Seventh Edition

B D Chaurasia's

Human Anatomy

Volume 4

Regional and Applied | Dissection and Clinical

Brain–Neuroanatomy

Volumes 3 & 4 sold together as one set

Available Free on CBSiCentral App

- Original Images from 1st Edition of BDC Human Anatomy (Vols 1–3) Hand-drawn by Dr BD Chaurasia
- Videos on Osteology and Soft Parts
- Frequently Asked Questions & Answers

Scratch Code on Inside Front Cover for Accessing CBSiCentral App

Wall Chart on Brain–Neuroanatomy

CBS Dedicated to Education
CBS Publishers & Distributors Pvt Ltd

Contents

5. Brain Stem 90

6. Cerebellum 105

7. Fourth Ventricle 115

8. Cerebrum 120

9. Third Ventricle, Lateral Ventricle and Limbic System 151

Glossary

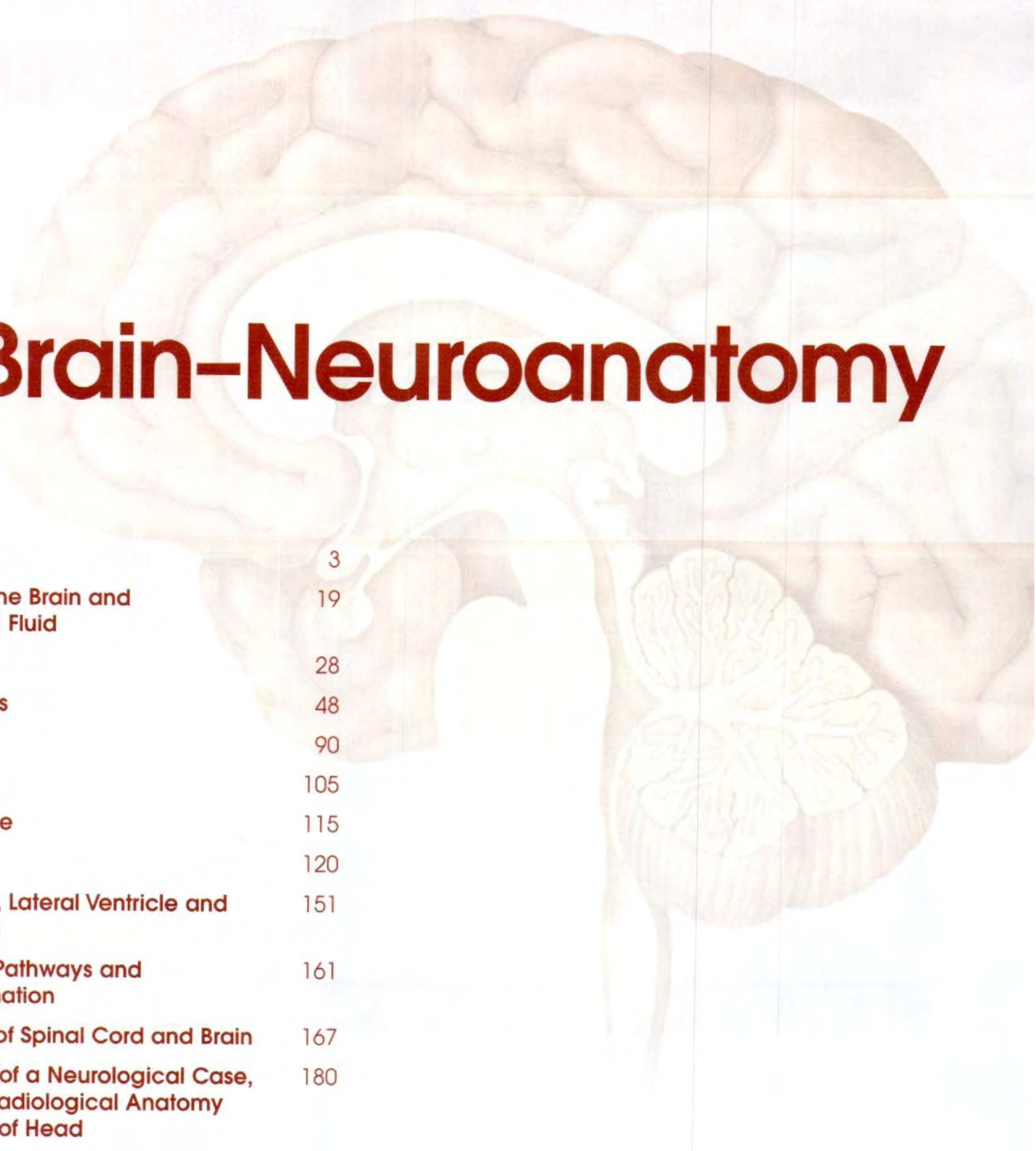
L: Latin word, Gr: Greek word

Allocortex	L. other bark	Old cortex, i.e. paleocortex and archicortex
Alveus	L. trough	White matter on the ventricular surface of hippocampus
Amygdala	L. almond	Nucleus in roof of inferior horn of lateral ventricle
Arachnoid	Gr. like spider's web.	Middle meningeal layer
Archicerebellum	Gr. old cerebellum	Phylogenetic cerebellum area in caudal region
Astereognosis	Gr. loss of knowledge	Inability to recognise solid objects
Astrocyte	Gr. star cells	A type of neuroglial cell
Ataxia	Gr. negative order	Loss of muscular coordination
Athetosis	Gr. without place	Bizzare movements
Autonomic	Gr. self law	Autonomic NS
Axolemma	Gr. axis back	Covering of axon
Basis pedunculi	—	Ventral part of midbrain
Brachium	L. arm	Fibres connecting 2 parts
Brainstem	—	Midbrain + pons + medulla oblongata
Bulb	—	Medulla oblongata
Calamus scriptorum	L. reed pen	Area in caudal part of IV ventricle
Calcar	L. spur	e.g. calcarine sulcus, calcar avis
Cauda equina	L. horse's tail	Lower lumbar and sacral nerve roots
Caudate nucleus	L. comma-shaped	Part of corpus striatum
Cerebellum	L. little brain	Part of brain
Cerebrum	L. brain	Cerebral cortex + diencephalon
Chorea	L. dance	Involuntary movement of limbs
Cinerium	L. ash coloured	e.g. tubercinerium
Cingulum	L. girdle	Name of association fibres
Claustrum	L. barrier	Grey matter between insula and lentiform nucleus
Colliculus	L. small swelling	e.g. dorsal part of midbrain and facial colliculus
Commissure	L. joined together	Type of white fibres joining identical parts of 2 cerebral hemispheres,
Corona	L. crown like	e.g. corona radiata
Corpus callosum	L. body hard	Main commissural fibre bundle
Corpus striatum	L. body striped	Grey matter at base of cerebral hemisphere
Cortex	L. bark	Outer layer (i.e. grey matter) in cerebellum and cerebrum.

Crus	L. leg.	e.g. crus cerebri or basis pedunculi
Cuneus	L. wedge	e.g. nucleus and fasciculus cuneatus and cuneus gyrus in cerebral cortex
Decussation	L. like X	Crossing over
Dentate	L. toothed	e.g. dentate gyrus of temporal lobe, dentate nucleus of cerebellum
Diencephalon	Gr. thro' brain	Thalamus + hypothalamus + epithalamus + subthalamus + metathalamus.
Dura mater	L. hard mother	Outer covering of brain
Emboliformis	Gr. plug like	One of the nuclei of cerebellum
Endoneurium	Gr. within nerve	Connective tissue sheath around each nerve fibre
Entorhinal	Gr. within nose	Anterior part of parahippocampal gyrus adjacent to uncus
Ependyma	Gr. upon garment	The lining epithelium of ventricles of brain and the central canal of spinal cord
Epithalamus	Gr. upon nerve	Sheath surround the nerve
Exteroceptor	L. external + receiver	Receiver for external environment
Falx	L. sickle	e.g. falx cerebri, falx cerebelli
Fasciculus	L. bundle	Bundle of white fibres
Fimbria	L. fringe	e.g. bundle of fibres along medial edge of hippocampus
Forceps	L. pair of tongs	e.g. forceps minor, forceps major
Fornix	L. arch	Part of limbic system
Ganglion	Gr. swelling	e.g. dorsal root ganglia, basal ganglia
Genu	L. knee (bend)	e.g. facial nerve, corpus callosum
Glia	Gr. glue	Neuroglia
Globus pallidus	L. ball +plate	e.g. medial part of lentiform nucleus
Glomerulus	L. ball of thread	e.g. glomeruli of olfactory bulb
Gracilis	L. slender	Nucleus and fasciculus gracilis
Habenula	L. rein	Swelling in epithalamus
Hemiballismus	Gr. half jumping	Violent movement of one side of body due to disease of subthalamic nucleus
Hemiplegia	Gr. half stroke	Paralysis of one side of the body
Hydrocephalus	Gr. water in head	Excessive CSF
Indusium	L. garment	Grey matter on dorsal surface of corpus callosum
Infundibulum	L. funnel	Stem of neurohypophysis
Insula	L. island	Part of cortex lying at the depth of lateral sulcus
Isocortex	Gr. same bark	Regions of cerebral cortex with 6 layers
Lemniscus	Gr. ribbon	Medial lemniscus
Lentiform	L. lens-like	Lentiform nucleus
Limbus	L. border, C-shaped	Limbic lobe, limbic system
Limen	L. threshold	Ventral part of insula
Locus ceruleus	L. place dark blue	e.g in floor of IV ventricle
Macula	L. spot	e.g. macula lutea
Mammillary body	L. nipple-shaped	mammillary bodies
Medulla	L. middle	medulla oblongata
Mesencephalon	Gr. middle brain	midbrain
Metathalamus	Gr. after + inner chamber	Medial and lateral geniculate bodies
Metencephalon	Gr. after + brain	e.g. pons + cerebellum
Microglia	Gr. small + glue	Type of neuroglial cells

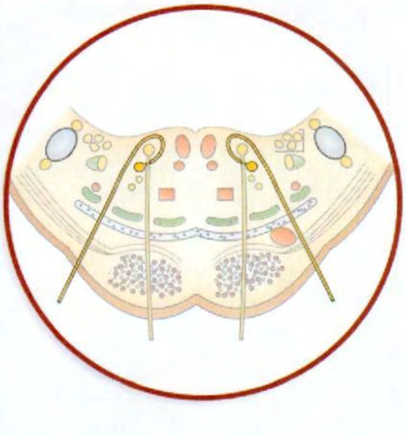
Molecular	L. mass	Tissue with large number of nerve fibres
Myelencephalon	G. marrow +brain	Medulla oblongata
Neostriatum	New + striped region	Caudate nucleus and putamen
Neurite	G. of nerve	Axons and dendrites of the neurons
Neurobiotaxis	G. nerve + living attraction	Nerve cells moving towards sources of stimuli
Neuroglia	G. nerve + glue	Cellular, non-nervous cells glueing the neurons
Neurolemma or neurilemma	G. nerve – husk	Sheath around the peripheral nerve fibre
Neuropil	G. nerve + felt	Nerve cell process between the bodies of neurons.
Nociceptive	L. to injure + to take	Response to painful stimuli
Obex	L. barrier	In fourth ventricle
Oligodendrocyte	G. few + processes	Type of neuroglia
Olive	L. oval	Olivary nuclei
Operculum	L. lid	Various opercula around the lateral sulcus to hide the insula
Paleocerebellum	G. ancient + small cerebellum	Old part of cerebellum
Paleostriatum	G. ancient + striped area	Old part of corpus striatum, i.e. globus pallidus.
Paraplegia	G. beside + stroke	Paralysis of lower part of trunk and both lower limbs
Perikaryon	G. around + nut	Neuron
Pes	L. foot	Pes hippocampi
Pineal	L. pine	Pineal gland
Plexus	L. palit	Interwoven fibres
Pneumoencephalogram	Air + brain + to write	Visualisation of ventricles and subarachnoid space by replacing of CSF by air
Pons	L. bridge	Part between midbrain and medulla oblongata
Proprioceptive	L. one's own + receptor	Afferents from joints, tendons, etc.
Prosencephalon	G. before + brain	Forebrain part
Ptosis	G. falling	Drooping of upper eyelid
Pulvinar	L. cushioned seat	Posterior projection of thalamus
Putamen	L. shell	Lateral part of corpus striatum
Pyriform	L. pear + form	Olfactory cortex is pear-shaped in lower animals
Quadriplegia	L. four + stroke	Paralysis of all four limbs
Raphe	G. seam	Midline structure
Reticular	L. net	Net formation
Rhinal	G. nose	Related to nose
Rhinencephalon	G. nose + brain	Components of olfactory system
Rhombencephalon	G. lozenge-shaped + brain	Refers to hindbrain vesicle
Rostrum	L. beak	Beak-shaped portion of corpus callosum
Rubro	L. red	Red nucleus
Satellite	L. attendant	Cells around neurons of dorsal root ganglion and autonomic ganglia
Septum pellucidum	L. partition transparent	Septum pellucidum of lateral ventricles
Somatic	G. bodily	Skeletal muscles (in neurology)
Somesthetic	G. body + perception	Sensation of pain, touch and temperature
Splenium	G. bandage	Posterior thick end of corpus callosum
Striatum	L. furrowed	Caudate nucleus and putamen
Subiculum	L. decreased layer	Transitional cortex between hippocampus and parahippocampal gyrus
Substantia gelatinosa	Substance + soft	Collection of small neurons at the apex of posterior horn of spinal cord

Substantia nigra	Substance + dark	Present in midbrain
Subthalamus	L. under + inner chamber	Region beneath thalamus
Synapse	G. to join	Site of contact between neurons
Syringomyelia	G. pipe + marrow	Cavities in grey matter around central canal
Tapetum	L. carpet	Fibres of body of corpus callosum
Tectum	L. roof	Roof of midbrain comprised of 4 colliculi
Tegmentum	L. to cover	Dorsal portion of pons and midbrain
Telachoroidea	L. web + membrane	Vascular connective tissue core of choroid plexus.
Telencephalon	G. end + brain	Cerebral hemisphere
Telodendria	G. end + tree	Terminal branches of the axon
Thalamus	G. inner chamber	Part of diencephalon
Tomography	G. cutting + write	Sectional radiography
Transducer	L. to change	Mechanism which changes one form of energy into another
Trapezoid body	Trapezium like	Transverse fibres at the juction of dorsal and ventral parts of pons for auditory pathway
Uncinate	L. hood-shaped	Uncinate fasciculus
Uncus	L. hood	Hook-shaped anterior end of parahippocampal gyrus
Uvula	L. little grape	Part of inferor vermis of cerebellun
Vallecula	L. valley	Depressed area on the inferior medullary vela
Ventricle	L. diminutive of belly	Ventricles of brain
Vermis	L. worm	Middle region of cerebellum
Zona incerta	—	Grey matter in subthalamus



Brain–Neuroanatomy

Anatomy Made Easy



Ichchak dana, beechak dana, dane upar dana
Hands naache, feet naache, brain hai khushnama
Ichchak dana
Seventh ka nucleus ghoom kar aaye fifth ke pass,
nucleus ambiguus laterally jaye
Spinal accessory neeche ko aaye,
motor sensory pass ho jayen,
kaisa aashikana—ichchak dana
Bolo kya—Neurobiotaxis, bolo kya—Neurobiotaxis

CHAPTER

1

Introduction

The capacity of the mind is as great as that of space
—Wei Lang

Nervous system is the chief controlling and coordinating system of the body.

It is responsible for judgement, 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.

Average weight of adult brain in air is 1500 grams. Since brain floats in cerebrospinal fluid, it only weighs 50 grams which is comfortable.

There are about 180–200 billion neurons in an adult brain (very rich).

DIVISIONS OF NERVOUS SYSTEM

ANATOMICAL

It is divided into:

1 Central nervous system (CNS) which 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.
2 Peripheral nervous system (PNS) includes 12 pairs of cranial nerves and 31 pairs of spinal nerves. These provide afferent impulses to CNS and carries efferent impulses to muscles, glands and blood vessels (Flowchart 1.1).

FUNCTIONAL

Peripheral nervous system functionally has two components:

1 *Afferent* component provides sensory information to CNS.
2 *Efferent* component carries motor information to muscles, glands, blood vessels and heart via:
   a. Somatic nervous system for the control of skeletal muscles.
   b. Autonomic nervous system for control of heart, smooth muscle of the organs, glands and blood vessels. It is subdivided into sympathetic and parasympathetic parts.

CELLULAR ARCHITECTURE

The nervous tissue is made up of:

1 Nerve cells or neurons (Fig. 1.1).
2 Neuroglial cells (neuroglia), forming the supporting (connective) tissue of the CNS. In peripheral nervous system, these are replaced by Schwann's cells.

Both types of cells are supplied by abundant blood vessels.

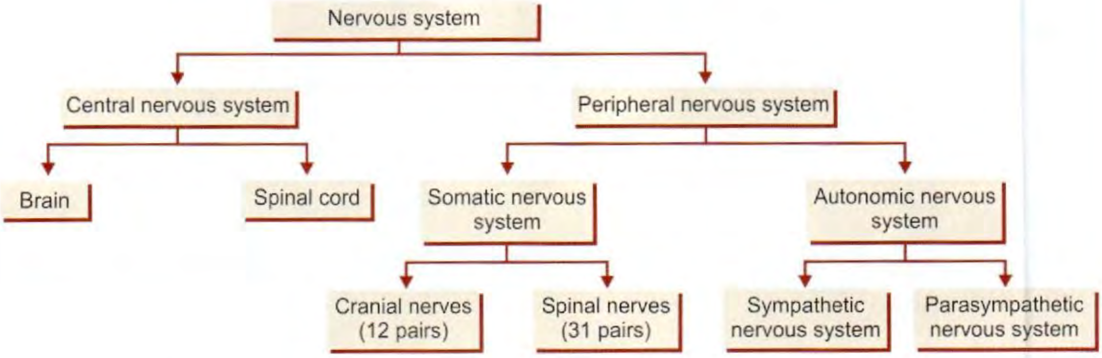
NEURON

Each neuron is made up of the following.

1 *A cell body:* Collectively they form grey matter and the nuclei in the CNS, and ganglia in the peripheral nervous system.
2 *Cell processes of two varieties:*
   a. Dendrites (Greek *branch of a tree*) are many, short, richly branched and often varicose (Fig. 1.1).
   b. The axon is a single elongated process. Collectively the axons form tracts (white matter) in the CNS, and nerves in the peripheral nervous system. The branches of axons often arise at right angles and are called the collaterals.

Functionally, each neuron is specialized for sensitivity and conductivity. The impulses can flow in them with great rapidity, in some cases about 125 meters per second. A neuron shows *dynamic polarity* in its processes. The impulse flows towards the cell body in the dendrites, and away from the cell body in the axon (Fig. 1.1).

Flowchart 1.1: Divisions of nervous system



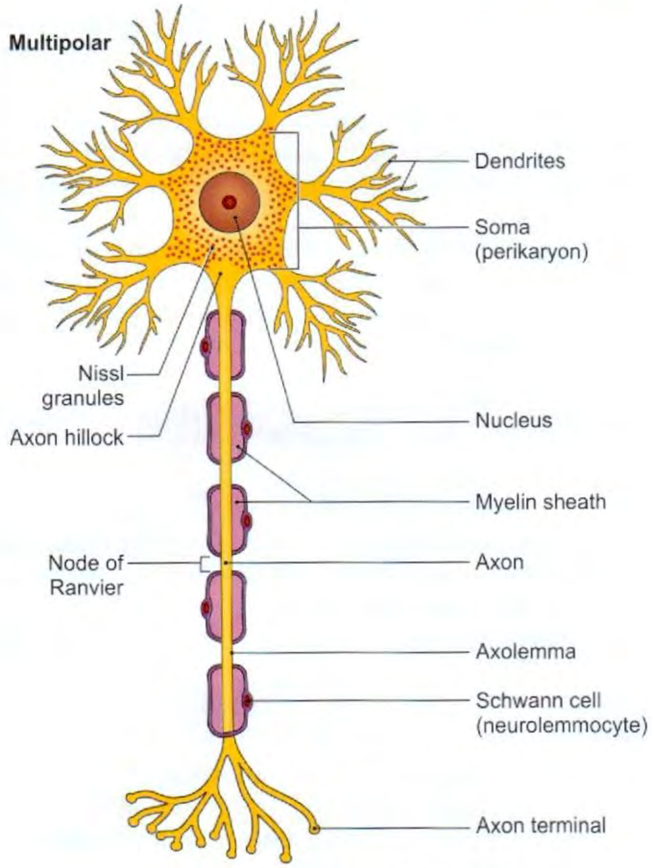


Fig. 1.1: Multipolar neuron

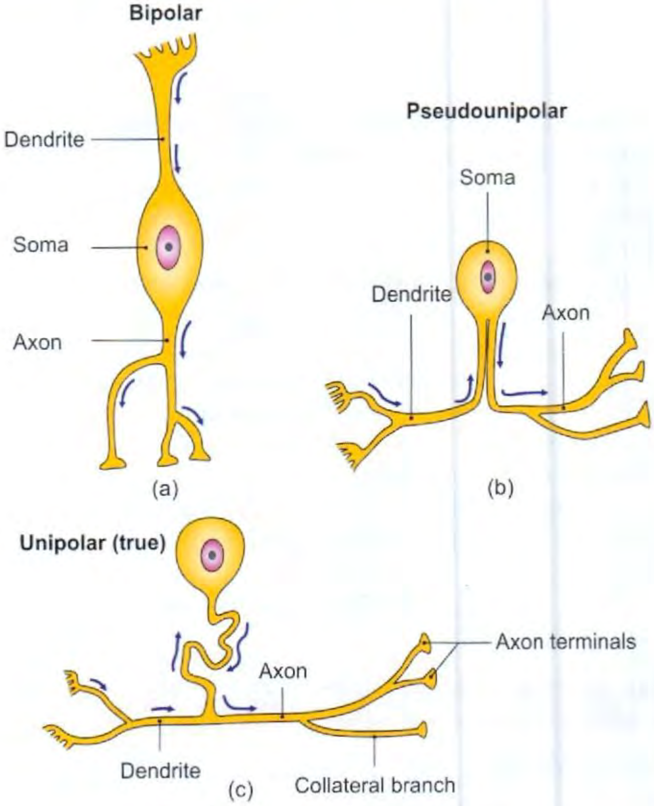
Classification of Neurons

According to the Number of their Processes

1 *Multipolar neurons.* Most of the neurons in man are multipolar, e.g. all motor and internuncial neurons (Fig. 1.1).

2 *Bipolar neurons* are confined to the first neuron of the retina, ganglia of eighth cranial nerve, and the olfactory mucosa (Fig. 1.2a).

3 *Pseudounipolar neurons* are actually unipolar to begin with but become bipolar functionally and are found in dorsal nerve root ganglia and sensory ganglia of the cranial nerves (Fig. 1.2b).



Figs 1.2a to c: Types of neurons

4 *Unipolar neurons* are present in the mesencephalic nucleus of trigeminal nerve and also occur during foetal life. These cells are more common in lower vertebrates (Fig. 1.2c).

According to Length of Axon

1 *Golgi Type I:* These neurons have long axons and numerous short dendrites. These are seen in pyramidal cells of cerebral cortex (Fig. 1.3a), Purkinje cells of cerebellum and anterior horn cells of spinal cord (Fig. 1.3b).

2 *Golgi Type II:* These are neurons with short axons, and establish synapses with neighbouring neurons. These are also seen in cerebral cortex and cerebellar cortex.

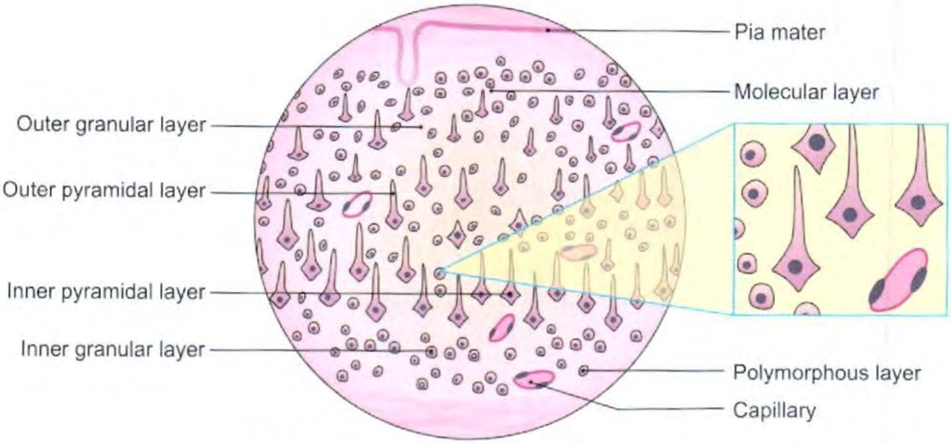


Fig. 1.3a: Pyramidal cells of cerebral cortex

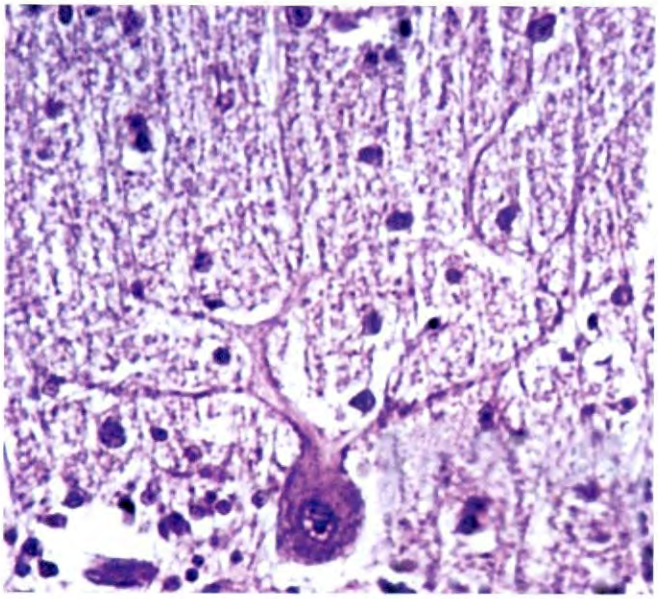


Fig. 1.3b: Purkinje cell of cerebellum

3 Amacrine neurons without axon, only with dendrite. They are seen in retina of eyeball.

Mature neuron is incapable of dividing. Recently some neurons in olfactory region and hippocampus have been seen to divide. Brain tumours arise chiefly from the neuroglial cells.

Functional Classification

Neurons are classified into sensory neurons, autonomic neurons, i.e. parasympathetic, sympathetic neurons and motor neurons.

Sensory neurons

These are of three types:

1 *Primary or 1st order sensory neurons* are present as spinal or sensory neurons in the dorsal root ganglion of spinal nerves (Fig. 1.2b).
2 *Secondary or 2nd order sensory neurons* are present in the grey matter of spinal cord and in brain stem.
3 *Tertiary or 3rd order sensory neurons* are seen in thalamus (*see* Fig. 3.14).

Motor neurons

These carry impulses from CNS to distal part of the body. These somatic motor neurons are of two types:

1 Upper motor neurons are situated in motor area of brain. These synapse with cranial nerve nuclei and anterior horn of spinal cord (*see* Fig. 10.1).
2 Lower motor neurons are located in cranial nerve nuclei and anterior horn of spinal cord. Nerves emerging from these nuclei supply the various skeletal muscles (*see* Fig. 3.10).

Parasympathetic neurons (autonomic)

1 Preganglionic neurons are located in cranial nerves III, VII, IX and X, also in sacral 2–4 segments of the spinal cord.

2 Postganglionic neurons are located close to the wall or within the wall of the viscera.
3 The parasympathetic outflow is called "craniosacral outflow".

Sympathetic neurons (autonomic)

1 Preganglionic neurons are located in the lateral horn of thoracic one to lumbar two segments of the spinal cord.
2 Postganglionic neurons are situated in the ganglia of the sympathetic trunk away from the viscera.
3 The sympathetic outflow is called "thoracolumbar outflow."

According to Shape (Fig. 1.4)

Stellate
Basket
Fusiform
Pyramidal

According to Size

Macroneuron: More than 7 µm size, e.g. Betz cells.
Microneuron: Less than 7 µm size, e.g. granular cells.

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 in 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). The impulse is transmitted across a synapse through biochemical neurotransmitters (acetylcholine).

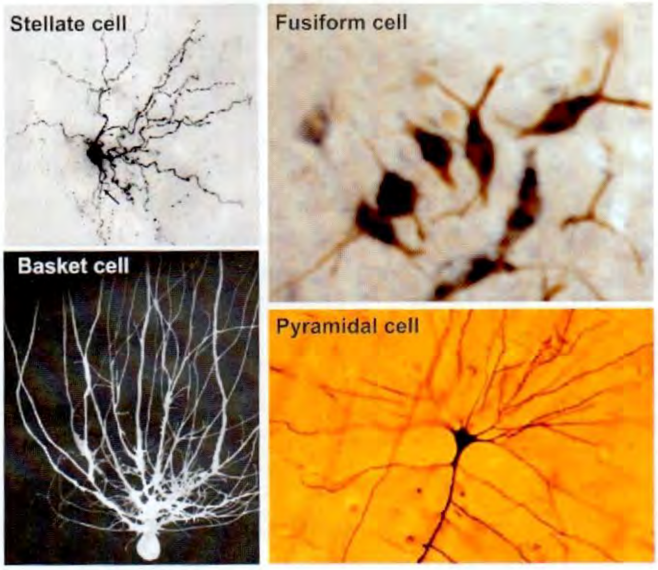


Fig. 1.4: Types of neurons

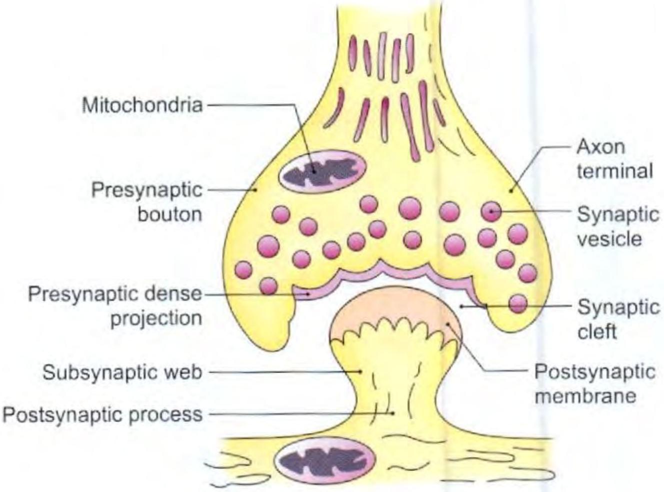


Fig. 1.5: Structure of a synapse

NEUROGLIAL CELLS

Various types of neuroglial (Greek *nerve glue*) cells are as follows:

1 Astrocytes are concerned with nutrition of the nervous tissue are star-shaped cells. These form *blood–brain barrier*. These are of two types, protoplasmic (Fig. 1.6a) and fibrous (Fig. 1.6b). Astrocytes are absent in pineal gland and posterior pituitary.
2 Oligodendrocytes (Greek *few processes*) are counterparts of the Schwann cells. Schwann cells myelinate the peripheral nerves. Oligodendrocytes myelinate the tracts (Fig. 1.6c).
3 Microglia (Greek *small glue*) behave like macrophages of the CNS. They develop from mesoderm (Fig. 1.6d).
4 Ependymal cells are columnar cells lining the cavities of the CNS (Fig. 1.6e).
5 Schwann cells.

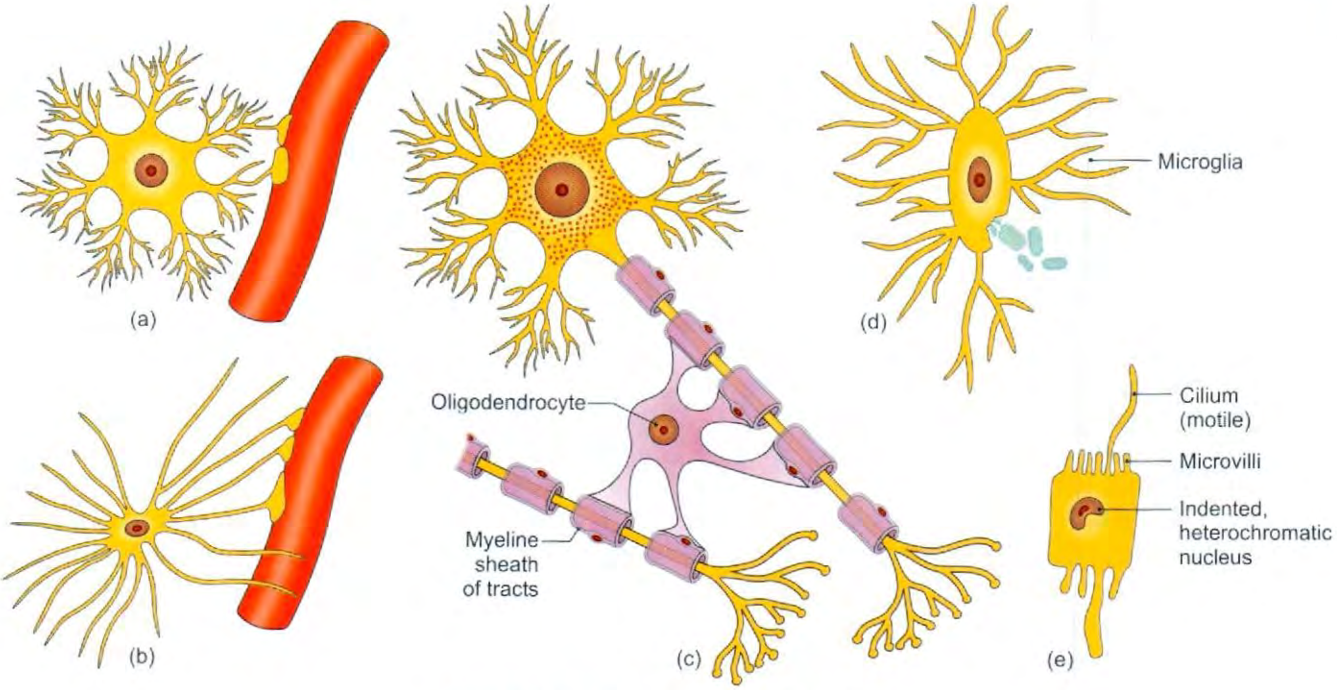
Various features of these cells are shown in Table 1.1.

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 tumours.

GREY MATTER AND WHITE MATTER

Unit of nervous tissue is the neuron, comprising of cell body, dendrites and axon. Neurons are supported by neuroglia and blood vessels.

Grey matter is the part of nervous tissue containing the cell body (soma), neuroglial cells and abundance of blood vessels. It covers the outer aspect of brain and is known as the cortex. Grey matter present within the depth of white matter is called ganglia/nuclei.



Figs 1.6a to e: Types of neuroglial cells

Table 1.1: Types of neuroglial cells

	Protoplasmic astrocyte	*Fibrous astrocyte*	*Oligodendrocyte*	*Microglia*
Cell size	Large	Large	Medium	Small, elongated
Shape 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

White matter comprises only the fibres, i.e. axons, dendrites, neuroglial cells and fewer blood vessels. In brain white matter lies deep to cortex of brain. In the spinal cord white matter lies superficial to the deeply placed "H-shaped" grey matter.

REFLEX ARC

A reflex arc is the functional unit of the nervous system. In its simplest form (monosynaptic reflex arc), it consists of:

1 A receptor, e.g. the skin/muscle.
2 The sensory neuron.
3 The motor neuron.
4 The effector, e.g. the muscle.

In complex forms of the reflex arc, the internuncial neurons (interneurons) are interposed between the sensory and motor neurons. An involuntary motor response to a sensory stimulus is known as the *reflex action*. Only cortical responses are voluntary in nature. All subcortical responses are involuntary and therefore are the reflex activities. Reflex action is chief function of spinal cord. Knee jerk and ankle jerk are monosynaptic reflex arcs (Fig. 1.8). Some common reflex arcs are shown in Table 1.2.

COMPONENTS OF CENTRAL NERVOUS SYSTEM

1 *The 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 and limbs and contains the motor neurons responsible for both voluntary and reflex movements. It also receives sensory information from the internal

Table 1.2: Some common reflexes

Name of reflex	*Way of eliciting*	*Result*	*Comment*
Biceps jerk	Striking biceps brachii tendon	Flexion of the elbow joint	C5, C6 segments intact Tendon jerks may be exaggerated in upper motor neuron lesion or lost in lower motor neuron lesion
Triceps jerk	Striking triceps brachii tendon	Extension of the elbow joint	C7, C8, segments intact
Knee jerk (Fig. 1.7)	Striking the ligamentum patellae	Extension of the knee joint	L3, L4 segments of spinal cord intact
Ankle jerk	Striking tendo calcaneus	Plantar flexion of the ankle joint	S1, S2 segments intact
Abdominal reflex	Striking a quadrant of abdomen	Contraction of abdominal muscles	Positive reflex indicates normal pyramidal tract with T7–T12 nerves intact
Plantar reflex	Scratching the sole of foot from lateral side towards big toe	Plantar flexion of the great toe and other toes	A normal plantar response indicates intact pyramidal tract
Babinski's sign (Fig. 1.8)	Same as in plantar reflex	Dorsiflexion of the great toe and fanning of other toes	Babinski's sign indicates pyramidal tract injury, except in infants

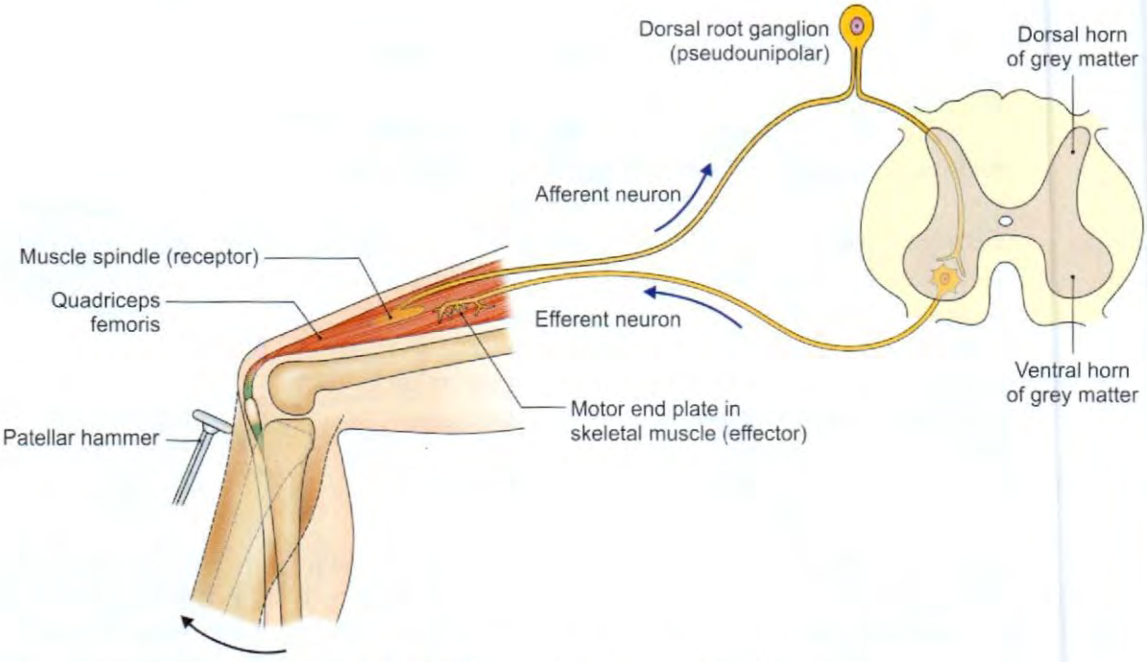


Fig. 1.7: Components of the knee jerk

organs and control many visceral functions. Within the spinal cord there is an orderly arrangement of 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 centre and white matter is at the periphery. CSF containing central canal lies in the grey matter.

2 *Brain stem*: It includes
   a. *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.
   b. *The pons*: It lies rostral to the medulla and contains a large number of neurons that relay information from the cerebral hemispheres to the cerebellum.
   c. *The midbrain*: This is the smallest brain stem component which lies rostral to the pons. The midbrain contains essential relay nuclei of the

Fig. 1.8: Babinski's sign

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.

3 *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.

4 *The 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.

5 *The cerebral hemispheres*: This is the largest region of the brain. It consists of the cerebral cortex/grey mater and the fibres 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 comprises 4 lobes, e.g. frontal, parietal, temporal and occipital lobes.

Each hemisphere has a flat medial surface which lie adjacent to each other separated by a longitudinal fissure. In the lower part of the fissure is present a thick band of fibres, the corpus callosum. The hemisphere shows infoldings in the form of sulci and gyri, giving more space for the neurons.

6 *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. IV ventricle is cavity of hind brain, 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.

7 *Protective coverings*: Brain and spinal cord are covered by 3 meninges 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. CNS is the most protected part of the body.

PARTS OF THE NERVOUS SYSTEM

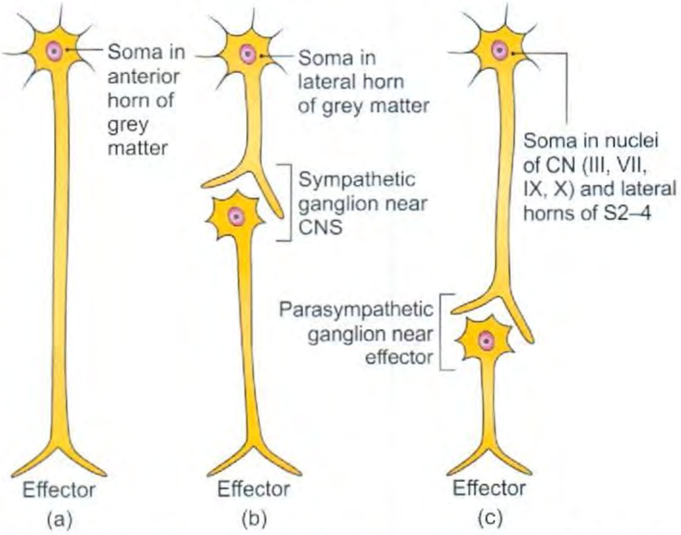
CENTRAL NERVOUS SYSTEM (CNS)

1 *Brain:* Occupies cranial cavity.

2 *Spinal cord:* Occupies upper two-thirds of the vertebral canal.

PERIPHERAL NERVOUS SYSTEM

1 Somatic (cerebrospinal) nervous system. It is made up of 12 pairs of cranial nerves and 31 pairs of spinal nerves. Its efferent fibres reach the effectors without interruption (Fig. 1.9a).



Figs 1.9a to c: Types of peripheral nervous system: (a) Somatic, (b) sympathetic, and (c) parasympathetic

2 Autonomic (splanchnic) nervous system. It consists of sympathetic and parasympathetic systems. Its efferent fibres first relay in a ganglion, and then the post-ganglionic fibres pass to the effectors (Figs 1.9b and c).

CLINICAL ANATOMY

Tumours of the nervous tissue arise mostly from the neuroglia, as developed neurons have lost the power of multiplication except in a few areas. Tumours from neuroglial cells are called gliomas. These are highly malignant and rapidly growing tumours.

Parts of Brain

The main parts and their subdivisions are shown in Table 1.3, Figs 1.10a and b.

The brain stem includes the midbrain, pons and medulla.

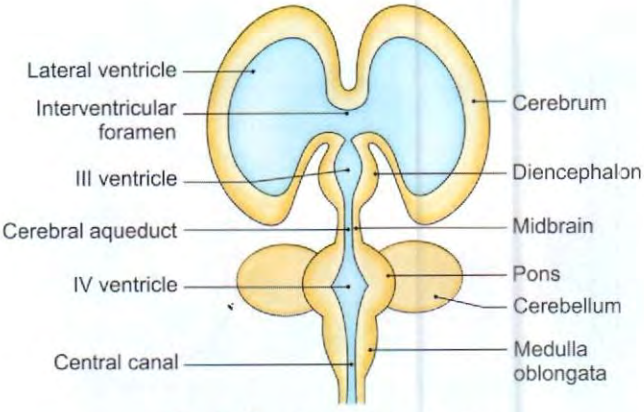


Fig. 1.10a: Parts of the brain

Hindbrain includes pons, medulla and cerebellum.

The dilated part of the central canal of spinal cord within the conus medullaris is known as the terminal ventricle. Similarly, the cavity of septum pellucidum is sometimes called the fifth ventricle.

Table 1.3: Parts of brain

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

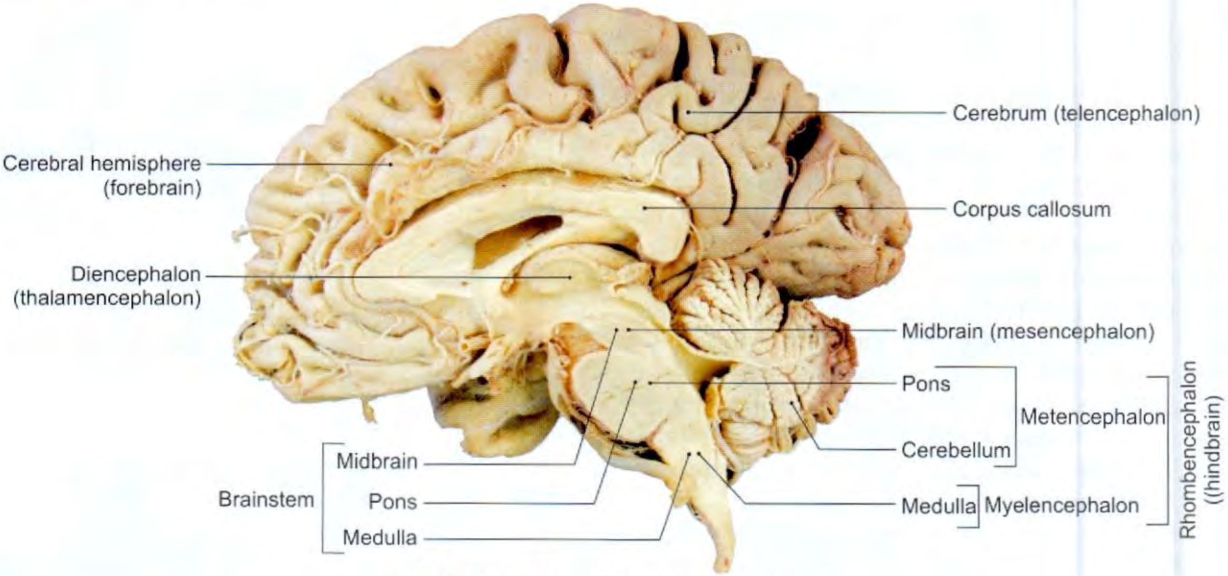


Fig. 1.10b: Parts of the brain (dissection)

DEVELOPMENT OF BRAIN

NEURAL TUBE

The whole of nervous system develops from ectoderm except the blood vessels and the microglia (neuroglial tissue).

At the beginning of 3rd week of development, the ectodermal germ layer has the shape of a flat disc that is broader in cephalic region than in the caudal region. With the appearance of the notochord and its inductive influence, ectoderm overlying the notochord thickens to form a slipper-shaped plate, called neural plate. Cells of the plate make up neuroectoderm and with induction, the process of neurulation starts. The plate is located in the mid-dorsal region in front of the primitive pit. Its lateral edges get raised to form the neural folds.

With further development, the neural groove between the two folds on either side becomes deeper. Eventually, the neural folds approach each other in midline and finally fuse, thus forming the neural tube. Fusion begins in the cervical region and proceeds in cephalocaudal direction. At the most cranial and caudal ends of the embryo, fusion is delayed and the cranial and caudal neuropores temporarily form open connections between the base of neural tube and the amniotic cavity.

Final closure of cranial neuropore occurs on 25th day and caudal neuropore two days later of the embryonic life, and eventually neuropores disappear leading to a closed tube.

Before the neural tube is completely closed, it is divisible into an enlarged cranial part with three divisions which forms brain and a caudal tubular part which forms spinal cord.

The cephalic end of the neural tube shows three divisions (Table 1.3):

1. Prosencephalon or forebrain
2. Mesencephalon or midbrain
3. Rhombencephalon or hindbrain.

MOLECULAR BASIS OF DEVELOPMENT OF SPINAL CORD AND BRAIN

Spinal Cord

Spinal cord comprises basal/motor plate and alar/sensory plate. Sonic hedgehog (SHH) is expressed in notochord. SHH ventralises neural tube and forms basal/motor plate.

Bone morphogenetic protein, BMP4 and BMP7 expressed from non-neural ectoderm at border of neural tube dorsalises the neural tube.

Brain

Hindbrain is regulated by HOX genes. Forebrain and midbrain regulated by LIMI and OTX2. Also governed by:

a. Anterior neural ridge → fibroblast growth factor 8 (FGF8) → cranial end of forebrain expresses BF1 → controls development of telencephalon.
b. Rhombencephalic isthmus → FGF8 → isthmus expresses → engrailed genes → controls development of midbrain and cerebellum.

Further Development of the Brain

Prosencephalon, mesencephalon and rhombencephalon are first arranged cephalocaudally. Soon it develops 4 flexures. These are:

a. Cervical flexure: It appears at the junction of rhombencephalon and spinal cord.
b. Cephalic or mesencephalic flexure: This flexure is located in the region of midbrain.
c. The mesencephalon is separated from rhombencephalon by a furrow called rhombencephalic flexure (Fig. 1.11).
d. When the embryo is 5 weeks old, the prosencephalon consists of 2 lateral outpocketings, the primitive cerebral hemispheres. At this stage, a deep furrow appears at the middle of rhombencephalon. This is called pontine flexure, and it divides rhombencephalon into metencephalon and myelencephalon. The flexures change orientation of various parts of brain.

The lumen of the spinal cord, the central canal is continuous with that of primitive brain vesicles.

The cavity of rhombencephalon is known as fourth ventricle, those of cerebral hemisphere are lateral ventricles and cavity of diencephalon is third ventricle.

Cavity of lateral ventricles communicates with that of third ventricle through interventricular foramen of Monro. Cavity of third and fourth ventricles is connected through narrow cerebral aqueduct of Sylvius (Fig. 1.12).

Neural Crest Cells and their Derivatives

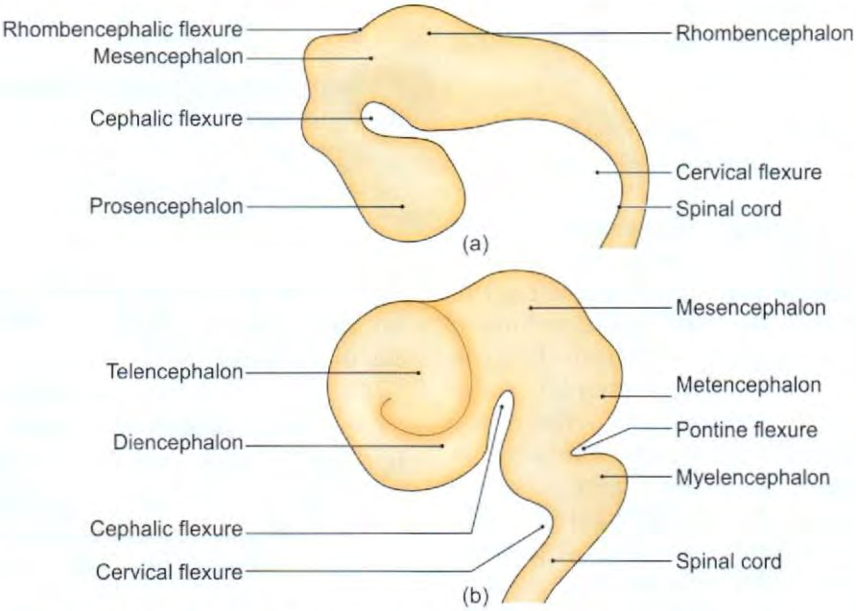
During folding of the neural tube, a group of cells are formed along each side of neural groove and after the formation of neural tube, lie between the surface ectoderm and neural tube. These cells (ectodermal in origin) migrate laterally, and are called neural crest cells. They extend from prosencephalon at the cranial end of the tube to the level of caudal somites (Fig. 1.13).

Derivatives are:

1. Primitive cranial ganglia
2. Primitive spinal ganglia.

1 *Primitive cranial ganglia*

- Sensory ganglia of V, VII, VIII, IX, X cranial nerves
- Parasympathetic ganglia



Figs 1.11a and b: Development of the various flexures of the brain

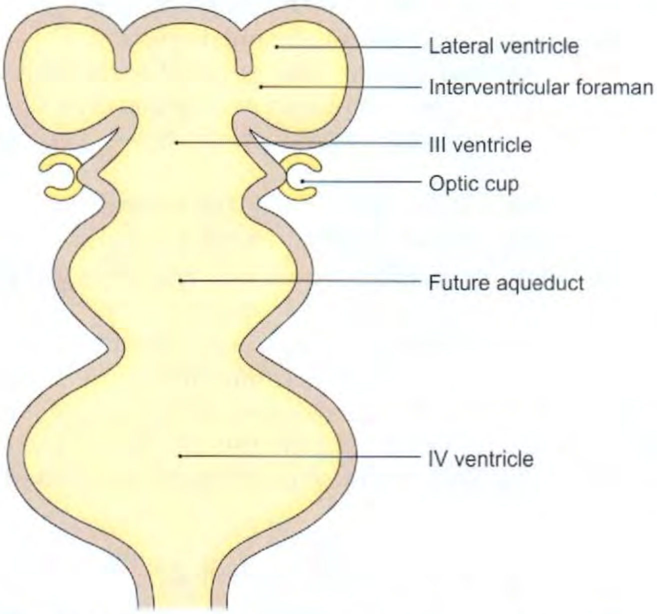


Fig. 1.12: Further development of the brain vesicles including the ventricles

- Ciliary, otic, submandibular and pterygopalatine
- Pia mater and arachnoid mater (leptomeninges)

2 *Primitive spinal ganglia*
- Dorsal root ganglia of spinal nerves
- Sympathetic ganglia
- Adrenal medulla

3 *From both 1 and 2*
- Pharyngeal cartilage cells
- Chromaffin cells
- Pigment cells (melanoblasts)
- Schwann cells
- Satellite cells
- Odontoblasts
- Mesenchyme of head region

Diencephalon

The median part of prosencephalon forms diencephalon. It comprises a roof plate and two alar plates. The choroid plexus of third ventricle is formed from ependymal cells of roof plate and the vascular mesenchyme.

