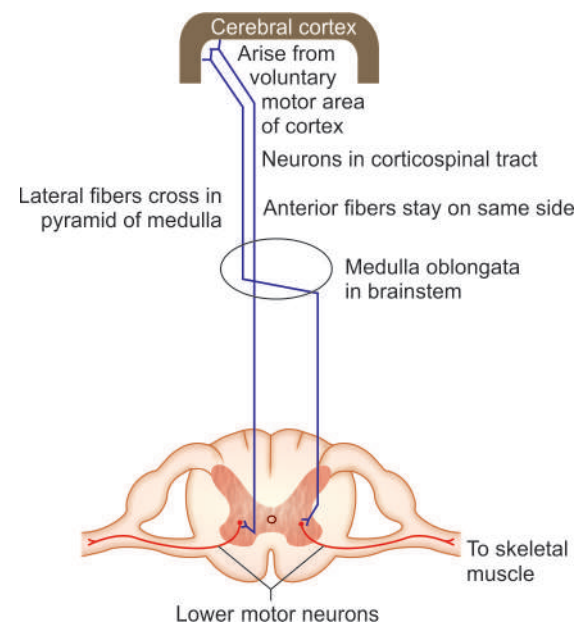


Fig. 1.20: Pyramidal/corticospinal tracts—course of corticospinal fibers

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

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 brain-stem, 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 spino-cerebellar (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

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.