After the formation of the telencephalon, the lateral wall of diencephalon becomes thickened and gets divided into 3 regions, by appearance of two sulci. These are called epithalamic and hyothalamic sulci, and the central part between the two sulci is called thalamus. The part above the epithalamic groove is a small region represented by habenular nuclei and pineal body. The part below the hypothalamic groove forms hypothalamus.

Pineal body or epiphysis develops from the most caudal part of roof plate. The pineal body initially appears as an epithelial lining in the midline, but by the 7th week of intrauterine life, it begins to evaginate. Eventually, it becomes a solid organ located on the roof of the mesencephalon. It serves as a channel through which light and darkness affect endocrine and behavioral rhythms, i.e. circadian rhythm. In the adult, calcium is frequently deposited in the epiphysis and it even serves as a landmark on an X-ray skull.

As a result of proliferative activity; the various nuclei of thalamus are formed by multiplication of cells in the mantle layer of the wall of diencephalon.

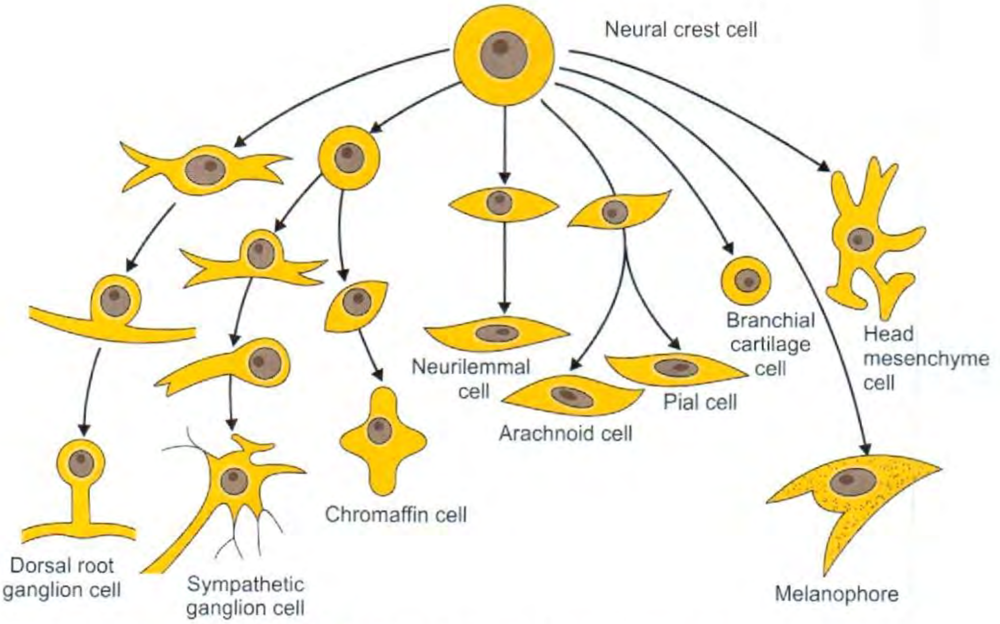


Fig. 1.13: Development of neural crest cells

Hypothalamus forming lower portion of the alar plate differentiates into a number of nuclear areas which serves as regulation centre of the visceral functions, i.e. sleep, digestion, body temperature and emotional behaviour.

The prominent group of these nuclei are mammillary body, which forms distinct protuberance on the ventral surface of the hypothalamus on each side of the midline.

Telencephalon

The telencephalon, consists of two lateral outpocketings, the cerebral; (right and left) hemispheres and a median portion, the lamina terminalis. The cavities of hemispheres, the lateral ventricles communicate with the lumen of diencephalon, through the interventricular foramen of Monro.

Cerebral Hemispheres

Cerebral hemispheres arise as bilateral (right and left) evaginations at the beginning of 5th week of development from the lateral wall of prosencephalon. By the middle of 2nd month of development, the basal part of hemisphere, i.e. the part which is initially formed by the forward extension of thalamus, begins to increase in size. As a result, this area bulges into the lumen of the lateral ventricle as well as into the foramen of Monro.

In the region where the wall of hemisphere is attached to the roof of diencephalon, the neuroblasts fail to develop and it remains very thin. Here the hemispheric wall consists of a single layer of ependymal cells covered by vascular mesenchyme and together they form choroid plexus. Due to disproportionate growth of various part of hemisphere, the choroid plexus protrudes into lateral ventricle along a line known as choroid fissure.

Above the choroid fissure, the wall of hemisphere is thickened, thus forming the hippocampus which mainly has an olfactory function and this part bulges into lateral ventricle.

With further growth and expansion, the hemispheres cover the lateral aspect of diencephalon, mesencephalon and cranial portion of metencephalon.

Corpus Striatum

Some of the cells of the mantle layer in thick basal part of lateral wall of hemisphere form corpus striatum. It expands posteriorly and gets divided into 2 parts:

a. A dorsomedial portion, the caudate nucleus
b. A ventrolateral portion, the lentiform nucleus.

This division occurs by axons passing to and from the cortex of the hemisphere. The fibre bundle thus formed is known as internal capsule (Fig. 1.14).

Lobes of Brain

Continuous growth of cerebral hemispheres in anterior, dorsal, posterior and inferior directions result in formation of frontal, parietal, occipital and temporal lobes. As the growth in the region of corpus striatum slows down, the area between temporal and frontal lobes becomes depressed and forms the insula. The area is later overgrown by adjacent lobes and at the time of birth is almost completely covered. In later part of fetal life due to growth in a limited area, the sulci and gyri make their appearance. This is to accommodate more neurons in a limited area (Fig. 1.15).

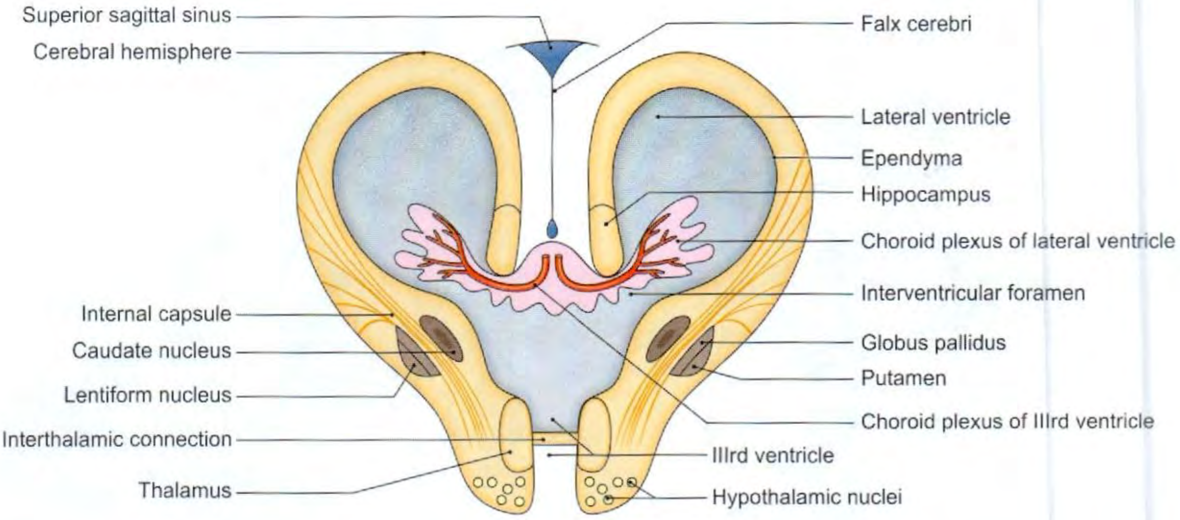


Fig. 1.14: Development of caudate and lentiform nuclei. Between these two nuclei, the fibres of internal capsule are seen

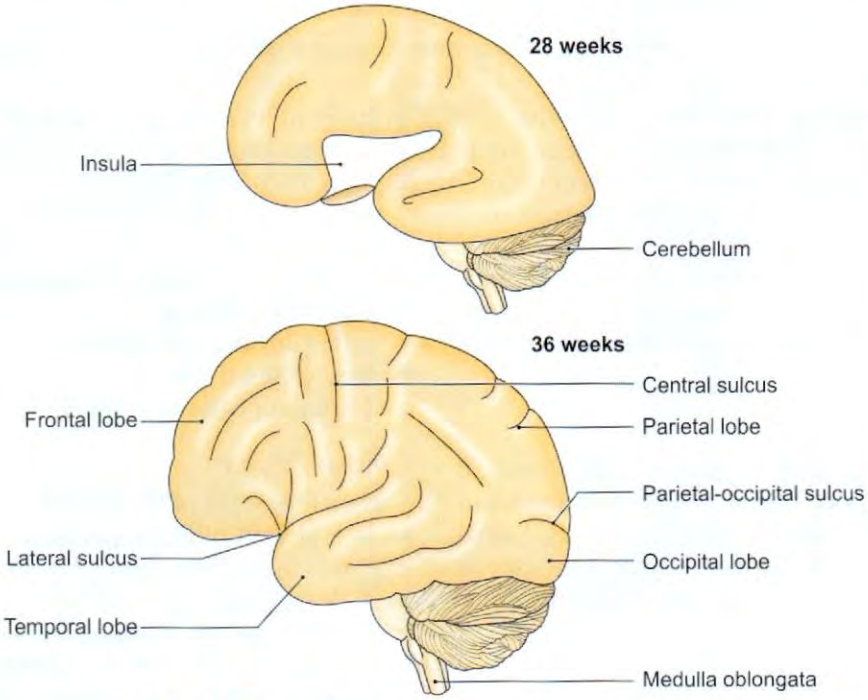


Fig. 1.15: Developmental stages of cerebral cortex

Cerebral Cortex

From development point of view, the cerebral cortex consists of:

a. The hippocampal cortex
b. Pyriform cortex
c. The neocortex

The developing telencephalon has a medial wall, apposed to the counterpart of the opposite side, a superolateral wall and a basal wall. The hippocampal cortex develops in medial wall, pyriform cortex in the marginal layer, superficial to corpus striatum, and neocortex in the superolateral region. Earlier formed cells are neuroblasts. Motor areas of the cortex are rich in pyramidal cells, while the sensory areas have abundance of granular cells.

Cerebral Commissures

In the adult, the right and left halves of the cerebral hemispheres are connected by a number of fibre bundles called commissures, which cross midline.

- The most important is lamina terminalis. It is part of the wall of the neural tube that closes the cranial end of the prosencephalon. After the appearance of telencephalic vesicles, lamina terminalis lies in the anterior wall of IIIrd ventricle. Neurons growing from one hemisphere pass to the other through, the lamina terminalis. So, it becomes thickened to form commissured plate.

- *Anterior commissure*: The first of the crossing bundles to appear is anterior commissure. It consists of fibres connecting the olfactory bulb and related brain areas of one hemisphere to those of opposite side.
- Hippocampal or fornix commissure is the second to appear.
- *Corpus callosum*: It is the most important commissure. It appears in the 10th week of development and connects non-olfactory areas of the right and left side.
- *Optic chiasma*: It appears in the anterior wall of diencephalon and contains fibres from medial halves of two retinas.

Development of Spinal Nerve Roots

Motor nerve begins to appear during the 4th week of development, arising from nerve cells located in the basal lamina (ventral horn) of spinal cord. Dorsal nerve roots form the collection of fibres arising from the cells of the dorsal root ganglia (spinal ganglion). Central processes from these ganglia form bundles that grow into spinal cord opposite the dorsal horns. Almost immediately spinal nerve divides into dorsal and ventral rami. Dorsal primary rami supply dorsal axial musculature and skin of back. Ventral primary rami supply limbs, ventral body wall and form major nerve plexuses, i.e. cervical, brachial and lumbosacral plexuses.

The peripheral processes of the dorsal nerve root ganglia grow upwards to form sensory component of the spinal nerve. Axons of neurons in the dorsal grey column enter marginal layer to form ascending tracts of the spinal cord, and the axons of cells of neurons developing in various parts of brain enter the marginal layer to form descending tracts.

As the mantle layer forms the dorsal and ventral columns, the white matter becomes subdivided into dorsal, ventral and lateral white columns.

Positional Changes of Spinal Cord

During the 3rd month of intrauterine life, the spinal cord extends the entire length of embryo. Due to rapid growth of dura mater and vertebral column as relative to the neural tube, the terminal end of spinal cord is located, at birth, at the level of 3rd lumbar vertebra. This process of recession continues after birth, as a result of which, in the adult, spinal cord usually ends at the upper border of 2nd lumbar or at lower border of 1st lumbar vertebra.

Below this level, a thread-like extension of pia mater forms filum terminale and is attached to the periosteum of coccyx. Nerve fibres below the level of cord are called cauda equina (horse's tail).

Because of this recession of spinal cord, the intervertebral foramen no longer lie at the level at which corresponding nerves emerge from the spinal cord. The nerves run obliquely to reach their respective foramen. The obliquity is least in lower cervical region, gradually increases and is more in lumbar, sacral and coccygeal regions (Fig. 1.16).

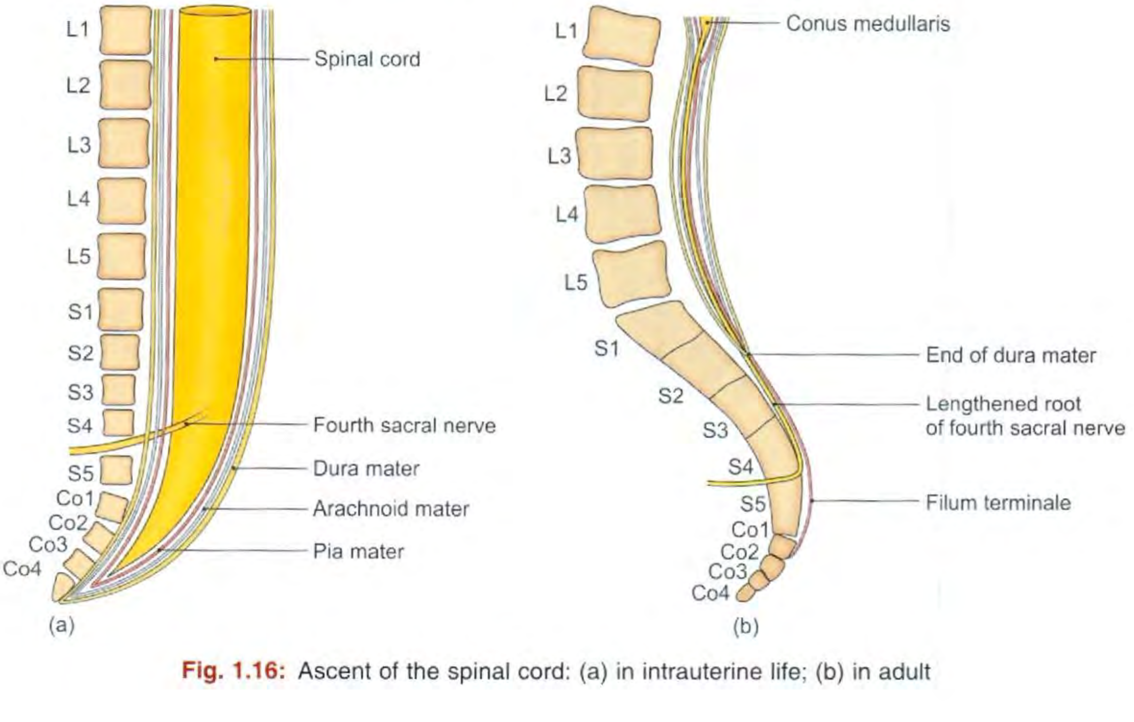


Fig. 1.16: Ascent of the spinal cord: (a) in intrauterine life; (b) in adult

One advantage of this recession of spinal cord is when cerebrospinal fluid is tapped for diagnostic purposes. During a lumbar puncture, the needle is inserted at the lower lumbar level, avoiding the lower end of the cord.

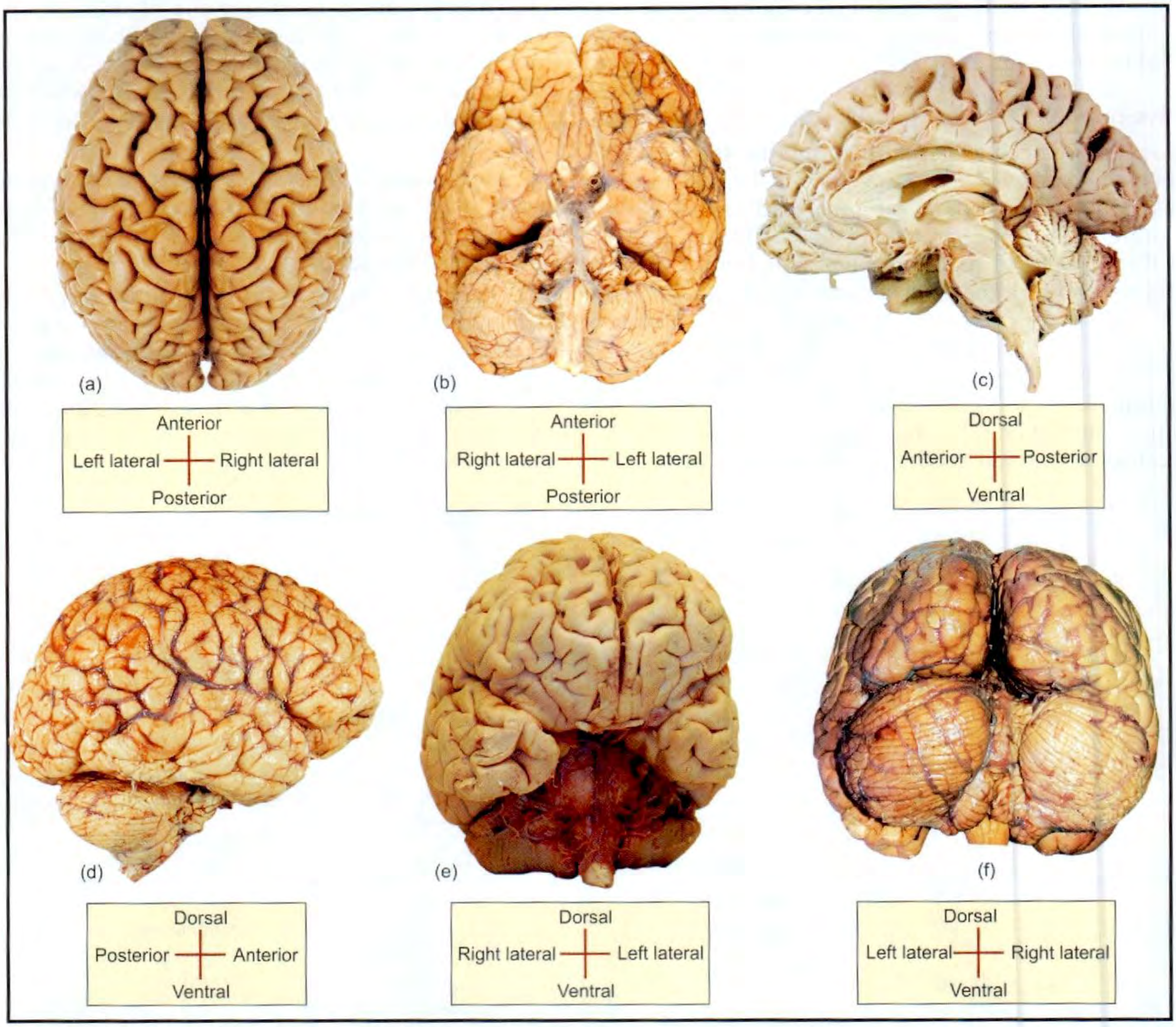
Development of medulla oblongata, pons and midbrain is given in Chapter 5. Development of cerebellum is incorporated in Chapter 6.

GROSS STUDY OF BRAIN

Brain can be studied by viewing it from following sites (Figs 1.17a to f).

Brain can be cut in the following planes:

1. *Coronal plane:* When brain is cut through dorsal and ventral surfaces in the coronal plane (Fig. 1.18A to C).
2. *Horizontal plane:* When it is cut from side to side (Fig. 1.18D).
3. *Sagittal plane:* When brain is cut in relation to longitudinal axis, i.e. from anterior to posterior aspect (Fig. 1.18E and F).
4. *Oblique plane*: When brain is cut at an angle from cerebral cortex down through the brain stem (Fig. 1.18G).



Figs 1.17a to f: Various views of the brain: (a) Superior view, (b) ventral view, (c) medial view, (d) superolateral surface, (e) anterior view, and (f) posterior view

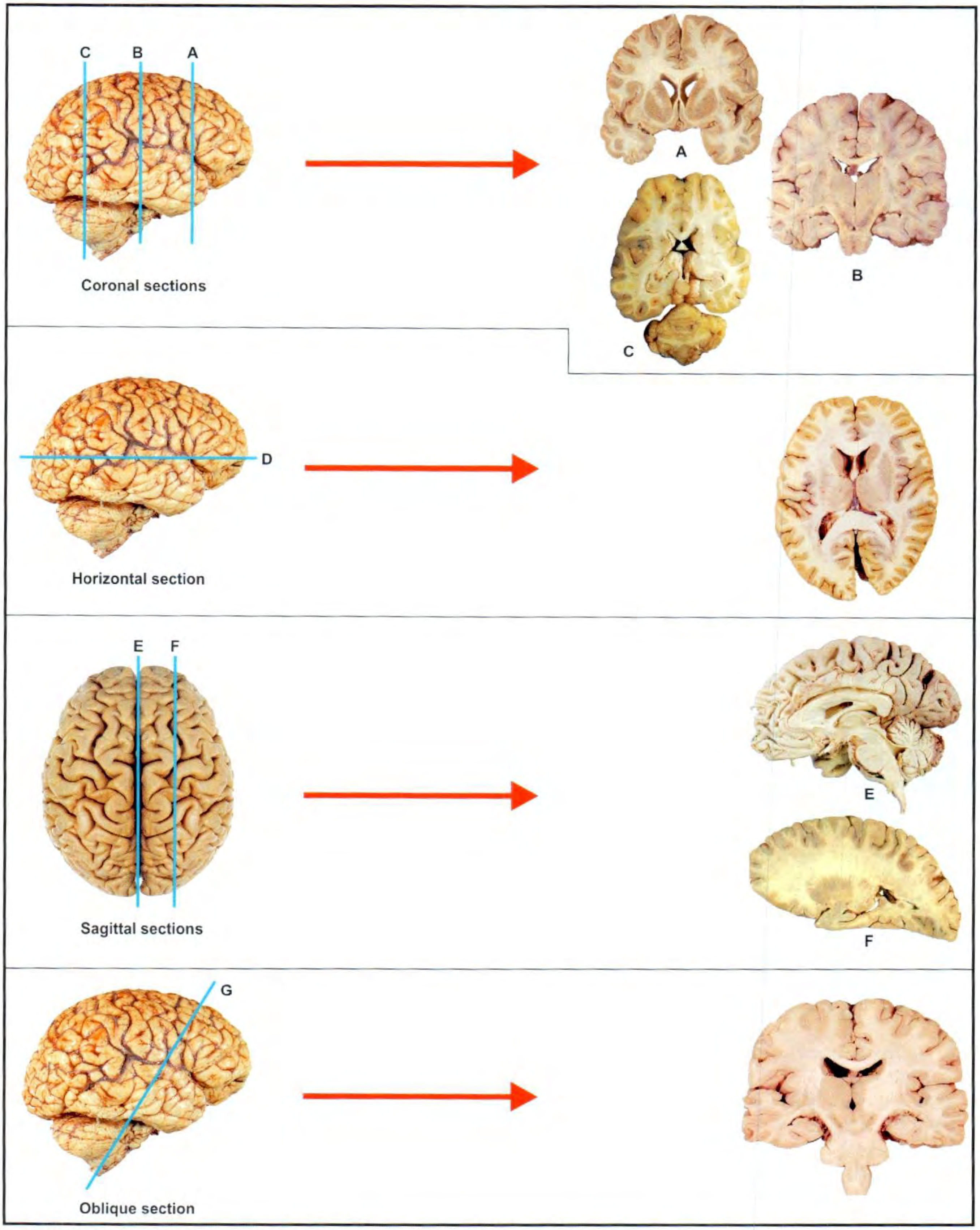


Fig. 1.18: Sections of brain in different planes: (A to C—coronal sections; D—horizontal section, E and F—sagittal sections; G—oblique section

FACTS TO REMEMBER

- Neurons in human brain are about 180–200 billion
- Mature neurons do not divide after birth except in olfactory region and in hippocampus.
- If neurons divide one will have fleating memory.
- Impulse travels from dendrite to cell body and then into axon
- Contact between neurons is by contiguity (like hand shake) and not by continuity
- Human has the largest cerebrum so far
- Ependymal cells are responsible for the formation of cerebrospinal fluid. Astrocytes form the blood–brain barrier.

CLINICOANATOMICAL PROBLEM

A man aged 60 and his son aged 12 had injuries to their arm region and wrist region respectively in an automobile accident.

- Who will have better return of functions?
- More effective regeneration will be in the father or son and why?

Ans. All repair occur faster in younger than older persons. So the son's injury will heal earlier.

More effective regeneration will be again in the son as the injury is in a distal area. In a distal area, a few structures are left to be supplied; so there are less chances of innervating the wrong structures during the reparative process.

FREQUENTLY ASKED QUESTION

1. Write short notes on:
   a. Synapse
   b. Neuroglial cells
   c. Parts of nervous system
   d. Reflex arc
   e. Babinski's sign

MULTIPLE CHOICE QUESTIONS

1. What nerve fibre convey impulses towards cell body of a neuron?
   a. Axon b. Dendrites
   c. Axon collaterals d. Axon terminals

2. Myelin sheath on peripheral nerves is contributed by:
   a. Axon itself b. Secretory vesicles
   c. Schwann cells d. Cell bodies of neuron

3. A neuron with many dendrites arising from cell body and carrying impulses away from the neuron via the axon is:
   a. Multipolar
   b. Bipolar
   c. Unipolar and sensory
   d. Bipolar and motor

4. The grey appearance of spinal grey matter is due to:
   a. Neuronal body b. Neuroglia
   c. Neurites d. Blood vessels

5. Which type of cells helps regulate composition of CSF?
   a. Astrocyte b. Oligodendeocyte
   c. Microglia d. Ependymal cells

6. Name the type of neuroglial cells that aid regeneration by forming a regeneration tube to help establish firm connection.
   a. Schwann cells b. Astrocytes
   c. Microglial d. Ependymal

7. What cells conduct message towards brain?
   a. Motor neuron b. Sensory neuron
   c. Interneuron d. Neuroglia

8. Myelin sheath is produced by:
   a. Neuron
   b. Axon
   c. Dendrite
   d. Schwann's cells/oligodendrocyte

9. The three regions of brain stem are:
   a. Cerebrum, diencephalon, midbrain
   b. Pons, cerebellum, midbrain
   c. Diencephalon, midbrain cerebrum
   d. Midbrain, pons, medulla oblongata

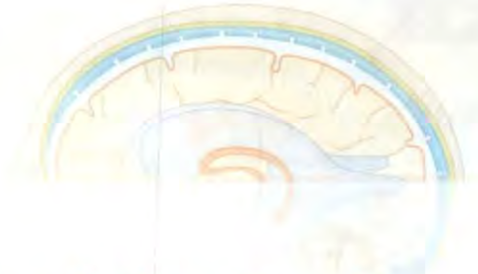
10. Three parts of hindbrain are:
   a. Cerebrum, pons, cerebellum
   b. Pons, medulla oblongata, cerebellum
   c. Pons, midbrain, cerebellum
   d. Thalamus, pons, cerebellum

ANSWERS

1. b **2.** c **3.** a **4.** a **5.** d **6.** a **7.** b **8.** d **9.** d **10.** b

CHAPTER

2



Meninges of the Brain and Cerebrospinal Fluid

The human brain contains more than 180 billion neurons.
The neurons are interconnected through an amazing network of 100000 miles of nerve fibres
—Anthony Robbins

INTRODUCTION

The brain is a very important delicate organ. It is protected by the following coverings.

1 Bony covering of the cranium.
2 Three membranous coverings (meninges):
   a. The outer dura mater (pachymeninx).
   b. The middle arachnoid mater.
   c. The inner pia mater. The arachnoid and pia are together known as the leptomeninges.
3 The cerebrospinal fluid 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 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. The CSF forms watery cushions around the blood vessels to give them shock-free environment.

THE MENINGES

DISSECTION

Cut through the fused endosteum and dura mater on the ventral aspect of brain from the inferolateral borders extending along the superolateral margin. Pull upwards the endosteum along with the fold of dura mater present between the adjacent medial surfaces of cerebral hemispheres, extending from the frontal lobe till the occipital lobe. This is falx cerebri. Pull backwards a similar but much smaller fold between two adjacent lobes of cerebellum—the falx cerebelli.

Separating the cerebrum and the cerebellum is another fold of dura mater called the tentorium cerebelli. Pull it on a horizontal plane. Thus, the fused endosteum and dura mater get separated from the underlying subarachnoid mater, pia mater and the brain.

Identify various venous sinuses between the endosteum and folds of dura mater. Underneath the dura mater and separated by a flimsy subdural space is the cobweb-like arachnoid mater. It is separated from the underlying pia mater by the subarachnoid space, containing cerebrospinal fluid and blood vessels of the brain. Cranial nerves also pass through this space. Near the superior sagittal sinus, arachnoid mater forms arachnoid villi. The subarachnoid space is dilated around the brain stem and at the base of the brain forming the subarachnoid cisterns.

Cerebrospinal fluid formed by choroid plexuses flows through the ventricles of the brain into the subarachnoid space to be absorbed via subarachnoid villi into the superior sagittal sinus.

DURA MATER

The cerebral dura (Latin *hard mother*) mater has been studied in detail with the head and neck in Chapter 12, Volume 3. However, it may be recapitulated that it 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 divide the cranial cavity into intercommunicating compartments for different parts of the brain (Figs 2.1 and 2.2 and Table 2.1).

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 enters following sulcus/ fissure.

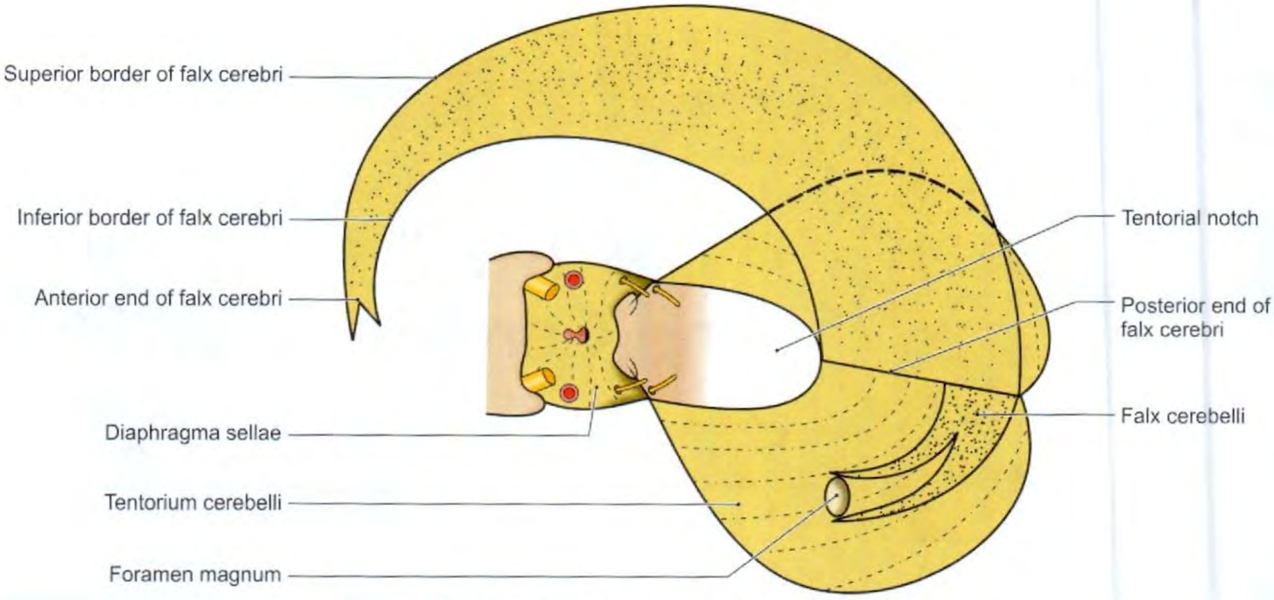


Fig. 2.1: Various folds of meningeal layer of dura mater

Table 2.1: The meningeal layer sends inwards following folds of dura mater

Folds	*Shape*	*Attachments*	*Venous sinuses enclosed*
Falx cerebri (Fig. 2.1)	Sickle-shaped, separates the right from left cerebral hemisphere	Superior, convex margins are attached to sides of the groove lodging the superior sagittal sinus	Superior sagittal sinus
		Inferior concave margin is free	Inferior sagittal sinus
		Anterior attachment is to crista galli and frontal crest Posterior attachment is to upper surface of cerebelli tentorium	Straight sinus
Tentorium cerebelli	Tent-shaped, separates the cerebral hemispheres from hindbrain and lower part of midbrain Lifts off the weight of occipital lobes from the cerebellum	Has a free anterior margin. Its ends are attached to anterior clinoid processes Rest is free and concave Posterior margin is attached to the lips of groove containing transverse sinuses, superior petrosal sinuses and to posterior clinoid processes	Transverse sinuses, superior petrosal sinuses
Falx cerebelli	Small sickle-shaped fold partly separating two cerebellar hemispheres	Base is attached to posterior part of inferior surface of tentorium cerebelli Apex reaches till foramen magnum	Occipital sinus
Diaphragma sellae	Small horizontal fold	Anterior attachment is to tuberculum sellae Posterior attachment is to dorsum sellae; laterally continuous with dura mater of middle cranial fossa	Anterior and posterior intercavernous sinuses

1 The stem of lateral sulcus where it is pushed by lesser wing of sphenoid.
2 The longitudinal cerebral fissure where it is carried in by falx cerebri.
3 It cannot be identified in the hypophyseal fossa.

Relations

It is separated from the dura by the subdural space, and from the pia by the subarachnoid space containing cerebrospinal fluid (CSF) and blood vessels.

Prolongations

1 It provides sheaths for the cranial nerves as far as their exit from the skull.
2 Arachnoid villi are small, finger-like processes of arachnoid tissue, projecting into the cranial venous sinuses. They absorb CSF. With advancing age, the arachnoid villi enlarge in size to form pedunculated tufts, called arachnoid granulations. These granulations may produce depressions in bone (Figs 2.3 and 2.4).

Fig. 2.2: Endosteal layer of dura mater

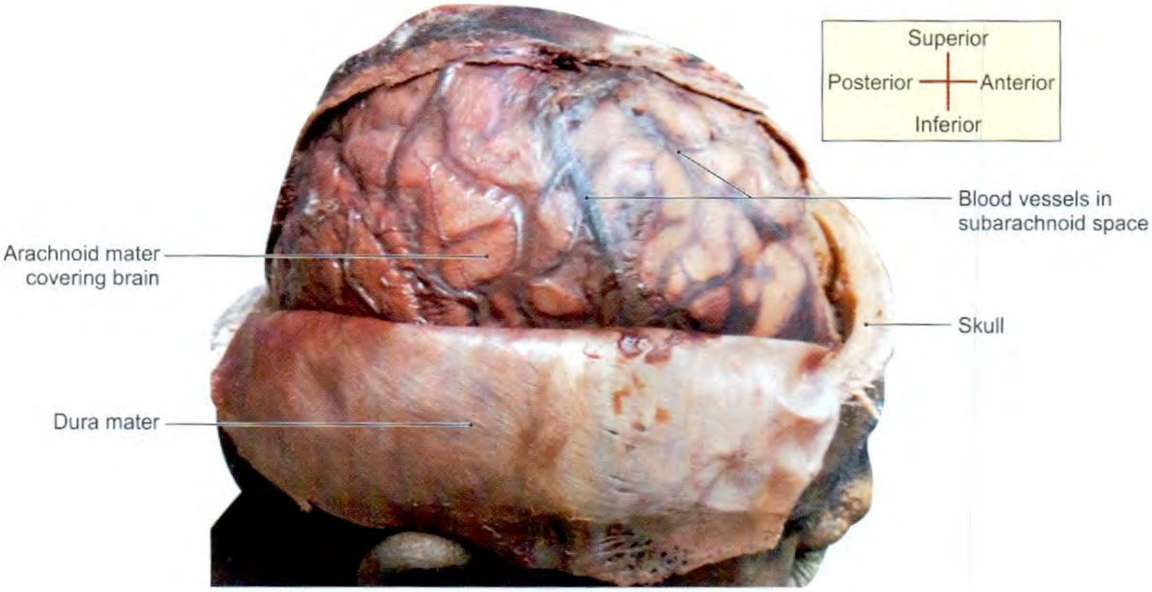


Fig. 2.3: Arachnoid mater

PIA MATER

The pia (Latin *loving mother*) mater is a thin vascular membrane which closely invests the brain, dipping into various sulci and other irregularities of its surface. It comprises epi-pia and pia-glia. On the cerebellum pia mater dips and forms folds in relation to larger fissures of cerebellum. It is pierced by blood vessels to nourish the brain and spinal cord (Figs 2.4 and 2.5).

Prolongations

1. It provides sheaths for the cranial nerves merging with the epineurium around them.
2. It also provides perivascular sheaths for the minute vessels entering and leaving the brain substance.
3. Folds of pia mater enclosing tufts of capillaries form the *telachoroidea*. Such pia mater lined by secretory ependyma form the *choroid plexus*.

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 dura mater. Vertebral epidural space is present between vertebral column and spinal duramatar. The subdural space is also a potential space between the dura and arachnoid maters. These become actual spaces in pathological conditions. The subdural space is traversed by cerebral veins on their path for draining into dural venous sinuses.

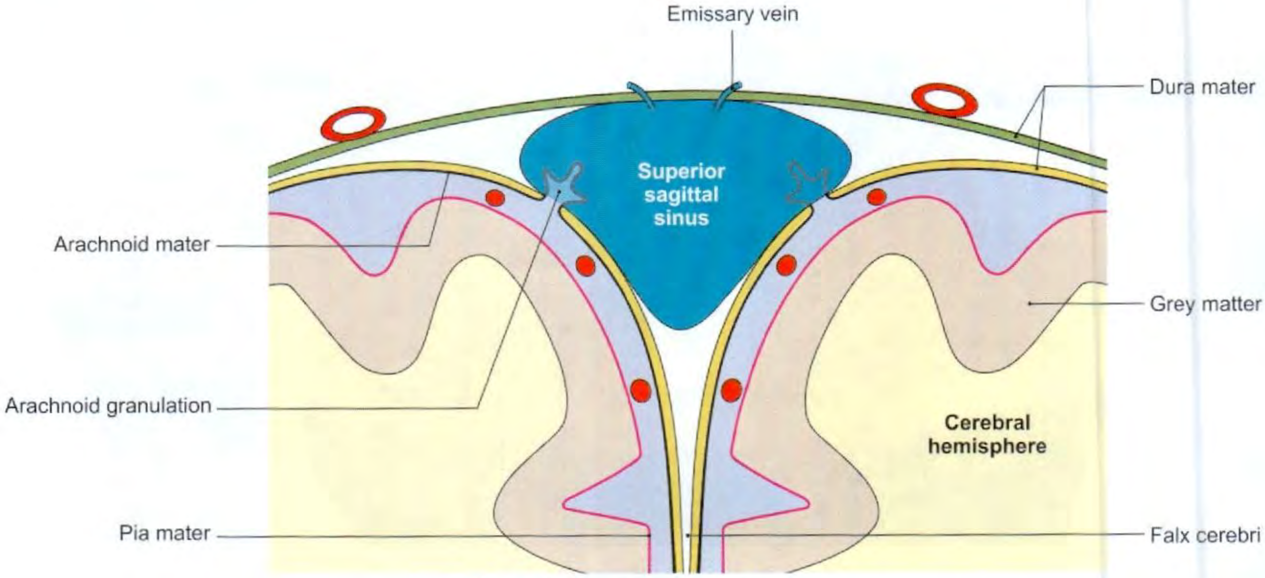


Fig. 2.4: Arachnoid granulation

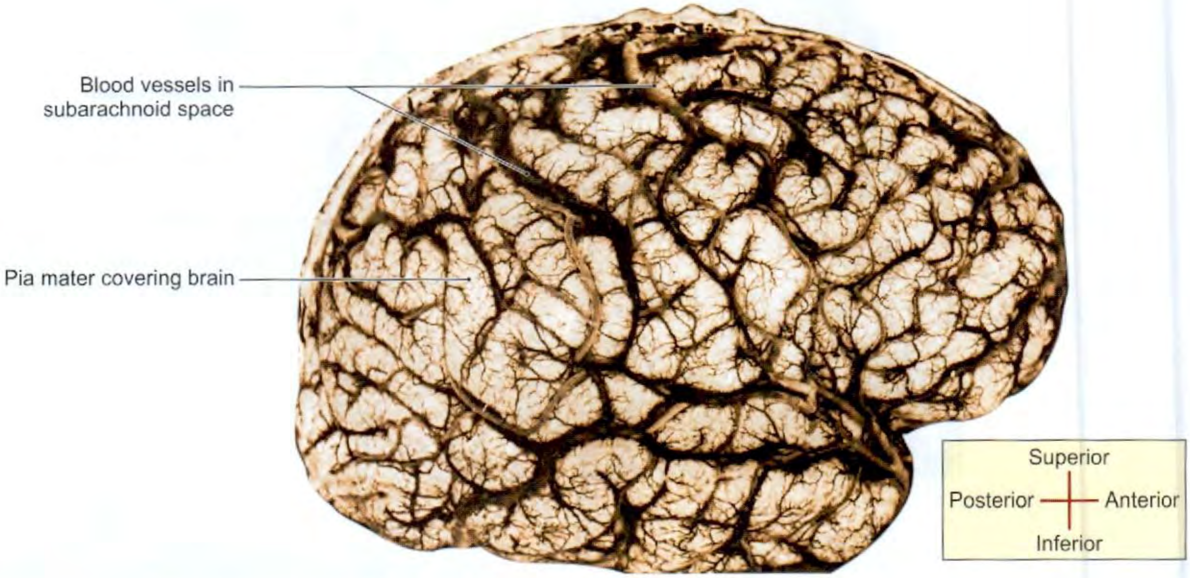


Fig. 2.5: Pia mater

SUBARACHNOID SPACE

This is the space between the arachnoid and the pia maters. It is traversed by a network of arachnoid trabeculae which give it a sponge-like appearance (Fig. 2.5).

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.

Larger arteries lie in subarachnoid space. Smaller ones carry sheaths of pia. Subarachnoid space and perivascular spaces are separated by layer of pia matter. Space between the nervous tissue and fold of pia mater with arterioles is known as Virchow-Robin's perivascular space.

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 centres situated in the medulla. The subarachnoid cisterns are as follows.

1 *Cerebellomedullary cistern or cisterna magna:* It is the largest cistern lying in the angle between medulla oblongata, cerebellum and occipital bone. It is triangular in section. It bridges the interval between inferior surface of cerebellum and medulla oblongata (Figs 2.6a and b). It receives CSF from the fourth ventricle via the median foramen of Magendie and the paired lateral foramina of Luschka. The cerebellomedullary cistern contains:
   1. The vertebral artery and the origin of the postero-inferior cerebellar artery (PICA).
   2. The ninth (IX), tenth (X), eleventh (XI) and twelfth (XII) cranial nerves.
   3. The choroid plexus.

2 *Cisterna pontis:* It is present on the ventral aspect of pons. It is continuous with interpeduncular cistern cranially, with cerebellomedullary cistern behind and with spinal subarachnoid space caudally. It contains:
   1. The basilar artery and the origin of the antero-inferior cerebellar artery (AICA).
   2. The origin of the superior cerebellar arteries.
   3. The sixth (VI) cranial nerve.

3 *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 artery. It contains:
   1. The optic chiasma
   2. The bifurcation of the basilar artery.
   3. Peduncular segments of the PICA.
   4. Peduncular segments of the superior cerebellar arteries.
   5. Perforating branches of the PICA.
   6. The posterior communicating arteries (PCoA).
   7. The basal vein of Rosenthal.
   8. The third (III) cranial nerve, which passes between the posterior cerebral and superior cerebellar arteries.

4 *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.

5 *Cistern of great cerebral vein (cisterna ambiens):* This cistern lies in the space between splenium of corpus callosum and superior surface of cerebellum. It contains pineal gland and great cerebral vein of Galen.

6 *Lumbar cistern:* This is a large subarachnoid space in the lumbar region of the vertebral column distal to

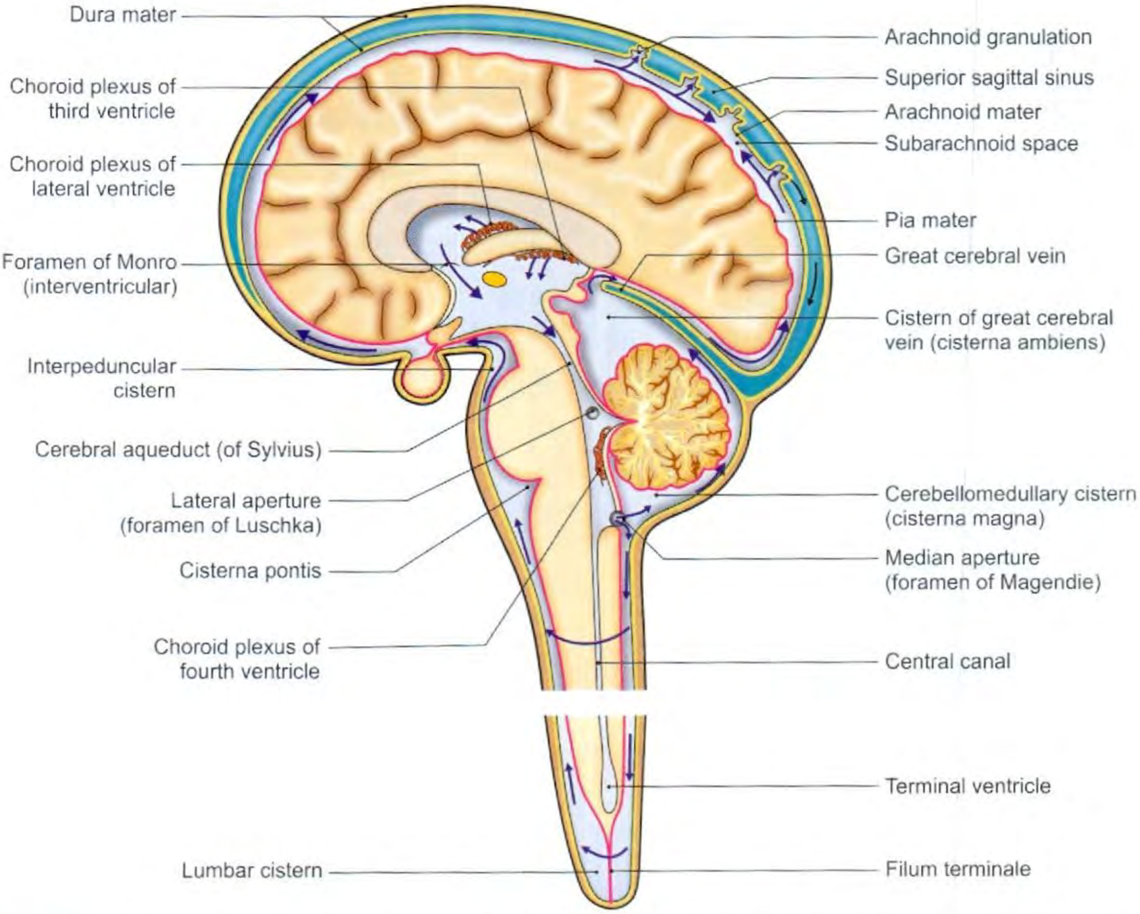


Fig. 2.6a: Various cisterns of the brain including formation, circulation and absorption of cerebrospinal fluid

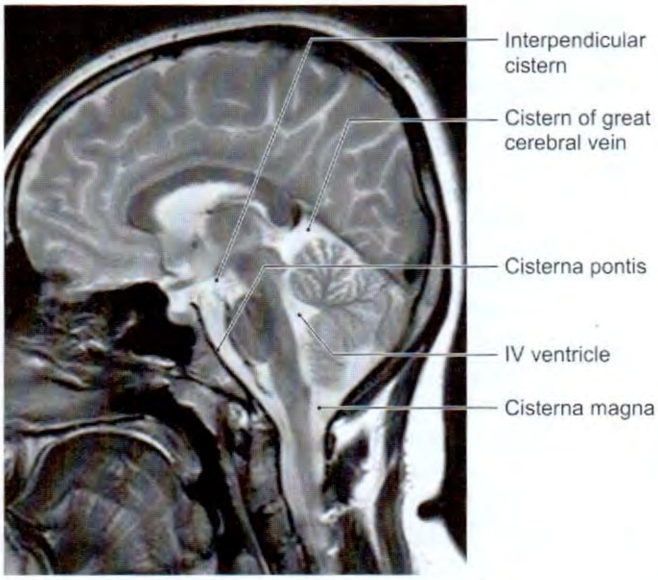


Fig. 2.6b: MRI depicting the cisterns

the termination of the spinal cord. In the space between L3 and L4 (which is part of the lumbar cistern), lumbar puncture is done to obtain a sample of CSF.

The arterial pulsations within the cisterns help to force the CSF from the cisterns onto the superolateral surface of the hemispheres. The cisterns themselves form cushions around the medulla.

Communications

The subarachnoid space communicates with the ventricular system of the brain at:

1 A median foramen of Magendie.
2 Two lateral foramina of Luschka, situated in the roof of the fourth ventricle. The CSF passes through these foramina from the fourth ventricle to the subarachnoid space.

Prolongations

1 The space is prolonged into the arachnoid sheaths around nerves where it communicates with the neural lymphatics, particularly around the first, second and eighth cranial nerves.
2 The space also extends into the pial sheaths around the vessels entering the brain substance (perivascular space). Thus, CSF comes into direct contact with nerve cells.

CLINICAL ANATOMY

- CSF can be obtained by:
  a. Lumbar puncture
  b. Cisternal puncture
  c. Ventricular puncture.

  Lumbar puncture is the easiest method and is commonly used.

  It is done by passing a needle in the interspace between the third and fourth lumbar spines.
- Biochemical analysis of CSF is of diagnostic value in various diseases.
- *Papilloedema:* The subarachnoid space sends extensions along the optic nerves till the back of eyeball. Increased CSF pressure compresses the wall of retinal vein leading to forward bulging of optic disc with oedema of the disc. Oedema of the optic disc is known as *papilloedema*. It can be viewed by an ophthalmoscope.
- *Lumbar epidural space:* The epidural space is the space between vertebral canal and dura mater. The procedure is same as lumbar puncture, the needle should reach only in the epidural space and not deep to it in the dura mater. Epidural space is utilized for giving anaesthesia or analgesia.
- Inflammation of pia mater and arachnoid mater is known as meningitis. This is commonly tubercular or pyogenic. It is characterised by fever, marked headache, neck rigidity, and a changed biochemistry of CSF.

CEREBROSPINAL FLUID (CSF)

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 (Fig. 2.6a).

FORMATION

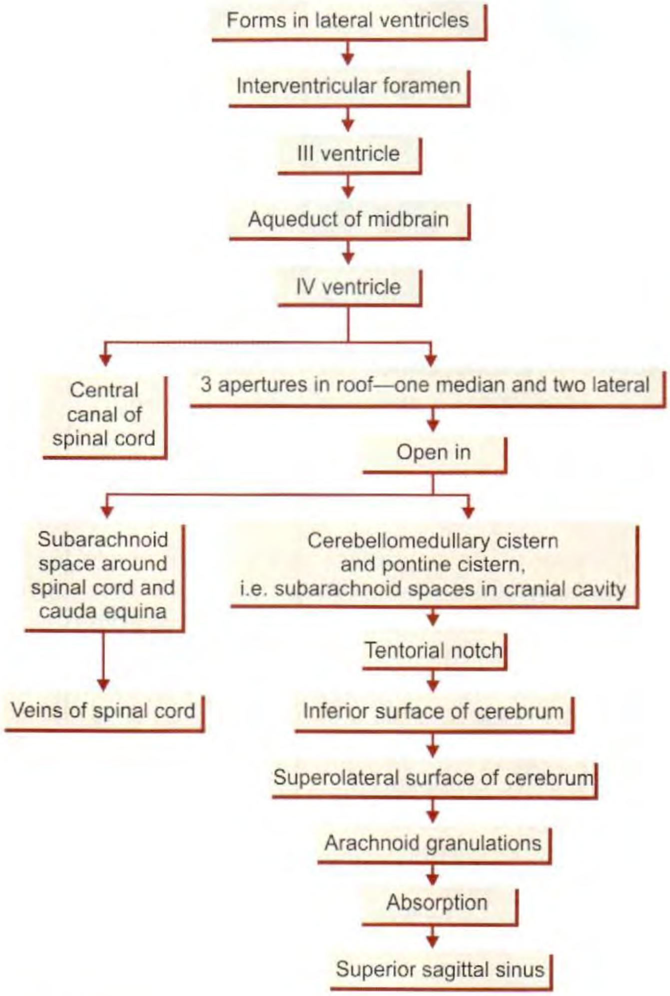
1 The bulk of the CSF is formed by the choroid plexuses of the lateral ventricles and lesser amounts by the choroid plexuses of the third and fourth ventricles.
2 Possibly, it is also formed by the capillaries on the surface of the brain and spinal cord.

The total quantity of CSF is about 150 ml. It is formed at the rate of about 200 ml per hour or 5000 ml per day. The normal pressure of CSF is 60 to 100 mm of water.

CIRCULATION

CSF passes from each lateral ventricle to the third ventricle through the interventricular foramen of Monro. From the third ventricle, it passes to the fourth ventricle through the cerebral aqueduct. 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 2.1). Some of it passes down the central canal of spinal cord.

Flowchart 2.1: Circulation of cerebrospinal fluid (CSF)



ABSORPTION

1 CSF is absorbed chiefly through the arachnoid villi and granulations, and is thus drained into the cranial venous sinuses.

2 It is also absorbed partly by the perineural lymphatics around the first, second and eighth cranial nerves.

3 It is also absorbed by veins related to spinal nerves.

FUNCTIONS OF CSF

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

2 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.

3 Neurons cannot live without glucose and oxygen for more than 3–5 minutes. These are constantly provided by CSF.

4 Pineal gland secretions reach pituitary gland via CSF.

5 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.

6 There is no CSF brain barrier, so drugs can reach the neurons through CSF.

7 There is blood CSF barrier. There are no antibodies in CNS, making infections of brain very serious entity.

CLINICAL ANATOMY

- Drainage of CSF at regular intervals is of therapeutic value in meningitis. Certain intractable headaches of unknown aetiology are also known to have been cured by a mere lumbar puncture with drainage of CSF.
- Obstruction in the vertebral canal produces *Froin's syndrome or loculation syndrome.* This is characterised by yellowish discolouration of CSF (xanthochromia) below the level of obstruction, and its spontaneous coagulation after withdrawal due to a high protein content. Biochemical examination of such fluid reveals that the protein content is raised, but the cell content is normal. This is known as *albuminocytologic dissociation*.
- *Hydrocephalus:* It is the dilatation of the ventricular system and occurs due to obstruction of CSF circulation. It may be of the following types:
  a. *Communicating:* If the obstruction is outside the ventricular system, usually in the subarachnoid space or arachnoid granulations, it is termed as communicating. This occurs due to fibrosis following meningitis. It is also called external hydrocephalus.

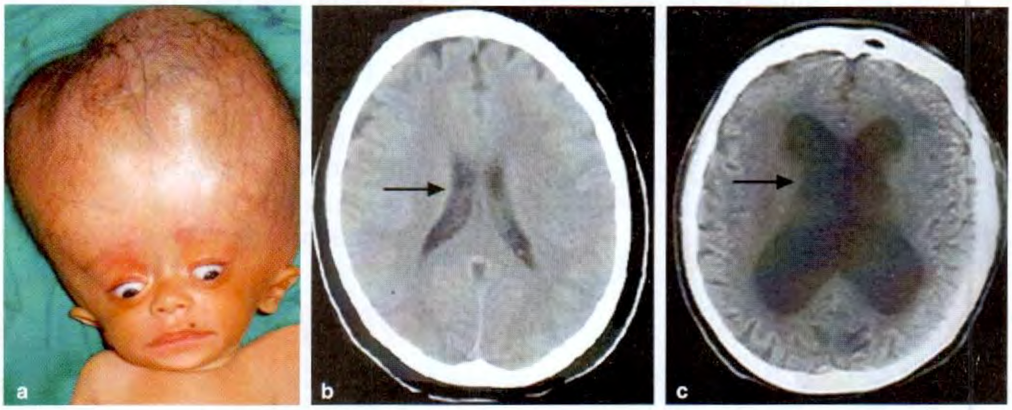
  Clinical features are:
  - Head size is rather large.
  - Tense anterior fontanelle
  - Dilated veins over thin scalp.

  b. *Non-communicating:* If the obstruction is within the ventricular system. It is called non-communicating or internal hydrocephalus. This is usually caused by a tumour or inflammation (Figs 2.7a and c). A shunt procedure is employed to divert the CSF from the ventricular system into the peritoneal cavity.

Mnemonics

PAD

P – *Pia mater*
A – *Arachnoid mater*
D – Dura mater



Figs 2.7a to c: (a) Hydrocephalic child, (b) normal ventricles, and (c) dilated ventricles in hydrocephalic child

FACTS TO REMEMBER

- Cisterns contain increased amount of CSF to protect the big veins, circle of Willis, etc.
- CSF is present outside the brain in the subarachnoid space; within the brain in its ventricles. Thus, the brain is floating in CSF and its weight is not felt by the person.
- Cerebrospinal fluid is present in the central canal of spinal cord and in subarachnoid space around the spinal cord.
- Increased formation or decreased absorption or any obstruction in its flow leads to hydrocephalus.

CLINICOANATOMICAL PROBLEM

An infant of 3 months was brought to a neurologist for abnormal large size of her head with differently looking eyes. On examination, she showed large and tense fontanelles.

- What are the various types of this condition?

Ans: The condition is called hydrocephalus. It is due to blockage of flow of CSF. If excessive CSF collects within, ventricular system, it is called internal hydrocephalus.

If excessive fluid collects in the subarachnoid space, it is called external hydrocephalus.

The treatment is surgery.

FREQUENTLY ASKED QUESTIONS

1. Describe the folds of meningeal layer of dura mater under the following headings: Name, shape, attachments, and venous sinuses enclosed.
2. Describe the various cisterns of the brain.
3. Write short notes on:
   a. Formation and circulation of CSF
   b. Arachnoid granulations
   c. Lumbar puncture

MULTIPLE CHOICE QUESTIONS

1. 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
2. In region where two layers of dura mater separate, the gap between them contains:
   a. Dural venous sinus
   b. Epidural veins
   c. Subdural fluid
   d. Subarachnoid fluid
3. Largest of cranial dural partition is:
   a. Sella turcica
   b. Falx cerebri
   c. Tentorium cerebelli
   d. Falx cerebelli
4. Dura and arachnoid extend up to the lower border of which vertebra?
   a. 2nd lumbar
   b. 3rd lumbar
   c. 2nd sacral
   d. 5th sacral

5. CSF perform which of the following functions?
   a. Provide buoyancy for brain
   b. Cushion neural structure from sudden jerks
   c. Deliver nutrition and chemical messengers
   d. All of the above

6. Which structure produces CSF in each ventricle?
   a. Choroid plexus
   b. Arachnoid villus
   c. Arachnoid granulation
   d. Diaphragma sellae

7. From subarchnoid space, CSF flows into dural venous sinus through:
   a. Lateral apertures
   b. Median aperture
   c. Arachnoid villi
   d. Arachnoid trabeculae

8. Blood–brain barrier of CNS is missing or markedly reduced in which of the following locations?
   a. Spinal cord and cerebellum
   b. Pituitary gland and thalamus
   c. Choroid plexus, pons and medulla oblongata
   d. Choroid plexus, hypothalamus and pineal gland

9. How much is the total volume of CSF in ml?
   a. 50 b. 100
   c. 150 d. 275

ANSWERS

1. c **2.** a **3.** b **4.** c **5.** d **6.** a **7.** c **8.** d **9.** c

CHAPTER

3

Spinal Cord

Software can never replace grey ware
—Anonymous

INTRODUCTION

The spinal cord is the long cylindrical lower part of central nervous system. It is the main pathway for information connecting the brain and peripheral nervous system. It occupies upper two-thirds of vertebral canal and is enclosed in the three meninges. It gives rise to 31 pairs of spinal nerves and retains the basic structural pattern.

DISSECTION

Study the spinal cord after it was removed from vertebral canal (*see* Chapter 11, Volume 3) and separated from the dura mater and arachnoid mater. Identify the dorsal root by the presence of dorsal root ganglion or spinal ganglion. Note the position of cervical enlargement in the upper part and lumbosacral enlargement in the lower part. See the numerous nerve roots surrounding the filum terminale forming the cauda equina (Figs 3.2 and 3.3).

Cut transverse sections of spinal cord at cervical, thoracic, lumbar, and sacral regions to note the shape and size of the horns in relation to white matter (Table 3.2).

Features

The spinal cord is 18 inches or 45 cm in an adult male and 42 cm in adult female. The weight of spinal cord is 30 g. It is surrounded by the three meninges (Fig. 3.1).

It extends from upper border of atlas vertebra to the lower border of first lumbar vertebra in an adult. In children, it extends up to L3 vertebra. Superiorly, it is continuous with the medulla oblongata, inferiorly it terminates as conus medullaris (Fig. 3.2 and Table 3.1).

As the spinal cord is much shorter than the length of the vertebral column, the spinal segments do not lie opposite the corresponding vertebrae. In estimating the position of a spinal segment in relation to the surface of the body, it is important to remember that a vertebral spine is always lower than the corresponding spinal segment. The level of spinal segment with their vertebral level is shown in Table 3.1.

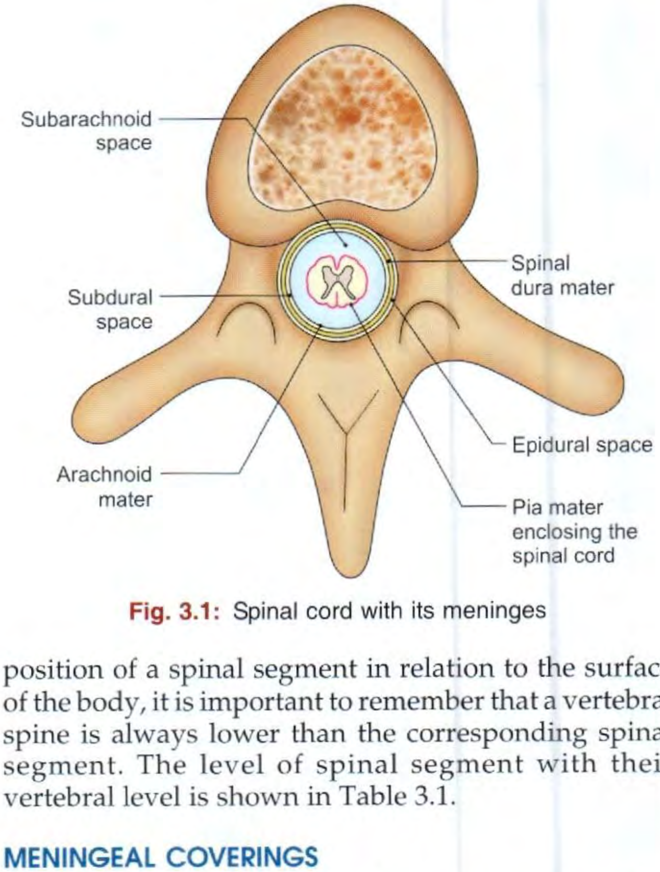


Fig. 3.1: Spinal cord with its meninges

MENINGEAL COVERINGS

The spinal cord is surrounded by three meninges. The outermost is the dura mater, the middle one is arachnoid

Table 3.1: Level of vertebral levels and spinal segments

Vertebral levels	*Spinal segments*
C1–C7	C1–C8
T1–T6	T1–T8
T7–T9	T9–T12
T10–T11	L1–L5
T12–L1	S1–S5 and Co1

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 (Fig. 3.1). 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 spinal cord is enclosed only by the meningeal layer of dura mater. The space between the meningeal layer and endosteum of the vertebral canal is called epidural space, where epidural anaesthesia can be given. The epidural space is filled with adipose tissue, and it contains a network of blood vessels.

The spinal pia mater undergoes modification as follows to keep the spinal cord in position during the movements of the vertebral column.

a. Ligamenta denticulata are 21 pairs of teeth-like projections. They fuse laterally with the arachnoid and dura mater midway between the exits of the roots of adjacent spinal nerves. The highest process attaches immediately superior to foramen magnum. The ligamentum denticulatum keeps the spinal cord in position.
b. Linea splendens is a thickening seen at the anteromedian sulcus in the lower part of the spinal cord.
c. 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. It consists of two parts:
   - Filum terminale internum, the upper part which is 15 cms long which extends up to lower border of second sacral vertebra.
   - Filum terminale externum, the lower part which is outside the dura mater and is attached to the first segment of the coccyx. Between the lower border of L1 and S2 vertebrae, the subarachnoid space contains spinal nerve roots which constitute the cauda equina. It is due to this feature that lumbar puncture is done below L2 vertebra without any danger to spinal cord.

The dura and arachnoid along with subarachnoid space containing CSF extend up to 2nd sacral vertebra.

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

a. 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. 3.2).
b. 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 (Fig. 3.3). These are called cauda

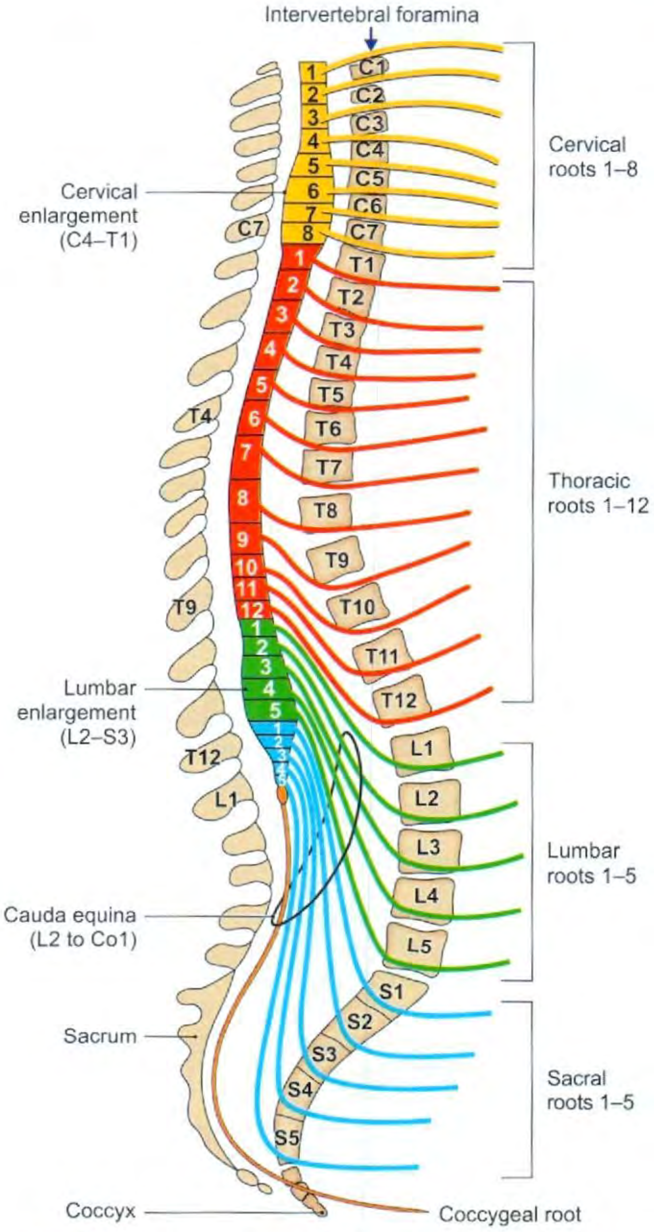


Fig. 3.2: The spinal cord with 31 pairs of spinal nerves

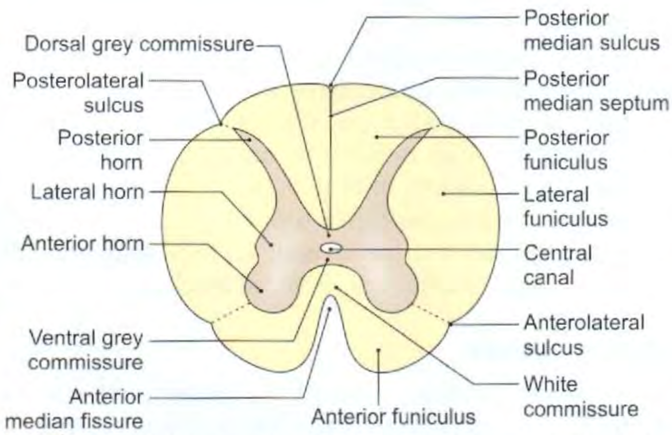


Fig. 3.3: Transverse section of thoracic segment of spinal cord

equina as these resemble a horse's tail. Dorsal and ventral nerve roots of one segment join together at respective intervertebral foramen to exit as the spinal nerve. There are 40 nerve roots at the beginning of cauda equina. These are dorsal and ventral nerve roots of right and left sides for each segment. So each segment has 4 nerve roots. Thus, there are 4 × 4 = 16 lumbar nerve roots; 4 × 5 = 20 sacral nerve roots and 4 × 1 = 4 coccygeal nerve roots, making it to 40 nerve roots. One dorsal root and one ventral root joins to form one spinal nerve and (Fig. 3.3) leaves through the foramen on one side. So at every intervertebral foramen 4 nerve roots exit the cauda equina; leaving it thinner. In the end only filum terminale remains to be attached to the coccyx.

EXTERNAL FEATURES OF SPINAL CORD

Anteriorly, the spinal cord reveals a deep anterior median fissure lodging the anterior spinal artery.

Posterior median sulcus is a thin longitudinal groove from which a septum runs in the depth of spinal cord (Fig. 3.3).

Each half is subdivided into anterior, lateral and posterior regions by anterolateral and posterolateral sulci. Ventral or motor nerve roots emerge from the anterolateral sulcus. Dorsal or sensory nerve roots enter spinal cord from posterolateral sulcus.

INTERNAL STRUCTURE

White matter, i.e. nerve fibres lie outside and grey matter lies inside. In the centre of grey matter is the central canal containing CSF (Fig. 3.3). The canal is lined by single layer of ependymal cells.

The grey matter is in the form of "H" with a grey commissure joining the grey matter of right and left sides.

Grey matter comprises one posterior horn and one anterior horn on each side in the entire extent of the cord. Only in T1–L2 and S2–S4 segments, there is an additional lateral horn for the supply of the viscera. This horn is a part of autonomic nervous system.

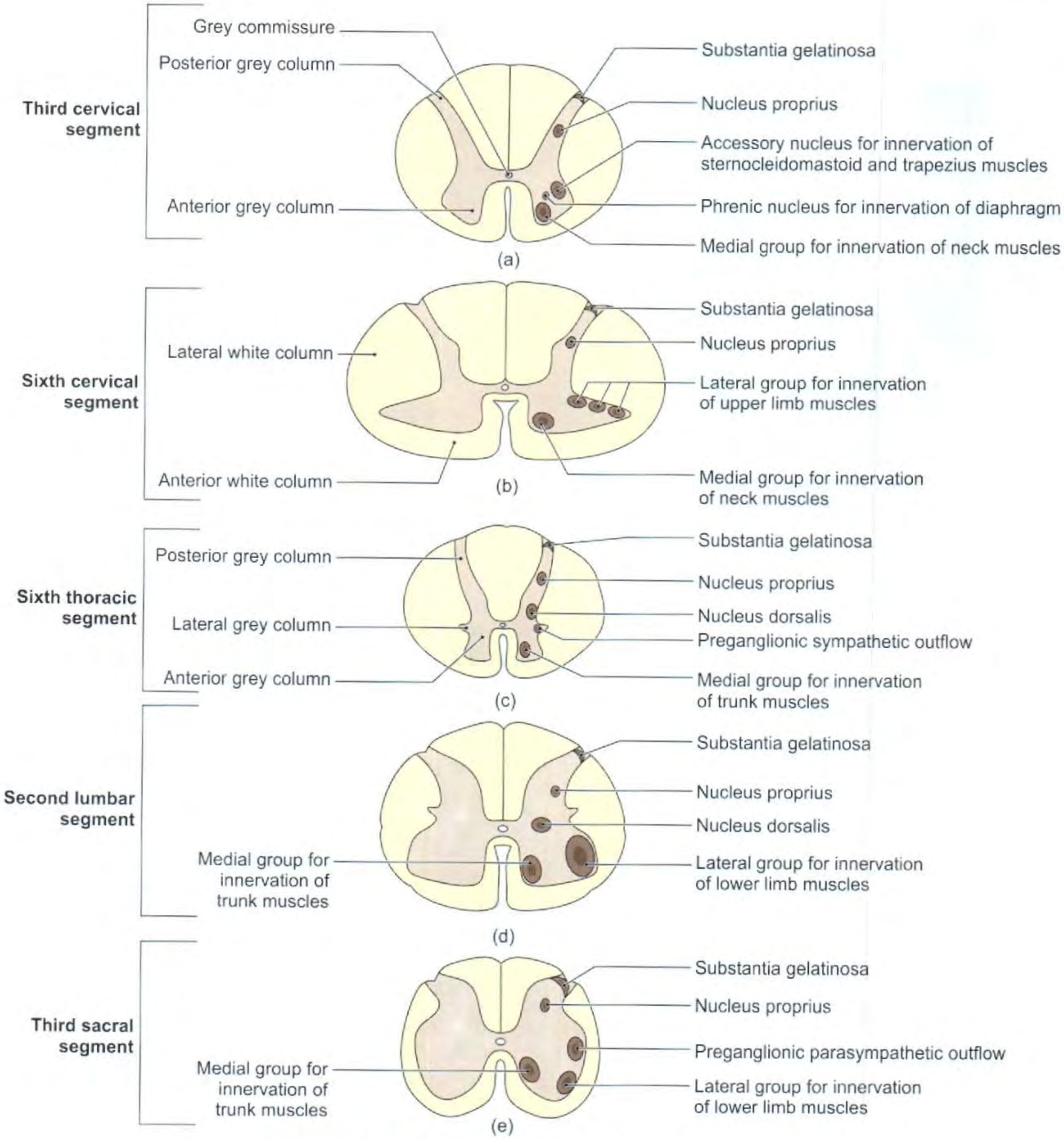
The dorsal horn is found at all spinal cord levels and is comprised of sensory neuron that receive and process incoming somatosensory information. From there, ascending projections emerge to transmit the sensory information to the diencephalon. The ventral horn comprises motor neurons that innervate skeletal muscle. Nerve cells in the grey substance are multipolar, varying much in their morphology. Many of them are Golgi type I and Golgi type II nerve cells. The axons of Golgi type I are long and pass out of the grey matter into the ventral spinal roots or the fibre tracts of the white matter. The axons and dendrites of the Golgi type II cells are largely confined to the neighboring neurons in the grey matter.

Shape and size of the horns differ in different segments due to functional reasons (Figs 3.4a to e) and shown in Table 3.2.

CLINICAL ANATOMY

- *Conus medullaris syndrome:* Due to injury to S2, S3, S4 segments of spinal cord. Features are:
  - a. Anaesthesia in the perineum. The region is supplied by these three segments.
  - b. Involvement of bladder and bowel is early S2, S3, S4 segments carry sacral component of the parasympathetic system which supplies the bladder and lower bowel.
  - c. Sexual functions are affected as same nerves carry out sexual functions as well.
- *Cauda equina syndrome:* Damage to cauda equina results in:
  - a. Lower motor neuron type of paralysis in the lower limbs due to compression of ventral nerve roots.
  - b. Root pain is an important symptom due to involvement of dorsal nerve roots.
  - c. Bladder and bowel involvement is late.
- *Poliomyelitis:* It is a viral disease which involves anterior horn cells leading to flaccid paralysis of the affected segments. It is a lower motor neuron paralysis (Figs 3.5 and 3.6).

  If poliomyelitis affects the upper cervical segments of spinal cord, it may be fatal because of the involvement of C4 segment which supplies the diaphragm through phrenic nerve.
- *Tabes dorsalis* (Fig. 3.6): It occurs during tertiary stage of syphilis. There is degenerative lesions of dorsal nerve roots and of posterior white columns. Its feature is severe pain in lower limbs, as the disease occurs in lower thoracic and lumbosacral segments. The lower limbs are mainly affected.



Figs 3.4a to e: Features of spinal cord at various levels

Table 3.2: Shape of horns in different segments of spinal cord

Segments of spinal cord	*Posterior horn*	*Lateral horn*	*Anterior horn*
Cervical, oval shape (Fig. 3.4)	Slender	Absent	Narrow in 1–3 segments Broad in C4 to C8 segments for supply of upper limbs
Thoracic, circular shape	Slender	Present for thoracolumbar outflow	Slender in T2–T12 segments, broad in T1 segment
Lumbar, circular shape	Bulbous	Present only in lumbar 1 and 2 segments	Bulbous for supply of lower limbs
Sacral, circular but smaller	Thick	Present in sacral 2–4 segments for sacral outflow	Bulbous for supply of lower limbs

Fig. 3.5: Poliomyelitis of right lower limb

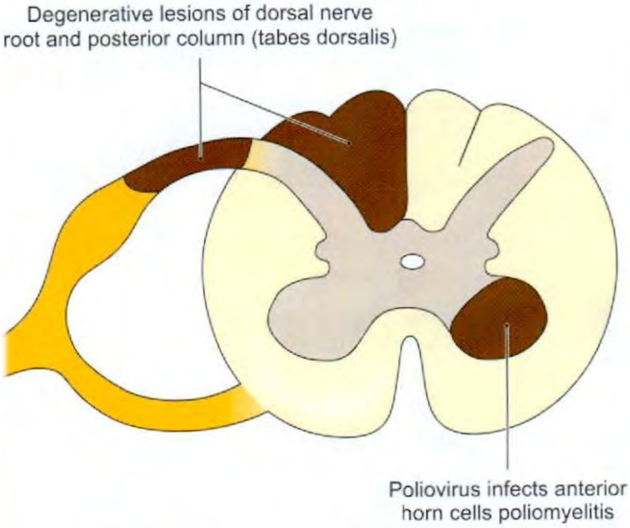


Fig. 3.6: Tabes dorsalis and poliomyelitis

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. 3.7).

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.

Dorsal Root Ganglion

As the dorsal rootlets converge, there is a swelling, the dorsal or posterior root ganglion (Fig. 3.7), which houses the cell bodies of all the sensory neurons in that particular nerve. The neurons are pseudounipolar type.

Branches of a Typical Nerve

Dorsal Ramus

It supplies the dorsal one-third of the body wall. Dorsal rami do not supply the limbs (Fig. 3.7).

Ventral Ramus

It supplies the ventral two-thirds of the body wall *including the limbs* (Fig. 3.7).

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.

Since length of spinal cord (45 cm) is smaller than the length of vertebral column (65 cm), the spinal segments do not correspond to the vertebral levels. Spinal segments being shorter lie above the corresponding vertebrae (Table 3.1).

During the third month of embryonic development, the spinal cord extends the entire length of the vertebral canal and both grow at about the same rate. As development continues, the body and the vertebral column continue to grow at a much greater rate than the spinal cord proper. The outcome of this uneven growth is that the adult spinal cord extends to the level of the first or second lumbar vertebrae, and the nerves grow to exit through the same intervertebral foramina as they did during embryonic development. This growth of the nerve roots occurring within the vertebral canal, results in the lumbar, sacral, and coccygeal roots extending to their appropriate vertebral levels. All spinal nerves, except the first, exit below their corresponding vertebrae.

NUCLEI OF SPINAL CORD

The grey matter of spinal cord is arranged in three horns. Anterior is motor, lateral being visceral efferent and afferent in function, and posterior is sensory in function.

Nuclei in Anterior Grey Column or Horn

The anterior horn is divided into a ventral part, the head and a dorsal part, the base. 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 fibres of muscle spindles. The cells in the anterior horn are arranged in the following three main groups.

1. *Medial group:* It is present throughout the entire extent of spinal cord and innervates the axial muscles of the body (Fig. 3.8).

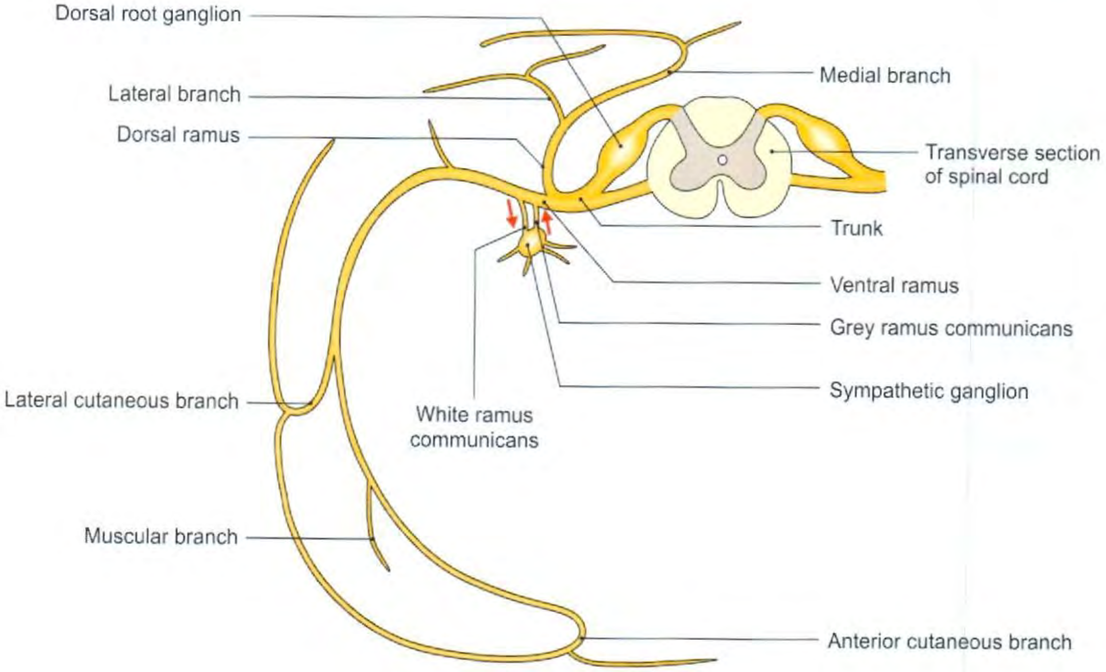


Fig. 3.7: Typical spinal nerve

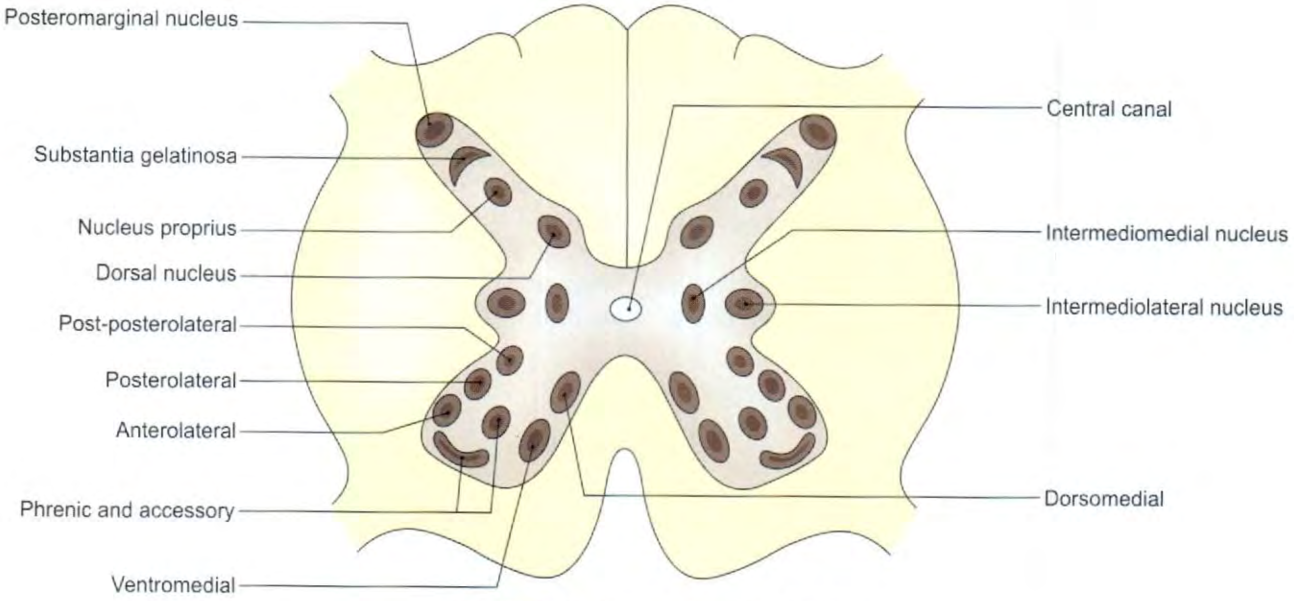


Fig. 3.8: Cell groups in spinal cord

2 *Lateral group:* Present only in the cervical and lumbar enlargements and supplies musculature of limbs. It is subdivided into three subgroups.
   a. Anterolateral supplying proximal muscles of limbs (shoulder and arm/gluteal region and thigh) (Fig. 3.4).
   b. Posterolateral supplying intermediate muscles of limbs (forearm/leg).
   c. Post-posterolateral innervating the distal segment (hand/foot).

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

Nuclei in Lateral Horn

Nuclei in lateral horn are as follows:

1 *Intermediolateral nucleus:* This acts as both efferent and afferent nuclear columns. This nucleus is seen at two levels.
   a. From T1 to L2 segments, giving rise to preganglionic sympathetic fibres (thoracolumbar outflow).

b. From S2 to S4 segments, giving rise to preganglionic parasympathetic fibres chiefly for the pelvic viscera (Fig. 3.4).

At these two levels, the intermediolateral cell column receives visceral afferent fibres.

2 *Intermediomedial nucleus:* This is mostly internuncial neuronal column.

Nuclei in Posterior Grey Column

Afferent Nuclear Group Column

The four main afferent nuclei are seen in this are:

1 *Posteromarginal nucleus:* Thin layer of neurons caps the posterior horn. It receives some of incoming dorsal root fibres.
2 *Substantia gelatinosa:* This is found at the tip of posterior horn through the entire extent of spinal cord.
3 *Nucleus proprius:* It lies subjacent to the substantia gelatinosa throughout the entire extent of cord (Fig. 3.4). 1–3 groups of nuclei are present in laminae I–IV.
4 *Nucleus dorsalis* of Clarke also known as thoracic nucleus at the medial part of base of posterior horn extending from C8 to L3 segments. These are situated in laminae V and VI.

LAMINAR ORGANISATION IN SPINAL CORD

In thick sections, spinal cord neurons appear to have a laminar (layered) arrangement. Ten layers of neurons are recognised, known also as laminae of Rexed. These are numbered consecutively by Roman numerals, starting at the tip of the dorsal horn and moving ventrally into ventral horn (Fig. 3.9).

Laminae I to IV, in general, are concerned with exteroceptive sensation and comprise the dorsal horn, whereas laminae V and VI are concerned primarily with proprioceptive sensations. Lamina VII is equivalent to the intermediate zone and acts as a relay between muscle spindle to midbrain and cerebellum, and laminae VIII–IX comprise the ventral horn and contain mainly motor neurons. The axons of these neurons innervate mainly skeletal muscle. Lamina X surrounds the central canal and contains neuroglia.

Lamina I: Corresponds to posteromarginal nucleus.

Lamina II: Corresponds to substantia gelatinosa.

Laminae III and IV: Correspond to nucleus proprius.

The neurons of laminae I–IV are related to exteroceptive sensations, i.e. crude touch, crude pressure pain and temperature. Their axons give rise to ventral and lateral spinothalamic tract.

Laminae V and VI: Correspond to base of dorsal column.

Neurons of laminae V and VI are meant for reflex proproceptive impulses. Their axons give rise to dorsal and ventral spinocerebellar tract.

Laminae VII: Occupies the territory between dorsal and ventral horns. This lamina contains many cells that function as interneurons. Three clear cell columns are recognised within this lamina. These are intermediolateral, intermediomedial and nucleus dorsalis (nucleus thoracis or Clarke's column). Nucleus dorsalis is present on the medial aspect of dorsal horn from C8 to L3 segments and its axons give rise to dorsal spinocerebellar tract. The sacral autonomic nucleus is an inconspicuous column of cells in the lateral part of lamina VII in segments S2, S3 and S4.

Lamina VIII: Corresponds to ventral horn in thoracic segments but at the level of limb enlargements of spinal cord, it lies on the medial aspect of ventral horn.

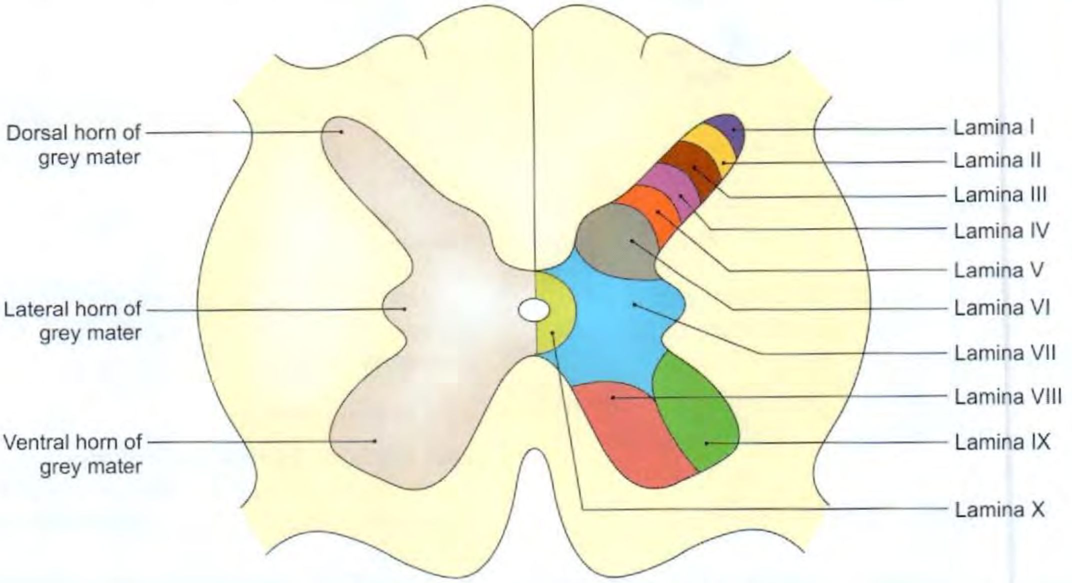


Fig. 3.9: Various laminae in spinal cord

Lamina IX: Includes the lateral group of nuclei of the ventral horn. The axons of these neurons leave the spinal cord to supply the striated or skeletal muscles of limbs.

Lamina X: Surrounds the central canal. It is composed of decussating axons, neuroglia and some neurons in the grey matter surrounding central canal that have properties of interneurons.

SENSORY RECEPTORS

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

Functional classification

1. *Exteroceptors:* These respond to stimuli from external environment, that is pain, temperature, touch and pressure.
2. *Proprioceptors:* These respond to stimuli in deeper tissues that is contraction of muscles, movements, position and pressure related to joints. These are responsible for coordination of muscles, maintenance of body posture and equilibrium. These actions are perceived both at unconscious level and at conscious level.
3. *Interoceptors/enteroceptors:* These include receptor end-organs in the walls of viscera, gland, blood vessels and specialised structures in the carotid sinus, carotid bodies and osmoreceptors. Also carry sensations of hunger, nausea and pain.
4. *Special sense receptors:* These are concerned with vision, hearing, smell, balance and taste.

TRACTS OF THE SPINAL CORD

A collection of nerve fibres 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 following tracts are seen in a transverse section through the spinal cord. Their location should be identified.

DESCENDING TRACTS

The descending tracts are of two types—pyramidal and extrapyramidal (Table 3.3).

Pyramidal or Corticospinal Tracts

The *pyramidal or corticospinal tract* consists of two parts:

1. Lateral corticospinal tract, which lies in the lateral funiculus.
2. Anterior corticospinal tract, which lies in the anterior funiculus.

The pyramidal or corticospinal tract (Fig. 3.10) is formed by the axons of pyramidal cells predominantly lying in the motor area of cerebral cortex. There is some contribution to it from axon of cells in premotor and sensory areas. From here, the fibres course through the posterior limb of internal capsule, midbrain, pons and medulla oblongata. At the lower level of medulla oblongata, 80% of fibres cross to the opposite side. This is known as pyramidal *decussation*. The fibres that have

Table 3.3: The descending tracts

Name	*Function*	*Crossed and uncrossed*	*Beginning*	*Termination*
Pyramidal tracts				
1. Lateral corticospinal	Main motor tract for skillful voluntary movements	Crosses in medulla	Motor area of cortex (areas 4, 6)	Anterior grey column cells (alpha motor neurons)
2. Anterior corticospinal	Facilitates flexors	Crosses in corresponding spinal segment	Motor area of cortex (areas 4, 6)	Anterior grey column cells (alpha motor neurons)
Extrapyramidal tracts				
1. Rubrospinal	Efferent pathway for cerebellum and corpus striatum	Crossed	Red nucleus of midbrain	Anterior grey column cells
2. Medial reticulospinal	Extrapyramidal tract Facilitates extensors	Uncrossed	Reticular formation of grey matter of pons	Anterior grey column cells (interneurons)
3. Lateral reticulospinal	Extrapyramidal tract Facilitates flexors	Uncrossed and crossed	Reticular formation of grey matter of medulla oblongata	Anterior grey column cells (interneurons)
4. Olivospinal	Extrapyramidal tract	Uncrossed	Inferior olivary nucleus	Anterior grey column cells
5. Lateral vestibulospinal	Efferent pathway for equilibratory control	Uncrossed	Lateral vestibular nucleus	Anterior grey column cells
6. Tectospinal	Efferent pathway for visual reflexes	Crossed	Superior colliculus	Anterior grey column cells

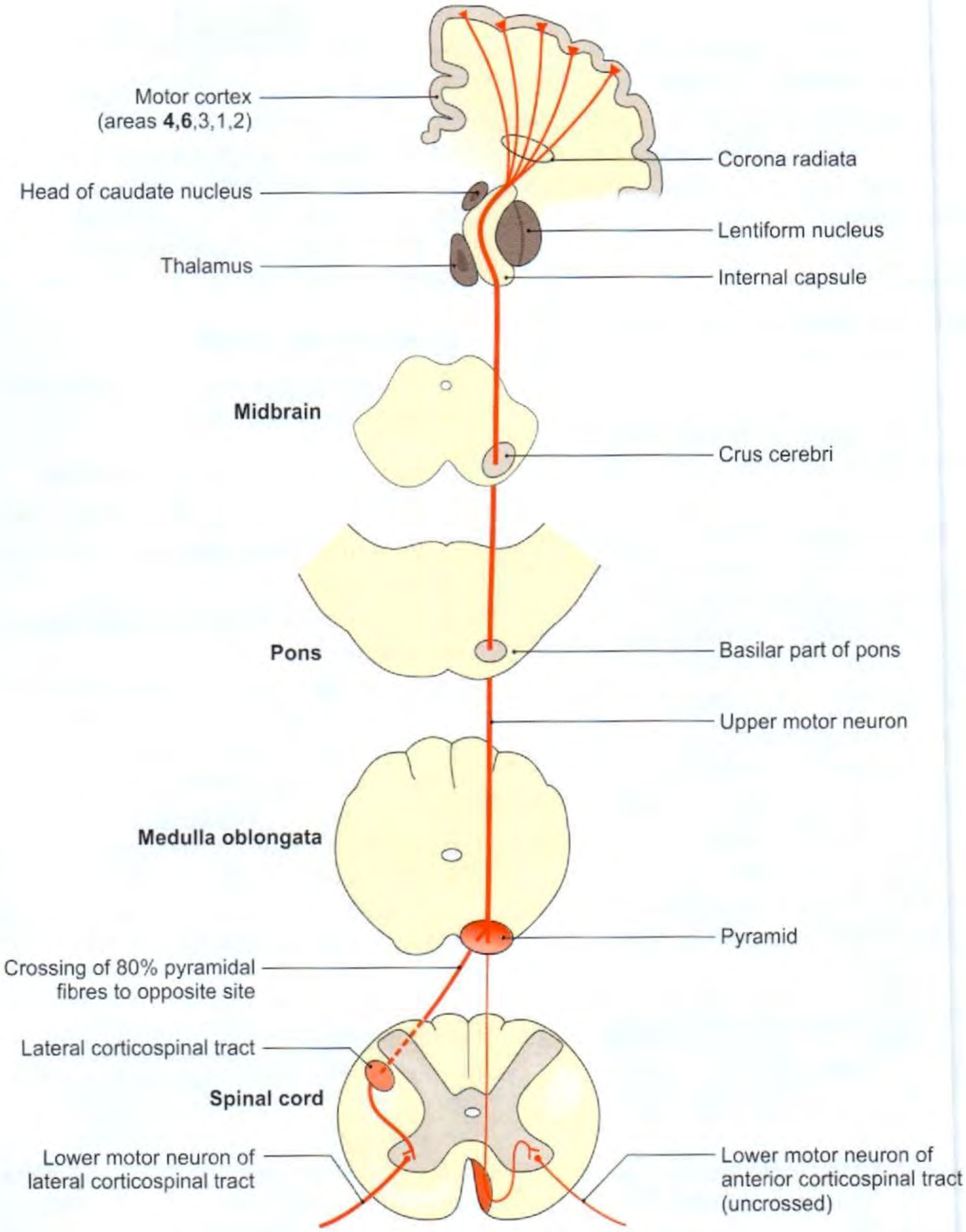


Fig. 3.10: Pyramidal/corticospinal tracts course of corticospinal fibres

crossed enter lateral column of white matter of spinal cord and descend as lateral corticospinal tract. Most of these fibres terminate by synapsing through the internuncial neurons at the anterior horn cells (Fig. 3.11).

The 15% of fibres that do not cross enter anterior white column of spinal cord to form anterior corticospinal tract. The fibres of this tract also cross at appropriate levels to reach grey matter of the opposite half of spinal cord and synapse with internuncial neurons similar to those of lateral corticospinal tract (Fig. 3.11). Only 5% corticospinal fibres 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 3.3).

Functional Significance

1. The cerebral cortex controls gross and fine skilled voluntary movements of opposite half of body through anterior horn cells.
2. Influence of this tract is supposed to be facilitatory for flexors and inhibitory for extensors.
3. Anterior corticospinal tract controls voluntary gross movement like walking and running.
4. Corticospinal tract facilitates superficial reflexes and muslce tone.

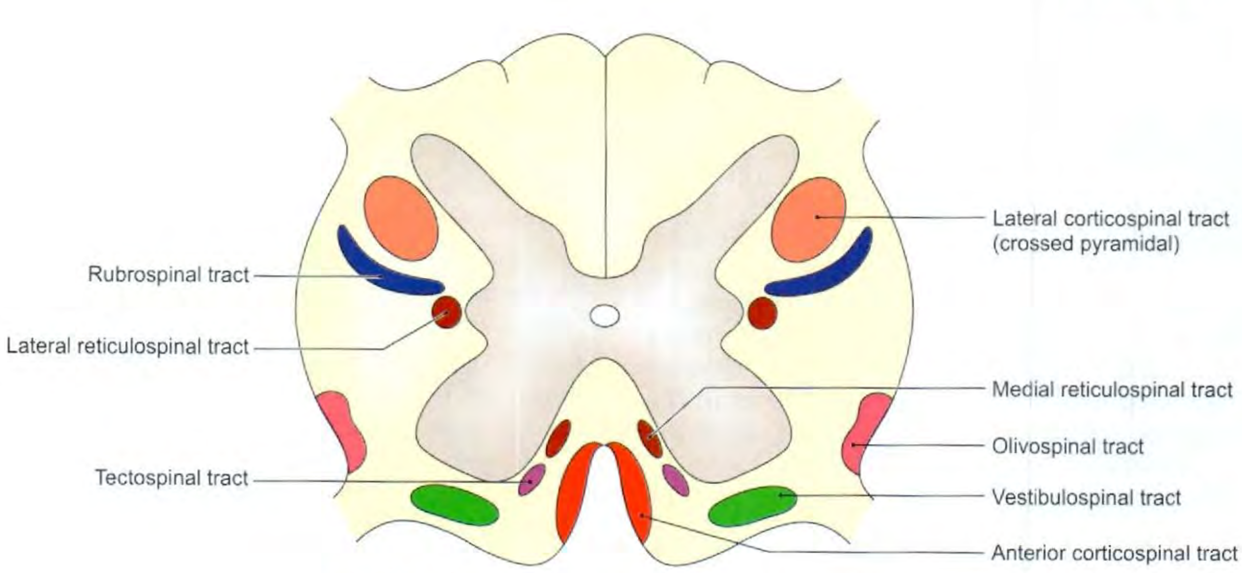


Fig. 3.11: Location of descending tracts in spinal cord

5 Actions of basal ganglia and cerebellum are mediated by corticospinal tracts.

Extrapyramidal Tracts

These are:

1 Rubrospinal tract.
2 Medial reticulospinal tract.
3 Lateral reticulospinal tract.
4 Olivospinal tract.
5 Vestibulospinal tract.
6 Tectospinal tract.

1 *Rubrospinal tract:* This tract is formed by the axons of red nucleus, situated in the midbrain. The fibres cross with the fibres of the opposite side in the tegmentum of midbrain; thus constituting the *ventral tegmental decussation* (*see* Fig. 5.14). The tract descends through the pons and medulla oblongata and enters the lateral white column of spinal cord. The fibres terminate by synapsing through internuncial neurons with anterior horn cells (Fig. 3.11). It controls the tone of limb flexor muscles by being excitatory to motor neurons of these muscles.

2 *Medial reticulospinal tract:* The medial reticulospinal tract is formed by the fibres 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 fibres (Fig. 3.11). It influences voluntary movement, reflex activity and muscle tone by controlling the activity of both alpha and gamma neurons.

3 *Lateral reticulospinal tract*: The lateral reticulospinal tract originates from reticular formation in brainstem (midbrain, pons and medulla oblongata) and descends up to thoracic segments of spinal cord. It has both crossed and uncrossed fibres. It lies in the anterolateral white column of spinal cord. Both the tracts terminate by synapsing with the neurons in lamina VII of the spinal cord.

4 *Olivospinal tract:* Its fibres 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.

5 *Vestibulospinal tract:* The fibres arise from lateral vestibular nucleus lying at pontomedullary junction. The fibres descend uncrossed to spinal cord. This tract is situated in the anterior white column of spinal cord. These fibres synapse with anterior horn cells. It has 2 types:

a. *Lateral*—controls extensors muscle tone
b. *Medial*—for movement of head.

6 *Tectospinal tract:* The tract is formed by the axons of neurons lying in the superior colliculus of the midbrain (*see* Fig. 5.14). The fibres cross to the opposite side thus forming *dorsal tegmental decussation* in midbrain. The tract descends through pons, medulla and anterior white column of spinal cord. The fibres terminate on the cells of anterior horn through internuncial neurons. It mediates reflex movements of head and neck in response to visual stimulus.

All these descending tracts control the voluntary movements of skeletal muscles of the body through anterior horn cells directly or through internuncial neurons. The influence is on both alpha and gamma neurons. Gamma neurons also affect alpha neurons through muscle spindles. So, all influences finally reach alpha neurons. Pyramidal and extrapyramidal tracts have been compared and shown in Table 3.7.

ASCENDING TRACTS

1 Lateral spinothalamic tract (Fig. 3.12).
2 Anterior spinothalamic tract.
3 Fasciculus gracilis (medially) (Fig. 3.13).
4 Fasciculus cuneatus (laterally).

5 Dorsal or posterior spinocerebellar tract.
6 Ventral or anterior spinocerebellar tract
7 Spino-olivary tract.
8 Spinotectal tract.

For the sensory pathways, the first neuron fibres always start in the dorsal root ganglia which has pseudounipolar cells. The peripheral process of these cells form the sensory fibres of peripheral nerves. The central process of the neurons in the dorsal root ganglia enter the spinal cord through dorsal nerve root and terminate either by synapsing with cells in posterior grey column of spinal cord or at higher level in the medulla oblongata with the cells of nucleus gracilis and nucleus cuneatus.

After relay in the nuclei, second neuron fibres start and ascend to either thalamus or cerebellum.

The cerebellum finally receives second neurons fibres, whereas from the thalamus relayed third neuron fibres are projected to the sensory areas in the cerebral cortex (Table 3.4).

Exteroceptive Sensations

1 *Lateral spinothalamic tract:* This tract carries the sensation of pain and temperature. The first neuron fibres start in the dorsal root ganglia. These relay by synapsing with neurons lying in the grey matter of laminae II and III. Pain fibres relay in lamina II (substantia gelatinosa). The second neuron fibres *cross immediately* to opposite side close to the central canal and ascend as tract in the lateral white column of spinal cord (Figs 3.12 and 3.13).