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

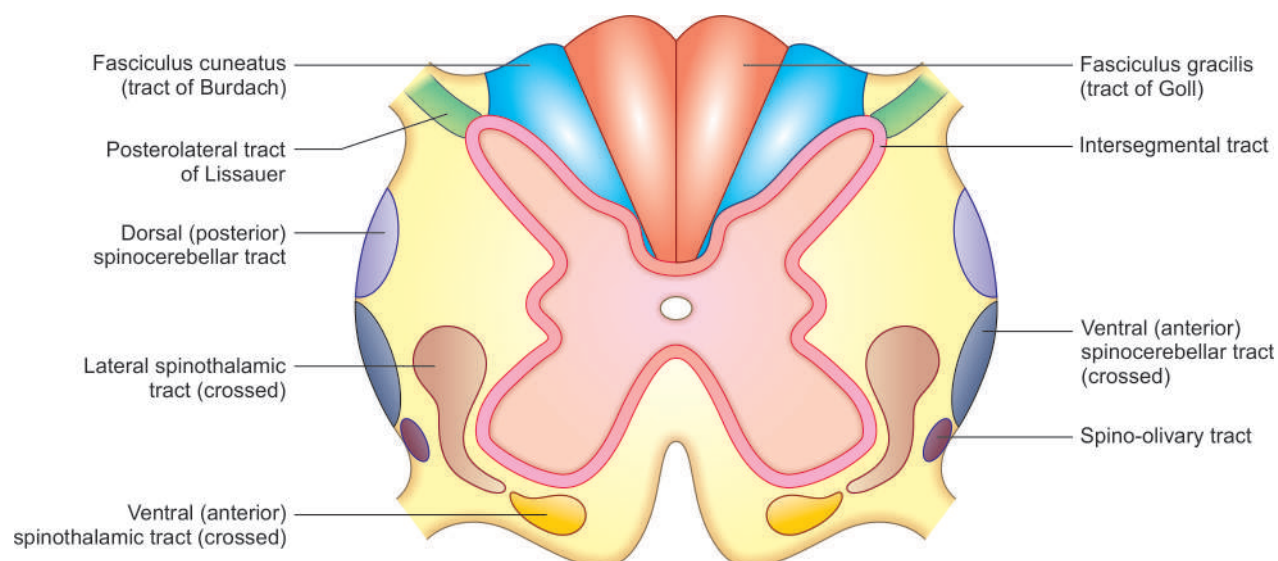


Fig. 1.21: Location of ascending tracts in spinal cord

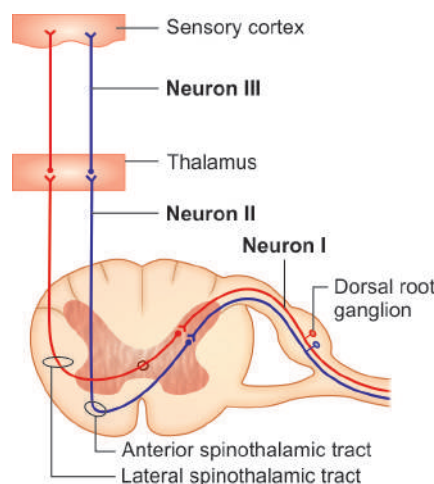


Fig. 1.22: Spinothalamic pathways

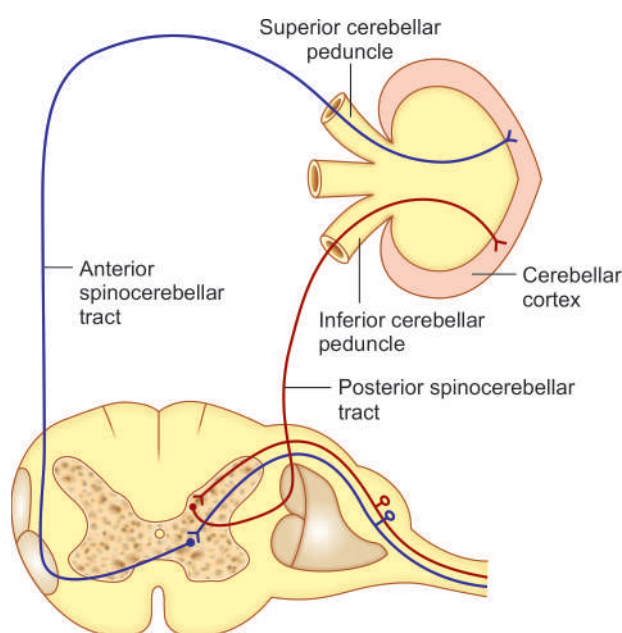


Fig. 1.24: Pathway of posterior and anterior spinocerebellar tract

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).