Table 3.4: Neurons of sensory tracts

Tracts	*1st*	*2nd*	*3rd*	*Clinical tests*
Lateral spinothalamic	Dorsal root ganglion	Substantia gelatinosa	Posterolateral ventral nucleus of thalamus	1 Pain with pinprick 2 Temperature with hot and cold water in the test tubes
Anterior spinothalamic	Dorsal root ganglion	Nucleus proprius		1 Joint sense 2 Vibration sense 3 Tactile localisation 4 Tactile discrimination 5 Rhomberg's test 6 Stereognosis 7 Crude touch 8 Crude pressure
Fasciculus gracilis	Dorsal root ganglion	Nucleus gracilis in medulla oblongata	Posterolateral ventral nucleus of thalamus	
Fasciculus cuneatus	Dorsal root ganglion	Nucleus cuneatus in medulla oblongata	Posterolateral ventral nucleus of thalamus	
Dorsal spinocerebellar	Dorsal root ganglion	Clarke's column	Nil	All cerebellar tests, like the finger-nose and heel-knee tests for intention tremors
Ventral spinocerebellar	Dorsal root ganglion	Nucleus proprius	Nil	

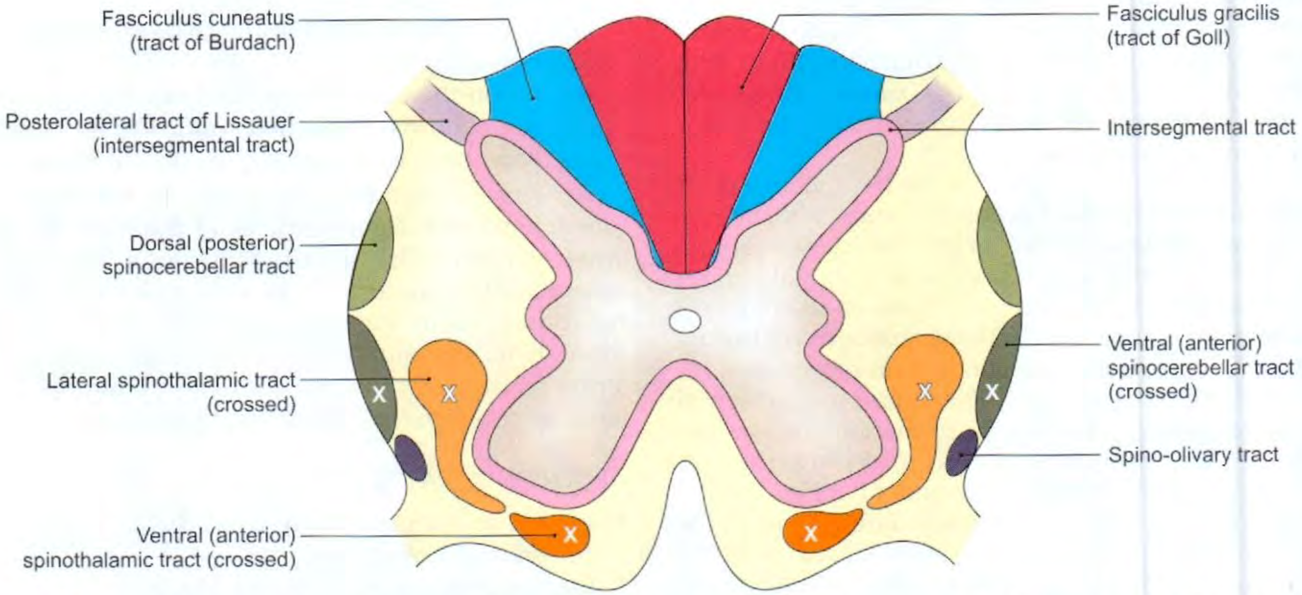


Fig. 3.12: Location of ascending tracts in spinal cord. Three tracts marked '**X**' are crossed and remaining tracts are uncrossed

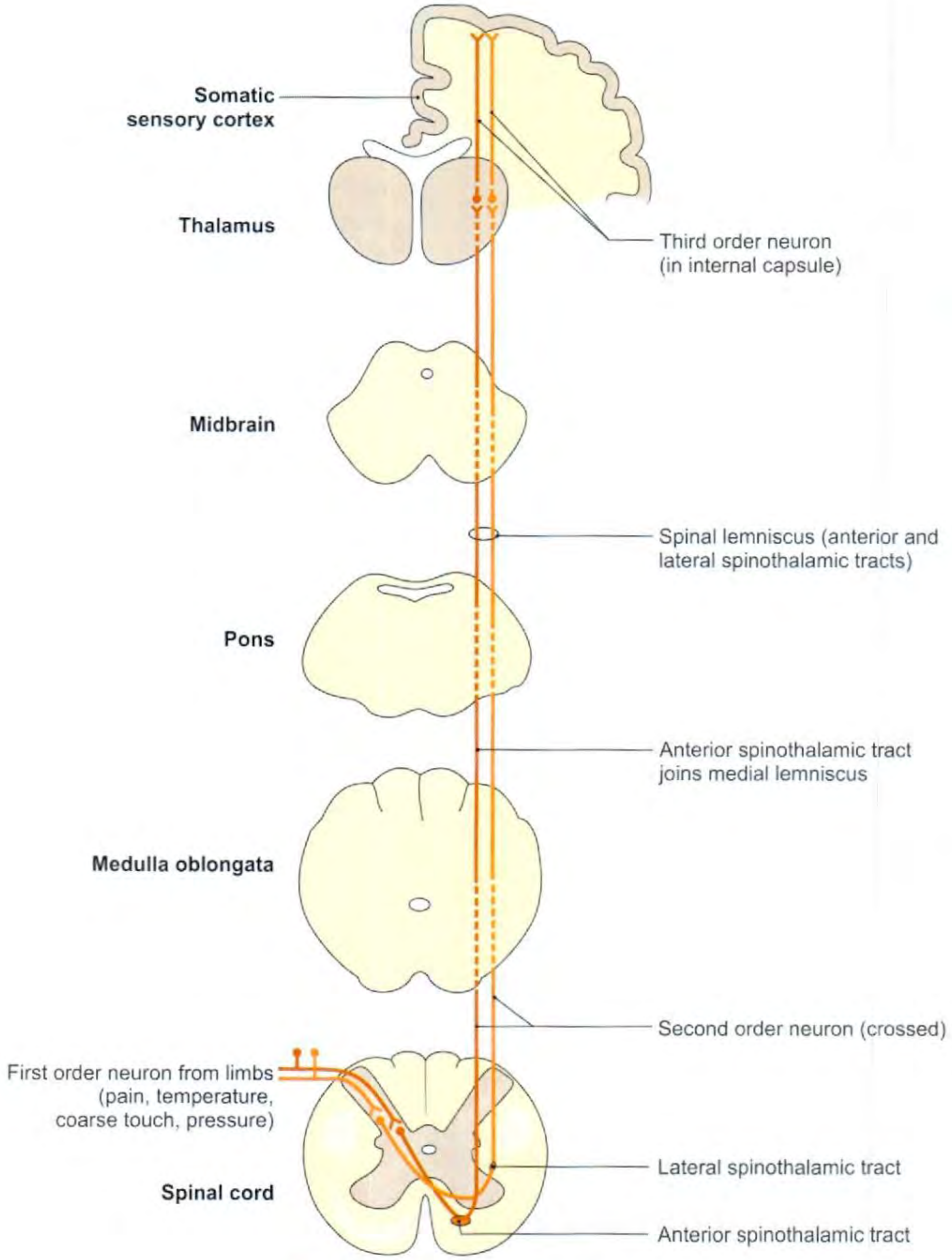


Fig. 3.13: Spinothalamic pathways

2 *Anterior spinothalamic tract:* This tract carries the fibres for crude touch and pressure, tickle and itch. First neuron fibres are in the dorsal root ganglia. These relay in the grey matter of posterior horn or nucleus proprius (laminae III and IV). The second neuron fibres *ascend for 1–2 segments and cross* to opposite side in the white commissure and ascend as a tract in the anterior white column of spinal cord (Fig. 3.13).

The anterior and lateral spinothalamic tracts carry exteroceptive sensations from the opposite half of body (Fig. 3.12).

These lie in continuity with each other in the anterolateral white column of spinal cord showing somatotopic lamination. The sensations of pressure, touch, temperature and pain are lying medial to lateral. Pressure sensations are medial most near the anterior median fissure. Cervical segments are facing medially and sacral segments face laterally.

Proprioceptive Sensations

The sensations like deep touch, pressure, tactile localisation (the ability to locate exactly the proprioceptive part touched), tactile discrimination (the ability to localise two separate points on the skin that is touched), stereognosis (ability to recognise shape of object held in hand) and sense of vibration are carried by fasciculus gracilis and fasciculus cuneatus.

1 *Fasciculus gracilis (tract of Goll):* It commences at the caudal limit of spinal cord and is composed mainly of the long ascending branches of the medial division of fibres of dorsal nerve roots. These are the first order neuron fibres from dorsal root ganglia. These run directly upwards (without relaying in the spinal grey matter) in the posterior column of white matter of spinal cord. As the tract ascends, it receives accession from each dorsal root. The fibres which enter in the coccygeal and lower sacral region are thrust medially by fibres which enter at higher levels. Fasciculus gracilis which contains fibres derived from lower thoracic, lumbar, sacral and coccygeal segments of spinal cord occupies the medial part of posterior column of upper part of spinal cord and is separated from fasciculus cuneatus by postero-intermediate septum (Figs 3.14 and 3.15).

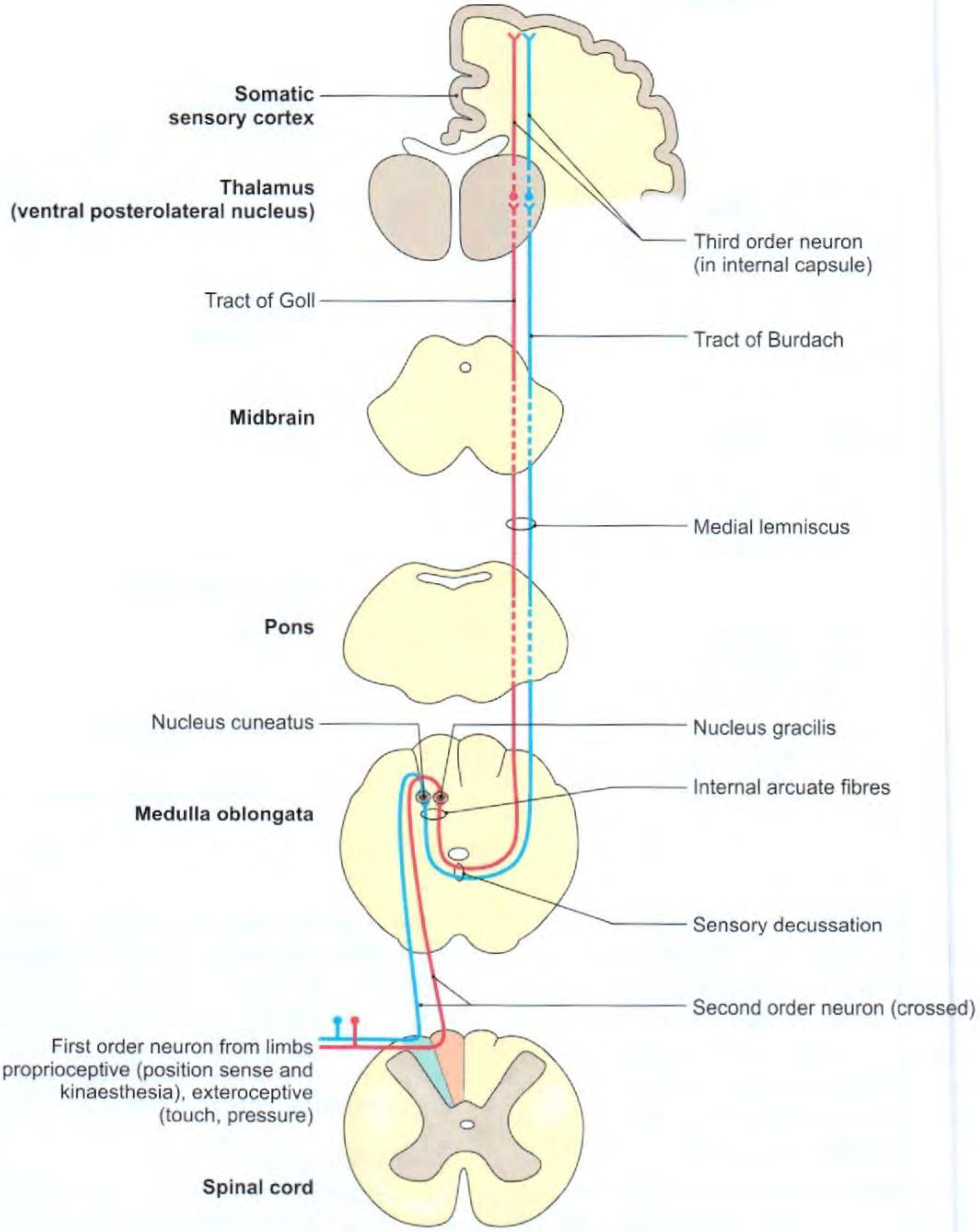


Fig. 3.14: Tracts of dorsal columns

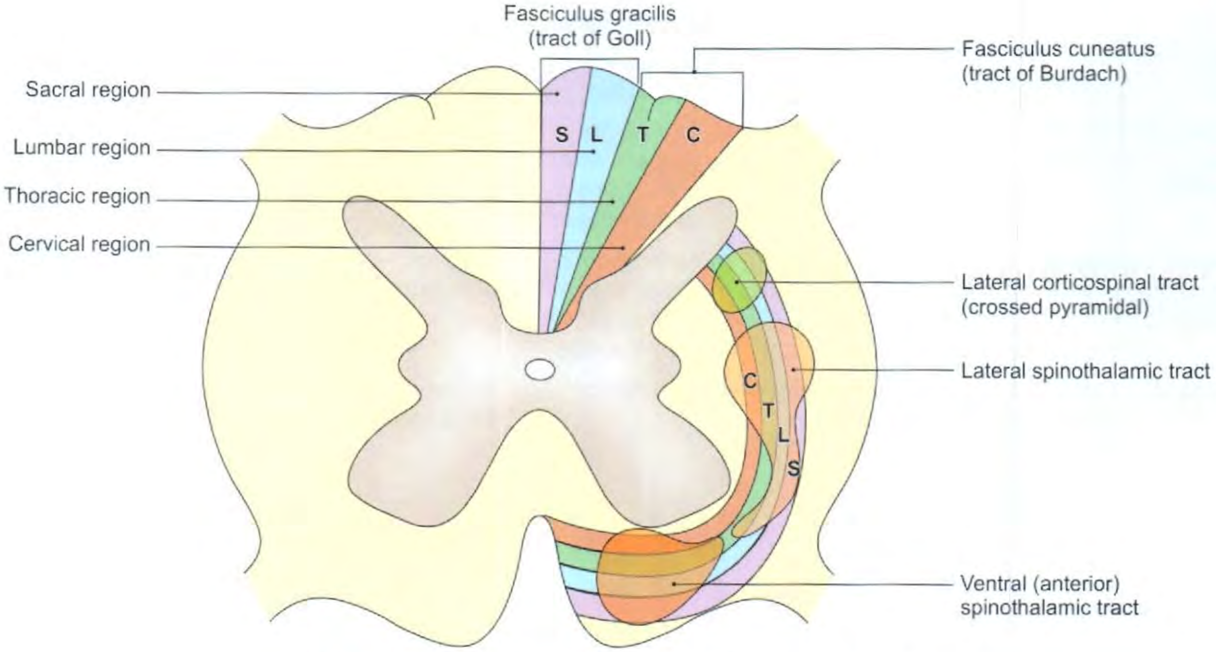


Fig. 3.15: Somatopic lamination of tracts in spinal cord

2 *Fasciculus cuneatus (tract of Burdach):* It commences in mid-thoracic region. It derives its fibres from upper thoracic and cervical segments.

Both fasciculi contain first neuron fibres from central process of dorsal root ganglia and end by synapsing with the neurons in nucleus gracilis and nucleus cuneatus, situated in the medulla oblongata from where second neuron fibres take origin.

Reflex Proprioceptive Sensations

The reflex proprioceptive sensations are carried by dorsal and ventral spinocerebellar tracts. They convey to the cerebellum both exteroceptive (touch) and unconscious proprioceptive impulses arising in Golgi tendon organ and muscle spindle and are essential for the control of posture (Table 3.5).

1 *Dorsal or posterior spinocerebellar tract:* It begins at the level of 3rd lumbar segment of spinal cord. The first neuron fibres are the central processes of dorsal root ganglia. These relay in the dorsal nucleus (thoracic or Clarke's column) which lies on the medial side of the base of posterior grey column in these segments. This relay gives rise to second neuron fibres which form dorsal spinocerebellar tract. This uncrossed tract ascends in the lateral column of white matter of spinal cord. Here it is situated as a flattened band at the posterior region of lateral column, medially in contact with lateral corticospinal tract. It ascends to the level of medulla oblongata where its fibres pass through inferior cerebellar peduncle to reach the cerebellum (Fig. 3.16).

2 *Ventral or anterior spinocerebellar tract:* The first neuron fibres are the central processes of dorsal root ganglia.

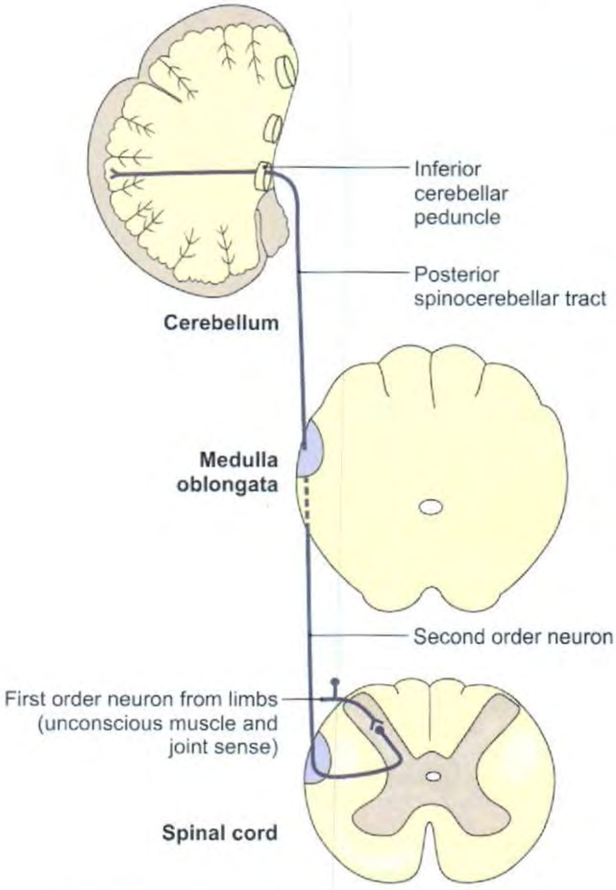


Fig. 3.16: Pathway of dorsal spinocerebellar tract

Table 3.5: The ascending tracts of the spinal cord

Name	*Function*	*Crossed and uncrossed*	*Beginning*	*Termination*
1. Lateral spinothalamic (axons of 2nd order neurons)	Pain and temperature from opposite half of body	Crosses to opposite side in the same spinal segment	Laminae I–IV of posterior grey column	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 fibres 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)	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
7. Spino-olivary (axons of 2nd order neurons)	Proprioceptive sense	Uncrossed	Laminae I–IV column	Dorsal and medial accessory olivary nuclei
8. Spinotectal (axons of 2nd order neurons)	Afferent limb of reflex movements of eyes and head towards	Crossed	Laminae I–IV column	Tectum or superior colliculus of midbrain

The second neuron fibres are derived from the large cells of posterior grey column (laminae V, VI) in the lumbar and sacral segments. The second neuron fibres cross to opposite side. These ascend in the lateral white column of spinal cord anterior to the fibres of dorsal spinocerebellar tract to pass through the medulla oblongata and pons. These fibres finally curve along lateral aspect of superior cerebellar peduncle, and recross with superior cerebellar peduncle to regain their original side of origin (Fig. 3.17).

Functionally, both spinocerebellar tracts control the coordination and movements of muscles controlling posture of the body. The ventral tract conveys muscle and joint information from the entire lower limb, while the dorsal tract receives information from individual muscles of lower limb (Table 3.5).

3 The other ascending tracts, the *spino-olivary* and *spinotectal,* are responsible for proprioceptive and visual reflexes.

INTERSEGMENTAL TRACTS

These are formed of fibres connecting various segments of spinal cord. These are present in anterior, posterior and lateral columns of white matter adjacent to the grey matter of spinal cord. Tract of Lissauer is also an intersegmental tract.

BLOOD SUPPLY OF THE 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 fissure. At the level of medulla, the paired anterior spinal arteries join to form a single artery that lies in the anterior median fissure of the spinal cord. 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). In addition to these channels, the pia mater covering the spinal cord has an arterial plexus (called the *arteria vasocorona)* which also sends branches into

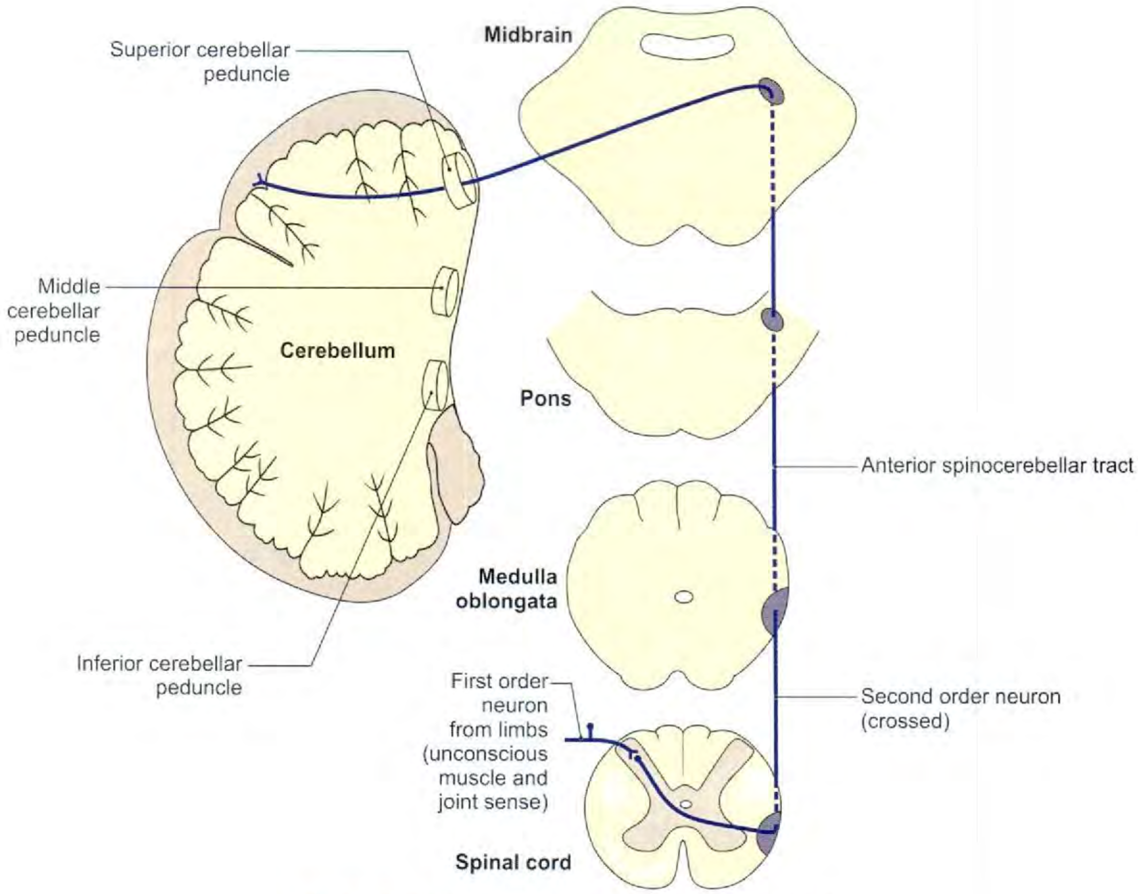


Fig. 3.17: Pathway of ventral spinocerebellar tract

the substance of the cord (*see* Fig. 11.2). 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. Many of these radicular branches are small and end by supplying the nerve roots. A few of them, which are larger, contribute blood to the spinal arteries. Frequently, one of the anterior radicular branches is very large and is called the *arteria radicularis magna.* Its position is variable. This artery may be responsible for supplying blood to as much as the lower two-thirds of the spinal cord.

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.

SUMMARY

Sensations enter the spinal cord via dorsal roots and ascend in the dorsal column as medial lemniscal system and in the anterolateral column as spinothalamic pathways. Both sensory systems decussate, but at different levels (Figs 3.13 and 3.14). Medial leminiscus dicussates in medulla oblongata, while spinothalamic decussate in spinal cord.

Cerebellum gets information about the trunk and legs through dorsal and ventral spinocerebellar tracts and from arm and neck via cuneocerebellar tracts.

Sensations from the face and mouth get carried via trigeminal nerve.

Motor fibres start from motor areas of brain, pass through corona radiata, posterior limb of internal capsule and brainstem. In the lowest part of the medulla oblongata, most of fibres cross to opposite side and terminate on anterior horn cells (Fig. 3.10).

Fibres arising from motor cortex till they reach anterior horn cells are called upper motor neuron fibres. Anterior horn cells and fibres arising from the cells till they reach the muscle are called lower motor neuron fibres.

CLINICAL ANATOMY

Amyotrophic lateral sclerosis: It is a degenerative disease which is caused due to damage of the cells in the ventral horn. The clinical features involve weakness, atrophy of muscles of hands and arms and later extending to the lower limb.

Subacute combined degeneration: The posterior and lateral funiculi are degenerated bilaterally and it is caused due to deficiency of intrinsic factor which helps in absorption of vitamin B_{12}. The symptoms include upper motor neuron lesion features , loss of position and vibratory sensation of lower limbs.

- In lower motor neuron lesion there is flaccidity, hyporeflexia, wasting and it is ipsilateral.

  If all motor neurons reaching a muscle get affected, muscle will be fully paralysed. It will feel flaccid. Since no impulses reach muscle, it will not respond to reflexes.

  As a result of denervation, it will atrophy soon. The paralysis is ipsilateral.
- In upper motor neuron lesion there is spasticity, hyperreflexia, usually no wasting, and it is contralateral.
  a. If upper motor neurons to a muscle get affected, initiation of movement may get lost. Since lower motor neurons are intact, basal ganglia may cause increase in muscle tone, leading to spasticity.
  b. Also reflexes get disinhibited, leading to hyperreflexia.
  c. Muscles do not show wasting except by disuse.
  d. Mostly upper motor neuron lesions are in internal capsule and since these fibres have not yet decussated, the functional loss will be on the contralateral side.

Table 3.6 shows comparison between lower motor neuron (LMN) and upper motor neuron (UMN) paralysis.

Table 3.7 shows the comparison between pyramidal and extrapyramidal tracts.

- *Brown-Séquard's syndrome:* This is caused due to hemisection of the spinal cord (Fig. 3.18). Various features are:

  Below the level of lesion
  a. Ipsilateral upper motor neuron paralysis caused by pyramidal tract damage.
  b. Ipsilateral loss of conscious proprioceptive sensations caused due to damage to posterior white column (Fig. 3.18).
  c. Contralateral loss of pain and temperature and touch caused due to damage to lateral spinothalamic and anterior spinothalamic tracts.

  At the level of lesion:
  a. Ipsilateral lower motor neuron paralysis caused due to damage to ventral nerve roots.
  b. Ipsilateral anaesthesia over the skin of the segment due to injury to the ventral nerve roots.

  Above the level: Ipsilateral hyperaesthesia above the level of lesion due to irritation of dorsal nerve roots.
- *Syringomyelia (Central spinal cord syndrome):* There is formation of cavities around the central canal usually in the lower cervical region. Its features are:
  a. Bilateral loss of pain and temperature occurs due to injury to the decussating fibres of lateral spinothalamic fibres (Fig. 3.19).
  b. Bilateral loss of touch occurs due to injury to anterior spinothalamic tract.

  As the decussation of lateral and anterior spinothalamic tracts occurs at different levels, there is dissociated sensory loss.

  As this disease occurs in lower cervical and upper thoracic regions there is problem in both the upper limbs and front of chest.

  Syringomyelia disrupts the crossing fibres of anterolateral system. The medial lemniscal system is spared.
- *Partial cord lesion (unilateral):* In high cervical lesions, there is weakness of finger movements accompanied by dragging of the leg.
  a. Upper motor neuron paralysis on the side of lesion.
  b. Sensory loss: Numbness on the side of lesion. Joint position sense and two-point discrimination impaired on the side of lesion.
  c. Burning pain, pinprick and temperature sensation impaired on the opposite side.

  Pyramidal fibres synapse with anterior horn cells. These control fine movements of hand and fingers.

  Extrapyramidal fibres have multiple synapses. These are concerned with large muscle groups used in posture and locomotion.

  Thrombosis of anterior spinal artery leads to loss of tracts and loss of motor neurons in anterior two-thirds spinal cord. This results in motor loss due to involvement of the motor neurons in ventral horn of spinal cord, including corticospinal tracts and spinothalamic tracts. It is also known as anterior spinal artery syndrome. Fasciculus gracilis and fasciculus cuneatus remain normal as these are supplied by postrior spinal artery.

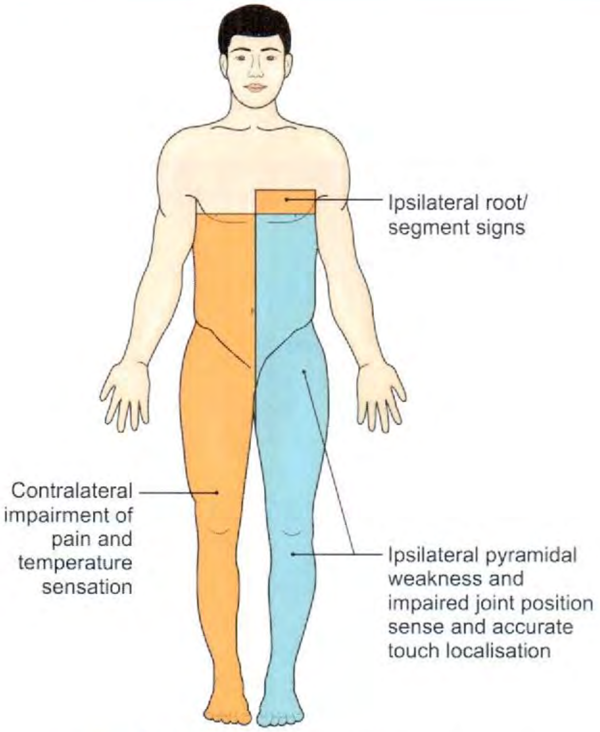


Fig. 3.18: Brown-Séquard's syndrome

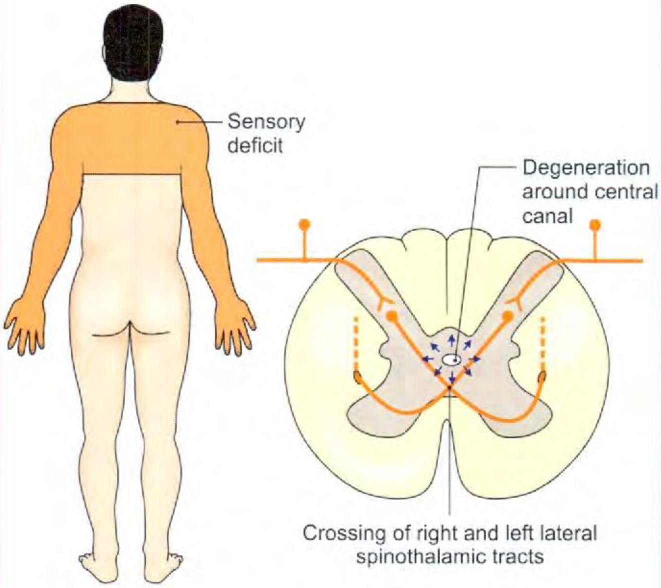


Fig. 3.19: Syringomyelia (*Central spinal cord syndrome*)

Complete Transaction of Spinal Cord

Severe trauma usually results in complete cutting (transaction) of spinal cord. The result is loss of sensation and paralysis of muscles on both the sides at the level of section and below the level of section of spinal cord. Initially this is a stage of "spinal shock". There is flaccid paralysis of all the muscles including loss of all superficial and deep reflexes below the label of injury. There is retention of urine and feces. This stage usually lasts for 3 weeks.

After 3 weeks smooth muscles and skeletal muscles activity reappears but both types of reflexes are exaggerated. There is spastic paralysis.

If transaction occurs above C5, there is paralysis of all 4 limbs (quadriplegia). If injury occurs between T1 and L1 segment, then there is paralysis of both lower limbs (paraplegia).

Treatment of nerve cell injury is at experimental level only by stem cell transplantation. "Prevention is the only cure". Aggression while driving may cost a life or lifelong disability/dependence.

Pain is the most important sensation. The receptors of pain (free nerve endings) are called nociceptors. These get stimulated by burn, chemicals, physical injury, prostaglandins, histamine, etc.

Pain can be treated by giving salicylates, which decreases the prostaglandin formation. Local anaesthetic can also be used to decrease pain temporarily. Even dorsal nerve roots can be cut, but with this, all afferents are abolished. Lastly cordotomy can be done as pain fibers lie superficial in the spinal cord.

Table 3.6: Comparison between lower motor neuron (LMN) paralysis and upper motor neuron (UMN) paralysis

LMN paralysis	*UMN paralysis*
Muscle tone abolished	Muscle tone increased
Leads to flaccid paralysis	Leads to spastic paralysis
Muscles atrophy later	No atrophy of muscles
Reaction of degeneration seen	Reaction of degeneration not seen
Tendon reflexes absent	Tendon reflexes exaggerated
Limited damage	Extensive damage
Ipsilateral	Mostly contralateral
Babinski sign negative	Babinski sign positive
All superficial and deep reflexes lost due to damage to motor pathways	Superficial reflexes like abdominal, cremasteric, plantar are lost due to damage to corticospinal tracts
May affect single muscle group as in poliomyelitis and Bell's palsy	Affects many groups of muscles as in hemiplegia. Damage to corticospinal tract removes the inhibitory effect on the superficial reflexes, resulting in Babinski positive sign
	There is loss of control on lower motor neurons, which become hyperactive, leading to spastic paralysis

Table 3.7: Comparison of pyramidal and extrapyramidal tracts

Pyramidal tracts	*Extrapyramidal tracts*
Recent in evolution	Older in evolution
These comprise only corticospinal and corticonuclear tracts	These comprise olivospinal, vestibulospinal, tectospinal, reticulospinal, rubrospinal tracts
Origin from motor cortex	Thes arise from olivary vestibular, tectum (collicular) reticular and red nuclei
The impulse passes directly to anterior horn cells	Impulse passes by polysynaptic route via cortex, basal ganglia, cerebellum and brainstem
Function is to perform voluntary skilled movement	Control tone and equilibrium. These facilitate/inhibit flexor/ extensor reflexes
Injury leads to increased muscle tone and loss of motor activity	Injury leads to increased muscle tone with clasp knife rigidity

FACTS TO REMEMBER

- Spinal cord shows cervical enlargement for the supply of upper limb muscles. It also shows lumbar enlargement for the supply of lower limb muscles.
- Spinal cord in adult is much shorter than the vertebral canal. The cord ends at the lower border of lumbar one (L1) vertebra.
- Lateral horn is only present in T1–L2 and S2–S4 segments of spinal cord.
- Sympathetic fibres (white ramus communicans) start from lateral horn → ventral root → trunk of spinal nerve → ventral primary ramus → sympathetic ganglion (Fig. 3.7).
- The sympathetic ganglion gives grey ramus communicans (grc), after receiving and relaying the white ramus communicans (wrc).
- Corticospinal fibres cross to the opposite side; 80% cross in pyramidal decussation, 15% cross in the spinal cord and 5% do not cross.
- Out of 6 main ascending tracts; Two going to the cerebellum and reach the ipsilateral side sooner/ later. Two relay in nuclei of spinal cord to reach opposite side. Two relay in the nuclei present in the medulla oblongata to reach the opposite side.
- Polio virus affects the neurons of anterior horn cells of the spinal cord. Polio drops as a vaccine has eradicated the dreadful disease.

CLINICOANATOMICAL PROBLEMS

Case 1

A 7-year-old boy has been having high grade fever for 5 days. One evening he complained of weakness in his right lower limb. Soon he could not support the weight.

- What is the probable diagnosis?
- Which part of the nervous system is affected?
- What type of paralysis is it and what are its features?

Ans: The likely diagnosis is the viral infection of poliomyelitis. The part of the nervous system affected is the anterior horn cells of the spinal cord from lumbar 2 to sacral 5 segments of spinal cord. The type of paralysis is the lower motor neuron paralysis. Muscles feel flaccid, tendon reflexes get absent, reaction of degeneration is seen. Later there is muscular atrophy. The limb becomes thinner and shorter than the opposite limb.

Case 2

A young person is involved in an automobile accident with injury at cervical 5 and cervical 6 vertebrae. He develops paralysis of all four limbs

- What type of paralysis is the person suffering from?
- What are the differences between upper motor neuron and lower motor neuron paralysis?

Ans: The young person has developed upper motor neuron paralysis in his limbs. His symptoms are:

- Loss of power of voluntary movements
- Tendon reflexes are exaggerated
- Babinski sign is positive (*see* Fig. 1.7)
- Reaction of degeneration is absent

The differences between upper motor neuron and lower motor neuron types of paralysis are mentioned in clinical anatomy of this chapter.

FREQUENTLY ASKED QUESTIONS

1. Describe the ascending tracts of spinal cord.
2. Describe the descending tracts of spinal cord.
3. Write short notes on:
   a. Sensory receptors
   b. Nuclei in posterior grey column
   c. Syringomyelia
   d. Differences between upper motor neuron and lower motor neuron paralysis

MULTIPLE CHOICE QUESTIONS

1. In spinal cord, myelin sheath is formed by:
   a. Schwann cells   b. Oligodendrocytes
   c. Astrocytes   d. Microglia

2. Medial lemniscus carries:
   a. Pain and temperature sensation from trunk and limbs
   b. Proprioceptive sensations from trunk and limbs
   c. Proprioceptive sensation from head
   d. Auditory sensation

3. Regarding spinal cord, the following are true *except:*
   a. It has cervical and lumbar enlargements
   b. It ends in adults at lower border of 3rd lumbar vertebra
   c. It is traversed by the central canal
   d. It begins at level of foramen magnum as a continuation of medulla oblongata

4. Regarding corticospinal tract all of the following are true *except:*
   a. Most of fibres decussate at lower end of medulla oblongata
   b. It arises from motor area of cerebral cortex
   c. It ends in anterior horn cells
   d. Its lesion at level of pons produces paralysis of ipsilateral side

5. Injury of lateral spinothalamic tract results in:
   a. Ipsilateral loss of pain and temperature
   b. Contralateral loss of touch and pressure
   c. Contralateral loss of pain and temperature
   d. None of the above

6. Following tracts are present in lateral white column *except:*
   a. Lateral spinothalamic
   b. Rubrospinal
   c. Ventral spinocerebellar
   d. Fasciculus gracilis

7. Regarding spinal cord, all are true *except:*
   a. It ends in adults at lower border of L1
   b. The cord is covered by 3 meninges
   c. It shows thoracic and lumbar enlargements
   d. Grey matter occupy its central part

8. Lateral corticospinal tract terminates at:
   a. Clarke's column
   b. Substantia gelatinosa
   c. Anterior horn cells of spinal cord
   d. Ventroposterolateral nucleus of thalamus

9. Pyramidal fibres mostly arise from Brodmann's cortical area:
   a. 3, 1, 2   b. 8
   c. 4   d. 18

10. Which of the following tracts contains primary afferent neuron fibres?
   a. Fasciculus gracilis and fasciculus cuneatus
   b. Anterior spinothalamic tract
   c. Lateral spinothalamic
   d. Dorsal spinocerebellar

ANSWERS

1. b	**2.** b	**3.** b	**4.** d	**5.** c	**6.** d	**7.** c	**8.** c	**9.** c	**10.** a

CHAPTER

4

Cranial Nerves

Stolen kisses are always the sweetest
—Leigh Hunt

INTRODUCTION

The 12 pairs of cranial nerves supply muscles of eyeball, face, palate, pharynx, larynx, tongue and two large muscles of neck, lungs, heart and most of the part of gastrointestinal tract. Besides these, they are afferent to special senses like smell, sight, hearing, taste and touch.

Some nerves form the afferent loop and others form the efferent loop of the reflex arc. Olfactory takes the sense of smell and stimulates dorsal nucleus of vagus for enhanced secretion if the smell is good. Optic nerve is afferent from eye while III, IV and VI are efferent to the eye muscles. CN V, the largest cranial nerve, is mainly sensory to the face. The motor nerve of face is VII nerve. To come close to V nerve nucleus, VII nucleus winds around VI nucleus so that a reflex arc can be mediated between the afferent and efferent loops of the arc. It is termed as "neurobiotaxis". Statoacoustic nerve is afferent for hearing and balance while spinal root accessory acts as its efferent component for turning the face to the side from where sound is heard. VII, IX and X are carrying sensation of taste from tongue and efferent component is XII nerve for movements of tongue and nucleus ambiguus gives fibres to IX, X, and cranial root of XI for the muscles of palate, pharynx and larynx.

FEATURES

There are 12 pairs of cranial nerves. Each cranial nerve has a number and a name as follows:

	Mnemonic
I – Olfactory	oh,
II – Optic	oh,
III – Oculomotor	oh,
IV – Trochlear	try,
V – Trigeminal	try,
VI – Abducent	again
VII – Facial	failure,
VIII – Vestibulocochlear (statoacoustic)	victory
IX – Glossopharyngeal	give
X – Vagus	value
XI – Accessory	and
XII – Hypoglossal	happiness

Attachment of the nerves to brain:

I, II to the forebrain.

III, IV to midbrain.

V, VI, VII VIII to the pons.

IX, X, XI, XII to the medulla oblongata (Fig. 4.1).

EMBRYOLOGY

During early stages of development, the wall of the neural tube is made up of three layers:

a. The inner ependymal layer.
b. The middle mantle layer.
c. The outer marginal layer.

The mantle layer represents grey matter and the marginal layer, the white matter.

Soon the mantle layer differentiates into a dorsal alar lamina (sensory) and a ventral basal lamina (motor), the two are partially separated internally by the sulcus limitans.

Functional components of cranial nerves:

In the spinal cord, though grey matter forms a compact fluted column in the centre, it shows differentiation into two somatic and two visceral functional columns. The somatic columns are the general somatic efferent (motor or anterior horn) and the general somatic afferent (sensory or posterior horn).

These supply structures derived from somites. The visceral columns are the general visceral efferent (motor) and the general visceral afferent (sensory).

These are autonomic columns and supply the viscera, vessels and glands (Fig. 4.2a).

In the brain stem, particularly hindbrain, the alar and basal laminae come to lie in the same ventral plane

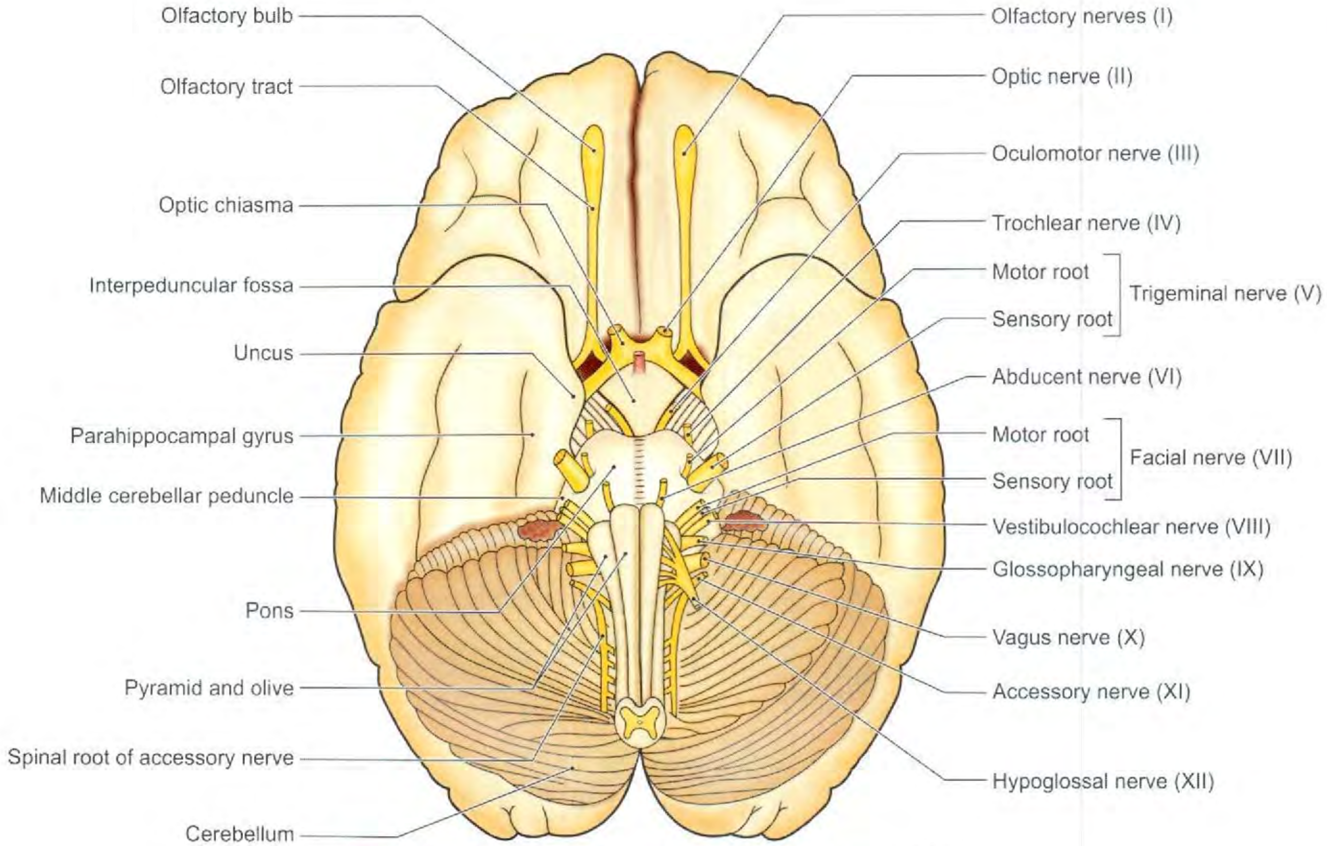


Fig. 4.1: Attachment of cranial nerves to the base of brain

because of stretching of the roof plate (dorsal wall) of neural tube by pontine flexure. Further, the grey matter forms separate longitudinal functional columns, where the motor columns (from basal lamina) are medial and the sensory columns (from alar lamina) lateral in position.

In addition to the four functional columns differentiated in the spinal cord, there appear two more columns (a motor and a sensory) for the branchial apparatus of the head region, namely the special visceral (branchial) efferent and the special visceral afferent; and one column more for the special sense, namely the special somatic afferent. Thus a total of seven columns (3 motor and 4 sensory) are formed. Each column, in its turn, breaks up into smaller fragments to form nuclei of the cranial nerves (Fig. 4.2b).

NUCLEI

The details of the nuclei of cranial nerves are summarized in Table 4.1.

General Somatic Efferent (GSE) Nuclei

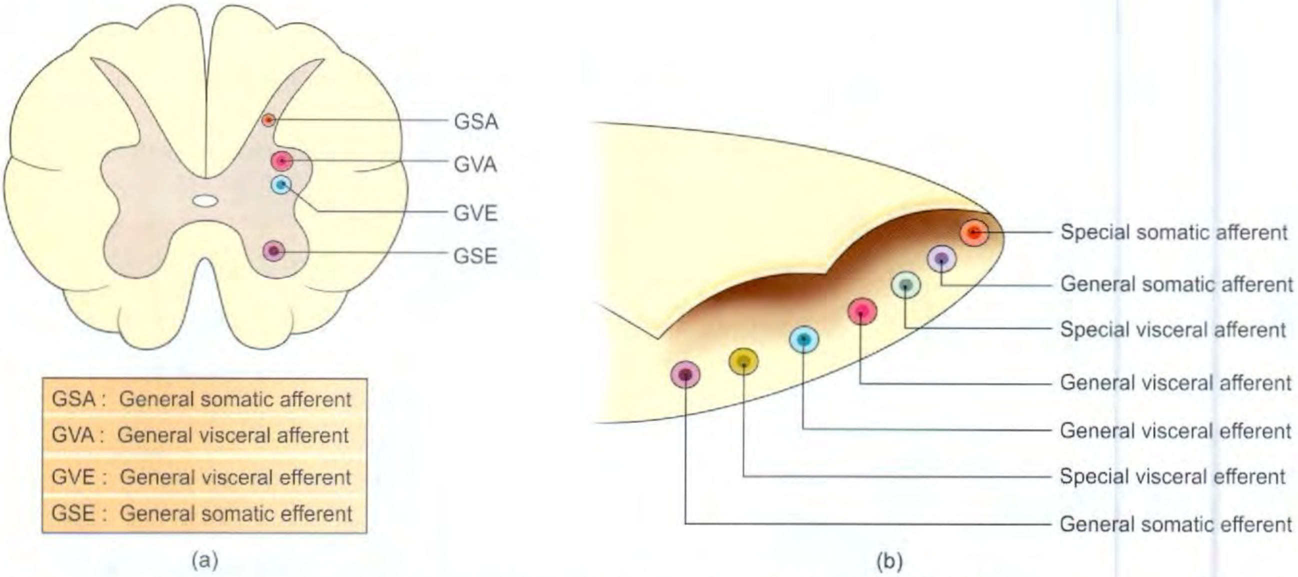
These nuclei supply skeletal muscle of somatic origin (Figs 4.3 and 4.4a).

1. The *oculomotor nucleus* is situated in the midbrain at the level of the superior colliculus. Its fibres enter the oculomotor nerve and supply five extrinsic muscles of the eyeball except the lateral rectus and the superior oblique.
2. The *trochlear nucleus* is situated in the midbrain at the level of the inferior colliculus. It supplies only the superior oblique muscle through the trochlear nerve.
3. The *abducent nucleus* is situated in the lower part of the pons. It supplies only the lateral rectus muscle through the abducent nerve.
4. The *hypoglossal nucleus* lies in the medulla. It is elongated and extends into both the open and closed parts of the medulla. It supplies seven out of eight muscles of the tongue through the hypoglossal nerve.

Special Visceral Efferent/Branchial Efferent Nuclei

These nuclei supply striated muscle derived from the branchial arches.

1. The *motor nucleus of the trigeminal nerve* lies in the upper part of the pons. It supplies the muscles of mastication through the mandibular nerve.
2. The *nucleus of the facial nerve* lies in the lower part of the pons. It supplies the various muscles innervated by the facial nerve.



Figs 4.2a and b: Transverse section of an embryo showing the arrangement of functional/nuclear columns of cranial nerve nuclei. (a) Spinal cord, and (b) in brain stem

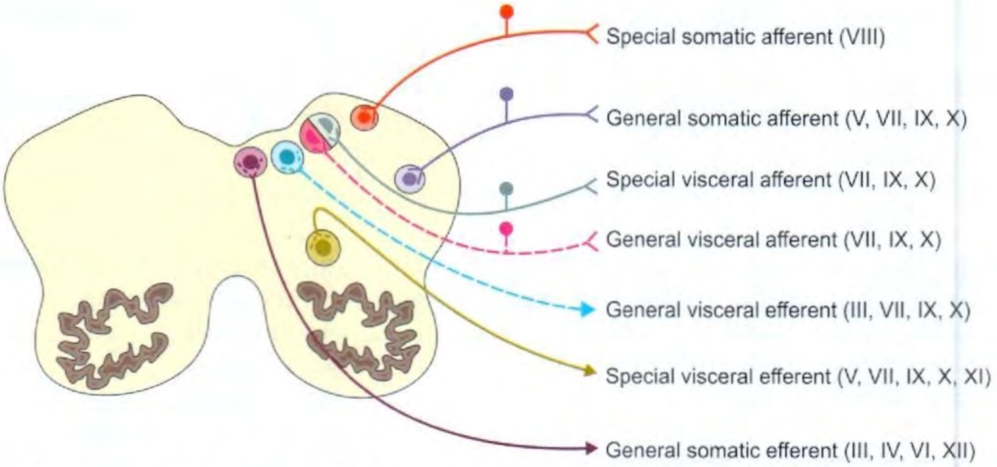


Fig. 4.3: Transverse section of medulla oblongata showing the position of cranial nerve nuclear columns

3 The *nucleus ambiguus* lies in the medulla. It forms an elongated column lying in both the open and closed parts of the medulla. It supplies:
   a. The stylopharyngeus muscle through the glossopharyngeal nerve; and
   b. The muscles of the soft palate, the pharynx and the larynx through the vagus and the cranial part of the accessory nerve (Fig. 4.3).

General Visceral Efferent Nuclei

These nuclei give origin to preganglionic neurons that relay in a peripheral autonomic ganglion. Postganglionic fibres arising in the ganglion supply smooth muscles or glands (Fig. 4.4a).

1 The *Edinger-Westphal nucleus* lies in the midbrain in close relation to the oculomotor nucleus. Its fibres pass through the oculomotor nerve to the ciliary ganglion to supply the sphincter pupillae and the ciliaris muscles.

2 The *lacrimatory nucleus* lies near the salivatory nuclei (in the lower pons). It gives off fibres that pass through the facial nerve and its branch, the greater petrosal nerve to relay in the pterygopalatine ganglion and supply the lacrimal, nasal, palatal and pharyngeal glands.

3 The *superior salivatory nucleus* lies in the lower part of the pons. It sends fibres through the facial nerve and its chorda tympani branch to the submandibular ganglion for supply of the submandibular, sublingual salivary glands and glands in the oral cavity.

4 The *inferior salivatory nucleus* lies in the lower part of the pons just below the superior nucleus. It sends fibres through the glossopharyngeal nerve to the otic ganglion for supply of the parotid gland (Fig. 4.4b).

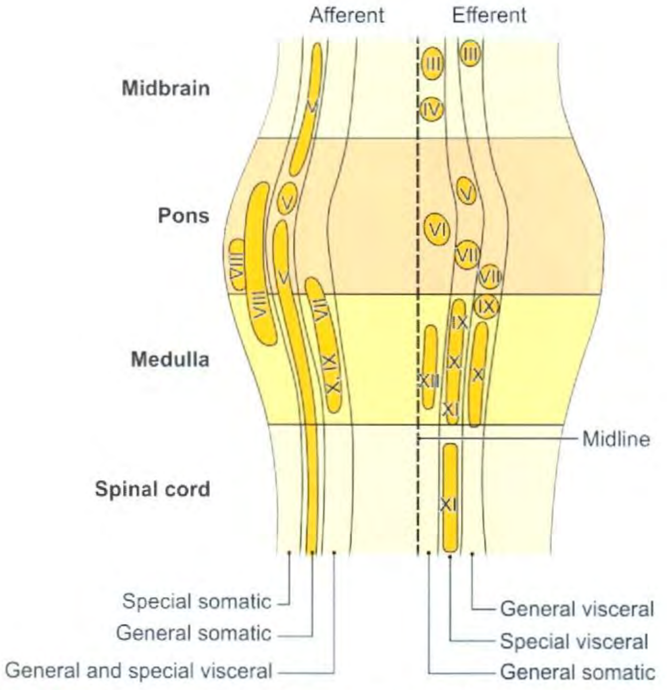


Fig. 4.4a: Position of cranial nerve nuclear columns in brain stem

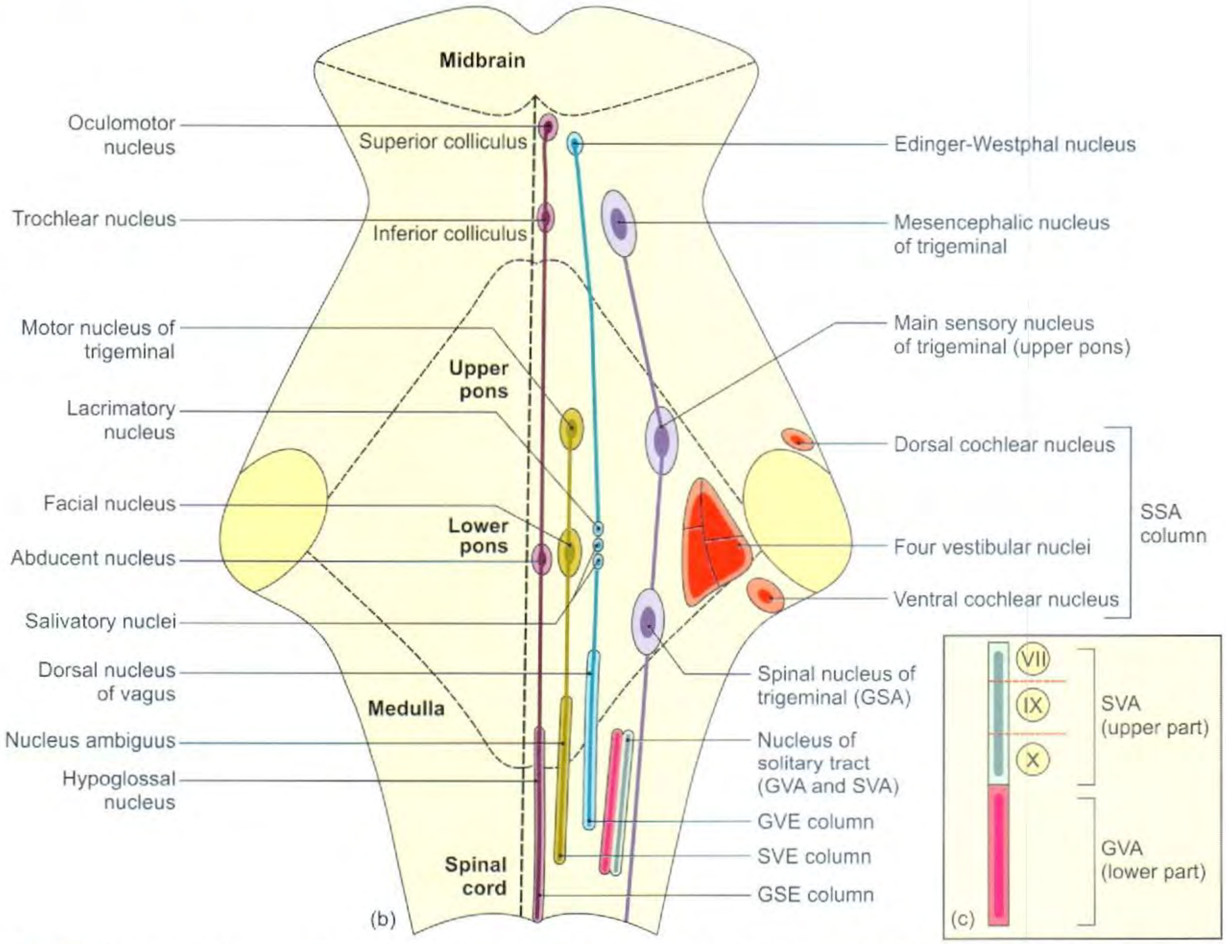
5 The *dorsal nucleus of the vagus* is a long column extending into the open and closed parts of the medulla. It gives off fibres that pass through the vagus nerve to be distributed to thoracic and abdominal viscera (the ganglia concerned are present in the walls of the viscera supplied).