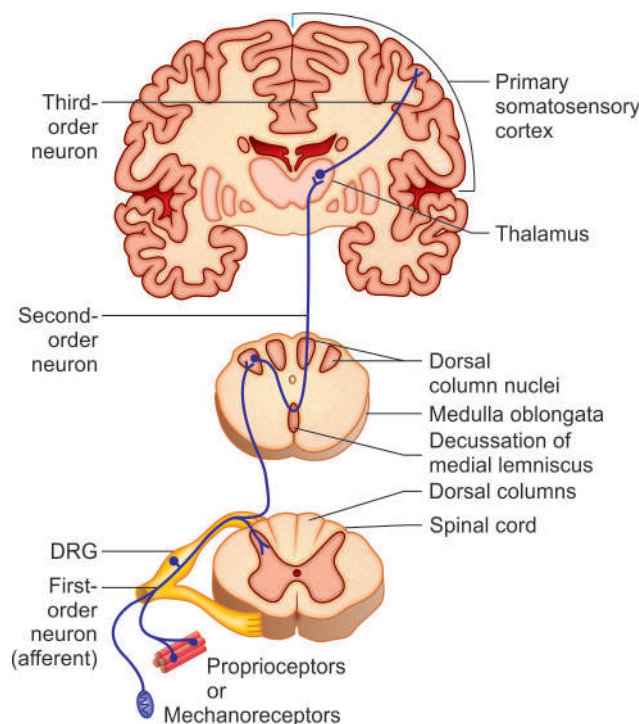


Fig. 1.23: Tracts of dorsal columns

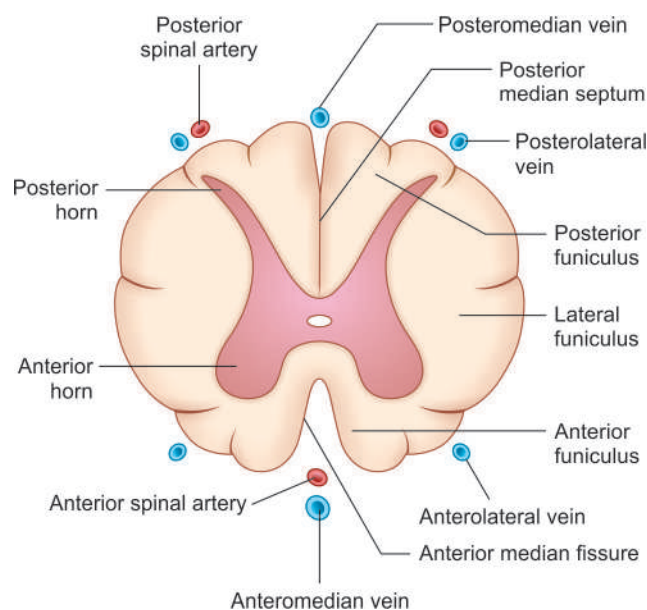


Fig. 1.25: Blood supply of spinal cord

External Features

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

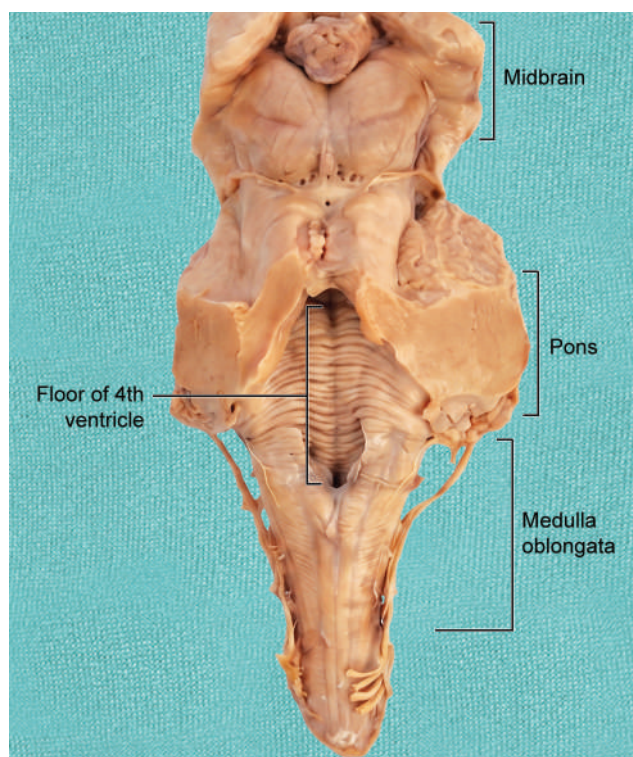


Fig. 1.26: Gross anatomy of brainstem

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 Fig. 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:

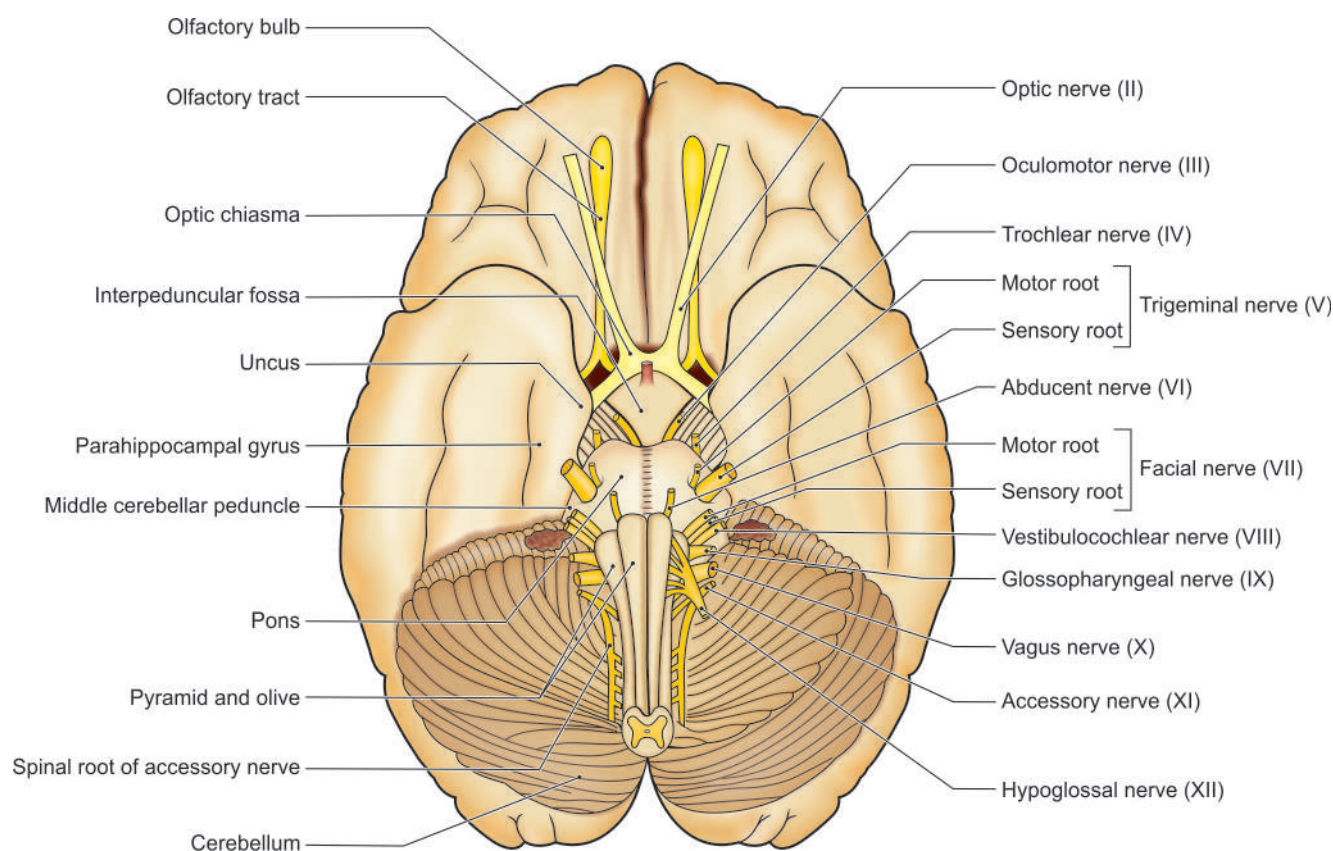


Fig. 1.27: Attachment of cranial nerves to the ventral surface of brainstem with external features of medulla oblongata, pons and midbrain

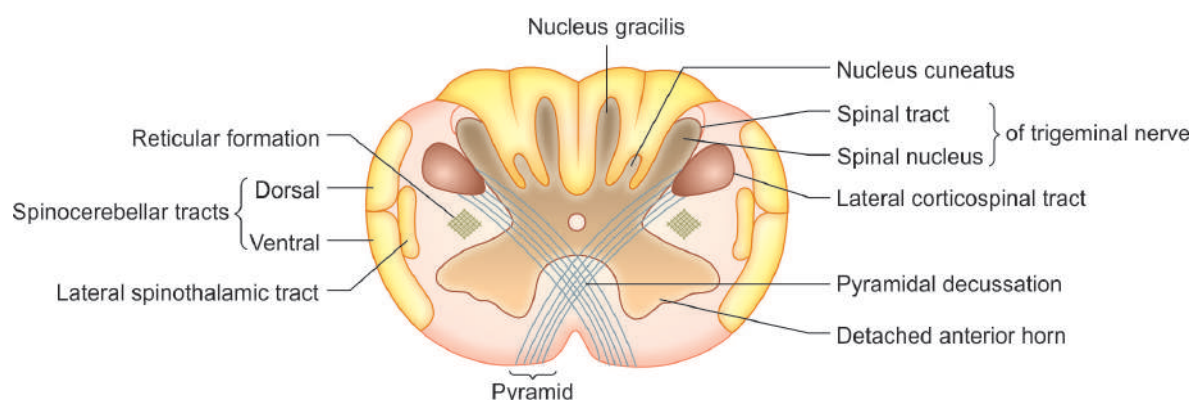


Fig. 1.28: Transverse section of medulla oblongata at the level of pyramidal decussation

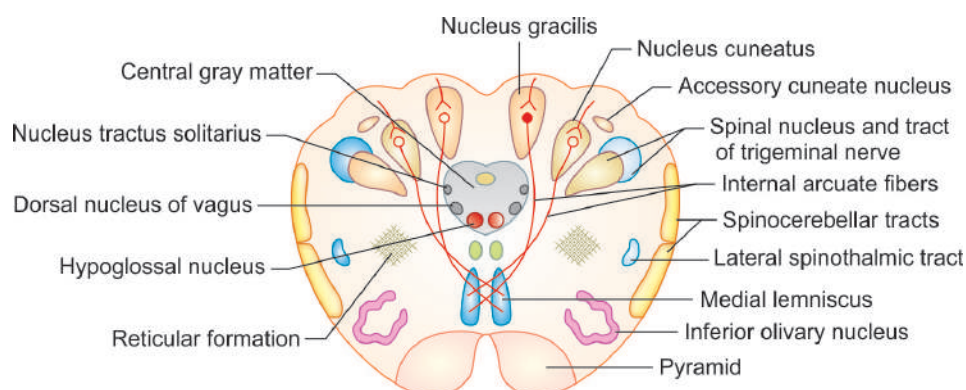


Fig. 1.29: Transverse section of medulla oblongata at the level of sensory decussation

- 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).