General Visceral Afferent Nucleus and Special Visceral Afferent Nucleus (Table 4.1)

The only nucleus in this category is the *nucleus of solitary tract* or tractus solitarius. It lies in the medulla and extends into both its closed and open parts.

Its lower part receives *general visceral sensations* as follows:

a. Through the glossopharyngeal nerve from the tonsil, pharynx, posterior part of the tongue, carotid body and carotid sinus.
b. Through the vagus nerve from the pharynx, larynx, trachea, oesophagus and other thoracic and abdominal viscera.



Figs 4.4b and c: (b) Scheme to show the cranial nerve nuclei as projected on to the posterior surface of the brain stem with four vestibular nuclei, and (c) parts of nucleus of tractus solitarius: VII—facial; IX—glossopharyngeal and X—vagus

Table 4.1: Nuclei of the cranial nerves

Nerves	*Nuclei*	*Location*	*Functions*	*Function of the nerve component*
I	—	—	SVA	Smell
II	—	—	SSA	Sight
III	Oculomotor nucleus	Midbrain, level of superior colliculus	GSE	Movements of eyeball
			GVE	Contraction of pupil, accommodation
			GSA*	Proprioceptive
IV	Trochlear nucleus	Midbrain, level of inferior colliculus	GSE	Movement of eyeball (superior oblique)
			GSA*	Proprioceptive
V	1 Motor nucleus	Upper pons	BE/SVE	Movement of mandible
	2 Mesencephalic nucleus	Midbrain	GSA	Proprioceptive, muscles of mastication, face and eye
	3 Superior sensory nucleus	Upper pons	GSA	Touch and pressure from skin and mucous membrane of facial region
	4 Spinal nucleus	From upper pons to C2 segment of spinal cord	GSA	Pain and temperature of face
VI	Abducent nucleus	Lower pons	GSE	Lateral movement of eyeball
			GSA*	Proprioceptive
VII	1 Motor nucleus	Lower pons	BE/SVE	Facial expressions, elevation of hyoid
	2 Nucleus of tractus solitarius	Lower pons	SVA	Taste, anterior two-thirds of tongue
	3 Superior salivatory nucleus	Lower pons	GVE	Secretomotor to submandibular and sublingual salivary glands
	4 Lacrimatory nucleus	Lower pons	GVE	Secretomotor to lacrimal gland, nasal and palatal glands, etc.
			GSA	Proprioceptive
VIII cochlear	Two cochlear nuclei, dorsal and ventral	Junction of medulla and pons	SSA	Hearing
Vestibular	Four vestibular nuclei, superior, spinal, medial and lateral	Junction of medulla and pons	SSA	Equilibrium of head
IX	1 Nucleus ambiguus	Medulla	BE/SVE	Elevation of larynx
	2 Inferior salivatory nucleus	Medulla	GVE	Secretomotor to parotid gland
	3 Nucleus of tractus solitarius	Medulla	SVA	Taste from posterior one-third of tongue
			GVA*	Sensations from mucous membrane of pharynx and posterior one-third of tongue go to dorsal nucleus of vagus and spinal nucleus of V nerve
			GSA*	Proprioceptive
X and cranial part of XI	1 Nucleus ambiguus	Medulla	BE/SVE	Movements of palate, pharynx and larynx distributed through to X
	2 Dorsal nucleus of vagus	Medulla	GVE	Motor and secretomotor to bronchial tree and gut; inhibitory to heart
			GVA	Sensations from viscera
	3 Nucleus of tractus solitarius	Medulla	SVA	Taste from posterior most part of tongue and epiglottis
			GSA*	Sensations from the skin of external ear go to the spinal nucleus of V nerve
Spinal part of XI	Spinal nucleus of accessory nerve	Spinal cord, CI-5 segments	BE/SVE	Sternocleidomastoid and trapezius
XII	Hypoglossal nucleus	Medulla	GSE	Movements of tongue
			GSA	Proprioceptive

GSE: general somatic efferent; BE: branchial efferent; GVE: general visceral efferent; GVA: general visceral afferent; SVA: special visceral afferent; GSA: general somatic afferent; SSA: special somatic afferent.

* These components do not have corresponding nuclei and terminate in the nuclei of different nerves.

Its upper part also receives *sensations of taste* (special visceral afferent) as follows:

a. From the anterior two-thirds of the tongue, and the palate except circumvallate papillae through the facial (VII) nerve in its superior part (Fig. 4.4c).
b. From the posterior one-third of the tongue through the glossopharyngeal nerve (IX) including the circumvallate papillae in its middle part.
c. From the posteriormost part of the tongue and from the epiglottis through the vagus (X) nerve in its inferior part.

General Somatic Afferent Nuclei

These are all related to the trigeminal nerve.

1 The *main or superior sensory nucleus of the trigeminal nerve* lies in the upper part of the pons (Fig. 4.1).

2 The *spinal nucleus of the trigeminal nerve* descends from the main nucleus into the medulla. It reaches the upper two segments of the spinal cord (Fig. 4.4b). Its parts are:
   a. Pars caudalis which receives impulses of pain, temeprature from forehead
   b. Pars interpolaris receives impulses from cheek
   c. Pars oraris receive impulses from around mouth.

3 The *mesencephalic nucleus of the trigeminal nerve* extends upwards from the main sensory nucleus into the midbrain. It is the only example of primary sensory neuron whose cell bodies are within CNS.

These nuclei receive the following fibres:

a. Exteroceptive sensations (touch, pain, temperature) from the skin of the face, through the trigeminal nerve; and from a part of the skin of the auricle through the vagus (auricular branch) and through the facial nerve.
b. Proprioceptive sensations from muscles of mastication reach the mesencephalic nucleus through the trigeminal nerve. The nucleus is also believed to receive proprioceptive fibres from the ocular, facial and lingual muscles, teeth and temporomandibular joint.

Special Somatic Afferent Nuclei

1 The *cochlear nuclei* (dorsal and ventral) that receive impulses of hearing through the cochlear nerve.

2 The *vestibular nuclei* (superior, spinal, medial and lateral) that receive fibres from the semicircular canals, the utricle and the saccule through the vestibular nerves (Table 4.1).

Special Features

Muscles of facial expression of lower face are supplied only from contralateral motor cortex.

The muscles of upper face are supplied both from ipsilateral and contralateral motor cortex (Fig. 4.5a).

Cranial part of nucleus ambiguus gives fibres to IX, X and cranial root of XI nerve. The caudal part of this nucleus gives fibres to spinal root of XI nerve (Fig. 4.5b).

The genioglossus muscle of the tongue receives fibres from contralateral motor cortex only. Rest of the muscles of the tongue receive from both ipsilateral cortex and contralateral motor cortex (Fig. 4.5c).

Highlights of the cranial nerves are shown in Fig. 4.6.

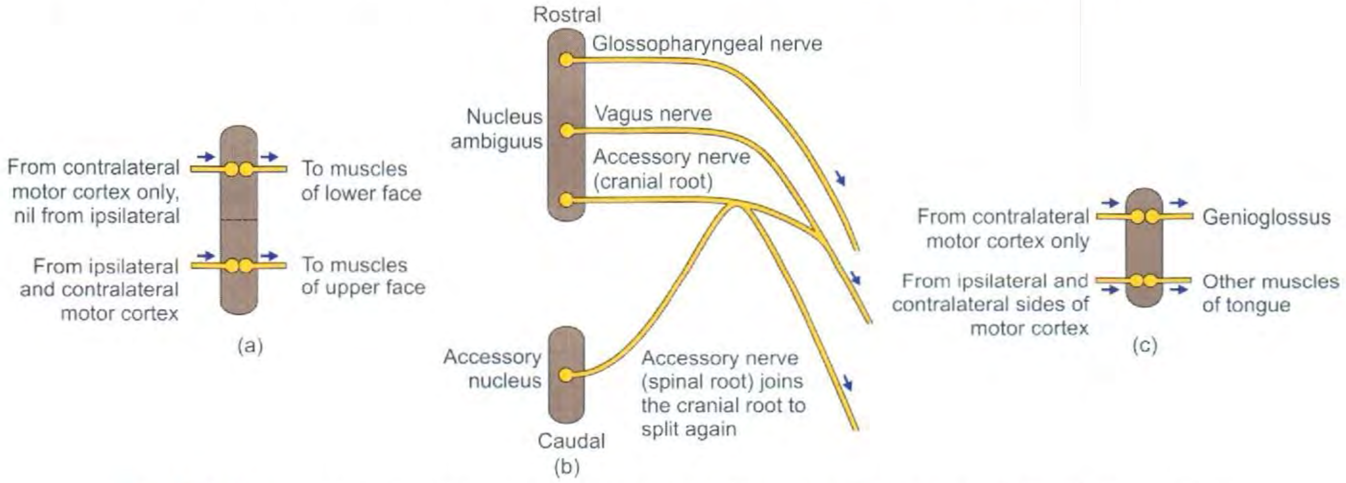
FIRST CRANIAL NERVE

OLFACTORY (SMELL) PATHWAY

It belongs to special visceral afferent column.

Receptors and the First Neuron

1 The *olfactory cells* (16–20 million in man) are bipolar neurons. They lie in the olfactory part of the nasal mucosa, and serve both as receptors as well as the first neurons in the olfactory pathway.



Figs 4.5a to c: (a) Nucleus of facial nerve, (b) nucleus ambiguus, and (c) nucleus of hypoglossal nerve

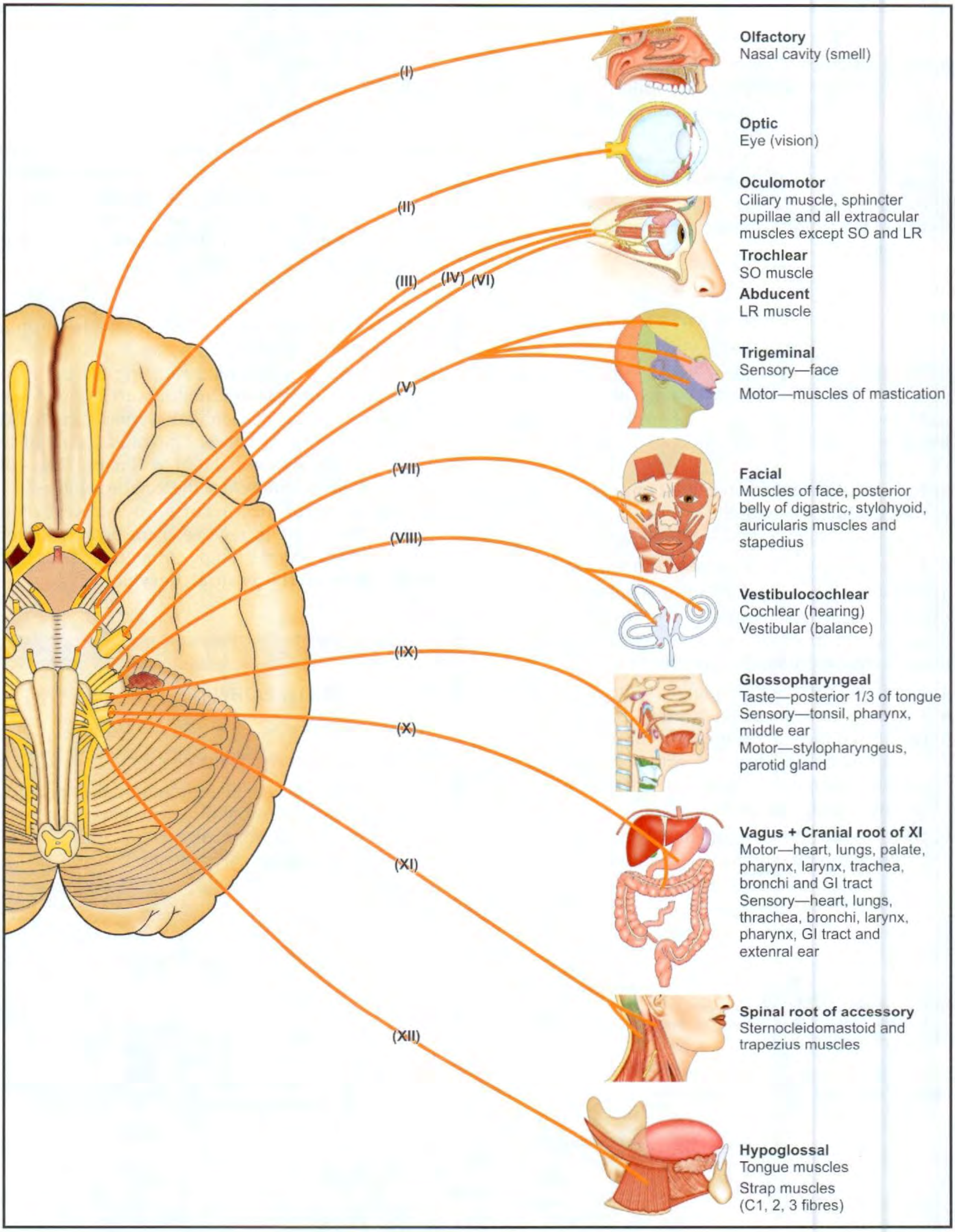


Fig. 4.6: Highlights of the cranial nerves

2 The *olfactory* nerves, about 20 in number, represent central processes of the olfactory cells. They pass through the cribriform plate of ethmoid and make synaptic glomeruli with cells of olfactory bulb.

Second Neuron

The mitral and tufted cells in the olfactory bulb give off fibres that form the *olfactory tract* and reach the primary olfactory areas (Fig. 4.7a). These are located in the primary olfactory cortex which includes the anterior perforated substance, periamygdaloid and prepiriform area .

Third Neuron

Third neuron located in the primary olfactory cortex which includes the anterior perforated substance, and several small masses of grey matter around it like periamygdaloid area and prepiriform area.

Fourth Neuron

Fibres arising in the primary olfactory cortex go to the secondary olfactory cortex (entorhinal area) located in the uncus and anterior part of the parahippocampal gyrus, tertiary olfactory cortex in posterior part of orbitofrontal cortex.

Smell is perceived in both the primary and secondary olfactory areas (Fig. 4.7a).

Some impulses from uncus travel via medial forebrain bundle and reticular formation to dorsal nucleus of vagus and salivatory nuclei in medulla oblongata, where these may increase or decrease gastric secretion according to type of smell (Fig. 4.7b).

Olfactory afferent pathway comprises only two neurons. The fibres reach the cerebral cortex without synapsing in any of the thalamic nuclei.

CLINICAL ANATOMY

- *Anosmia:* Loss of olfactory fibres with ageing.
- Sense of smell is tested separately in each nostril.
- Allergic rhinitis causes temporary olfactory impairment.
- *Head injury:* Olfactory bulbs may be torn away from olfactory nerves as these pass through fractured cribriform plate of ethmoid leading to anosmia. Such a fracture may also cause CSF rhinorrhoea, i.e. CSF leakage through the nose.
- Abscess of frontal lobe of brain or meningioma in the anterior cranial fossa may press on the olfactory bulb or olfactory tract resulting in anosmia.
- *Uncinate fits:* Lesion of lateral olfactory area may cause temporal lobe epilepsy or uncinate fits. These fits are of imaginary disagreeable odors with involvement of tongue and lips.

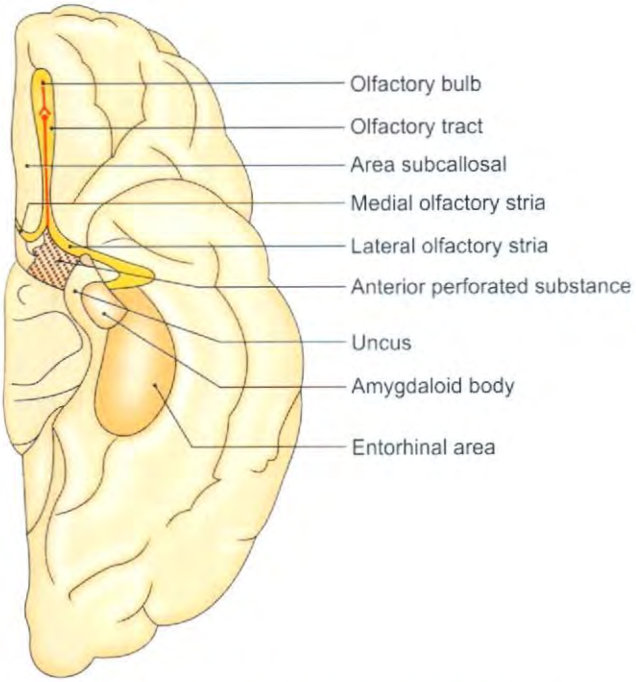


Fig. 4.7a: Inferior view of brain showing olfactory areas

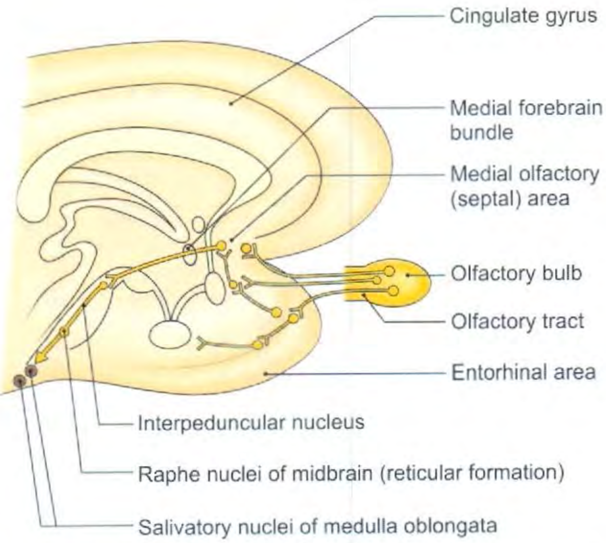


Fig. 4.7b: Some connections of olfactory cortical areas

SECOND CRANIAL NERVE

HUMAN VISION

Human vision is binocular, though one sees with both the eyes, the inverted images formed are seen as one and straight only (Fig. 4.8).

Human vision is stereoscopic, i.e. one sees height, width and thickness of the object.

Human vision is coloured, one sees different colours put up by nature.

When one looks at an object, both eyes are focused on it. Right eye sees a little additional of right side whereas left eye sees a little additional of left side of the object. These visions are monocular visions. Main part is the binocular vision.

OPTIC PATHWAYS

Field of Vision

It includes four fields as upper temporal, lower temporal, upper nasal and lower nasal. Nasal fields are smaller than the temporal fields. Larger right temporal and smaller right nasal fields of vision fuse to form right part of binocular field. Left halves of field of vision, i.e. larger temporal half and smaller nasal half of left field of vision form left half of binocular field.

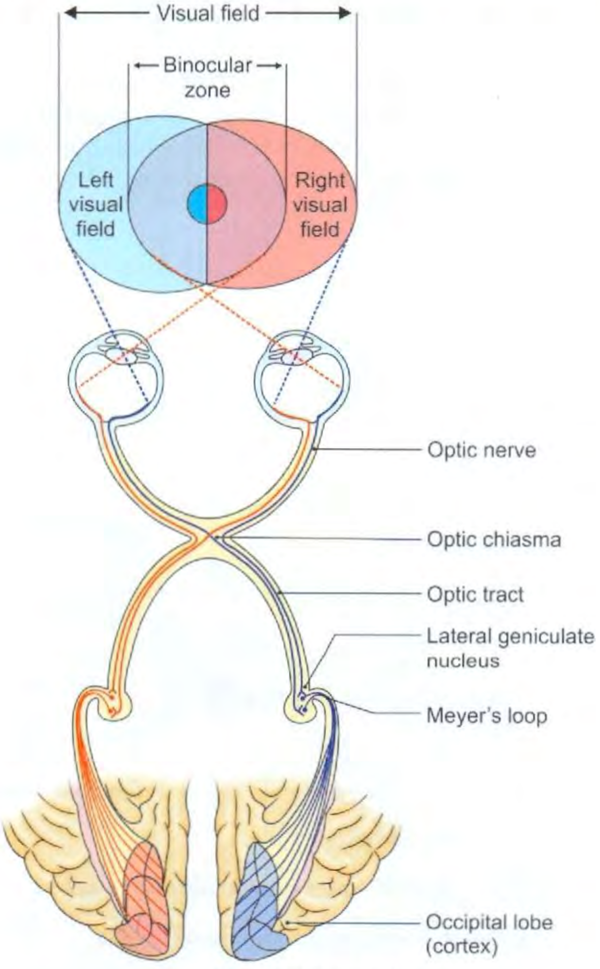


Fig. 4.8: Visual pathways

Most importantly there is a macular vision which is the most acute or sharp and coloured vision.

Retina: Retina is also divided into temporal and nasal parts and each is further subdivided into upper and lower parts. Temporal field is seen by nasal hemiretina and vice versa. Fibres from the nasal parts of the two retinae decussate to form the optic chiasma and travel to the contralateral side in the optic tract. Fibres from the temporal hemiretinae continue ipsilaterally in the optic tract.

Right optic tract carries the fibres of the right temporal hemiretina and the left nasal hemiretina and vice versa. Macular fibres lie in the central part of optic tract, upper retinal fibres project downwards and lower retinal fibres project upwards.

Retina

It is described in Chapter 19 of Volume 3. First order neurons are represented by the bipolar cells of retina. They receive impulses from the rods and cones present in the retina.

Optic Nerve

Optic nerve is made up of axons of ganglion cells of the retina which form the second order neurons. In a strict sense, the optic nerve is not a peripheral nerve because its fibres have no neurilemmal sheaths. It is a tract. Its fibres have no power of regeneration. The nerve is described in Chapter 13 of Volume 3.

Optic Chiasma

In the chiasma, the nasal fibres (i.e. fibres of the optic nerve arising in the nasal, or medial half of the retina) including those from the nasal half of the macula, cross the midline and enter the opposite optic tract. The temporal (lateral) fibres pass through the chiasma to enter the optic tract of the same side (Fig. 4.8).

Optic Tract

Each optic tract winds round the cerebral peduncle of the midbrain. Near the lateral geniculate body, it divides into lateral and medial roots. The lateral root is thick and terminates in the lateral geniculate body. A few of its fibres pass to the superior colliculus, the pretectal nucleus and the hypothalamus. The medial root is believed to contain the supraoptic commissural fibres.

Each optic tract contains temporal fibres of retina of the same side and nasal fibres of the opposite side.

Lateral Geniculate Body

Lateral geniculate body receives the lateral root of the optic tract. Medially, it is connected to the superior colliculus, and laterally, it gives rise to the optic radiation.

The cells in this body are arranged in six layers which form the third order neurons.

Layers 2, 3, 5 receive ipsilateral fibres, and layers 1, 4, 6 receive contralateral fibres.

Optic Radiation (Geniculocalcarine Tract)

Optic radiation begins from the lateral geniculate body, passes through the retrolentiform part of internal capsule, and ends in the visual cortex (Fig. 4.8).

Visual Cortex

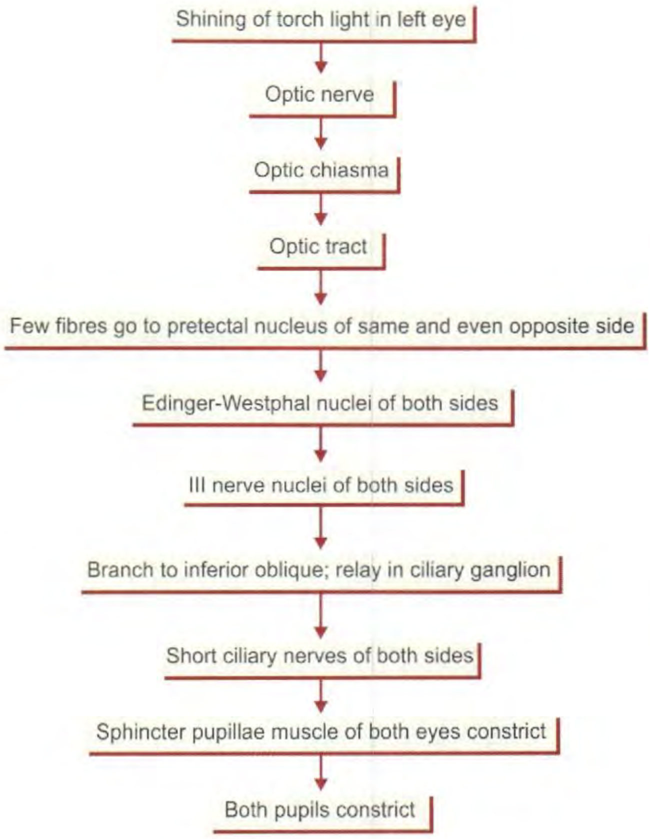
The optic radiation terminate in the striate area where the colour, size, shape, motion, illumination and transparency are appreciated separately. Objects are identified by integration of these perceptions with past experience stored in the parastriate and peristriate areas 18 and 19.

The area of the visual cortex that receives impulses from the macula is relatively much larger than the part related to the rest of the retina.

REFLEXES

These are: (1) pupillary light reflex (Fig. 4.9 and Flowchart 4.1), (2) accommodation reflex (Fig. 4.10 and Flowchart 4.2), (3) dilation of pupil (Flowchart 4.3), (4) corneal/conjunctival reflex (Fig. 4.11 and Flowchart 4.4), (5) visual body reflex (Fig. 4.12 and Flowchart 4.5).

Flowchart 4.1: Pupillary light reflex



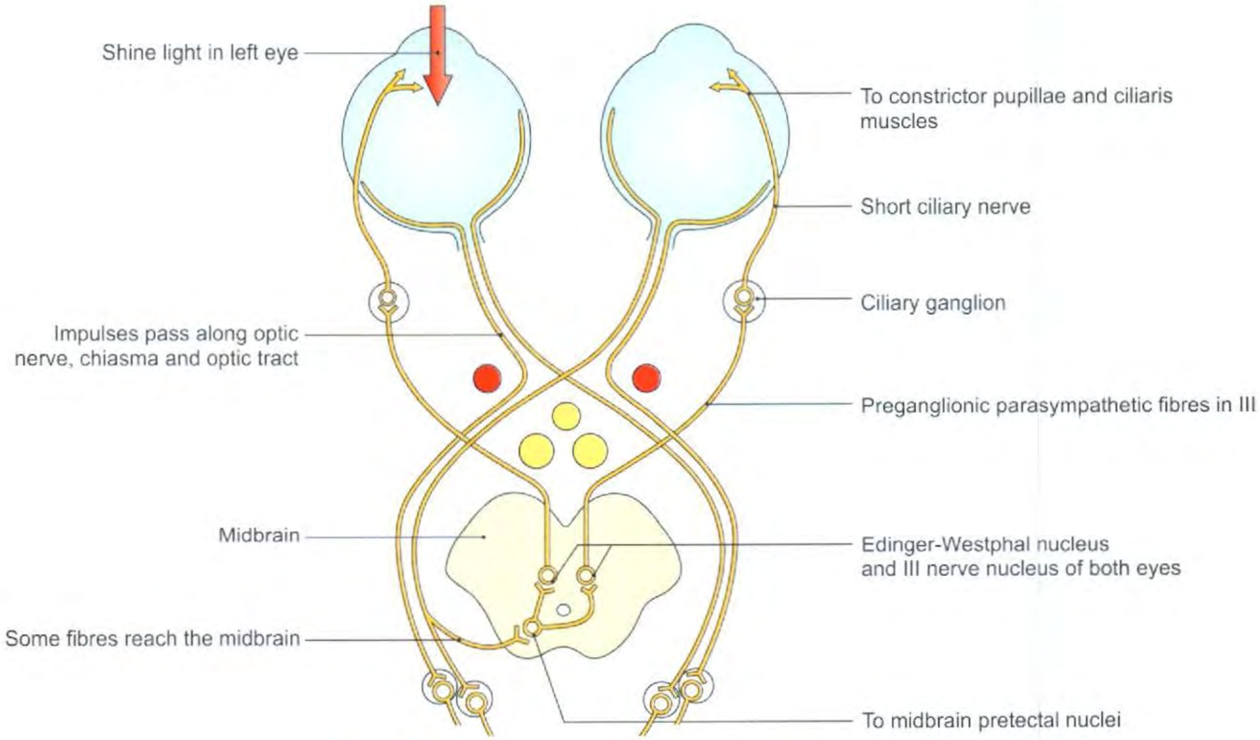


Fig. 4.9: Pupillary light and consensual light reflex

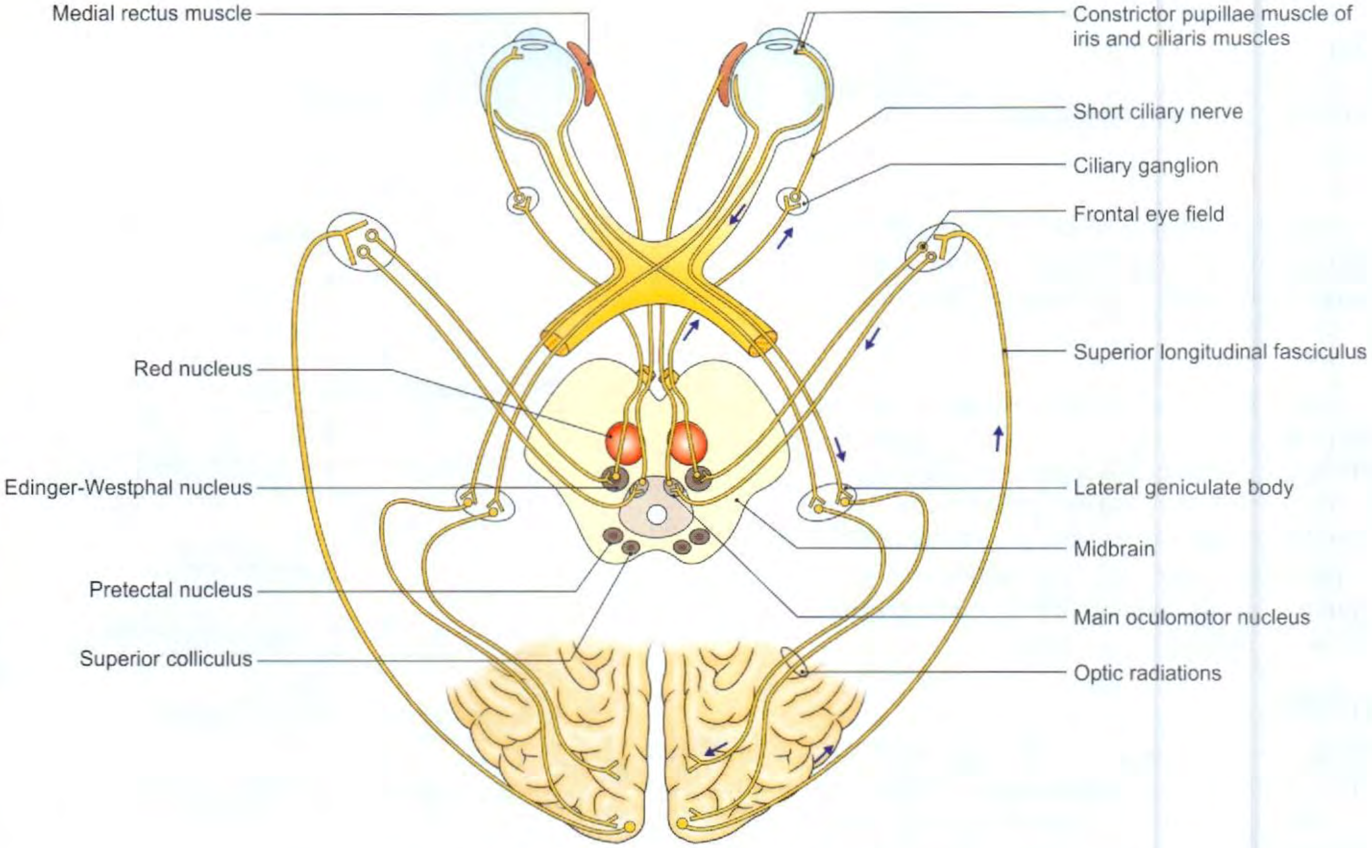


Fig. 4.10: Accommodation reflex

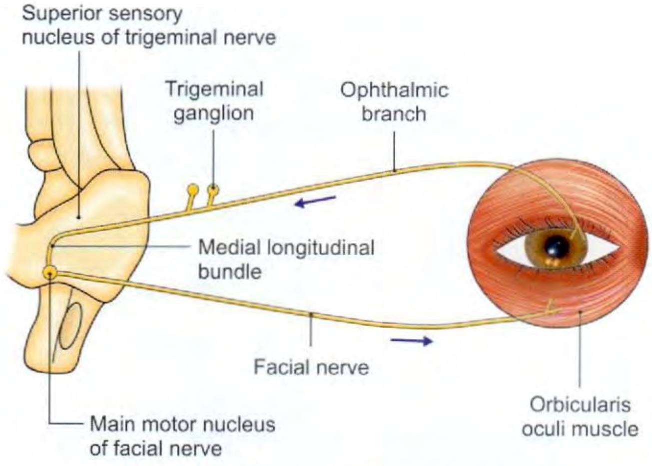


Fig. 4.11: Corneal/conjunctival reflex

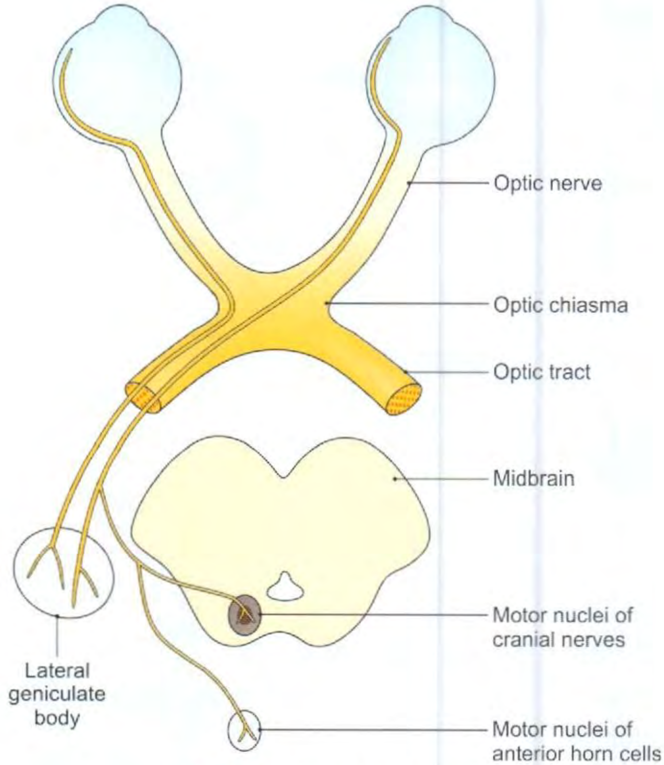
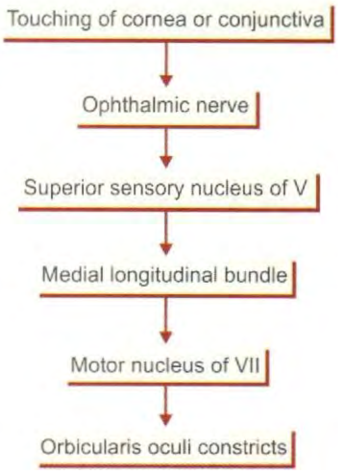


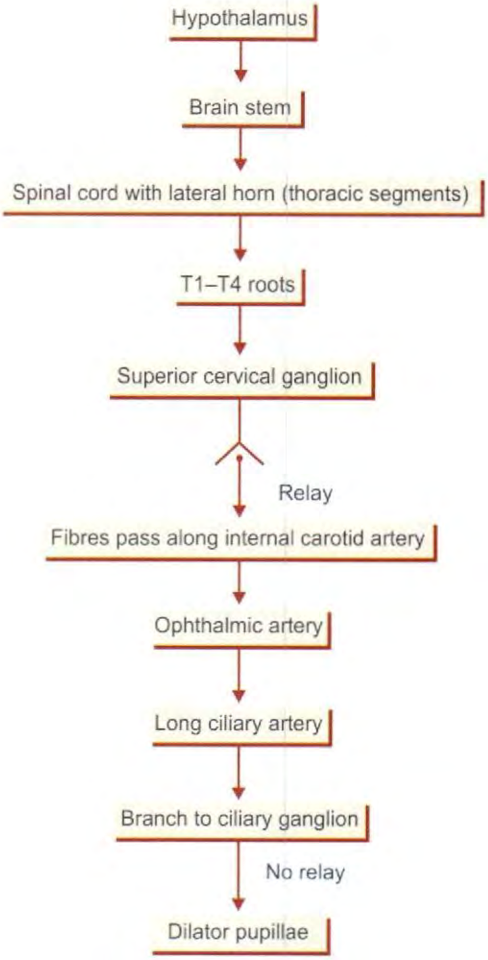
Fig. 4.12: Visual body reflex

Flowchart 4.2: Accommodation reflex

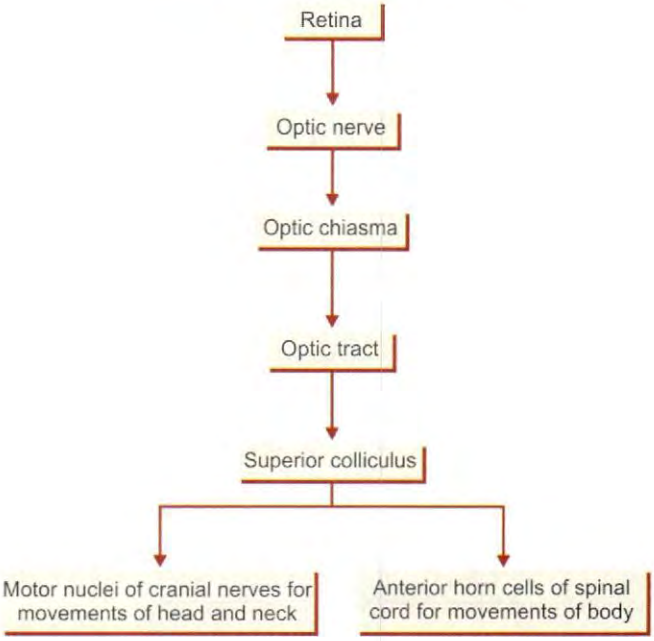
Flowchart 4.4: Corneal/conjunctival reflex



Flowchart 4.3: Dilation of pupil



Flowchart 4.5: Visual body reflex



CLINICAL ANATOMY

- Lesion in retina leads to scotoma, that is certain points may become blind spots.
- Loss of vision in one half (left or right) of visual field is called hemianopia.
  If the defect is in same halves of both eyes, it is called homonymous. If defect is in different halves, it is called heteronymous.
- Optic nerve damage results in complete blindness of that eye (Fig. 4.13).
- Optic chiasma lesion if central will lead to bitemporal hemianopia, but if peripheral on both sides will lead to binasal hemianopia (Fig. 4.13).
- Complete destruction of optic tract, lateral geniculate body, optic radiation or visual cortex of one side results in loss of the opposite half of field of vision.
- A lesion on the right optic tract leads to left homonymous hemianopia (left half of field of vision).
- *Papilloedema:* Results due to increased intracranial pressure. It leads to swelling of optic disc due to blockage of tributaries of the retinal veins.
- *Optic neuritis:* Lesion of optic nerve that results in decrease of visual acuity. Optic disc appears pale and smaller. Methyl alcohol is a usual toxic chemical leading to blindness.
- Argyll Robertson pupil: In this condition. The accommodation reflex is present but the light reflex is absent. The pretectal area is affected (*see* Fig. 5.14).
- Foster Kennedy syndrome—tumour at the base of frontal lobe resulting in compression of nerve .

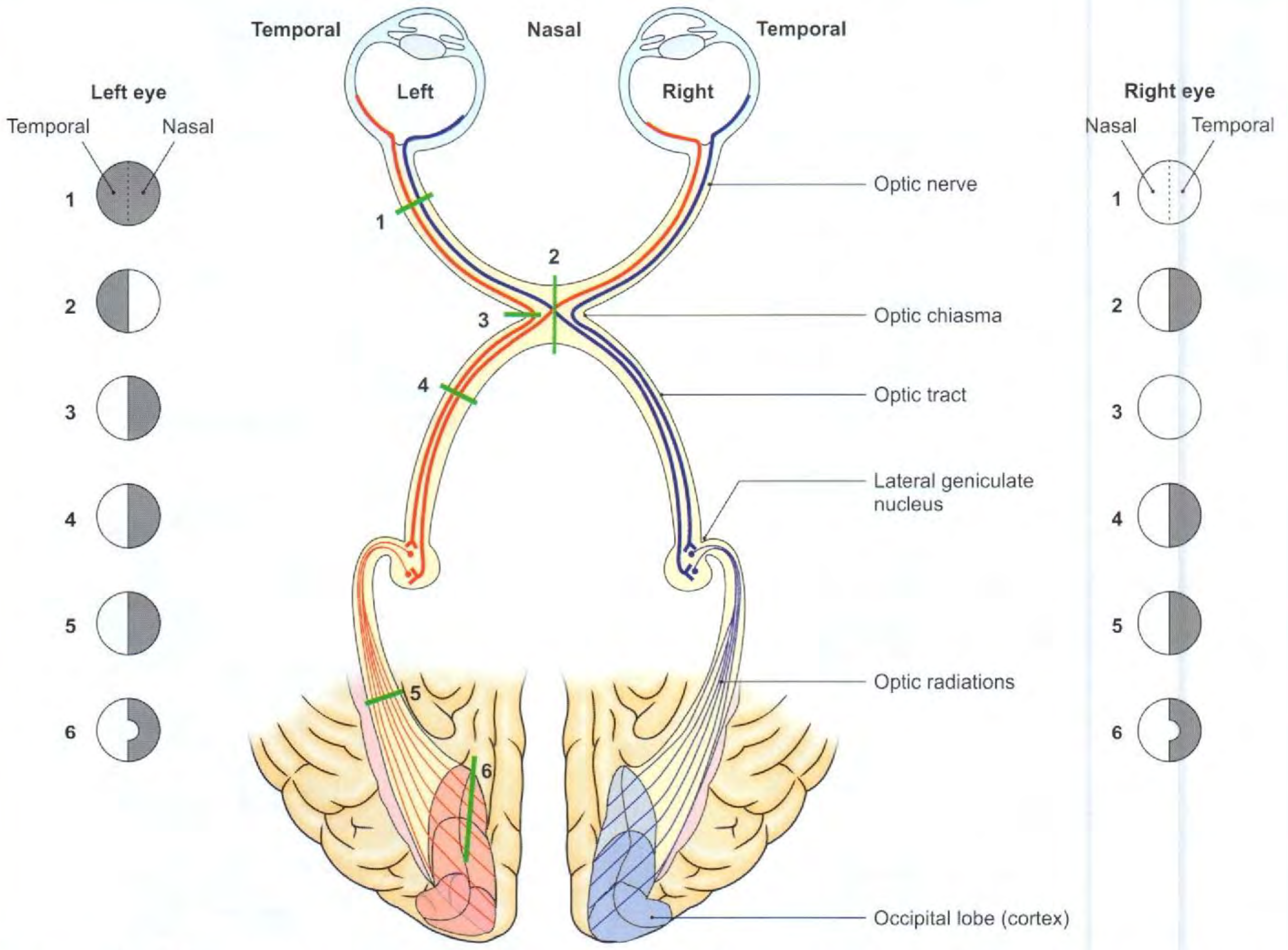


Fig. 4.13: Field defects associated with lesion of visual pathway. (1) Blindness of left eye, (2) bitemporal hemianopia, (3) left nasal hemianopia, (4) right homonymous hemianopia with macular involvement, (5) right homonymous hemianopia, and (6) right homonymous hemianopia with macular sparing

THIRD CRANIAL NERVE

OCULOMOTOR NERVE

This is the third cranial nerve. It is distributed to the extraocular as well as the intraocular muscles. Since it is a somatic motor nerve, it is in series with the IV, VI and XII cranial nerves, and also with the ventral root of spinal nerves.

Functional Components

1. General somatic efferent, for muscles of eyeball which help in its movements (Fig. 4.14).
2. General visceral efferent or parasympathetic, for contraction of pupil and accommodation.
3. General somatic afferent column carries proprioceptive fibres from the extraocular muscles to mesencephalic nucleus of V.

Nucleus

The oculomotor nucleus is situated in the ventromedial part of central grey matter of midbrain at the level of superior colliculus. Ventrolaterally, it is closely related to the medial longitudinal bundle.

The nucleus is connected:

a. To the pyramidal tracts of both sides which form the supranuclear pathway of the nerve.
b. To the pretectal nuclei of both sides for the light reflex.
c. To the fourth, sixth and eighth nerve nuclei by medial longitudinal bundle for coordination of the eye movements.
d. To the tectobulbar tract for visuoprotective reflexes.

The nuclear complex includes the following parts:

- Dorsolateral—to supply inferior rectus muscle
- Intermediate—to inferior oblique

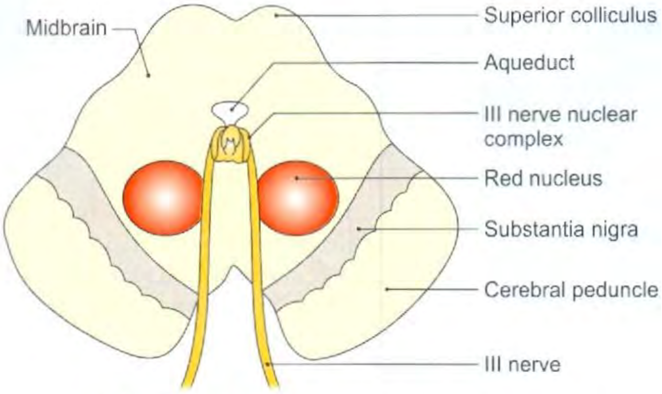


Fig. 4.14: Third cranial nerve and its nucleus

- Ventro-medial—to medial rectus
- Caudal central—to levator palpabrae superioris
- Median raphe—to superior rectus
- Edinger-Westphal—to ciliaris and sphincter papillae muscles.

Course and Distribution

1. In their *intraneural course,* the fibres arise from the nucleus and pass ventrally through the tegmentum, red nucleus and substantia nigra.
2. *At the base of the brain,* the nerve is attached to the oculomotor sulcus on the medial side of the crus cerebri (Fig. 4.1).
3. The nerve passes between the superior cerebellar and posterior cerebral arteries, and runs forwards in the interpeduncular cistern, on the lateral side of posterior communicating artery to reach the cavernous sinus (Fig. 4.15).

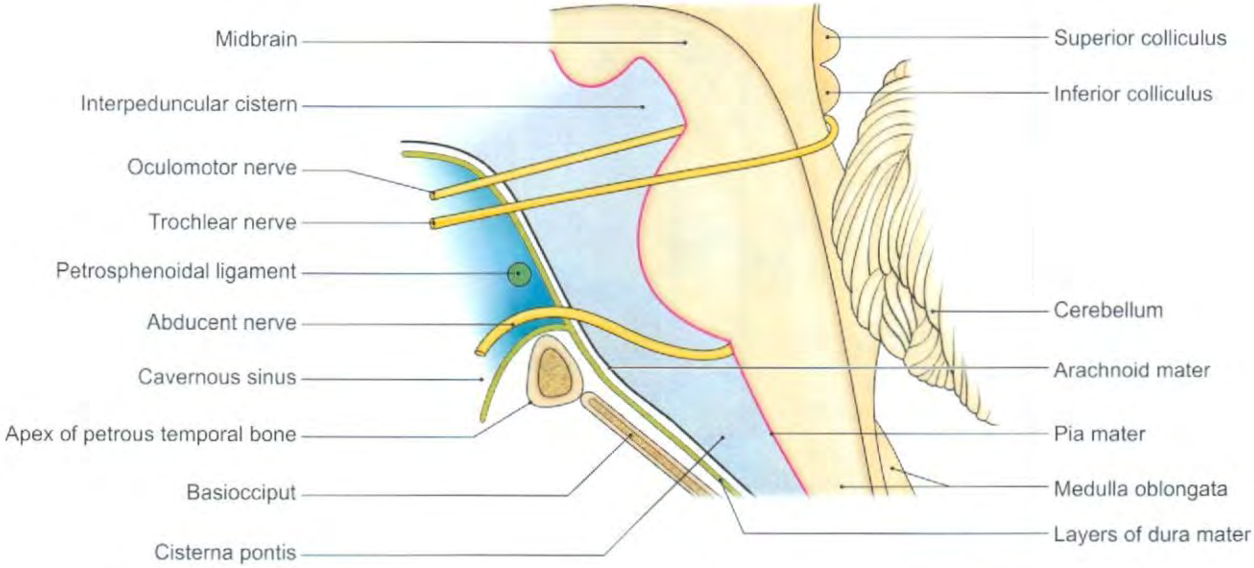


Fig. 4.15: Scheme to show the precavernous courses of the third, fourth and sixth cranial nerves

4 The nerve *enters the cavernous sinus* (Fig. 4.16) by piercing the posterior part of its roof on the lateral side of the posterior clinoid process. It descends to the lateral wall of the sinus where it lies above the trochlear nerve. In the anterior part of the sinus, the nerve divides into upper and lower divisions.

5 The two divisions of the nerve *enter the orbit* through the middle part of the superior orbital fissure. In the fissure, the nasociliary nerve lies in between the two divisions while the abducent nerve lies inferolateral to them.

6 *In the orbit,* the smaller upper division ascends on the lateral side of optic nerve, and supplies the superior rectus and part of the levator palpebrae superioris.

The larger, lower, division divides into three branches for the medial rectus, the inferior rectus and the inferior oblique. The nerve to the inferior oblique is the longest of these. It gives off the parasympathetic root to the ciliary ganglion and then supplies the inferior oblique muscle (Fig. 4.17).

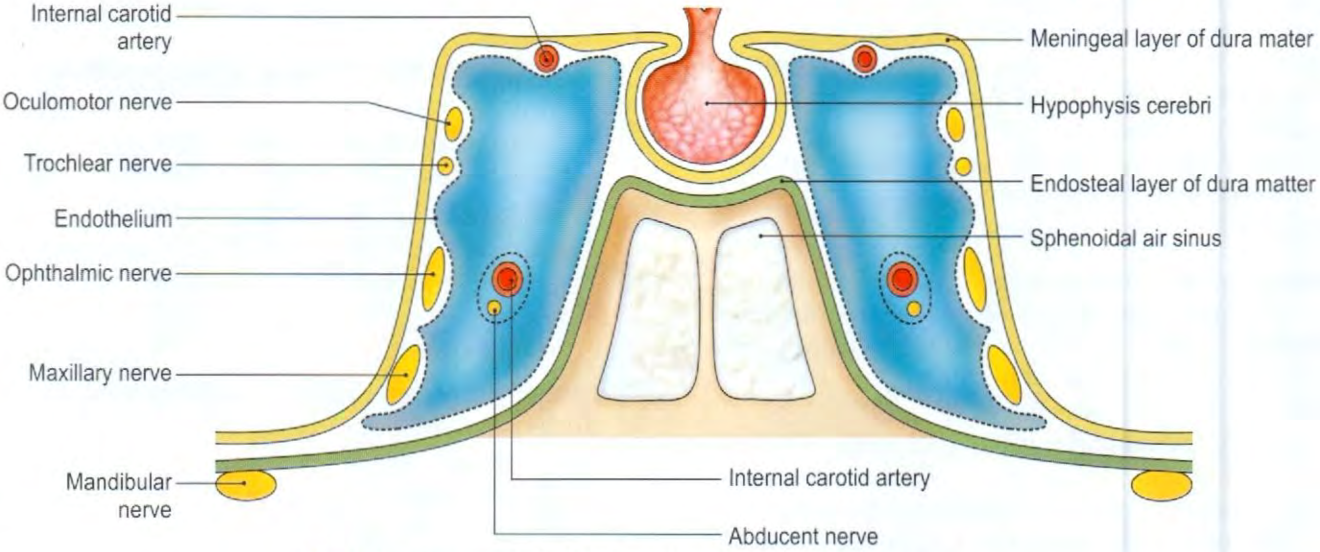


Fig. 4.16: Course of III, IV, V and VI nerves in the cavernous sinus

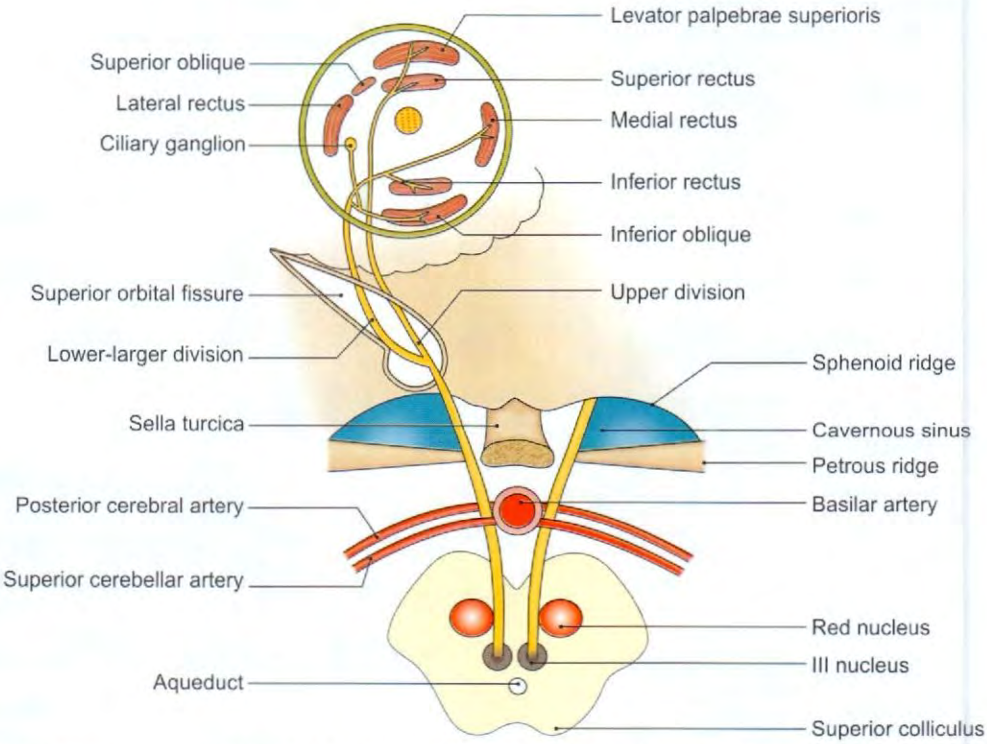


Fig. 4.17: The origin, course and the distribution of oculomotor nerve. Superior oblique and lateral rectus also seen

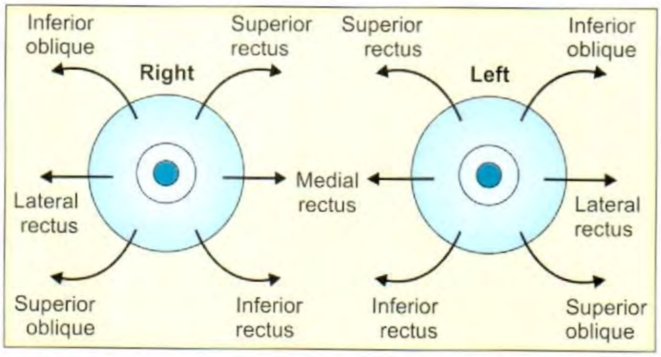


Fig. 4.18: Action of individual extraocular muscle. Arrows indicate direction of movement

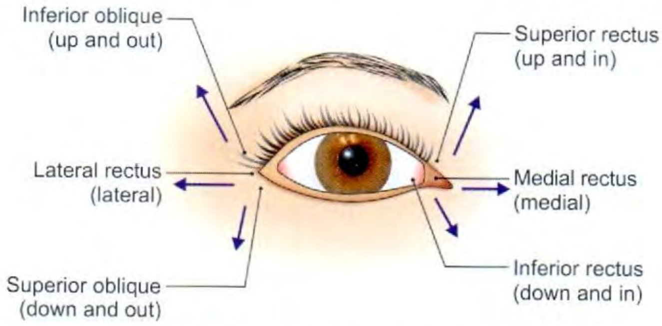


Fig. 4.19: Movements in the six different directions

All branches enter the muscles on their ocular surfaces except that for the inferior oblique which enters its posterior border.

Figures 4.18 and 4.19 show the actions of extraocular muscles.

CLINICAL ANATOMY

- Complete and total paralysis of the third nerve results in:
  - a. Ptosis, i.e. drooping of the upper eyelid.
  - b. Lateral squint
  - c. Dilatation of the pupil (Fig. 4.20)
  - d. Loss of accommodation
  - e. Slight proptosis, i.e. forward projection of the eye.
  - f. Diplopia or double vision.
- Ptosis or drooping of upper eyelid due to paralysis of voluntary part of levator palpebrae superioris muscle.
- Pupillary light reflex in affected eye is absent.
- Dilatation of pupil due to paralysis of parasympathetic fibres to sphincter pupillae muscle.
- Eyeball gets turned downwards and laterally due to unopposed action of lateral rectus and superior oblique muscles.
- Loss of accommodation due to paralysis of ciliary muscles.
- Pupil dilates and becomes fixed to light.
- A midbrain lesion causing contralateral hemiplegia and ipsilateral paralysis of the third nerve is known as *Weber's syndrome*.
- Supranuclear paralysis of the third nerve causes loss of conjugate movement of the eyes.
- *Compression of III nerve:* Compression of III nerve due to extradural haematoma causes dilatation of pupil. Parasympathetic fibres lying superficial get affected first. Pupil dilates on affected side and there is little response to light.
- *Aneurysm of posterior cerebral or superior cerebellar artery:* Aneurysm of any of these two arteries may compress III nerve as it passes between them.

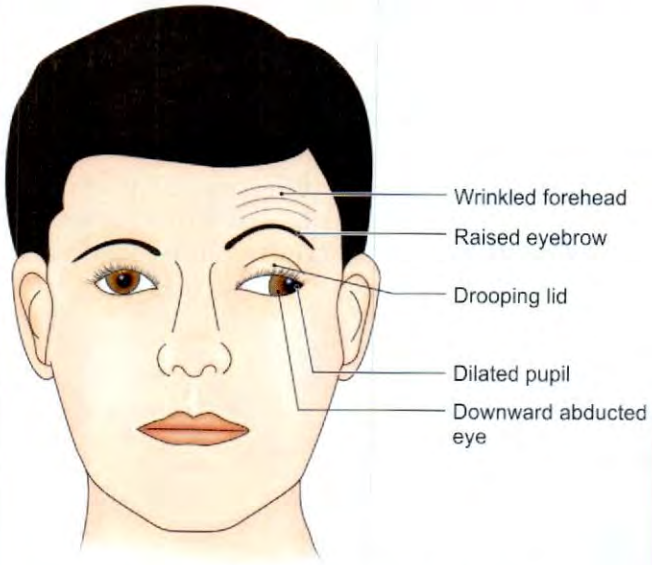


Fig. 4.20: Paralysis of left third nerve

FOURTH CRANIAL NERVE

TROCHLEAR NERVE

It supplies only the superior oblique muscle of the eyeball (Fig. 4.23). It is the only cranial nerve which emerges on the dorsal aspect of the brain stem.

Functional Components

1. General somatic efferent, for lateral movement of the eyeball.
2. The general somatic afferent, for proprioceptive impulses from the muscle to the mesencephalic nucleus of V nerve.

Nucleus

The trochlear nucleus is situated in the ventromedial part of the central grey matter of midbrain at the level of inferior colliculus. Ventrally, it is closely related to the medial longitudinal bundle.

The connections of the nucleus are similar to those of the oculomotor nucleus, except for the pretectal nuclei.

Course and Distribution

1 In its *intraneural course,* the nerve runs dorsally round the central grey matter to reach the upper part of the superior or anterior medullary velum where it decussates with the opposite nerve to emerge on the opposite side (Fig. 4.21).

2 *Surface attachment*: Trochlear nerve is attached to the superior medullary velum one on each side of the frenulum veli just below the inferior colliculus. It is the only cranial nerve which emerges on the dorsal aspect of the brain stem (Fig. 4.1).

3 The nerve winds round the superior cerebellar peduncle and the cerebral peduncle just above the pons. It passes between the posterior cerebral and superior cerebellar arteries to appear ventrally between the temporal lobe and upper border of pons.

4 The nerve *enters the cavernous sinus* by piercing the posterior corner of its roof. Next it runs forwards in the lateral wall of cavernous sinus between the oculomotor and ophthalmic nerves. In the anterior part of sinus, it crosses over the oculomotor nerve (Fig. 4.16).

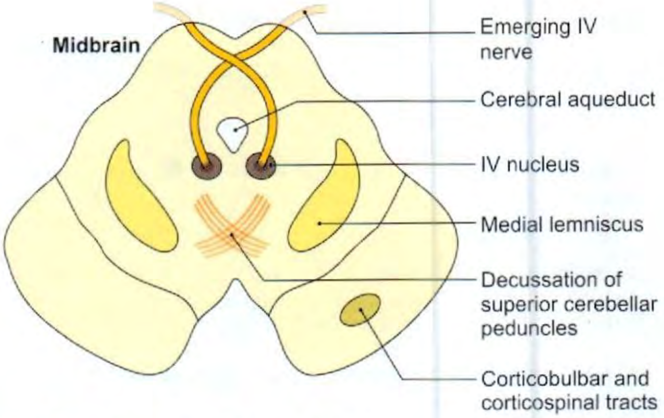


Fig. 4.21: Emerging fibres of trochlear nerves with their nuclei

5 Trochlear nerve *enters the orbit* through the lateral part of the superior orbital fissure.

6 *In the orbit,* it passes medially, above the origin of levator palpebrae superioris and ends by supplying the superior oblique muscle on its orbital surface (Fig. 4.22).

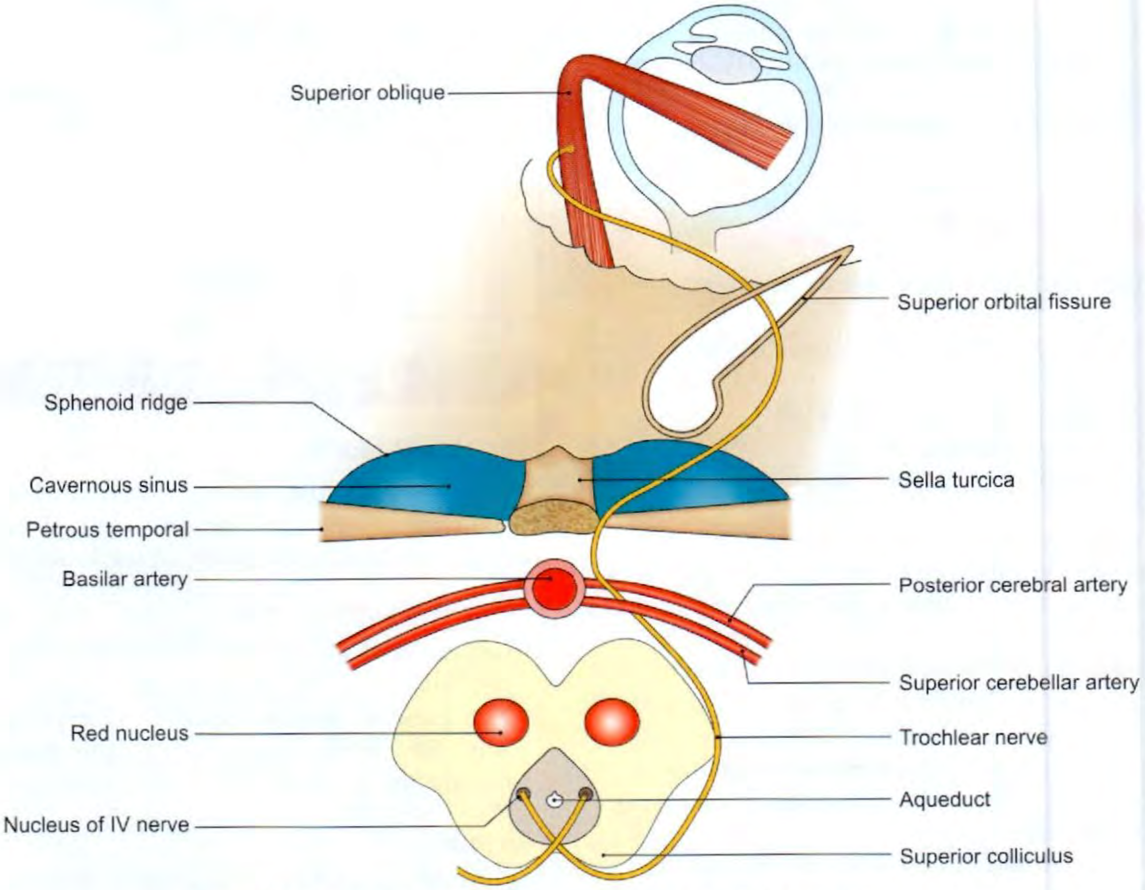


Fig. 4.22: The origin, course and the distribution of the trochlear nerve

CLINICAL ANATOMY

- When trochlear nerve is damaged, diplopia occurs on looking downwards; vision is single so long as the eyes look above the horizontal plane.
- Paralysis of the trochlear nerve results in:
  a. Defective depression of the adducted eye.
  b. Diplopia.

SIXTH CRANIAL NERVE

ABDUCENT NERVE

It supplies the lateral rectus muscle of the eyeball (Fig. 4.23). It has a long intracranial course.

Functional Components

1. General somatic efferent, for lateral movement of the eyeball.
2. The general somatic afferent, for proprioceptive impulses from the muscle to the mesencephalic nucleus of V nerve.

Nucleus

Abducent nucleus is situated in the upper part of the floor of fourth ventricle in the lower pons, beneath the facial colliculus. Ventromedially, it is closely related to the medial longitudinal bundle.

Connections of the nucleus are similar to those of the third nerve, except for the pretectal nuclei.

Course and Distribution

1. In their *intraneural course*, the fibres of the VI nerve run ventrally and downwards through the trapezoid body, medial lemniscus and basilar part of pons to reach the lower border of the pons.
2. The nerve is attached to the lower border of the pons, opposite the upper end of the pyramid of the medulla (Fig. 4.1).
3. The nerve runs upwards, forwards and laterally through the cisterna pontis and usually dorsal to the anterior inferior cerebellar artery to reach the cavernous sinus.
4. The abducent nerve *enters the cavernous sinus* by piercing its posterior wall at a point lateral to the dorsum sellae and superior to the apex of the petrous temporal bone. As the nerve crosses the superior border of the petrous temporal bone, it passes beneath the petrosphenoidal ligament, and bends sharply forwards. In the cavernous sinus, at first it lies lateral to the internal carotid artery and then inferolateral to it (Fig. 4.16).
5. The abducent nerve *enters the orbit* through the middle part of the superior orbital fissure. Here it lies inferolateral to the oculomotor and nasociliary nerves.
6. *In the orbit*, the nerve ends by supplying only the lateral rectus muscle. It enters the ocular surface of the muscle (Fig. 4.24).

CLINICAL ANATOMY

- In increased intracranial pressure it gets compressed resulting in medial squint and diplopia.
- Sixth nerve paralysis is one of the commonest false localizing signs in cases with raised intracranial pressure. Its susceptibility to such damage is due to its long course in the cisterna pontis, to its sharp bend over the superior border of petrous temporal bone and the downward shift of the brain stem towards the foramen magnum resulting in medial squint and diplopia.

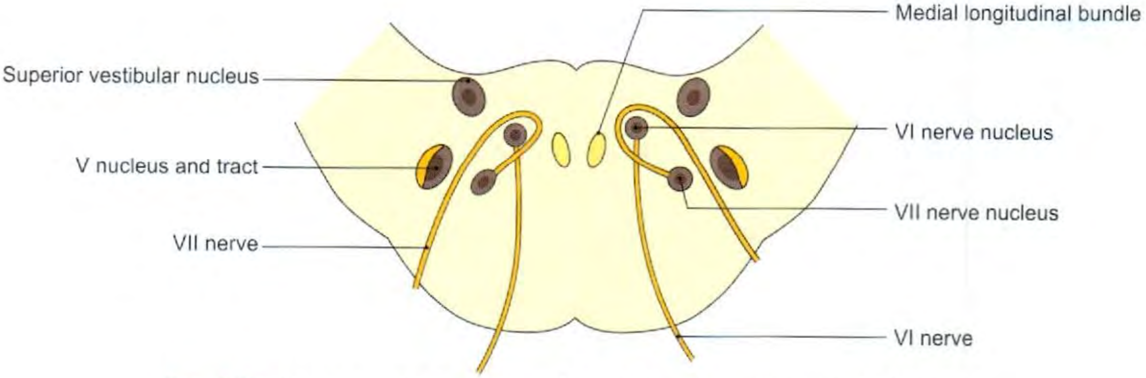


Fig. 4.23: VI nerve with its nucleus. It includes unusual course of VII nerve

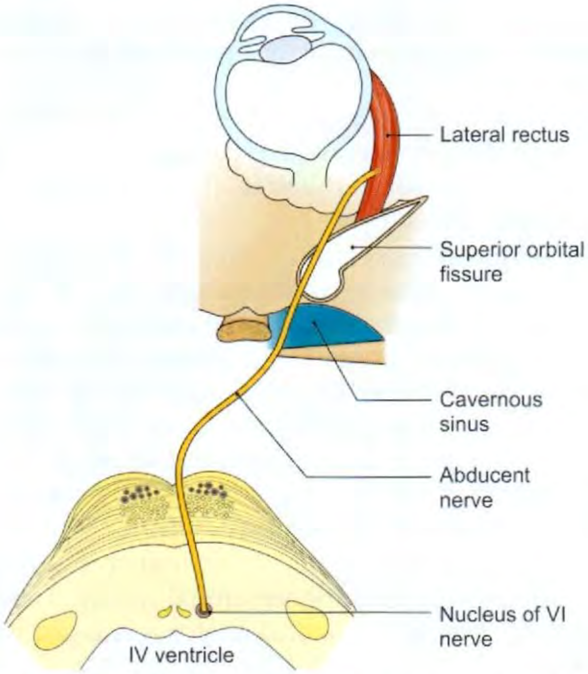


Fig. 4.24: The origin, course and distribution of the abducent nerve

- Sixth nerve paralysis causes failure of abduction of the affected eye (Fig. 4.25).
- Diplopia occurs due to paralysis of right lateral rectus muscle.

Conjugate position of eyes in primary position

No abduction of right eye on looking to the right paralysed side

Fig. 4.25: Paralysis of right sixth nerve

FIFTH CRANIAL NERVE

TRIGEMINAL NERVE

Fifth cranial nerve is the largest cranial nerve. It comprises three branches, two of which are purely sensory and third, the largest branch is mixed nerve. Trigeminal nerve is the nerve of first brachial arch.

Branches of this nerve provide sensory fibres to the four parasympathetic ganglia associated with cranial outflow of parasympathetic nervous system. These are ciliary, pterygopalatine, otic and submandibular.

Ophthalmic, the first division carries sensory fibres from the structures derived from frontonasal process. Maxillary, the second division conveys afferent fibres from structures derived from maxillary process. Mandibular, the third mixed division carries sensory fibres derives from mandibular process.

Nuclear Columns

1 *General somatic afferent column:* This column has three nuclei. These are:
   a. *Spinal nucleus of V nerve:* Fibres conveying pain and temperature sensations from most of the face area relay here (Fig. 4.26).
   b. *Principle sensory nucleus of V nerve:* Fibres carrying touch and pressure relay in this nucleus.
   c. *Mesencephalic nucleus:* This nucleus extends in the midbrain. It receives proprioceptive impulses from muscles of mastication, temporomandibular joint and teeth.

2 *Branchial efferent column:* The nucleus of V nerve is situated at the level of upper pons. The fibres of the motor nucleus supply eight muscles derived from first branchial arch.

Sensory Components of V Nerve

Sensations of pain, temperature, touch and pressure from skin of face, mucous membrane of nose, most of the tongue, paranasal air sinuses travel along axons. Their cell bodies lie in the V ganglion (Fig. 4.27) or semilunar ganglion or Gasserian ganglion. This ganglion is equivalent to the spinal ganglia of other nerves. It lies at the apex of petrous temporal bone in a dural cave, the Meckel's cave. Peripheral processes form the three nerves.

The central processes of V ganglion form sensory root. Some fibres ascend and other descend. Ascending fibres end in superior sensory nucleus. Descending fibres end in the spinal nucleus of V nerve.

Pain and temperature reach spinal nucleus. Touch and pressure sensations go to superior sensory nucleus (Fig. 4.28).

Ophthalmic nerve fibres end in the inferior part, maxillary nerve fibres end in the middle part and mandibular nerve fibres terminate in the upper part of spinal nucleus.

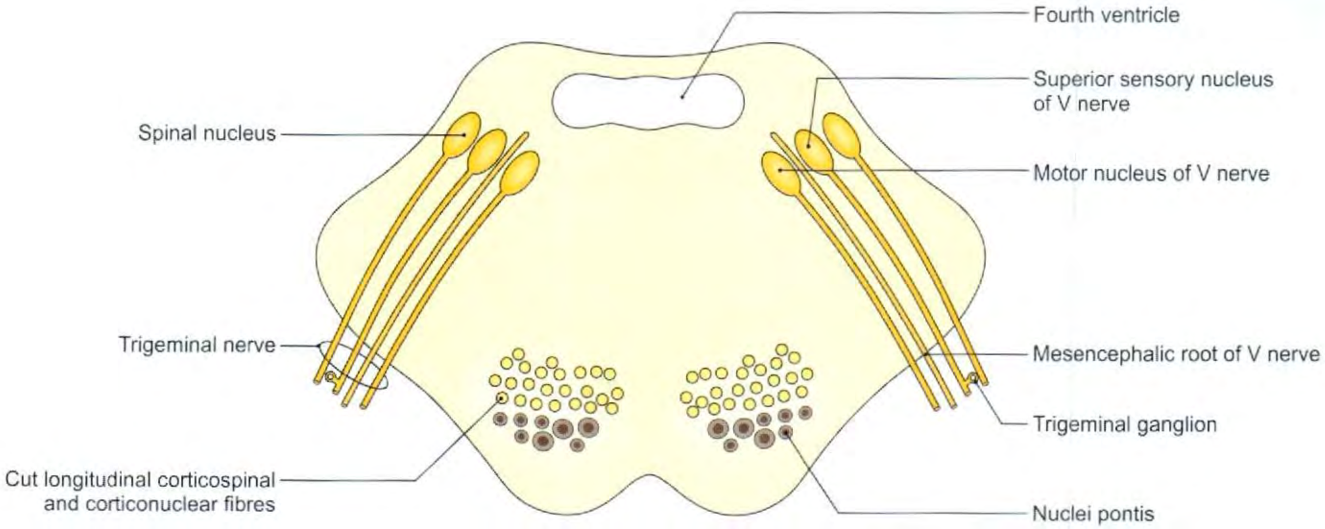


Fig. 4.26: Nuclei of trigeminal nerve at level of upper pons

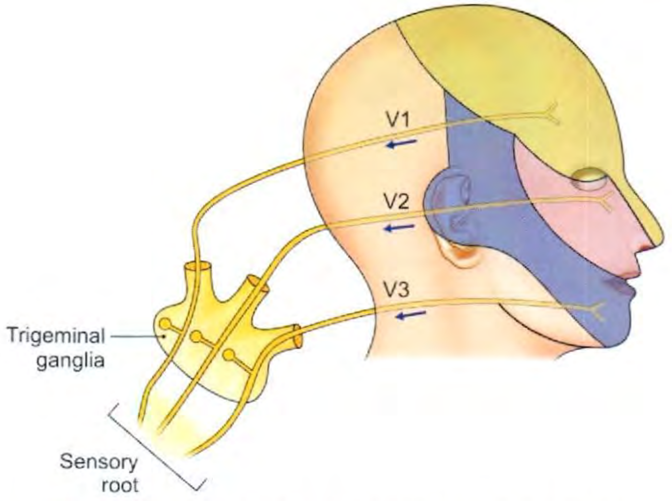


Fig. 4.27: Trigeminal ganglia and its three branches

According to another view, the ophthalmic fibres lie in the median part, maxillary fibres in the medial part and the mandibular fibres in the lateral part of the nucleus.

Proprioceptive fibres from muscles of mastication, extraocular muscles and facial muscles bypass V ganglion to reach unipolar cells of mesencephalic nucleus.

Axons of neurons of spinal nucleus, superior sensory nucleus and central processes of cells of mesencephalic nucleus cross to the opposite side and ascend as trigeminal lemniscus. The lemniscus ends in the ventral posteromedial nucleus of thalamus, where these fibres relay. The third neuron fibres end in areas 3, 1 and 2 of cerebral cortex.

Motor Component for the Muscles

The motor nucleus receives impulses from the right and left cerebral hemispheres, red nucleus and mesencephalic nucleus. Fibres of motor root supply four muscles of mastication temporalis, masseter, lateral pterygoid and medial pterygoid and four other muscles which are tensor veli palatini, tensor tympani, mylohyoid and anterior belly of digastric.

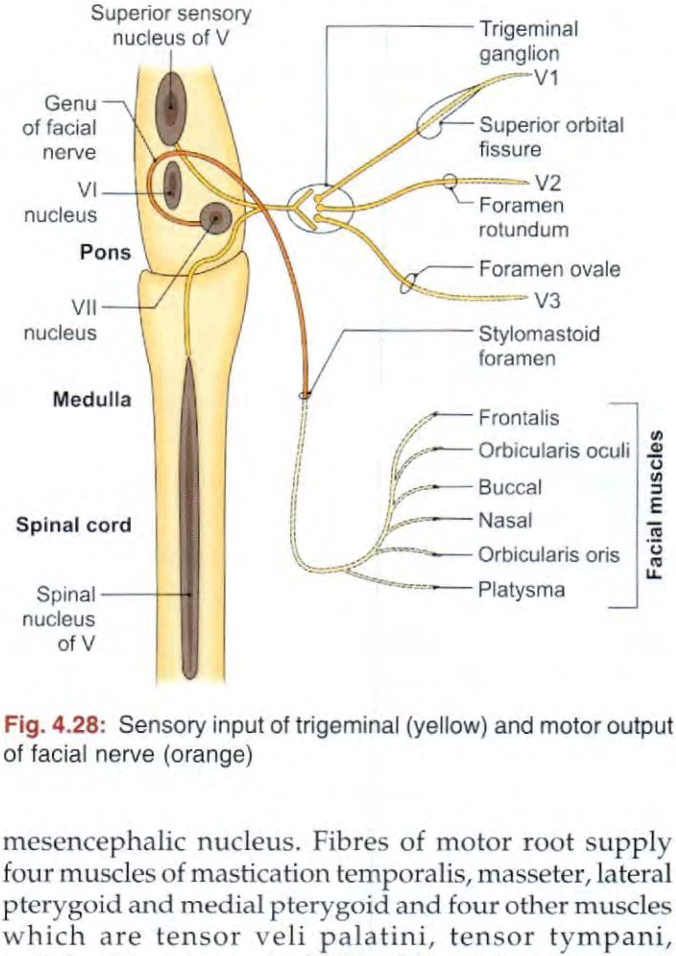


Fig. 4.28: Sensory input of trigeminal (yellow) and motor output of facial nerve (orange)

Branches of Trigeminal Nerve

Cranial nerve V/trigeminal nerve comprise three branches, ophthalmic V1, maxillary V2 and mandibular V3 (Fig. 4.29).

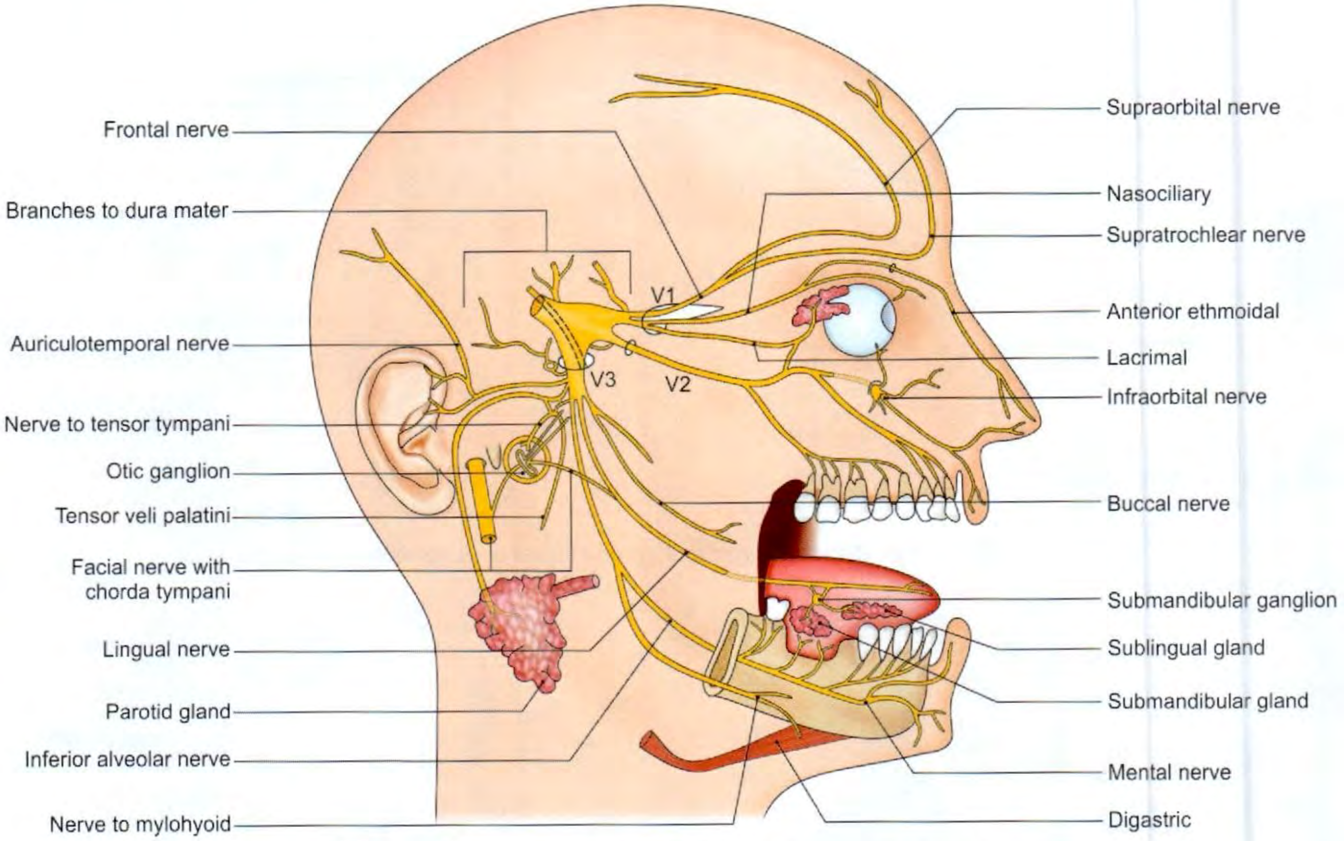


Fig. 4.29: Distribution of three branches of trigeminal nerve

Ophthalmic Nerve Division (Sensory)

Ophthalmic nerve is sensory. Its branches are:

Frontal

1. *Supratrochlear:* Upper eyelid, conjunctiva and lower part of forehead.
2. *Supraorbital:* Frontal air sinus, upper eyelid, forehead and scalp till vertex (Fig. 4.29).

Nasociliary

1. *Long ciliary:* Sensory to eyeball.
2. Branch to ciliary ganglion.
3. *Posterior ethmoidal:* Sphenoidal air sinus, posterior ethmoidal air sinuses.
4. *Anterior ethmoidal:*
   a. Middle and anterior ethmoidal sinuses
   b. Medial internal nasal
   c. Lateral internal nasal
   d. External nasal: Skin of ala of vestibule and tip of nose.
5. *Infratrochlear:* Both eyelids, side of nose, lacrimal sac.

Lacrimal

Lateral part of upper eyelid; conveys secretomotor fibres from zygomatic nerve to lacrimal gland.

Maxillary Nerve Division (Sensory)

It is sensory and gives branches as follows:

In Middle Cranial Fossa

Meningeal branch

In Pterygopalatine Fossa

1. Ganglionic branches
2. Zygomatic:
   a. Zygomaticotemporal } Sensory
   b. Zygomaticofacial }
3. Posterior superior alveolar

In Infraorbital Canal

1. Middle superior alveolar
2. Anterior superior alveolar

On Face

Infraorbital
a. Palpebral }
b. Labial } Sensory
c. Nasal }

Mandibular Nerve Division (Sensory and Motor)

It is a mixed nerve and it branches are:

From Trunk

1. Meningeal
2. Nerve to medial pterygoid supplies:
   a. Tensor veli palatini
   b. Tensor tympani
   c. Medial pterygoid.

From Anterior Division

1. Deep temporal
2. Lateral pterygoid
3. Masseteric
4. Buccal—skin of cheek (Fig. 4.29).

From Posterior Division

1. Auriculotemporal (Fig. 4.29):
   a. Auricular
   b. Superficial temporal
   c. Articular to temporomandibular joint
   d. Secretomotor to parotid gland.
2. Lingual—general sensation from anterior two-thirds of tongue.
3. Inferior alveolar—lower teeth, mental for skin of chin and nerve to mylohyoid which also supplies:
   a. Mylohyoid
   b. Anterior belly of digastric.

CLINICAL ANATOMY

- Fifth cranial nerve subserves sensation from face and neighbouring areas. It also innervates the muscles of mastication.
- Proprioceptive fibres terminate in mesencephalic nucleus.
- Light touch fibres end in the main sensory or superior sensory nucleus.
- Pain and temperature fibres terminate in nucleus of spinal tract of trigeminal.
- Motor fibres begin from the motor nucleus of trigeminal.
- The separate location of main sensory nucleus and spinal nucleus account for dissociated sensory loss, i.e. low pontine or medullary lesion will result in loss of pain and temperature sensation while light sensation is preserved.
- Low pontine, medullary and cervical lesions produce a characteristic 'onion skin' distribution of pin prick and temperature loss (Fig. 4.30).

Sensory examination:

- An ascending lesion spares the openings of nose and mouth (muzzle area) till last.
- Test with pin prick, temperature and light touch over each side of the whole face.
- The sensations in three branches of V nerve can be tested clinically.

Motor examination:

- Look for wasting or thinning of temporalis muscle. There may be 'hollowing out' of the temporal fossa.
- Ask the patient to press upper and lower teeth together and feel for temporalis and masseter muscles.
- Ask patient to open the mouth. If pterygoid muscles are weak, the jaw would deviate to weak side as the normal muscles will push the jaw to the weak side.

In injury to:

- *Ophthalmic nerve:* There is loss of corneal blink reflex. This reflex is mediated by V1 which is afferent pathway and VII nerve which subserves as efferent pathway (Figs 4.11 and 4.31).
- *Maxillary nerve:* There is loss of sneeze reflex. This branch is the afferent path of sneeze reflex. Efferent pathway of sneeze reflex is nucleus ambiguus, respiratory centre in medulla oblongata, phrenic nerve nucleus, motor cells of spinal cord for intercostal muscles.

  Mandibular nerve: There is loss of jaw jerk reflex (Fig. 4.32).
- Flaccid paralysis of muscles of mastication in injury of mandibular nerve leading to decrease strength for biting.
- Hypoacusis, i.e. partial deafness to low pitched sounds due to paralysis of tensor tympani muscle.
- *Trigeminal neuralgia:* Pain along the distribution of the nerve which is caused due to local lesion or unknown cause. The principal disease affecting sensory root of V nerve is characterized by attacks of severe pain in the area of distribution of maxillary or mandibular divisions. Maxillary nerve is most frequently involved.
- The trigeminal ganglion harbours the herpes simplex virus causing herpes (shingles) in the distribution of the nerve.

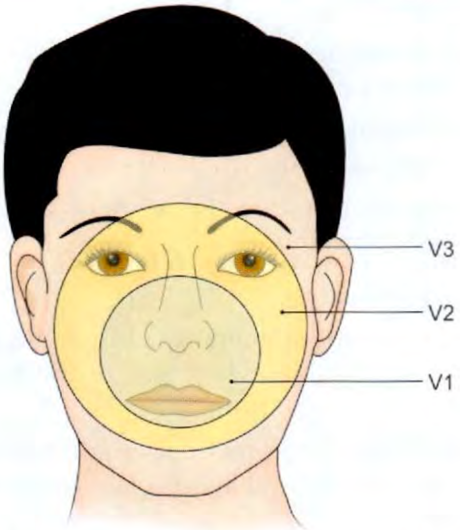


Fig. 4.30: Brain stem lesion of trigeminal nerve

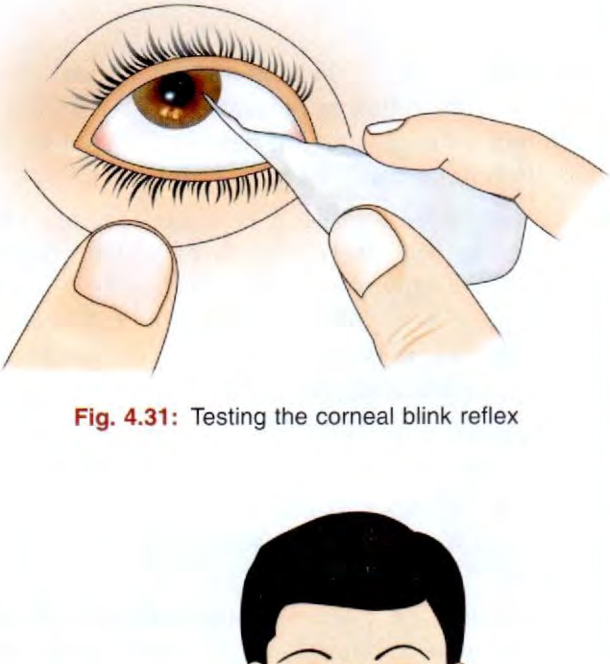


Fig. 4.31: Testing the corneal blink reflex

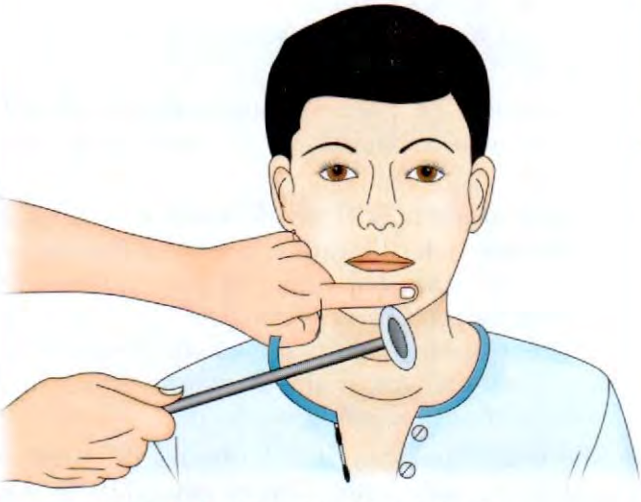


Fig. 4.32: Elicitation of jaw jerk reflex

SEVENTH CRANIAL NERVE

FACIAL NERVE

Facial nerve is the nerve of the second branchial arch.

Functional Components

1. Special visceral or *branchial efferent* (SVE), responsible for muscles of facial expression and for elevation of the hyoid bone (Table 4.1 and Fig. 4.36).
2. *General visceral efferent* (GVE) or parasympathetic fibres. These fibres are secretomotor to the submandibular and sublingual salivary glands, the lacrimal gland, glands of the nose, palate and pharynx (Figs 4.4a and b).
3. *General visceral afferent* (GVA) component carries afferent impulses from the above mentioned glands.
4. *Special visceral afferent* (SVA) fibres carry tastes sensations from the palate and from anterior two-thirds of the tongue except from vallate papillae.
5. *General somatic afferent* (GSA) fibres probably innervate a part of the skin of the ear. The nerve does not give any direct branches to the ear, but some fibres may reach it through communications with the vagus nerve. Proprioceptive impulses from muscles of the face travel through branches of the trigeminal nerve to reach the mesencephalic nucleus of the nerve.

Nuclei

The fibres of the nerve are connected to four nuclei situated in the lower pons.

1. Motor nucleus or branchiomotor (Fig. 4.32).
2. Superior salivatory nucleus or parasympathetic.
3. Lacrimatory nucleus is also parasympathetic.
4. Nucleus of the tractus solitarius which is gustatory. It also receives afferent fibres from the glands (Figs 4.4b and c).

The motor nucleus lies deep in the reticular formation of the lower pons. The part of the nucleus that supplies muscles of the upper part of the face receives cortico-nuclear fibres from the motor cortex of both the right and left sides.

In contrast, the part of the nucleus that supplies muscles of the lower part of the face receive corticonuclear fibres only from the opposite cerebral hemisphere (Fig. 4.5a).

Course and Relations

The facial nerve is attached to the brain stem by two roots, motor and sensory. The sensory root is also called the *nervus intermedius* (Fig. 4.33).

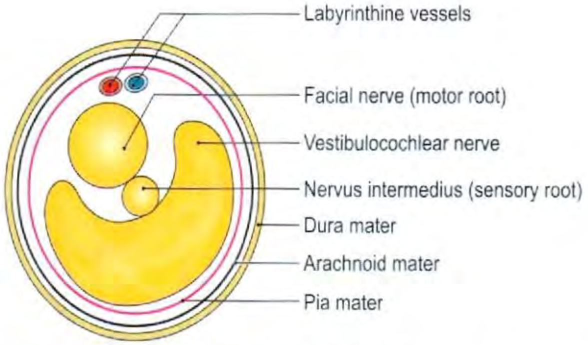


Fig. 4.33: Structures in the left internal acoustic meatus

The two roots of the facial nerve are attached to the lateral part of the lower border of the pons just medial to the eighth cranial nerve. The two roots run laterally and forwards, with the eighth nerve to reach the internal acoustic meatus.

In the meatus, the motor root lies in a groove on the eighth nerve, with the sensory root intervening (Fig. 4.33). Here the seventh and eighth nerves are accompanied by the labyrinthine vessels. At the bottom or fundus of the meatus, the two roots, sensory and motor, fuse to form a single trunk, which lies in the petrous temporal bone (Fig. 4.34).

Within the canal, the course of the nerve can be divided into three parts by two bends (Fig. 4.35).

The first part is directed laterally above the vestibule; the second part runs backwards in relation to the medial wall of the middle ear, above the promontory. The third part is directed vertically downwards behind the promontory.

The first bend at the junction of the first and second parts is sharp. It lies over the anterosuperior part of the promontory, and is also called the *genu*. The geniculate ganglion of the nerve is so called because it lies on the genu. The second bend is gradual, and lies between the promontory and the aditus to the mastoid antrum.

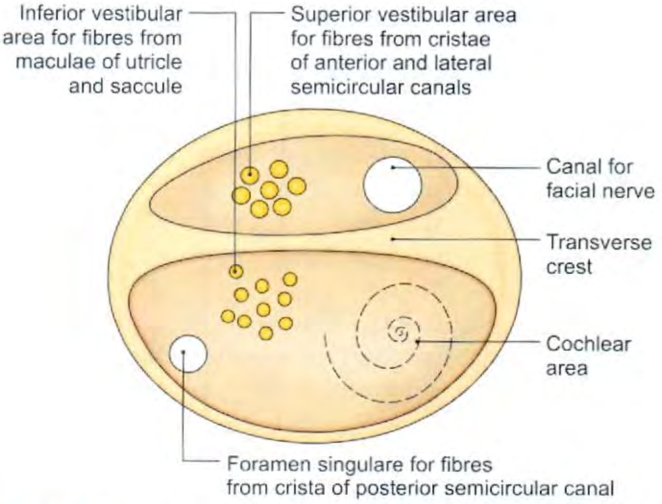


Fig. 4.34: Some features seen on the fundus of the left internal acoustic meatus

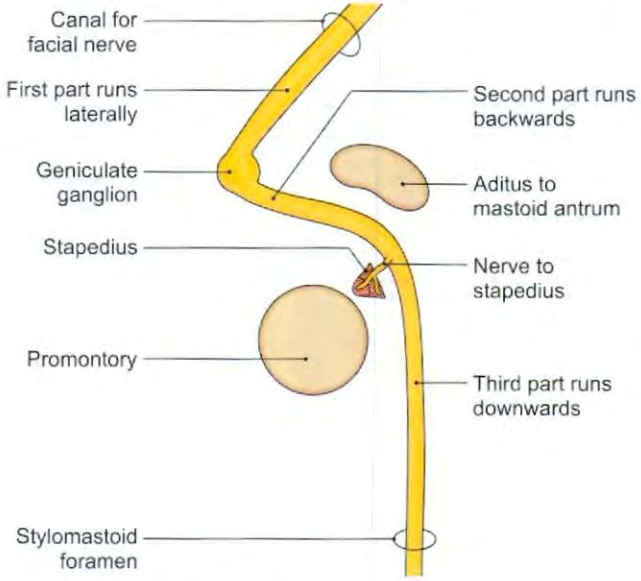


Fig. 4.35: Course of facial nerve

The facial nerve leaves the skull by passing through the stylomastoid foramen.

In its *extracranial course,* the facial nerve crosses the lateral side of the base of the styloid process. It enters the posteromedial surface of the parotid gland, runs forwards through the gland crossing the retromandibular vein and the external carotid artery. Behind the neck of the mandible, it divides into its five terminal branches which emerge along the anterior border of the parotid gland.

Branches and Distribution

1 Within the facial canal:
   a. Greater petrosal nerve
   b. The nerve to the stapedius
   c. The chorda tympani (Fig. 4.36).
2 At its exit from the stylomastoid foramen:
   a. Posterior auricular
   b. Digastric
   c. Stylohyoid.
3 Terminal branches within the parotid gland:
   a. Temporal
   b. Zygomatic
   c. Buccal
   d. Marginal mandibular
   e. Cervical.
4 Communicating branches with adjacent cranial and spinal nerves.

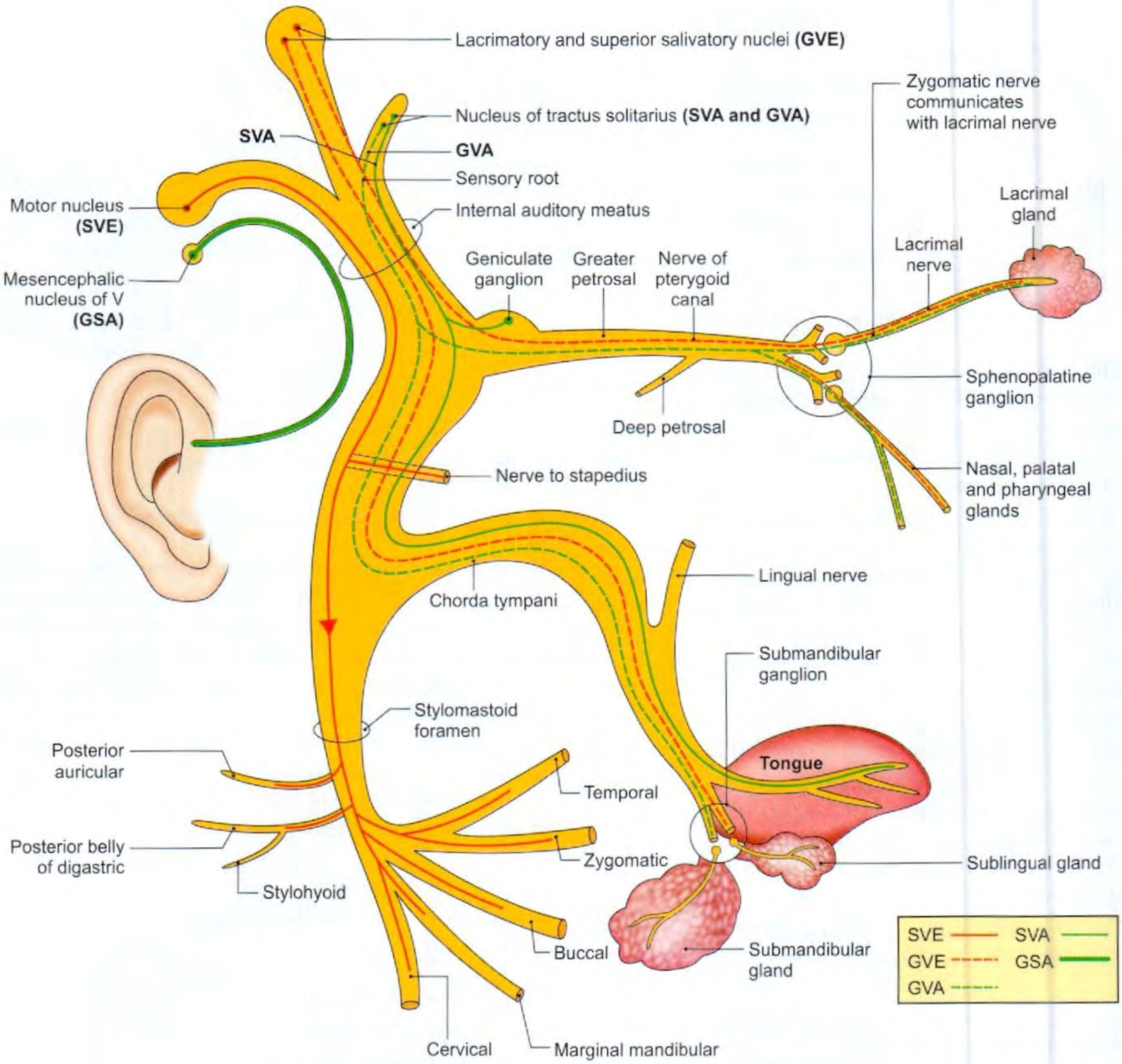


Fig. 4.36: Distribution of functional components of VII nerve

Greater petrosal nerve—course has been traced in Flowchart 4.6.

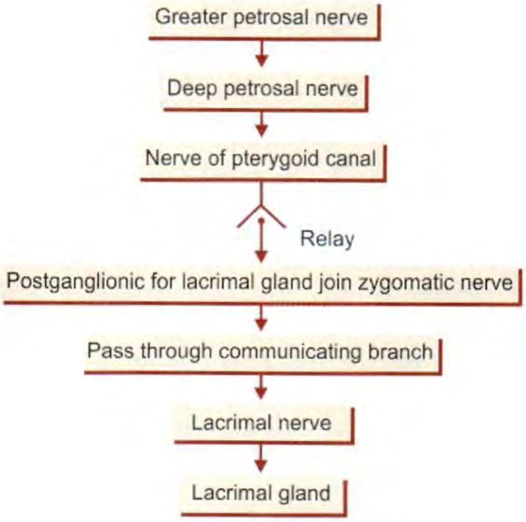
The *nerve to the stapedius* arises opposite the pyramid of the middle ear, and supplies the stapedius muscle. The muscle dampens excessive vibrations of the stapes caused by high-pitched sounds. In paralysis of the muscle, even normal sounds appear too loud and is known as *hyperacusis* (Fig. 4.36).

The *chorda tympani* arises in the vertical part of the facial canal about 6 mm above the stylomastoid foramen. It runs upwards and forwards in a bony canal. It enters the middle ear and runs forwards in close relation to the tympanic membrane. It leaves the middle ear by passing through the petrotympanic fissure. It then passes medial to the spine of the sphenoid and enters the infratemporal fossa. Here it joins the lingual nerve through which chorda tympani nerve is distributed. It carries:

a. Preganglionic secretomotor fibres to the submandibular ganglion for supply of the submandibular and sublingual salivary glands.
b. Taste fibres from the anterior two-thirds of the tongue except circumvallate papillae.

The *posterior auricular nerve* arises just below the stylomastoid foramen. It ascends between the mastoid process and the external acoustic meatus, and supplies:

Flowchart 4.6: Tracing nerve supply of lacrimal gland



a. Auricularis posterior
b. Occipitalis
c. Intrinsic muscles on the back of auricle.

The *digastric branch*, arises close to the previous nerve. It is short and supplies the posterior belly of the digastric.

The *stylohyoid branch*, arises with the digastric branch, is long and supplies the stylohyoid muscle.

The *temporal branches* cross the zygomatic arch and supply:

a. Auricularis anterior
b. Auricularis superior
c. Intrinsic muscles on the lateral side of the ear
d. Frontalis
e. Orbicularis oculi
f. Corrugator supercilii.

The *zygomatic branches* run across the zygomatic bone and supply the orbicularis oculi.

The *buccal branches* are two in number. The upper buccal branch runs above the parotid duct and the lower buccal branch below the duct. They supply muscles in that vicinity especially the buccinator.

The *marginal mandibular branch* runs below the angle of the mandible deep to the platysma. It crosses the body of the mandible and supplies muscles of the lower lip and chin.

The *cervical branch* emerges from the apex of the parotid gland, and runs downwards and forwards in the neck to supply the platysma.

Communicating branches: For effective coordination between the movements of the muscles of the first, second and third branchial arches, the motor nerves of the three arches communicate with each other. The facial nerve also communicates with the sensory nerves distributed over its motor territory.

Ganglia

The ganglia associated with the facial nerve are as follows.

1. The geniculate ganglion (Fig. 4.36) is located on the first bend of the facial nerve, in relation to the medial wall of the middle ear. It is a *sensory ganglion*. The taste fibres present in the nerve are peripheral processes of pseudounipolar neurons present in the geniculate ganglion.
2. The submandibular ganglion is a *parasympathetic ganglion* for relay of secretomotor fibres to the submandibular and sublingual glands. The preganglionic fibres come from the chorda tympani nerve (Table 4.2). It is described in Chapter 7 of Volume 3.
3. The pterygopalatine ganglion is also a *parasympathetic ganglion*. Secretomotor fibres meant for the lacrimal gland relay in this ganglion. The fibres reach the ganglion from the nerve to the pterygoid canal (Table 4.2). It is described in Chapter 15 of Volume 3.