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).

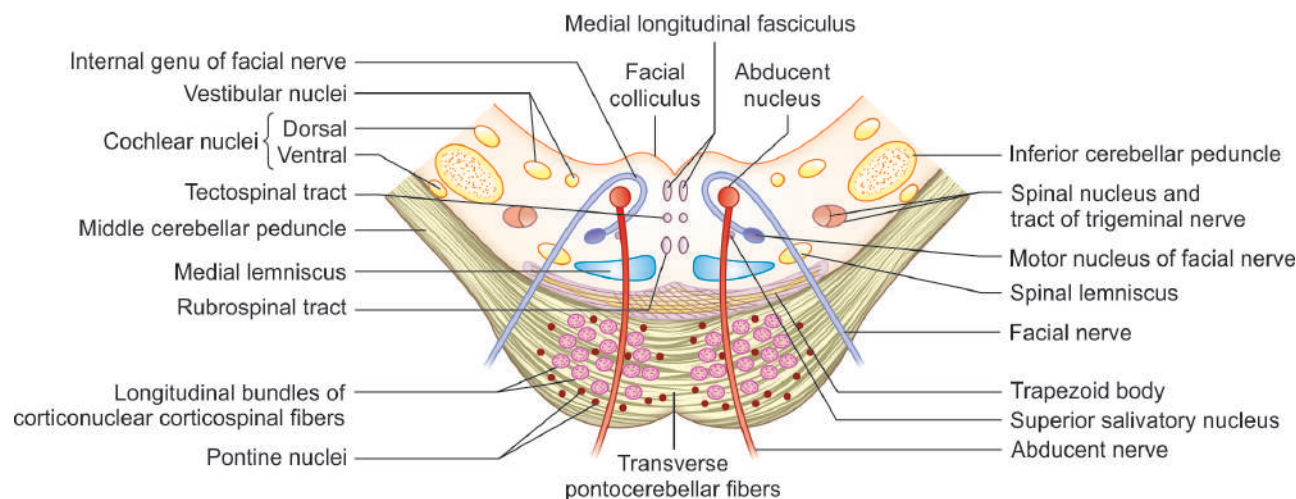


Fig. 1.30: Transverse section of lower part of pons at the level of facial colliculus