CLINICAL ANATOMY

- *Bell's palsy:* Sudden paralysis of facial nerve at the stylomastoid foramen, results in asymmetry of corner of mouth, inability to close the eye, disappearance of nasolabial fold and loss of wrinkling of skin of forehead on the same side (*see* Fig. 2.20 of Volume 3).
- Lesion above the origin of chorda tympani nerve will show symptoms of Bell's palsy plus loss of taste from anterior two-thirds of tongue except vallate papillae (Fig. 4.37).
- Lesion above the origin of nerve to stapedius will cause symptoms 1, 2 (Fig. 4.37). It also causes hyperacusis.
- Lesions 1, 2 and 3 (Fig. 4.37) are lower motor neuron type. Upper motor neuron paralysis will not affect the upper part of face, i.e. orbicularis oculi, only lower half of opposite side of face is affected. The upper half of face has bilateral representation, whereas lower half has only contralateral representation (Fig. 4.5a).
- Facial nerve can be injured at any level during its course. Figure 4.37 shows symptoms according to level of injury of VII nerve.

  Lower motor neuron paralysis of VII nerve causes paralysis of ipsilateral half of face, i.e. both upper quadrant and lower quadrant of same side as the injury.

Upper motor neuron paralysis of VII nerve results in paralysis of contralateral lower quadrant of face only.

- For clinical testing of the facial nerve, and for different types of facial paralysis—infranuclear (*see* Fig. 2.20 and for supranuclear *see* Fig. 2.21 of Volume 3).
- *Facial nerve palsy in newborn:* The mastoid process is absent in newborn and stylomastoid foramen is superficial. Manipulation of baby's head during delivery may damage the VII nerve. This leads to paralysis of facial muscles especially the buccinator, required for sucking the milk.
- *Crocodile tears syndrome:* Lacrimation during eating occurs due to aberrant regeneration after trauma.
- In case of damage to facial nerve proximal to geniculate ganglia, regenerating fibres for submandibular salivary gland grow in endoneural sheaths of preganglionic secretomotor fibres supplying the lacrimal gland. That is why patient lacrimates while eating food.
- *Ramsay-Hunt syndrome:* Involvement of geniculate ganglia by herpes zoster results in this syndrome. It shows following symptoms:
  a. Hyperacusis.
  b. Loss of lacrimation.
  c. Loss of sensation of taste in anterior two-thirds of tongue.
  d. Bell's palsy and lack of salivation.
  e. Vesicles on the auricle.

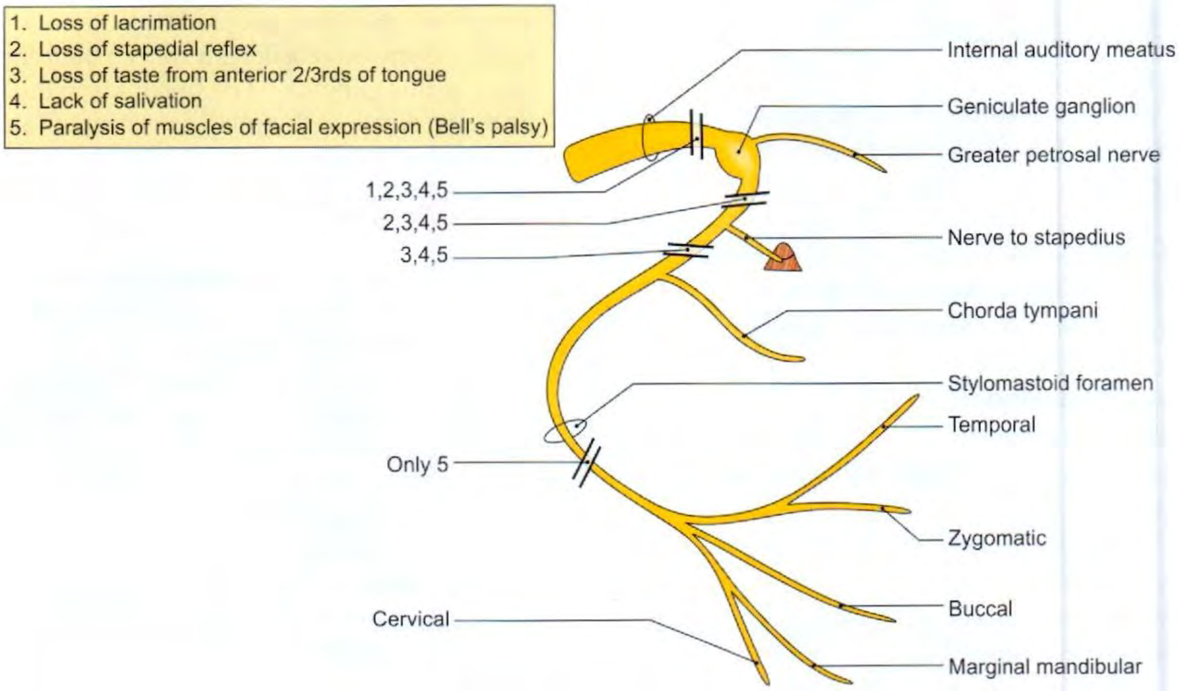


Fig. 4.37: Symptoms according to the level of injury to cranial nerve VII

EIGHTH CRANIAL NERVE

VESTIBULOCOCHLEAR NERVE

This nerve comprises hearing and vestibular parts. It belongs to special somatic afferent column (Table 4.2).

Pathway of Hearing

1 The first neurons of the pathway are located in the spiral ganglion. They are bipolar. Their peripheral processes innervate the spiral organ of Corti (Fig. 4.38), while central processes form the cochlear nerve (Fig. 4.39). This nerve terminates in the dorsal and ventral cochlear nuclei.

2 The second neurons lie in the dorsal and ventral cochlear nuclei. Most of the axons arising in these nuclei cross to the opposite side (in the trapezoid body) and terminate in the superior olivary nucleus. (many fibres end in the nucleus of trapezoid body or of the lateral lemniscus). Some fibres are uncrossed (Fig. 4.40).

3 The third neurons lie in the superior olivary nucleus. Their axons form the lateral lemniscus and reach the inferior colliculus.

Table 4.2: Connections of parasympathetic ganglia

Ganglia	*Sensory root*	*Sympathetic root*	*Secretomotor parasympathetic root*	*Motor root*	*Distribution*
Ciliary (Fig. A.1 of Volume 3)	From nasociliary nerve	Plexus along ophthalmic artery	Edinger-Westphal nucleus → oculomotor nerve → nerve to inferior oblique	—	Ciliaris muscles Sphincter pupillae
Otic	Branch from auriculotemporal nerve	Plexus along middle meningeal artery	Inferior salivatory nucleus → glosso-pharyngeal nerve → tympanic branch → tympanic plexus → lesser petrosal nerve	Branch from nerve to medial pterygoid	Secretomotor to parotid gland via auriculotemporal nerve Tensor veli palatini and tensor tympani via nerve to medial pterygoid (unrelayed)
Pterygopalatine	Two branches from maxillary nerve	Deep petrosal from plexus around internal carotid artery	Lacrimatory nucleus → nervus intermedius → facial nerve → geniculate ganglion → greater petrosal nerve + deep petrosal nerve = nerve of pterygoid canal	—	Mucous glands of nose, paranasal sinuses, palate, nasopharynx Some fibres pass through zygomatic nerve → zygomatico-temporal nerve → communicating branch to lacrimal nerve → lacrimal gland
Submandibular	Two branches from lingual nerve	Branch from plexus around facial artery	Superior salivatory nucleus → facial nerve → chorda tympani → joins the lingual nerve	—	Submandibular, sublingual, and anterior lingual glands

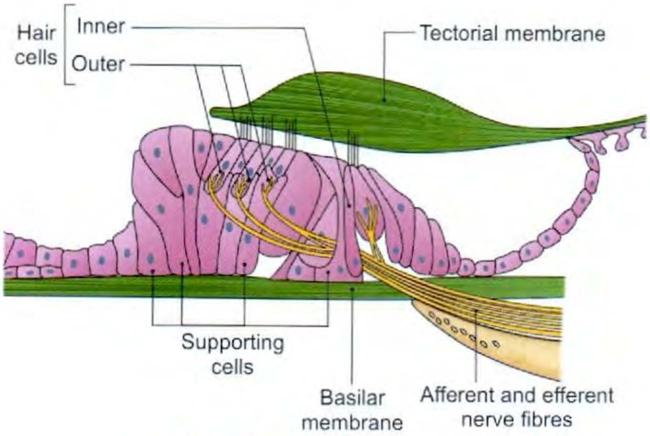


Fig. 4.38: Organ of Corti

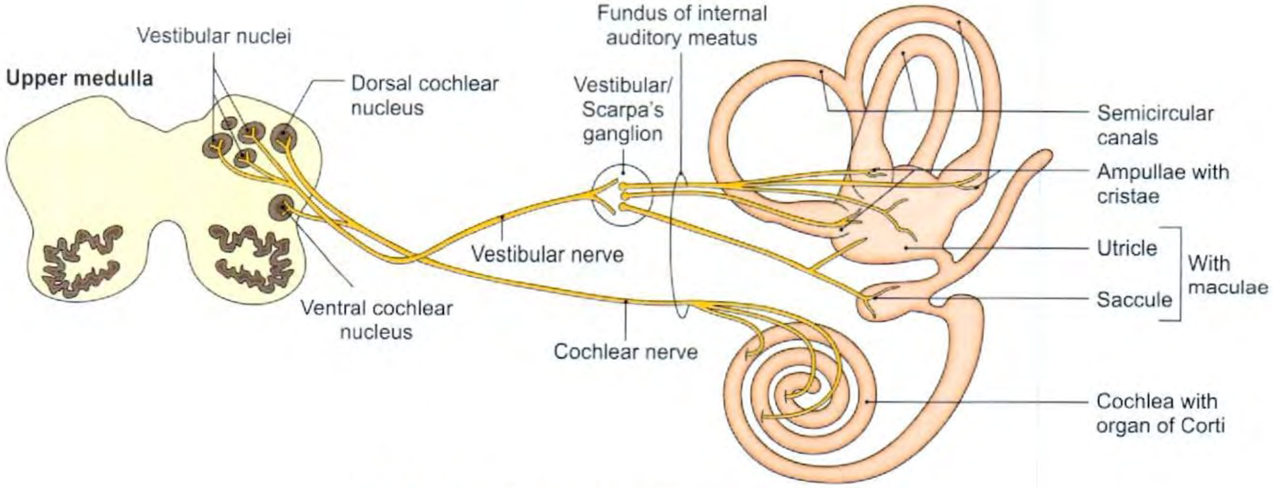


Fig. 4.39: Course of cochlear and vestibular nerves

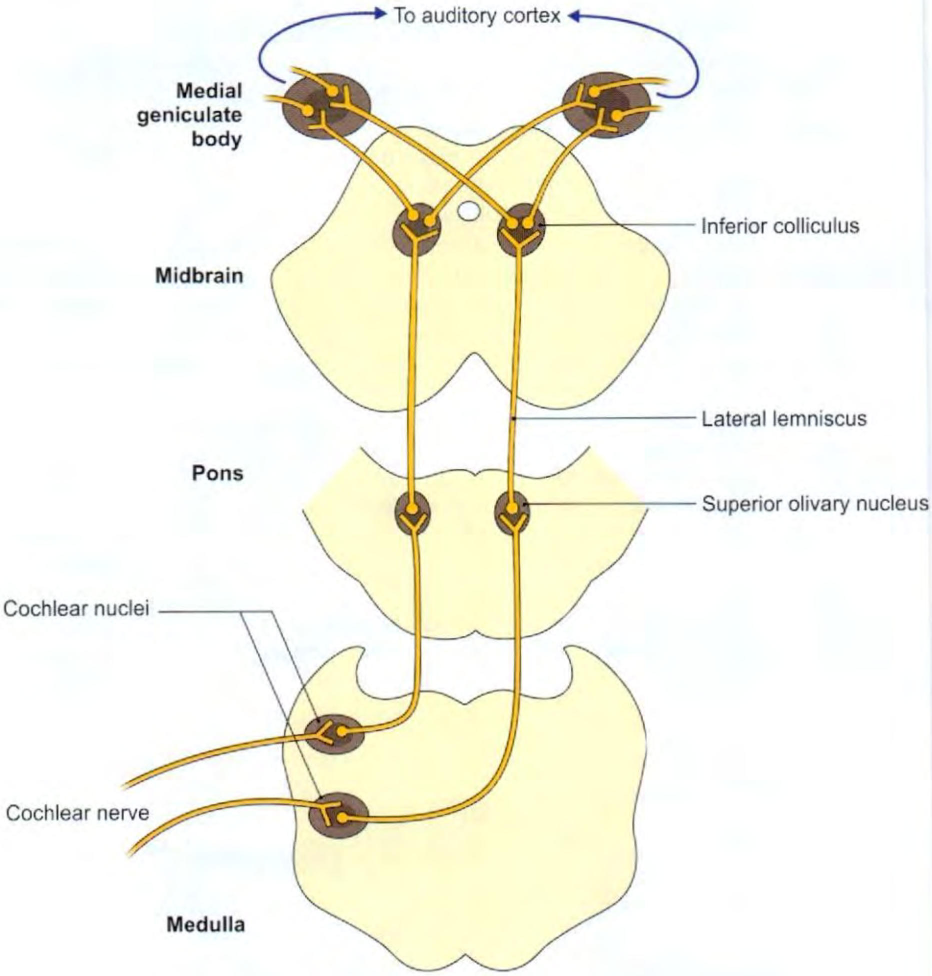
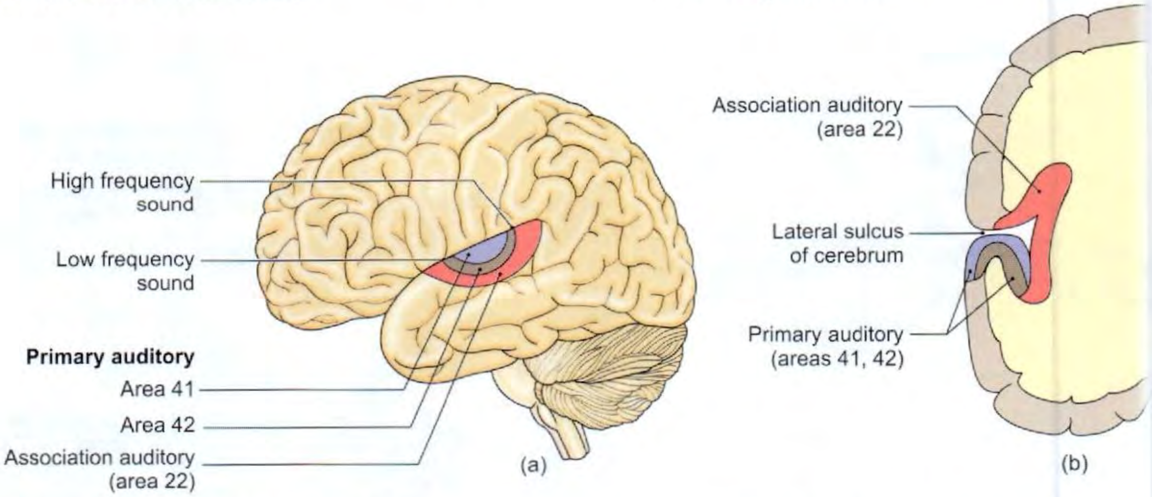


Fig. 4.40: Auditory pathway

4 The fourth neurons lie in the inferior colliculus. Their axons pass through the inferior brachium to reach the medial geniculate body. (Some fibres of lateral lemniscus reach the medial geniculate body without relay in the inferior colliculus.)

5 The fifth neurons lie in the medial geniculate body. Their axons form the auditory radiation, which passes through the sublentiform part of the internal capsule to reach the auditory area (Figs 4.41a and b) in the temporal lobe.



Figs 4.41a and b: Auditory cortex: (a) Posterior ramus of lateral sulcus, and (b) depth of lateral sulcus

Vestibular Pathway

The vestibular receptors are the maculae of the saccule and utricle (for static balance) (Fig. 4.42) and in the crista of the ampullaris of semicircular ducts (for kinetic balance) (Fig. 4.43). Fibres from cristae of anterior and lateral semicircular canals and some fibres from the two maculae lie in superior vestibular area of internal acoustic meatus.

Fibres of crista of posterior semicircular canal lie in foramen singulare.

Most of the fibres from maculae of utricle and saccule lie in inferior vestibular area (Fig. 4.34).

These three nerve divisions are peripheral processes of bipolar neurons of the vestibular ganglion. This ganglion is situated in the internal acoustic meatus. The central processes arising from the neurons of the ganglion form the vestibular nerve which ends in the vestibular nuclei.

The second neurons in the pathway of balance lies in the vestibular nuclei (Fig. 4.39). These nuclei send fibres:

a. To the archicerebellum through the inferior cerebellar peduncle (vestibulocerebellar tract).
b. To the motor nuclei of the brain stem (chiefly of the III, IV, VI and XI nerves) through the medial longitudinal bundle (Fig. 4.44).
c. To the anterior horn cells of the spinal cord through the vestibulospinal tract.
d. Fibers also reach thalamus and premotor cortex of frontal lobe.

Through the vestibular pathway, the impulses arising in the labyrinth can influence the movements of the eyes, the head, the neck and the trunk.

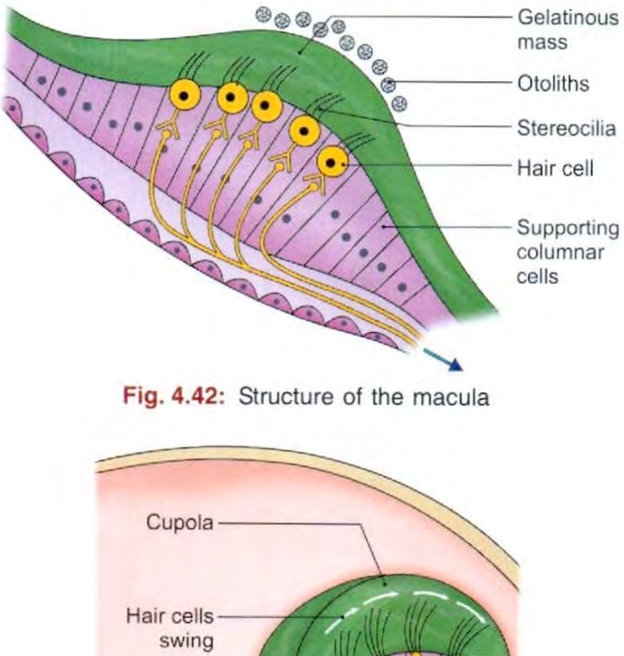


Fig. 4.42: Structure of the macula

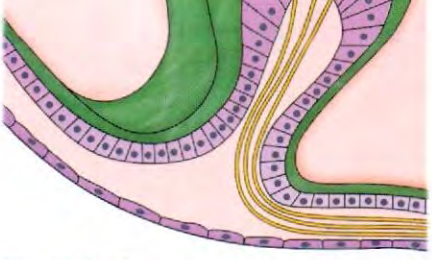


Fig. 4.43: Structure of crista ampullaris

CLINICAL ANATOMY

Deafness: Three types of hearing loss are seen:

1. Conductive deafness is the failure of sound waves to reach to the cochlea.
2. Sensorineural deafness is the failure of production or transmission of action potential due to cochlear disease, cochlear nerve disease or defects in cochlear nerve central connections.
3. Cortical deafness is a bilateral or dominant posterior temporal lobe lesion. It results in a failure to understand spoken language even though hearing is preserved.

Vertigo: This is an illusion of rotatory movement due to disturbed orientation of the body in space. The patient feels that the environment is moving. It is due to disease of vestibular nerve.

Tinnitis: It is a sensation of buzzing, ringing, hissing or singing quality. Tinnitus may be unilateral or bilateral; high or low pitch; continuous or intermittent.

Meniere's syndrome: It is characterized by recurrent attacks of tinnitis, vertigo and hearing loss accompanied by a sensitivity to noises. It affects middle aged or older persons. In this condition, there is an increase in volume of endolymph.

Acoustic neuroma: It is a slow growing benign tumor of neurolemmal cells. It causes an early loss of hearing.

NINTH CRANIAL NERVE

GLOSSOPHARYNGEAL NERVE

Glossopharyngeal is the ninth cranial nerve. It is the nerve of the third branchial arch.

It is motor to the stylopharyngeus. It is secretomotor to the parotid gland and gustatory to the posterior one-third of the tongue including the circumvallate papillae.

It is sensory to the pharynx, the tonsil, soft palate, the posterior one-third of the tongue, carotid body and carotid sinus.

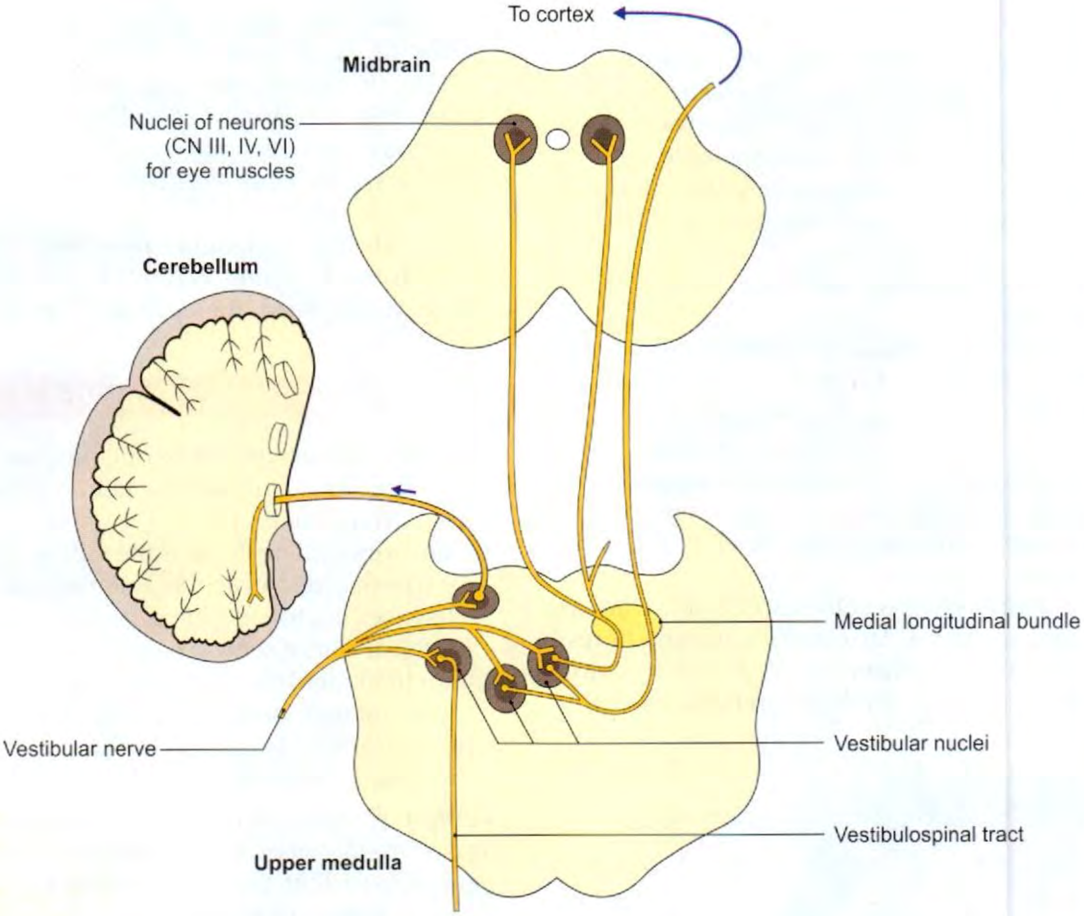


Fig. 4.44: Vestibular pathway

Functional Components

1 *Special visceral efferent* (SVE) fibres arise in nucleus ambiguus and supply the stylopharyngeus muscle (Fig. 4.45).

2 *General visceral efferent* (GVE) fibres (preganglionic) arise in inferior salivatory nucleus and travel to the otic ganglion. Postganglionic fibres arising in the ganglion to supply the parotid gland (Table 4.2).

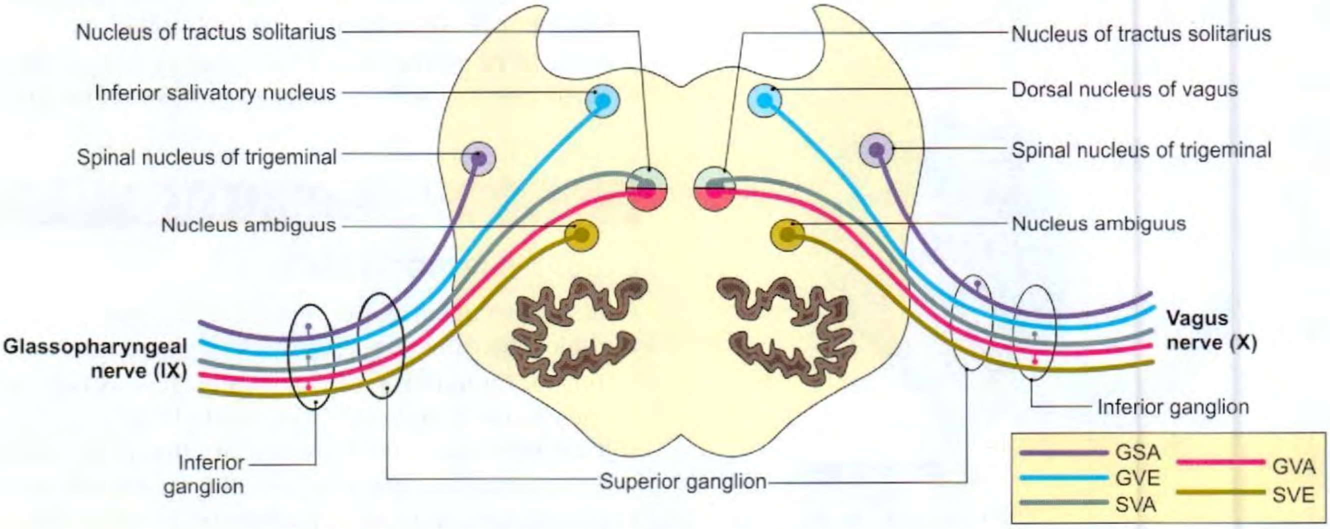


Fig. 4.45: Functional components and nuclei of IX and X cranial nerves

3 *General visceral afferent* (GVA) fibres are peripheral processes of cells in inferior ganglion of the nerve. These carry general sensations from the pharynx, palate, posterior one-third of tongue, tonsil, carotid body and carotid sinus to the ganglion. The central processes convey these sensations to lower part of the nucleus of the solitary tract.

4 *Special visceral afferent* (SVA) fibres are also peripheral processes of cells in the inferior ganglion. They carry sensations of taste from the posterior one-third of the tongue including circumvallate papillae to the inferior ganglion. The central processes convey these sensations to the nucleus of the solitary tract.

5 *General somatic afferent* (GSA) fibres are the peripheral processes of the cells in the inferior ganglion of the nerve. These carry general sensations from the middle ear, proprioceptive fibres from stylopharyngeus. The central processes carry these sensations to nucleus of spinal tract of trigeminal nerve.

Nuclei

The three nuclei in the upper part of medulla are named below:

1 Nucleus ambiguus (branchiomotor).
2 Inferior salivatory nucleus (parasympathetic).
3 Nucleus of tractus solitarius (gustatory).

Course and Relations

1 In their *intraneural course*, the fibres of the nerve pass forwards and laterally, between the olivary nucleus and the inferior cerebellar peduncle, through the reticular formation of the medulla.

2 At the base of the brain, the nerve is attached by 3 to 4 filaments to the upper part of the posterolateral sulcus of the medulla, just above the rootlets of the vagus nerve (*see* Fig. 5.1).

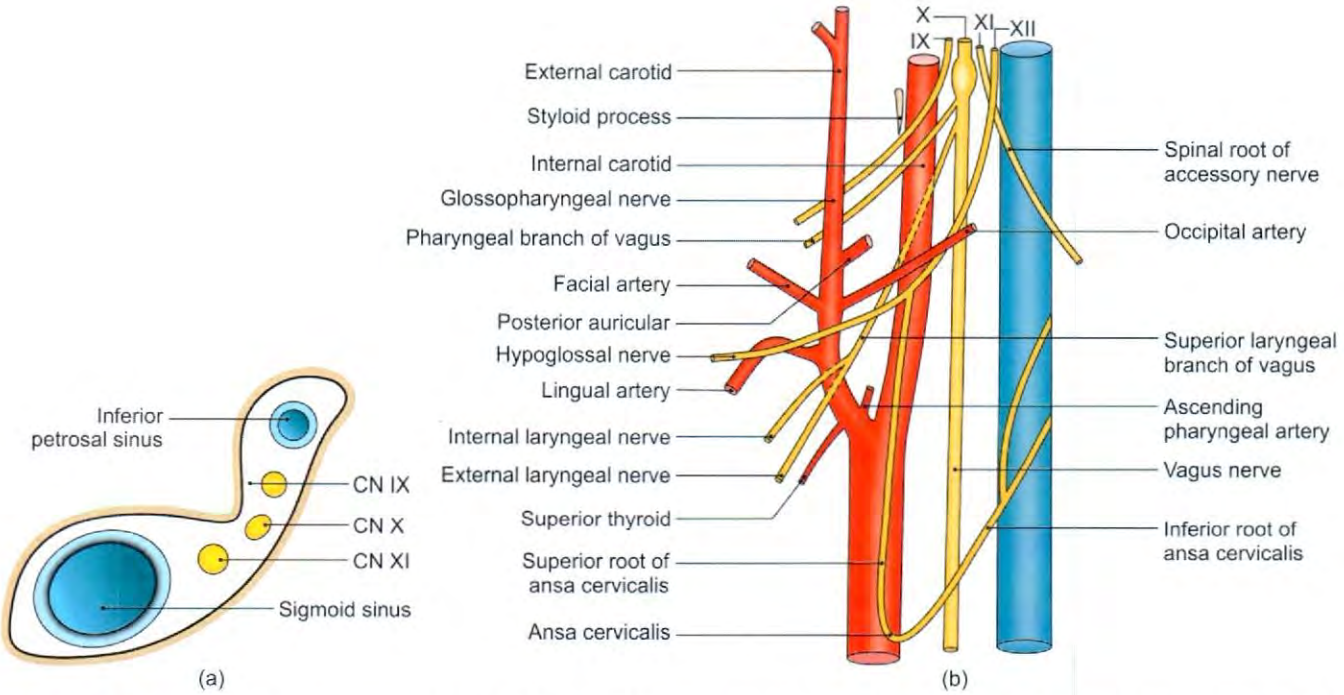
3 In their intracranial course, the filaments unite to form a single trunk which passes forwards and laterally towards the jugular foramen, crossing and grooving the jugular tubercle of the occipital bone.

4 The nerve *leaves the skull* by passing through the middle part of the *jugular foramen*, anterior to the vagus and accessory nerves. It has a separate sheath of dura mater (Fig. 4.46a).

5 In the jugular foramen, the nerve is lodged in a deep groove leading to the cochlear canaliculus, and is separated from the vagus and accessory nerves by the inferior petrosal sinus.

In its *extracranial course*, the nerve descends:

a. Between the internal jugular vein and the internal carotid artery, deep to the styloid process and the muscles attached to it.



(a) (b)

Figs 4.46a and b: (a) Structures passing through right jugular foramen (seen from above), and (b) relation of cranial nerves IX, X, XI, XII to carotid arteries and internal jugular vein

b. It then turns forwards winding round the lateral aspect of the stylopharyngeus, passes between the external and internal carotid arteries, and reaches the side of the pharynx (Fig. 4.46b). Here it gives pharyngeal branches.

c. It enters the submandibular region by passing deep to the hyoglossus (*see* Fig. 7.2), where it breaks up into tonsillar and lingual branches.

6 At the base of skull, ninth nerve presents a superior and an inferior ganglion. Superior ganglion is a detached part of the inferior, and gives no branches. The inferior ganglion is larger, occupies notch on the lower border of petrous temporal, and gives out communicating and tympanic branches.

Branches and Distribution

1 The *tympanic nerve* is a branch of the inferior ganglion of the glossopharyngeal nerve. It enters the middle ear through the tympanic canaliculus, takes part in the formation of the tympanic plexus in the middle ear and distributes its fibres to the middle ear, the auditory tube, the mastoid antrum and air cells. One branch of the plexus is called the *lesser petrosal nerve*. It contains preganglionic secretomotor fibres for the parotid gland and relays in the otic ganglion. Postganglionic fibres join auriculotemporal nerve to reach the gland.

2 The *carotid branch* descends on the internal carotid artery and supplies the carotid sinus and the carotid body (Fig. 4.47).

3 The *pharyngeal branches* take part in the formation of the pharyngeal plexus, along with vagal and sympathetic fibres. The glossopharyngeal fibres are distributed to the mucous membrane of the pharynx and palate.

4 The *muscular branch* supplies the stylopharyngeus (Fig. 4.47).

5 The *tonsillar branches* supply the tonsil and join the lesser palatine nerves to form a plexus from which fibres are distributed to the soft palate and to the palatoglossal arches.

6 The *lingual branches* carry taste and general sensations from the posterior one-third of the tongue including the circumvallate papillae.

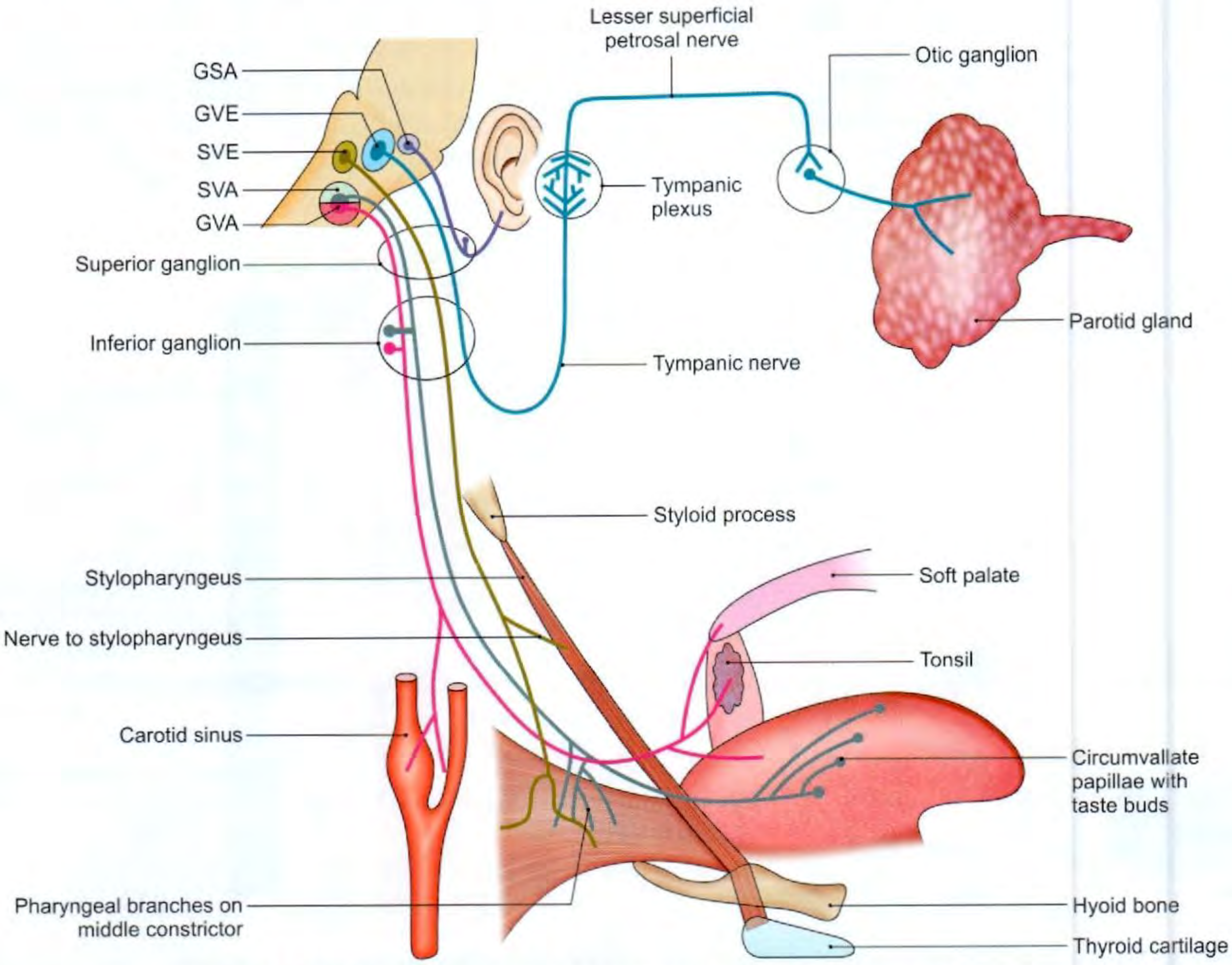


Fig. 4.47: Distribution of functional components of glossopharyngeal nerve

CLINICAL ANATOMY

- Lesion of this nerve causes:
  a. Absence of secretions of parotid gland.
  b. Absence of taste from posterior one-third of tongue and the circumvallate papillae.
  c. Loss of pain sensations from tongue, tonsil, pharynx and soft palate.
  d. Gag reflex is absent.
- *Glossopharyngeal neuralgia:* It is a short sharp severe attack of pain affecting posterior part of pharynx or tonsillar area.
- Jugular foramen syndrome is due to injury at the jugular foramen resulting in multiple cranial nerve palsies.
- The glossopharyngeal nerve is tested clinically in the following way:
  a. On tickling the posterior wall of the pharynx, there is reflex contraction of the pharyngeal muscles. No such contraction occurs when the ninth nerve is paralysed.
  b. Taste sensibility on the posterior one-third of the tongue can also be tested. It is lost in ninth nerve lesions.
- Isolated lesions of the ninth nerve are almost unknown. They are usually accompanied by lesions of the vagus nerve.
- Pharyngitis may cause referred pain in the ear as both are supplied by IX nerve. However, in these cases eustachian catarrh should be excluded.

TENTH CRANIAL NERVE

VAGUS NERVE

Vagus nerve is the tenth cranial nerve. It is so called because of its extensive ('vague') course, through the head, the neck, the thorax and the abdomen. The fibres of the cranial root of the accessory nerve are also distributed through it.

The vagus nerve bears two ganglia, superior and inferior. The *superior ganglion* is rounded and lies in the jugular foramen. The *inferior* ganglion is cylindrical and lies near the base of the skull.

Functional Components

1. *Special visceral efferent* fibres arise in the nucleus ambiguus and supply the muscles of the palate, pharynx and larynx (Fig. 4.45).
2. *General visceral efferent* fibres arise in the dorsal motor nucleus of the vagus. These are preganglionic parasympathetic fibres. They are distributed to thoracic and abdominal viscera. The postganglionic neurons are situated in ganglia lying close to (within) the viscera to be supplied.
3. *General visceral afferent* fibres are peripheral processes of cells located in the inferior ganglion of the nerve. They bring sensations from the pharynx, larynx, trachea, oesophagus and from the abdominal and thoracic viscera. These are conveyed by the central processes of the ganglion cells to the lower part of nucleus of tractus solitarius. Some of these fibres terminate in the dorsal nucleus of the vagus.
4. *Special visceral afferent* fibres are also peripheral processes of neurons in the inferior ganglion. They carry sensations of taste from the posteriormost part of the tongue and from the epiglottis. The central processes of the cells concerned terminate in the upper part of the nucleus of the tractus solitarius.
5. *General somatic afferent* fibres are peripheral processes of neurons in the superior ganglion and are distributed to the skin of the external ear. The central processes of the ganglion cells terminate in relation to the spinal nucleus of the trigeminal nerve (Fig. 4.4b).

The upper part of the nucleus of tractus solitarius comprises superior, middle and inferior parts. These parts receive fibres from VII, IX and X nerves, respectively (Fig. 4.4c).

Nuclei

1. Nucleus ambiguus (branchiomotor): Mostly a part of the cranial root of accessory nerve; partly of vagus.
2. Dorsal nucleus of vagus (parasympathetic): It is a mixed nucleus, being both motor (visceromotor and secretomotor) and sensory (viscerosensory). Its fibres form the main bulk of the nerve.
3. Nucleus of tractus solitarius (gustatory): Distributed through internal laryngeal nerve to the taste buds of epiglottis and vallecula.
4. Nucleus of spinal tract of trigeminal.

Course and Relations in Head and Neck

1. In the *intracranial course*, fibres run forwards and laterally through the reticular formation of medulla, between the olivary nucleus and inferior cerebellar peduncle.
2. The nerve is attached, by about ten rootlets, to the posterolateral sulcus of medulla (Fig. 4.1).
3. In the intracranial course, the rootlets unite to from a large trunk which passes laterally across the jugular tubercle along with the glossopharyngeal and cranial root of accessory nerves, and reaches the jugular foramen.
4. The nerve *leaves the cranial cavity* by passing through the middle part of the jugular foramen, between the sigmoid and inferior petrosal sinuses. In the foramen, it is joined by the cranial root of the accessory nerve.
5. Leaving the skull, the nerve descends within the carotid sheath, in between the internal jugular vein (laterally), and the internal and common carotid arteries (medially) (Fig. 4.46).

6 At the *root of the neck,* the right vagus enters the thorax by crossing the first part of the subclavian artery, and then inclining medially behind the brachiocephalic vessels, to reach the right side of the trachea. The left vagus enters the thorax by passing between the left common carotid and left subclavian arteries, behind the internal jugular and brachiocephalic veins.

7 Vagus bears, two ganglia, superior and inferior. The *superior ganglion* is rounded and lies in the jugular foramen. It gives meningeal and auricular branches of vagus, and is connected to glossopharyngeal and accessory nerves and to superior cervical ganglion of sympathetic chain. The *inferior ganglion* is cylindrical (2.5 cm) and lies near the base of skull. It gives pharyngeal, carotid, superior laryngeal branches and is connected to hypoglossal nerve, superior cervical ganglion and the loop between first and second cervical nerves.
Cranial root of XI nerve joins vagus nerve at the inferior ganglion.

Branches in Head and Neck

In the jugular foramen, the superior ganglion gives off:

- Meningeal, and
- Auricular branches.

The ganglion also gives off communicating branches to the glossopharyngeal and cranial root of accessory nerves and to the superior cervical sympathetic ganglion.

The branches arising from inferior ganglion in the neck are:

- Pharyngeal (Fig. 4.48)
- Carotid

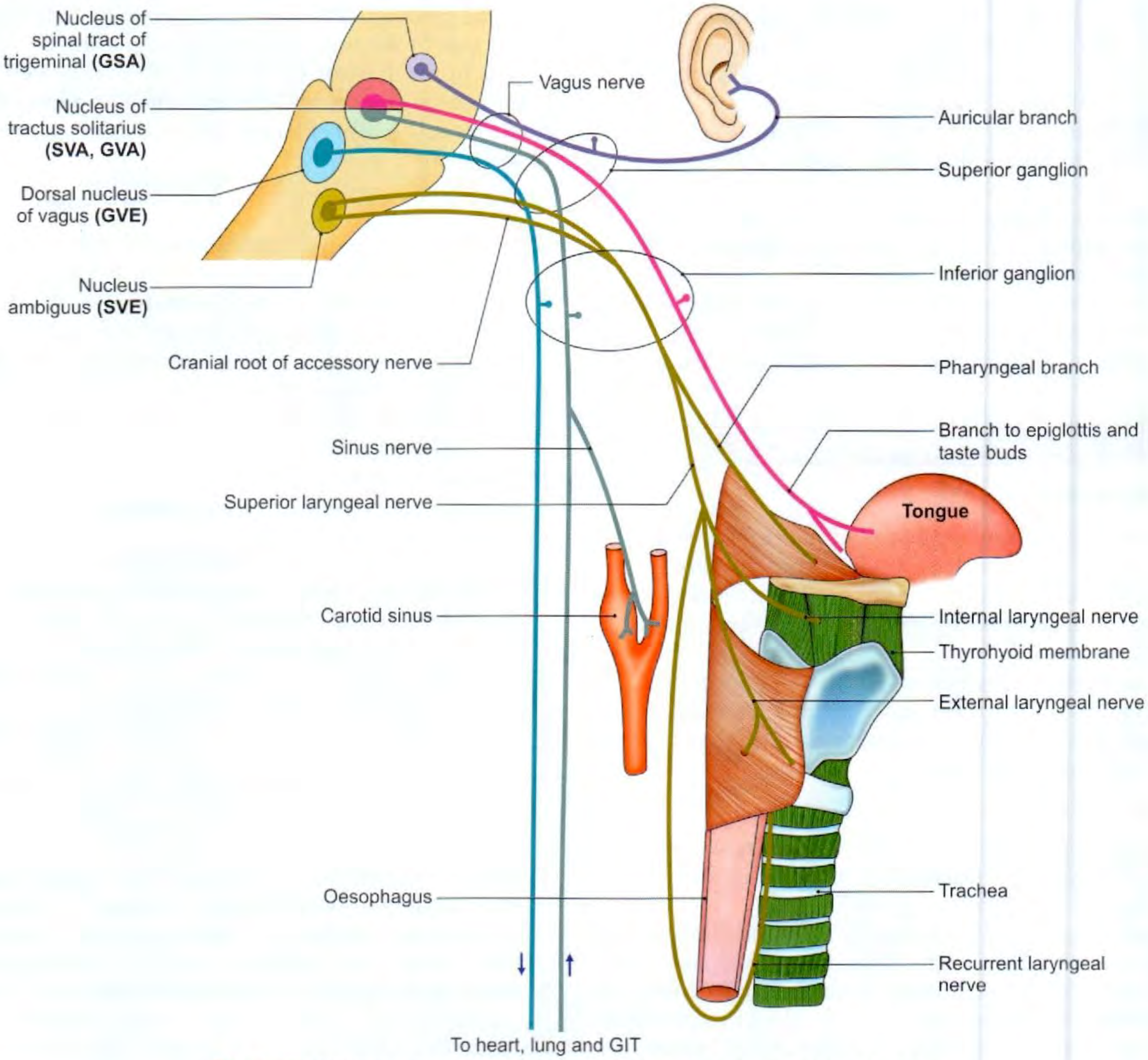


Fig. 4.48: Distribution of functional components of vagus in head and neck

- Superior laryngeal
- Right recurrent laryngeal
- Cardiac.

1 *Meningeal branch* supplies dura of the posterior cranial fossa. The fibres are derived from sympathetic and upper cervical nerves.

2 The *auricular branch* arises from the superior ganglion of the vagus. It passes behind the internal jugular vein, and enters the *mastoid canaliculus* (within the petrous temporal bone). It crosses the facial canal 4 mm above the stylomastoid foramen, emerges through the *tympanomastoid fissure*, and ends by supplying the concha and root of the auricle, the posterior half of the external auditory meatus, and the tympanic membrane (outer surface).

3 The *pharyngeal branch* arises from the lower part of the inferior ganglion of the vagus, and contains chiefly the fibres of the cranial root of accessory nerve. It passes between the external and internal carotid arteries, and reaches the upper border of the middle constrictor of the pharynx where it takes part in forming the pharyngeal plexus. Its fibres are ultimately distributed to the muscles of the pharynx and soft palate (except the tensor veli palatini which is supplied by the mandibular nerve).

4 The *carotid branches* supply the carotid body and carotid sinus.

5 The *superior laryngeal nerve* arises from the inferior ganglion of the vagus, runs downwards and forwards on the superior constrictor deep to the internal carotid artery, and reaches the middle constrictor where it divides into the external and internal laryngeal nerves.

The *external laryngeal nerve* is thin. It accompanies the superior thyroid artery, pierces the inferior constrictor and ends by supplying the cricothyroid muscle. It also gives branches to the inferior constrictor and to the pharyngeal plexus.

The *internal laryngeal nerve* is thick. It passes downwards and forwards, pierces the thyrohyoid membrane with the superior laryngeal vessels and enters the larynx. It supplies the mucous membrane of the larynx up to the level of the vocal folds.

6 The *right recurrent laryngeal nerve* arises from the vagus in front of the right subclavian artery, winds backwards below the artery, and they runs upwards and medially behind the subclavian and common carotid arteries to reach the tracheo-oesophageal groove. In the upper part of the groove, it is intimately related to the inferior thyroid artery. It supplies:

a. All intrinsic muscles of the larynx, except the cricothyroid.
b. Sensory nerves to the larynx below the level of the vocal cords.
c. Cardiac branches to the deep cardiac plexus.
d. Branches to the trachea and oesophagus.
e. To the inferior constrictor.

The *left recurrent laryngeal nerve* arises from the vagus in the thorax, as the latter crosses the left side of the arch of the aorta. It loops around the ligamentum arteriosum and reaches the tracheo-oesophageal groove. Its distribution is similar to that of the right nerve. It does not have to pass behind the subclavian and carotid arteries; and usually, it is posterior to the inferior thyroid artery.

7 The *cardiac branches* are superior and inferior. Out of the four cardiac branches of the vagi (two on each side), the left inferior branch goes to the superficial cardiac plexus. The other three cardiac nerves go to the deep cardiac plexus.

CLINICAL ANATOMY

- The vagus nerve is tested clinically by comparing the palatal arches on the two sides. On the paralysed side, there is no arching, and the uvula is pulled to the normal side.
- Paralysis of the vagus nerve produces:
  a. Nasal regurgitation of swallowed liquids.
  b. Nasal twang in voice.
  c. Hoarseness of voice.
  d. Flattening of the palatal arch (Fig. 4.49).
  e. Cadaveric position of the vocal cord.
  f. Dysphagia.
- Irritation of the auricular branch of the vagus in the external ear (by ear wax, syringing, etc.) may reflexly cause persistent cough (ear cough), vomiting, or even death due to sudden cardiac inhibition.
- Stimulation of the auricular branch may reflexly produce increased appetite.
- Irritation of the recurrent laryngeal nerve by enlarged lymph nodes in children may also produce a persistent cough.
- Some fibres arising in the geniculate ganglion of facial nerve pass into the vagus through communications between the two nerves. They reach the skin of auricle through the auricular branch of vagus. Sometimes a sensory ganglion

may have a viral infection (called herpes zoster) and vesicles appear on the area of skin supplied by the ganglion. In herpes zoster of the geniculate ganglion, vesicles appear on the skin of auricle.

- Injury to pharyngeal branch causes dysphagia. Paralysis of muscles of soft palate results in nasal regurgitation of fluids and nasal tone of voice. Lesions of superior laryngeal nerve produces anaesthesia in the upper part of larynx and paralysis of cricothyroid muscle. The voice is weak and gets tired easily.
- Injury to right recurrent laryngeal nerve results in hoarseness and dysphonia due to paralysis of the right vocal cord (Fig. 4.50).
- Paralysis of both vocal cords results in aphonia and inspiratory stridor (high pitched and harsh respiratory sound). It may occur during thyroid surgery.
- During thyroidectomy recurrent laryngeal nerve may injure resulting in fixed and paramedian vocal cords.
- In severe peptic ulcer vagotomy is done to relieve the symptoms.

Fig. 4.49: Paralysis of muscles of soft palate on left side

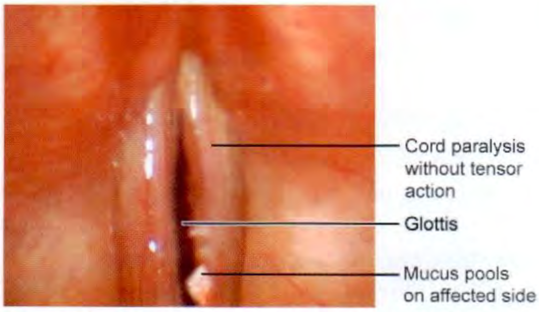


Fig. 4.50: Injury to right recurrent laryngeal nerve

ELEVENTH CRANIAL NERVE

ACCESSORY NERVE

Accessory nerve is the eleventh cranial nerve. It has two roots, cranial and spinal. The cranial root is assisting the vagus, and is distributed through its branches as vago-accesory complex. The spinal root has a more independent course (Fig. 4.51).

Functional Components

1 The cranial root is *special visceral (branchial) efferent.* It arises from the lower part of nucleus ambiguus. It is distributed through the branches of vagus to the muscles of the palate, the pharynx, the larynx, and possibly the heart (Fig. 4.51).

2 The spinal root is also special visceral efferent. It arises from a long spinal nucleus situated in the lateral part of the anterior grey column of the spinal cord extending between segments C1 to C5. Its fibres supply the sternocleidomastoid and the trapezius muscles.

Nuclei

The cranial root arises from the lower part of the *nucleus ambiguus*.

The spinal root arises from a long *spinal nucleus* situated on the lateral part of anterior grey column of spinal cord, extending from C1 to C5 segments. It is in line with nucleus ambiguus.

Course and Distribution of the Cranial Root

1 The cranial root emerges in the form of 4 to 5 rootlets which are attached to the posterolateral sulcus of the medulla. Just below, the rootlets soon join together to form a single trunk.

2 It runs laterally with the glossopharyngeal vagus and spinal accessory nerves, crosses the jugular tubercle, and reaches jugular foramen.

3 In the jugular foramen, the cranial root unites for a short distance with the spinal root, and again separates from spinal root as it passes out of the foramen (Fig. 4.51).

4 The cranial root finally fuses with the vagus at its inferior ganglion, and is distributed through the branches of the vagus to the muscles of the palate, the pharynx, the larynx and possibly the heart.