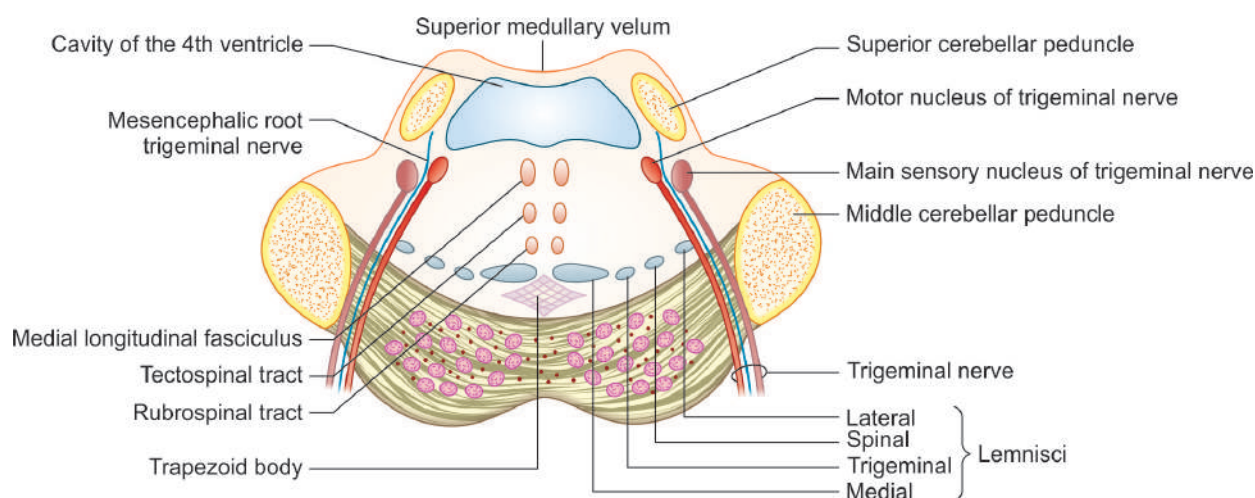


Fig. 1.31: Transverse section of upper pons

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

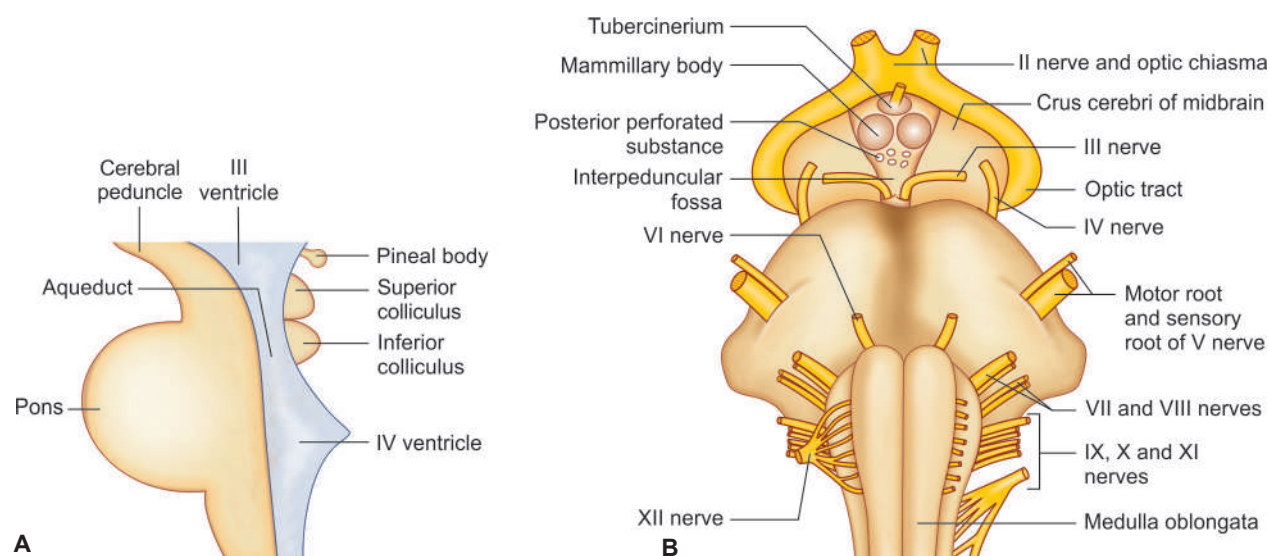
superior colliculus is connected to the lateral geniculate body by the superior brachium.

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.



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

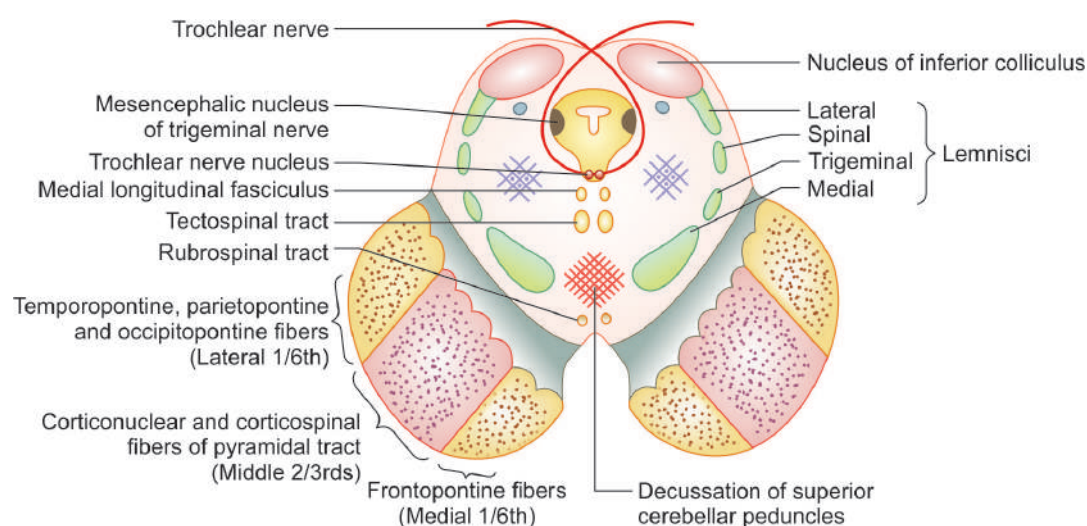


Fig. 1.33: Parts of midbrain and transverse section at the level of inferior colliculus

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.