Course and Distribution of the Spinal Root

1 It arises from the upper five segments of the spinal cord (Fig. 4.51).

2 It emerges in the form of a row of filaments attached to the cord midway between the ventral and dorsal nerve roots.

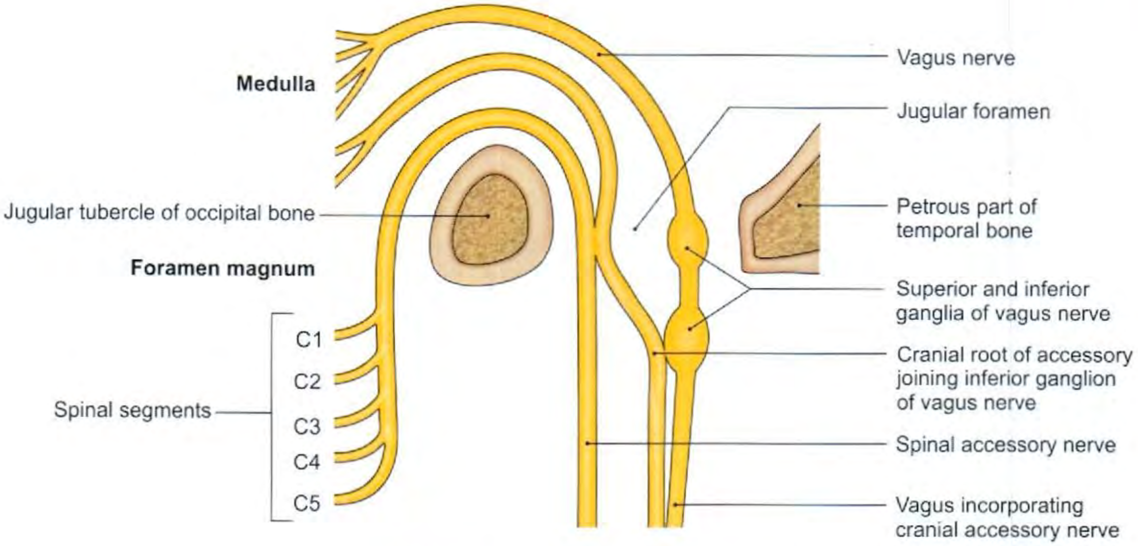


Fig. 4.51: Course of the accessory nerve

3. *In the vertebral canal,* the filaments unite to form a single trunk which ascends in front of the dorsal nerve roots and behind the ligamentum denticulatum.
4. The nerve *enters the cranium* through the foramen magnum lying behind the vertebral artery.
5. Within the cranium, the nerve runs upwards and laterally, crosses the jugular tubercle (with the ninth and tenth cranial nerves) and reaches the jugular foramen.
6. The nerve *leaves the skull* through the middle part of the jugular foramen where it fuses with a short length of the cranial root. It soon separates from the latter and passes out of the foramen.
7. In its *extracranial course,* the nerve descends vertically between the internal jugular vein and the internal carotid artery deep to the parotid and to the styloid process (Fig. 4.46). It reaches a point midway between the angle of mandible and the mastoid process. Then it runs downwards and backwards superficial to the internal jugular vein and is surrounded by lymph nodes.

   The nerve pierces the anterior border of the sternocleidomastoid at the junction of its upper one-fourth with the lower three-fourths, and communicates with second and third cervical nerves within the muscle.

   The nerve enters the posterior triangle of the neck by emerging through the posterior border of the sternocleidomastoid a little above its middle. In the triangle, it runs downwards and backwards embedded in the fascial roof of the triangle. Here it lies over the levator scapulae. It is related to the superficial lymph nodes. The nerve leaves the posterior triangle by passing deep to the anterior border of the trapezius 5 cm above the clavicle.

   On the deep surface of the trapezius, the nerve communicates with spinal nerves C3 and C4, and ends by supplying the trapezius.
8. *Distribution:* The spinal accessory nerve supplies:
   a. The sternocleidomastoid, the chin turning muscle.
   b. The trapezius, the shrugging muscle.

   Cervical nerves provide a proprioceptive sensations to these muscles.

CLINICAL ANATOMY

- The accessory nerve is tested clinically:
  a. By asking the patient to shrug his shoulders (trapezius) against resistance and comparing the power on the two sides.
  b. By asking the patient to turn the chin to the opposite side (sternocleidomastoid) against resistance and again comparing the power on the two sides.
- Lesions of spinal root of accessory nerve cause drooping of the shoulder and inability to turn chin to opposite side.
- Irritation of the nerve during biopsy of enlarged caseous lymph nodes, may produce torticollis or wry neck.
- Supranuclear connections act on the ipsilateral sternocleidomastoid and on the contralateral trapezius. This results in turning of the head away from relevant hemisphere during seizure.
- Spasmodic torticollis—irritation of the nerve resulting in clonic spasm of the sternocleidomastoid and trapezius muscles.

TWELFTH CRANIAL NERVE

HYPOGLOSSAL NERVE

Hypoglossal is the twelfth cranial nerve. It supplies the muscles of the tongue.

Functional Components/Nuclear Columns

1 *General somatic efferent column:* The fibres arise from the hypoglossal nucleus which lies in the medulla, in the floor of fourth ventricle deep to the hypoglossal triangle (Fig. 4.52).

2 *General somatic afferent column:* The nucleus is mesencephalic nucleus of (V) cranial nerve where proprioceptive fibres from tongue end.

Nucleus

The hypoglossal nucleus, 2 cm long, lies in the floor of fourth ventricle beneath the hypoglossal triangle. It is divided into a part for genioglossus and a part for a rest of the muscles (Fig. 4.5C).

Nucleus for genioglossus muscle receives only contralateral corticonuclear fibres. Nucleus for rest of the lingual muscles receives both ipsilateral and contralateral corticonuclear fibres.

Course and Relations

1 In their *intraneural course,* the fibres pass forwards lateral to the medial longitudinal bundle, medial lemniscus and pyramidal tract, and medial to the reticular formation and olivary nucleus (*see* Fig. 5.5).

2 The nerve is attached to the anterolateral sulcus of the medulla, between the pyramid and the olive, by 10 to 15 rootlets (Fig. 4.1).

The rootlets run laterally behind the vertebral artery, and join to form two bundles which pierce the dura mater separately near the hypoglossal canal.

The nerve leaves the skull through the hypoglossal (anterior condylar) canal.

Extracranial Course

1 The nerve first lies deep to the internal jugular vein, but soon inclines between the internal jugular vein and the internal carotid artery, crosses the vagus (laterally), and reaches in front of it (Fig. 4.46).

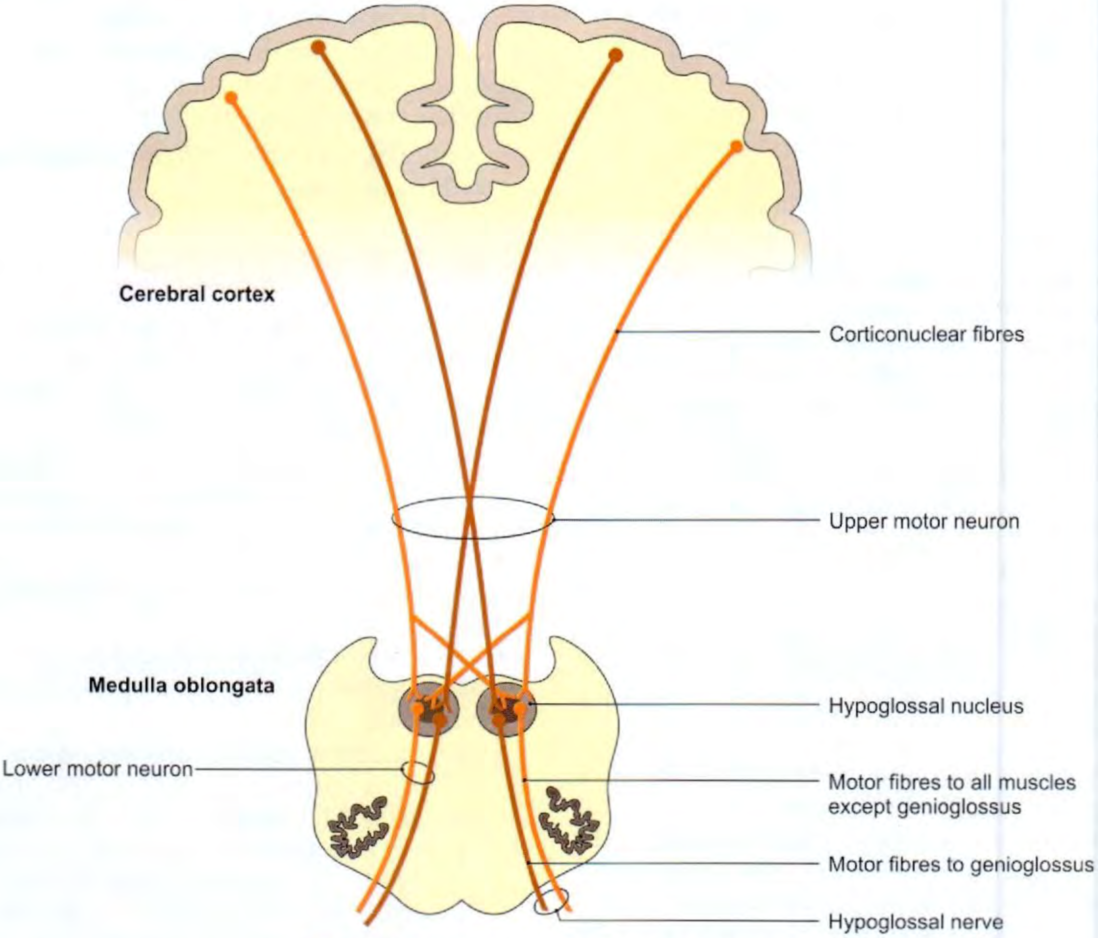


Fig. 4.52: Hypoglossal nerve with its nucleus

2 It then descends between the internal jugular vein and the internal carotid artery in front of the vagus, deep to the parotid gland, the styloid process, the posterior belly of the digastric.

3 At the lower border of the posterior belly of the digastric, it curves forwards, crosses the internal and external carotid arteries and the loop of the lingual artery, and passes deep to the posterior belly of the digastric again to enter the submandibular region .

4 The nerve then continues forwards on the hyoglossus and genioglossus, deep to the submandibular gland and the mylohyoid, and enters the substance of the tongue to supply all its intrinsic muscles and most of its extrinsic muscles (Fig. 4.53).

Branches and Distribution

Branches containing fibres of the hypoglossal nerve proper. They supply the extrinsic and intrinsic muscles of the tongue. Extrinsic muscles are styloglossus, genioglossus, hyoglossus and intrinsic muscles are superior longitudinal, inferior longitudinal, transverse and vertical muscles. Only extrinsic muscle, the palatoglossus is supplied by fibres of the cranial accessory nerve through the vagus and the pharyngeal plexus.

Branches of the hypoglossal nerve containing fibres of nerve C1. These fibres join the nerve at the base of the skull.

a. The *meningeal branch* contains sensory and sympathetic fibres. It enters the skull through the hypoglossal canal, and supplies bone and meninges in the anterior part of the posterior cranial fossa.

b. The *descending branch* continues as the descendens hypoglossi or the upper root of the ansa cervicalis.

c. Branches are also given to the thyrohyoid and geniohyoid muscles (Fig. 4.53).

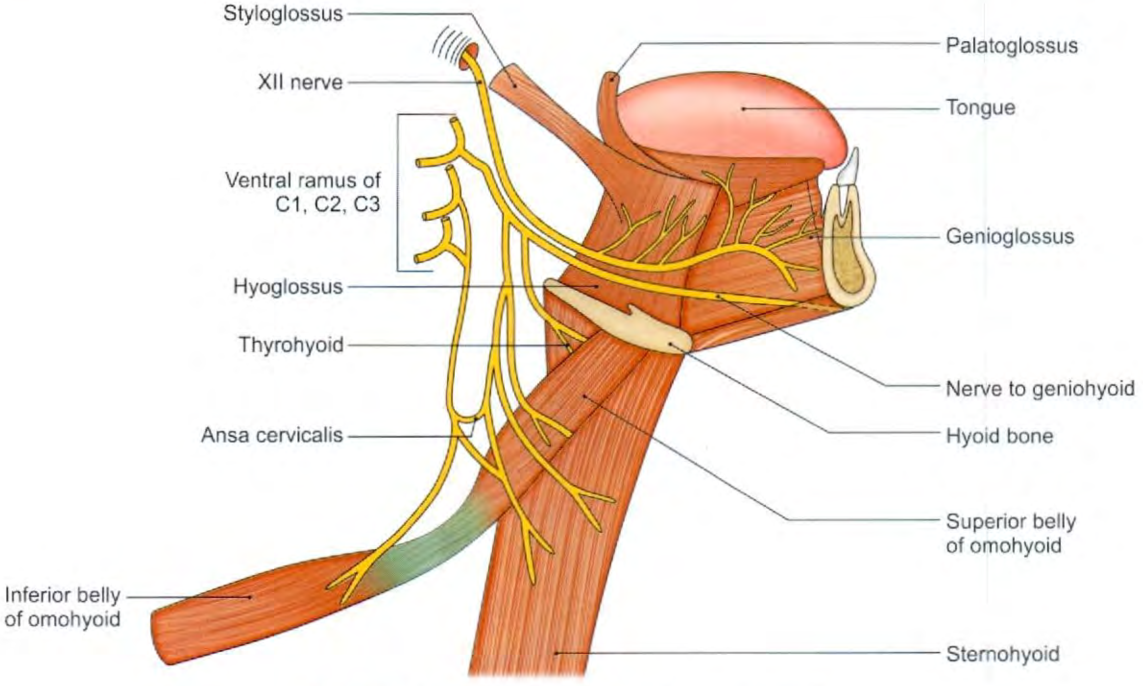


Fig. 4.53: Hypoglossal nerve and ansa cervicalis

CLINICAL ANATOMY

- The hypoglossal nerve is tested clinically by asking the patient to protrude his/her tongue. Normally, the tongue is protruded straight forwards. If the nerve is paralysed, the tongue deviates to the paralysed side (Fig. 4.54).
- An infranuclear unilateral lesion of the hypoglossal nerve produces paralysis of the tongue on that side. There is gradual atrophy of the paralysed half of the tongue. The tongue looks shrunken. On protrusion of tongue, its tip deviates to paralysed side as normal genioglossus muscle pulls the base towards normal side.

  Bilateral paralysis of XII nerves results in complete paralysis of the tongue. Protrusion of tongue is not possible. Speech and swallowing are affected, taste and touch sensations are normal.
- Supranuclear lesions of the hypoglossal nerve causes paralysis without wasting. The tongue moves sluggishly resulting in defective speech. On protrusion, the tongue deviates to opposite side.

Fig. 4.54: XII nerve paralysis on right side

Mnemonics

BELL'S Palsy

B*link reflex abnormal*
E*ar ache*
L*acrimation (deficient)*
L*oss of taste in anterior two-thirds of tongue*
S*udden onset*
Palsy *of muscles supplied by VII nerve*
All symptoms are ipsilateral

FACTS TO REMEMBER

- Cranial nerves I, II, VIII are almost sensory, cranial nerves III, IV, VI, XI, XII are motor, cranial nerves V, VII, IX, X are mixed nerves.
- III nerve carries parasympathetic fibres from Edinger-Westphal nucleus of midbrain to the ciliaris and constrictor pupillae muscles for accommodation.
- VII nerve carries parasympathetic fibres from lacrimatory nucleus to pterygopalatine ganglion for the lacrimal gland and glands in nasal cavity, palate and pharynx.
- VII nerve also carries parasympathetic fibres from superior salivatory nucleus to submandibular ganglion for the supply of submandibular, sublingual and glands in the oral cavity.
- IX nerve carries parasympathetic fibres from inferior salivatory nucleus to the otic ganglion for the supply of parotid gland.
- X nerve carries parasympathetic fibres from dorsal nucleus of vagus for the glands in the respiratory tract and glands in the digestive tract till right two-thirds of the transverse colon.
- S2, S3, S4 carry sacral outflow of the parasympathetic system to the distal part of digestive tract and other pelvic viscera.
- V, VII, IX, nerves are the nerves of 1st, 2nd, 3rd arches respectively.
- X, XI, i.e. vagoaccessory complex supplies structures developed from 4th and 6th branchial arches.

CLINICOANATOMICAL PROBLEM

A 40-year-old male had viral infection. One day he noticed tears running on his right side of face and saliva dribbling from his right angle of mouth.

- What is this paralysis called?
- How do you test for integrity of the facial muscles?

Ans: This paralysis is called Bell's palsy. It occurs due to viral infection of VII nerve as it exits from the stylomastoid foramen.

This nerve is tested as follows:

- Asking the patient to close the eye
- Asking the patient to look upwards without moving the head, so that horizontal lines are formed in the forehead
- Ask him to show the teeth
- Ask him to fill in air in the mouth and then force it out.

FREQUENTLY ASKED QUESTIONS

1. Describe oculomotor nerve under following headings: Origin, nuclei, course, distribution and clinical anatomy.
2. Distribution facial nerve under following headings: Origin, nuclei, course, distribution and clinical anatomy.
3. Write short notes on:
   a. Chorda tympani nerve
   b. Left recurrent laryngeal nerve
   c. Branches of ophthalmic division of V nerve
   d. Branches of mandibular nerve
   e. Roots and branches of pterygopalative ganglion
   f Ptosis
   g. Branches of hypoglossal nerve and effect of its paralysis

MULTIPLE CHOICE QUESTIONS

1. Cranial nerves which innervate extraocular muscles include:
   a. Oculomotor, abducent and trochlear
   b. Abducent, facial and trigeminal
   c. Trochlear, oculomotor and facial
   d. Oculomotor, facial and trigeminal

2. The 3 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

3. Cranial nerve that does not pass through superior orbital fissure in skull:
   a. Oculomotor
   b. Trochlear
   c. Facial
   d. Abducent

4. Cranial nerve that are mainly sensory of:
   a. Optic, vestibulocochlear and vagus
   b. Ophthalmic, optic and facial
   c. Ophthalmic, optic and vestibulocochlear
   d. Optic, olfactory and vestibulocochlear

5. Cranial nerves that carry taste from the tongue are:
   a. Trigeminal, facial and glossopharyngeal
   b. Facial, glossopharyngeal and hypoglossal
   c. Facial, glossopharyngeal and accessory
   d. Facial, glossopharyngeal and vagus

6. The cranial nerve that arise from both brain as well as spinal cord:
   a. Hypoglossal
   b. Accessory
   c. Vagus
   d. Glossopharyngeal

7. Which cranial nerve does not pass through jugular foramen?
   a. Glossopharyngeal
   b. Vagus
   c. Accessory
   d. Hypoglossal

8. Which is not a cranial nerve?
   a. Vagus
   b. Glossopharyngeal
   c. Phrenic
   d. Hypoglossal

9. Which structure is not innervated by vagus?
   a. Small intestine
   b. Heart
   c. Stomach
   d. Sternocleidomastoid

10. Which cranial nerve innervates muscle that raises the upper eyelid?
   a. Trochlear
   b. Oculomotor
   c. Abducent
   d. Facial

11. Which cranial nerve passes through stylomastoid foramen?
   a. Facial nerve
   b. Glossopharyngeal nerve
   c. Vagus nerve
   d. Hypoglossal nerve

12. 1st pharyngeal arch give rise to:
   a. Muscles of facial expression
   b. Muscles of mastication
   c. Muscles of soft palate
   d. Stylopharyngeus (muscle of pharynx)

13. Nucleus of tractus solitarius receives part of which 3 cranial nerves?
   a. III, IV and VI
   b. VII, IX and X
   c. IX, X and XI
   d. None of the above

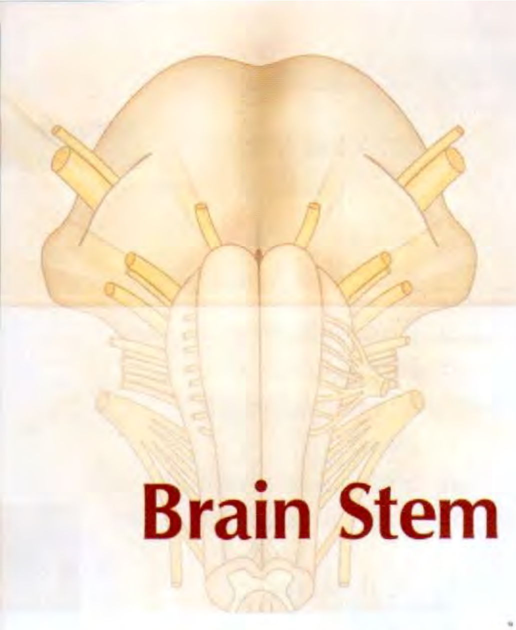
14. Nucleus ambiguus is present in:
   a. Midbrain
   b. Spinal cord
   c. Pons
   d. Medulla oblongata

15. Which cranial nerve is not involved in Wallenberg's syndrome?
   a. XII
   b. IX
   c. X
   d. XI

16. Which of the following is the largest cranial nerve?
   a. VI
   b. V
   c. XII
   d. VII

ANSWERS

1. a	**2.** b	**3.** c	**4.** d	**5.** d	**6.** b	**7.** d	**8.** c	**9.** d	**10.** b
11. a	**12.** b	**13.** b	**14.** d	**15.** a	**16.** b				



CHAPTER

5

Brain Stem

Knowledge is not something to be packed in some corner of the brain
—Sarvapalli Radhakrishnan

INTRODUCTION

The brain stem consists of the medulla oblongata, the pons and the midbrain. It connects the spinal cord to cerebrum. The various ascending and descending tracts pass through the three components of the brain stem. Medulla oblongata contains the respiratory and vasomotor centres. In hanging or capital punishment, the dens of axis vertebra breaks and strikes on these centres causing immediate death. Most of the cranial nerve nuclei are present in the brain stem only.

Midbrain contains nuclei of oculomotor and trochlear nerves. Pons has the nuclei of trigeminal, abducent, facial and statoacoustic nerves while medulla houses the nuclei of last four cranial nerves, i.e. glossopharyngeal, vagus, accessory and hypoglossal (*refer to BDC App*).

MEDULLA OBLONGATA

The medulla is the lowest part of brain stem, 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. It lies in the anterior part of posterior cranial fossa, extending down to the foramen magnum. Anteriorly, it is related to the clivus and meninges and posteriorly, to the vallecula of the cerebellum. Along with other parts of the hindbrain, medulla occupies the infratentorial space.

Parts:

1. *Open/superior part*—the dorsal surface of the medulla is formed by the fourth ventricle.
2. *Closed/inferior part*—fourth ventricle is narrowed at the obex and continues with the central canal.

EXTERNAL FEATURES

1. 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. 5.1).
2. 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 and corticobulbar fibres. In the lower part of the medulla, many fibres of the right and left pyramids cross in the midline forming the *pyramidal decussation*.
3. Some fibres run transversely across the upper part of the pyramid. These are the *anterior external arcuate fibres* which end in the cerebellum.
4. 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*. A bundle of fibres curving around the lower edge of the olive is the *circumolivary bundle*.
5. The rootlets of the hypoglossal nerve emerge from the anterolateral sulcus between the pyramid and the olive.
6. The rootlets of the cranial nerves IX and X and cranial part of the accessory nerve emerge through the posterolateral fissure, behind the olive.
7. 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 (Fig. 5.2). The upper ends of fasciculus gracilis and cuneatus expand to form the *gracile and cuneate tubercles*. These tubercles are formed by underlying masses of grey matter called the *nucleus gracilis* and *nucleus cuneatus*. Lateral to cuneate nucleus is an

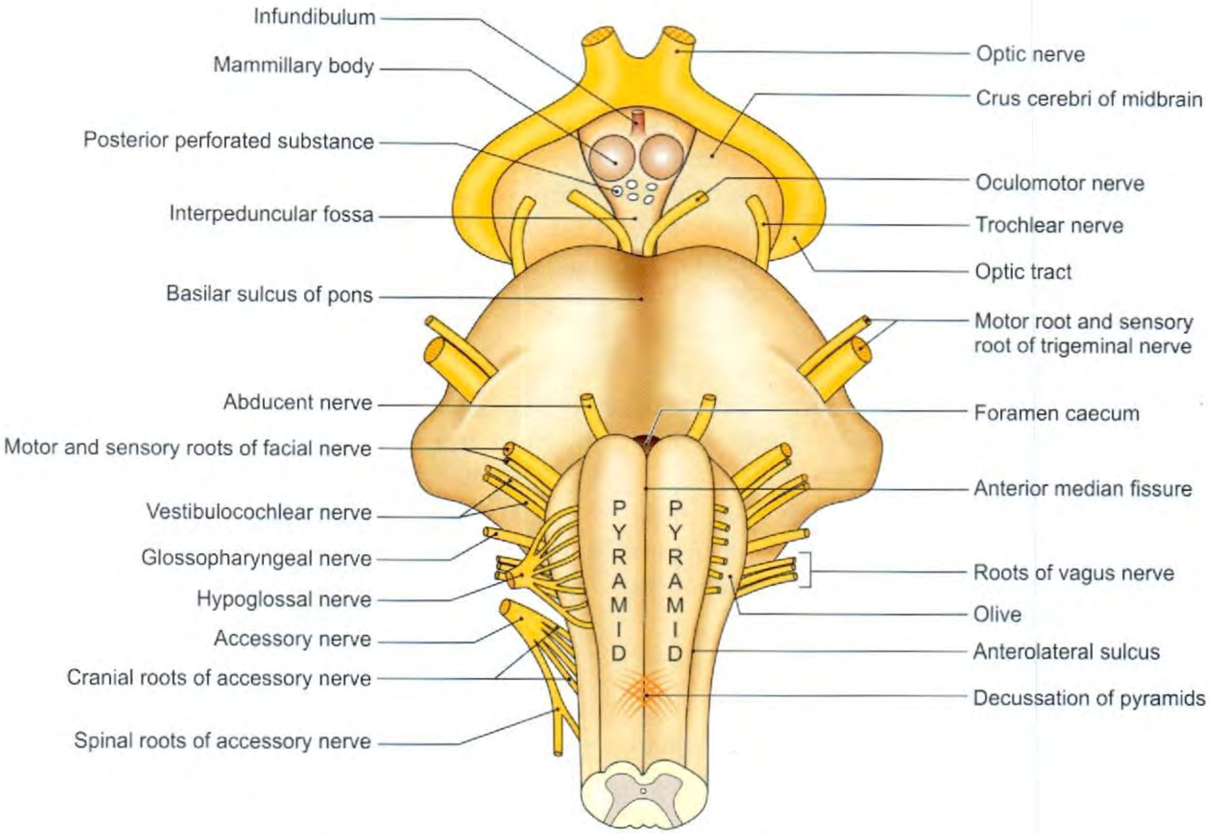


Fig. 5.1: Attachment of cranial nerves to the ventral surface of brain stem

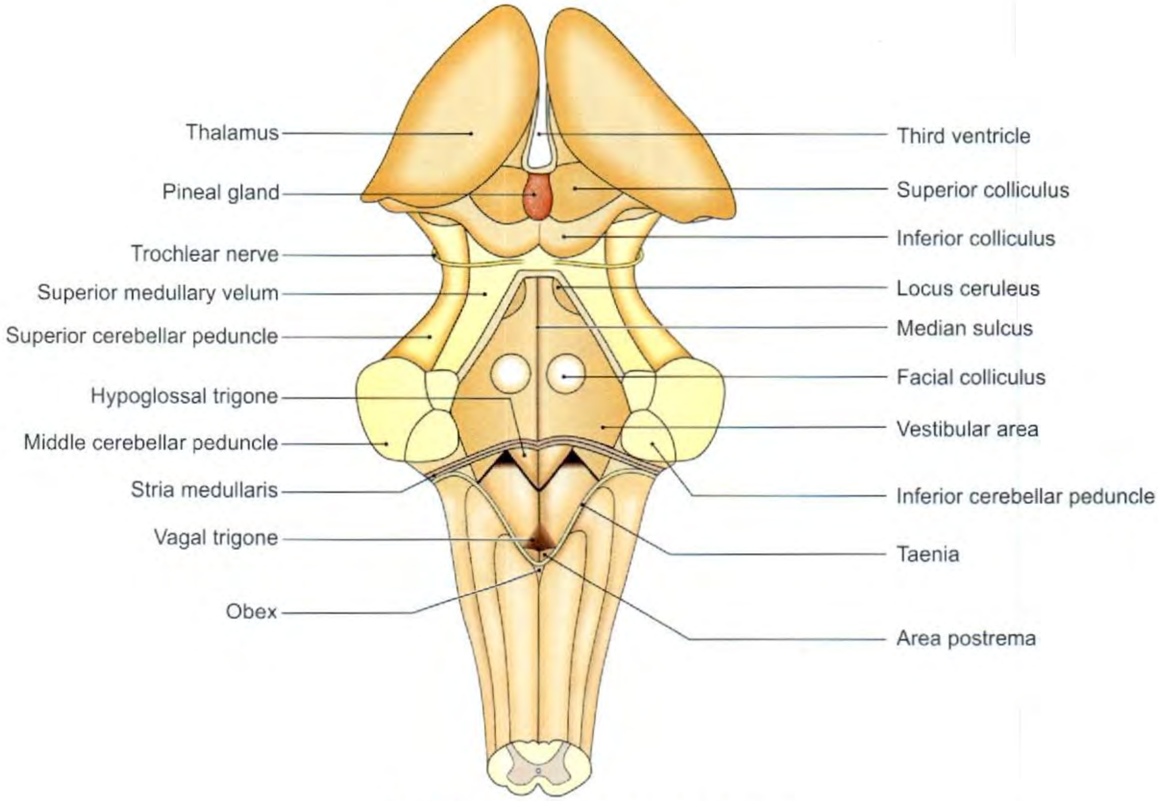


Fig. 5.2: Dorsal aspect of brain stem

accessory cuneate. Here the unconscious proprioceptive fibres of upper limb relay to terminate in the cerebellum via inferior cerebellar peduncle. This nucleus is equivalent to Clarke's column of spinal cord. These convey discriminative touch, pressure and senses of vibration, position and movements from ipsilateral part of the body. The fasciculus gracilis contains fibres from lower limb and lower part of the trunk, fasciculus cuneatus from upper limb and upper part of the trunk.

8 In the lower part of the medulla, there is another elevation the *tuber cinerium* lateral to the fasciculus cuneatus. It is produced by a mass of grey matter called the *spinal nucleus of the trigeminal nerve.*

9 The medulla is divided in two parts: The lower *closed part* with a central canal; and the upper *open part* where the central canal opens out to form the fourth ventricle.

Figure 5.3 shows attachment of cranial nerves as seen from lateral side.

Figure 5.4 shows the transverse sections of spinal cord, medulla obolongata, pons, and midbrain with their corresponding figures.

INTERNAL STRUCTURE

The internal structure of the medulla can be studied conveniently by examining transverse sections through it at three levels.

Transverse Section 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 (Fig. 5.5).

Grey Matter

1 The decussating pyramidal fibres separate the anterior horn from the central grey matter. The *separated anterior horn* forms the spinal nucleus of the accessory nerve laterally and the supraspinal nucleus for motor fibres of the first cervical nerve medially.
2 The central grey matter (with the central canal) is pushed backwards.
3 The nucleus gracilis and the nucleus cuneatus are continuous with the central grey matter.
4 Laterally, the central grey matter is continuous with the nucleus of the spinal tract of the trigeminal nerve. A bundle of fibres overlying this nucleus forms the spinal tract of the trigeminal nerve.

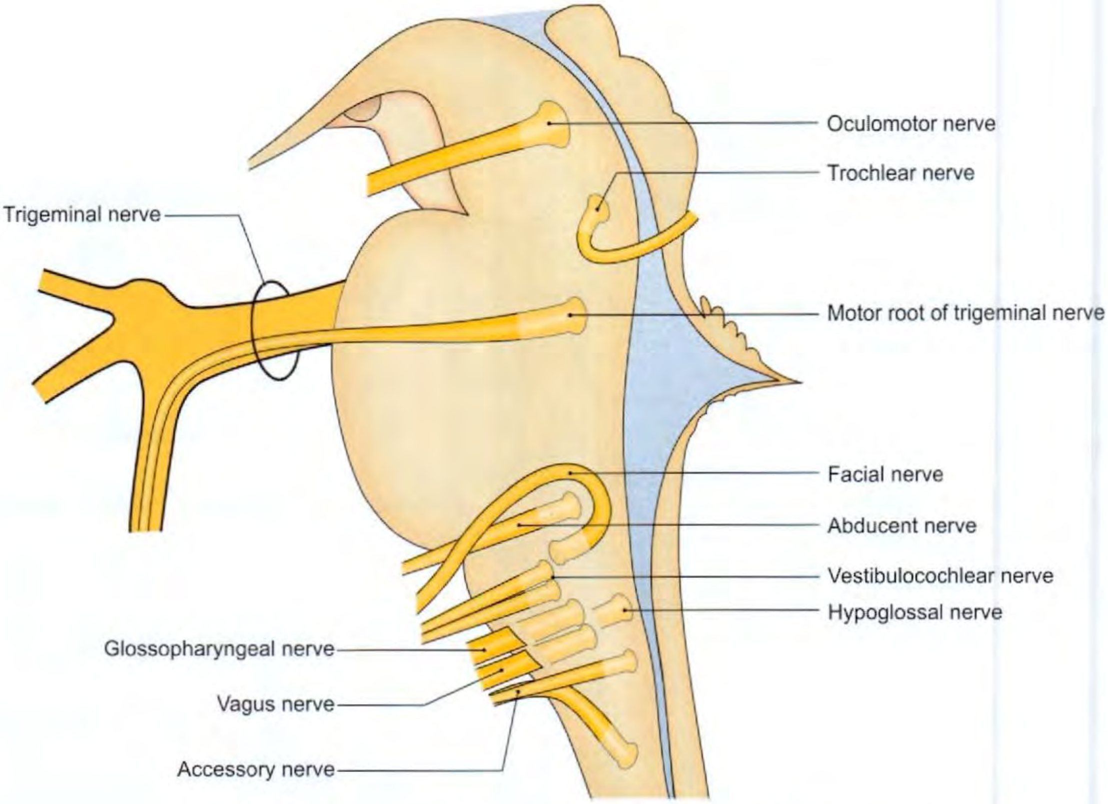


Fig. 5.3: Attachment of cranial nerves as seen from lateral side

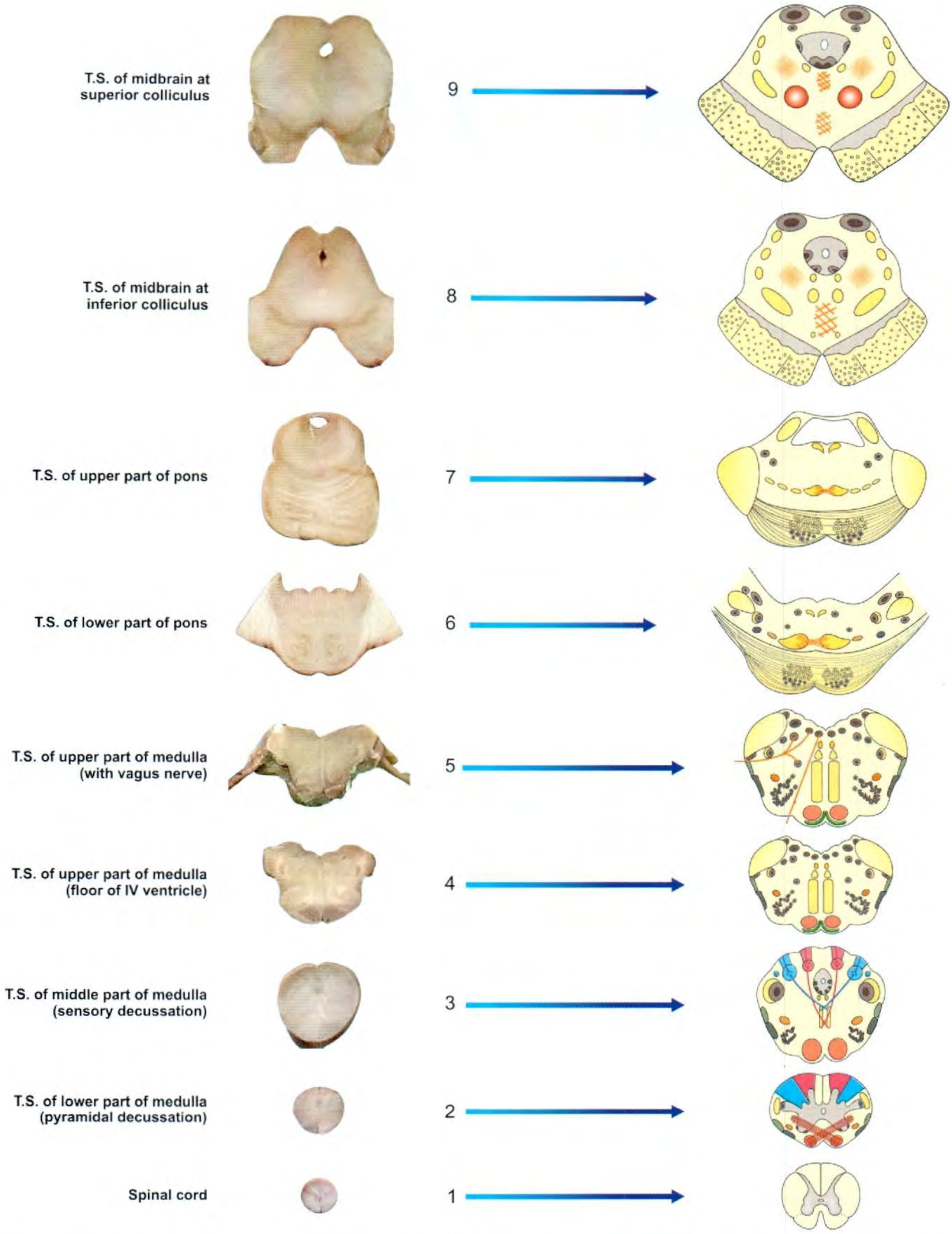


Fig. 5.4: Transverse sections of spinal cord (1); medulla oblongata (2–5); pons (6 and 7); midbrain (8 and 9) with their corresponding figures

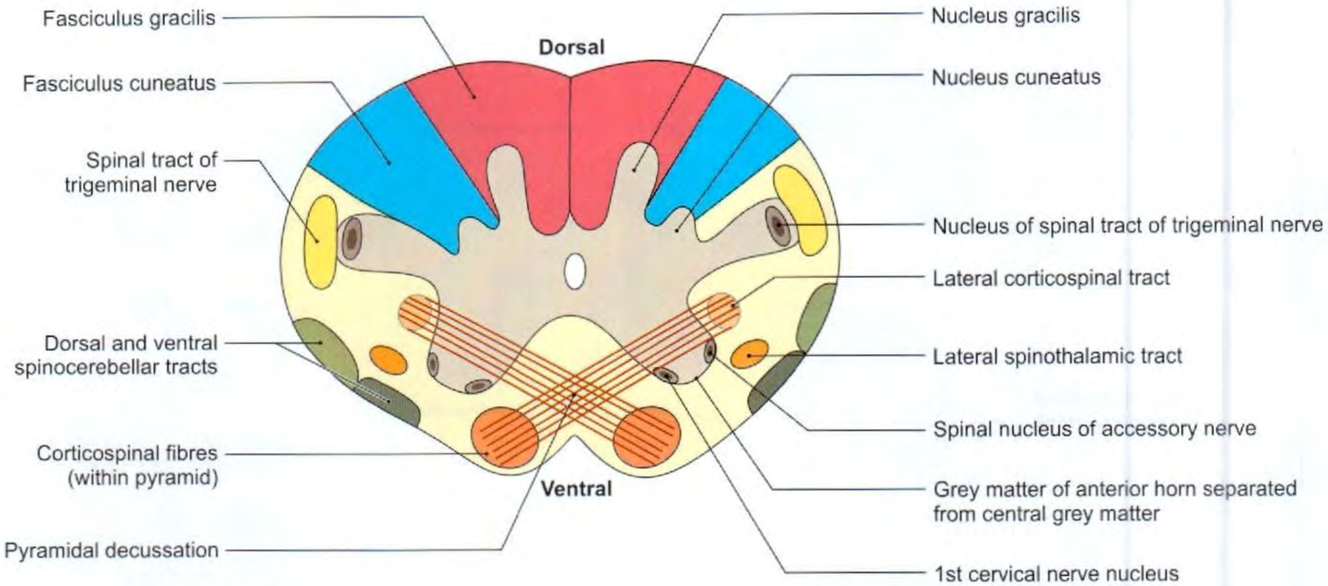


Fig. 5.5: Transverse section (TS) of medulla oblongata at the level of pyramidal decussation

White Matter

1. The pyramids, anteriorly.
2. The decussation of the pyramidal tracts forms the most important features of the medulla at this level. The fibres of each pyramid run backwards and laterally to reach the lateral white column of the spinal cord where they form the lateral corticospinal tract.
3. The fasciculus gracilis and the fasciculus cuneatus occupy the broad posterior white column.
4. The other features of the white matter are similar to those of the spinal cord (*see* Chapter 3).

Transverse Section through the Middle of Medulla Passing through the Sensory Decussation

Identify the following features as shown in Fig. 5.6.

Grey Matter

1. Lateral to the cuneate nucleus we see the *accessory cuneate nucleus* which relays unconscious proprioceptive fibres from the upper limbs. It is equivalent to nucleus dorsalis/Clarke's column.
2. The *nucleus of the spinal tract of the trigeminal nerve* is also separate from the central grey matter.
3. The lower part of the *inferior olivary nucleus* is seen.

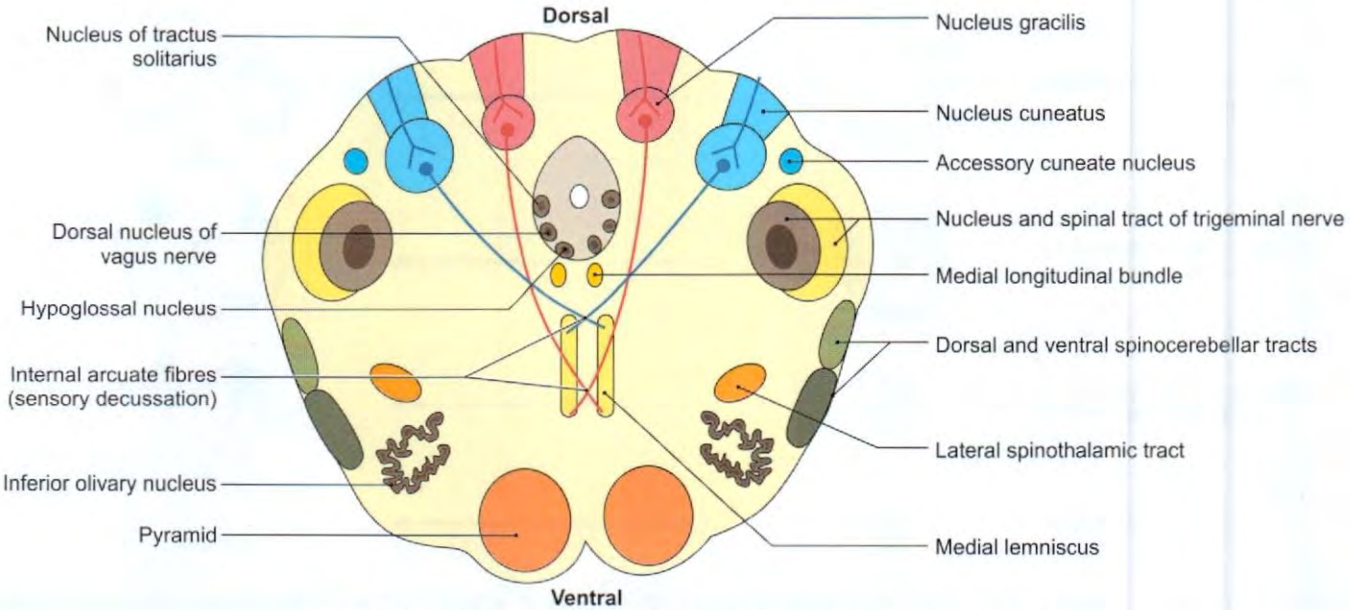


Fig. 5.6: TS of medulla oblongata at the level of sensory decussation

4 The central grey matter contains the following:
   a. Hypoglossal nucleus—an elongated nucleus about 2 cm long, supplies muscles of tongue except palatoglossus.
   b. Dorsal nucleus of the vagus—gives preganglionic parasympathetic fibres of heart and to smooth muscles and glands of respiratory and alimentary system.
   c. Nucleus of tractus solitarius— receives taste fibres.

White Matter

1 The nucleus gracilis and cuneatus give rise to the *internal arcuate fibres.* These fibres cross to the opposite side where they form a paramedian band of fibres, called the *medial lemniscus.* In the lemniscus, the body is represented with the head posteriorly and the feet anteriorly.
2 The *pyramidal tracts* lie anteriorly.
3 The *medial longitudinal bundle* lies posterior to the medial lemniscus.
4 The *spinocerebellar, lateral spinothalamic* and other tracts lie in the anterolateral area.
5 Emerging fibres of XII nerve.

Transverse Section through the Upper Part of Medulla Passing through the Floor of Fourth Ventricle/Open Part

Identify the following features as shown in Fig. 5.7.

Grey Matter

1 The nuclei of several cranial nerves are seen in the floor of the fourth ventricle:
   a. The *hypoglossal nucleus,* in a paramedian position.
   b. The *dorsal nucleus of the vagus,* lateral to the XII nerve nucleus.
   c. The *nucleus of the tractus solitarius,* ventrolateral to the dorsal nucleus of vagus.
   d. The *inferior and medial vestibular nuclei,* medial to the inferior cerebellar peduncle.
2 The *nucleus ambiguus* lies deep in the reticular formation of the medulla. It gives origin to motor fibres of the cranial nerves IX, X and XI.
3 The dorsal and ventral cochlear nuclei lie on the surface of the inferior cerebellar peduncle. These nuclei receive fibres of the cochlear nerve.
4 The *nucleus of the spinal tract* of the trigeminal nerve lies in the dorsolateral part.
5 The *inferior olivary nucleus* is the largest mass of grey matter seen at this level. It is responsible for producing the elevation of the olive. Its grey matter appears like a crumpled purse.
   Close to the inferior olivary nucleus there are the medial and dorsal accessory olivary nuclei. The nucleus receives the afferent fibres from cerebral cortex, red nucleus, periaqueductal grey of midbrain and spinal cord. The efferents form olivocerebellar fibres which terminate as climbing fibres at the cerebellar cortex.
6 The *arcuate nucleus* lies anteromedial to the pyramidal tract.
7 Visceral centres are:
   a. Respiratory centre
   b. Cardiac centre for regulation of heart rate
   c. Vasomotor centre for regulation of blood pressure.

White Matter

It shows the following important features.

1 The inferior cerebellar peduncle occupies the posterolateral part, lateral to the fourth ventricle.

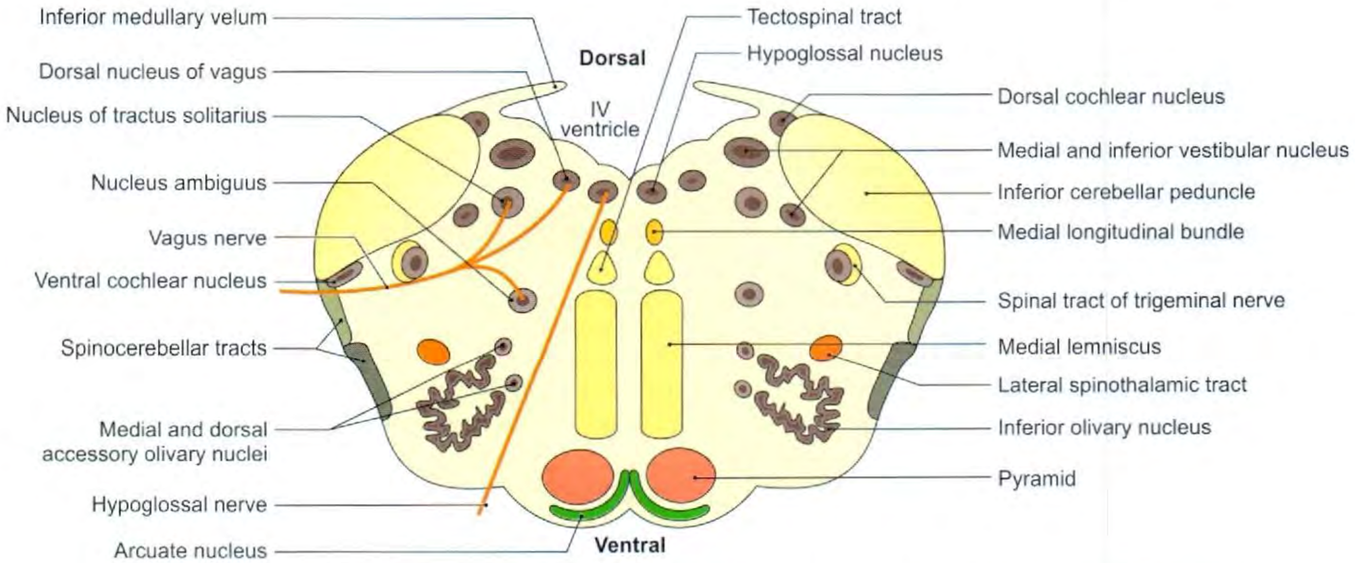


Fig. 5.7: TS of medulla oblongata at the level of olivary nucleus passing through floor of fourth ventricle

2 The *olivocerebellar fibres* are seen prominently in actual sections. The fibres emerge at the hilum of the inferior olivary nucleus and pass to the opposite inferior cerebellar peduncle, on their way to the opposite half of the cerebellum.

3 *Striae medullaris (external arcuate fibres)* are seen in the floor of the fourth ventricle.

4 Identify the various ascending tracts in the anterolateral part of medulla.

5 Emerging fibres of IX, X, XI nerves

BLOOD SUPPLY

- *Anterior spinal artery*: This supplies the whole medial part of the medulla oblongata.
- *Posterior inferior cerebellar artery*: This supplies the posterolateral part of the medulla.

DEVELOPMENT

From caudal myelencephalic part of the rhombencephalic vesicle. Neuroblasts from the alar plate of the neural tube at this level will produce the sensory nuclei of the medulla. The basal plate neuroblasts will give rise to the motor nuclei.

CLINICAL ANATOMY

- *Medial medullary/Dejerine syndrome:* It occurs due to blockage of anterior spinal artery. Features are:
  - a. Contralateral hemiplegia (Fig. 5.8) due to damage to pyramid of medulla.
  - b. Loss of sense of vibration and position due to damage to medial lemniscus.
  - c. Paralysis of muscles of tongue on the same side due to injury to XII cranial nerve.
- *Lateral medullary/Wallenburg syndrome:* Occurs due to blockage of posterior inferior cerebellar artery. Artery supplies areas behind the inferior olivary nucleus. Features are:
  - a. Ipsilateral paralysis of most of muscles of soft palate, pharynx and larynx due to injury to nucleus ambiguus which gives fibres to IX, X and XI cranial nerves (Fig. 5.8).
  - b. Loss of pain and temperature on same side of face due to involvement of spinal nucleus and spinal tract of trigeminal nerve.
  - c. Loss of pain and temperature on opposite side of the body due to involvement of lateral spinothalamic tract.
  - d. Giddiness due to involvement of vestibular nuclei.
  - e. Damage to inferior cerebellar peduncle, spinocerebellar tracts and part of cerebellum results in loss of equilibrium, i.e. ataxia of limbs on the same side.
  - f. The sympathetic fibres descend from hypothalamus to cells in lateral horn of spinal cord. As these fibers descend in the lateral part of medulla (which is damaged), there is Horner's syndrome, comprising ptosis, enophthalmos, miosis and anhydrosis.
- *Injury to lower part of medulla oblongata:* Injury in this part may be fatal due to injury to the vital centres like respiratory centre and vasomotor centre.
- *Bulbar palsy:* In this condition there is weakness of muscles supplied by VII–XII cranial nerves. These nerves supply muscles of facial expression, muscles of pharynx, tongue, palate and larynx. The lesion is of lower motor neuron type. The patient has difficulty in speaking, swallowing and in usage of muscles of facial expression.
- *Pseudobulbar palsy:* Occurs due to bilateral lesion of corticonuclear fibres. There is paralysis of muscles of tongue, lips, pharynx and palate. The causes of pseudobulbar palsy may be vascular infarction, syringomyelia and increased intracranial pressure.

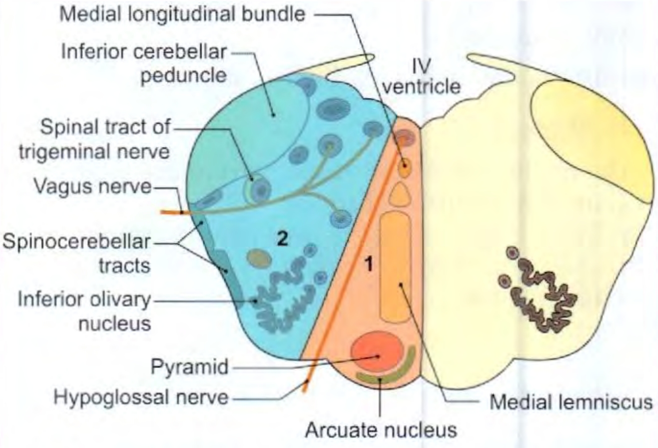


Fig. 5.8: Lesions of medulla oblongata. (1) Medial medullary syndrome, and (2) Lateral medullary syndrome

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. Cranial nerves V, VI, VII, VIII are attached here. Anterioly, it is related to clivus separated by basilar artery, laterally middle cerebellar peduncle and posteriorly to the fourth ventricle.

EXTERNAL FEATURES

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 (Fig. 5.1).

Laterally, the surface is continuous with the middle cerebellar peduncle.

The *trigeminal nerve* is attached to this surface at the junction of the pons with the peduncle. The nerve has two roots, a small motor root which lies medial to the much larger sensory root.

The attached abducent, facial and vestibulocochlear nerves are at the lower border of the ventral surface at the junction of pons and medulla oblongata.

The *dorsal or posterior surface* is hidden by the cerebellum, and forms the upper half of the floor of the fourth ventricle (Fig. 5.2).

Pons has 2 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 OF PONS

In transverse sections, the pons is seen to be divisible into ventral and dorsal parts. The ventral or *basilar part* is continuous inferiorly with the pyramids of the medulla, and on each side with the cerebellum through the middle cerebellar peduncle. The dorsal or *tegmental* part is a direct upward continuation of the medulla (excluding the pyramids).

Basilar Part/Ventral Part

The basilar part of the pons has a uniform structure throughout its length.

Grey Matter

It is represented by the *nuclei* pontis which are scattered among longitudinal and transverse fibres. The pontine nuclei form an important part of the cortico-ponto-cerebellar pathway. Some of these nuclei get displaced during development, and form the arcuate nucleus (*see* medulla) and the pontobulbar body. Fibres from all these nuclei go to the opposite half of the cerebellum.

White Matter

It consists of longitudinal and transverse fibres.

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

Tegmental Part

However, the structure of the tegmental part differs in the upper and lower parts of the pons.

Tegmentum in the Lower Part of Pons

Identify the following features as shown in Fig. 5.9.

Grey Matter

1 The *sixth nerve nucleus* lies beneath the facial colliculus.
2 The *seventh nerve nucleus* lies in the reticular formation of the pons.

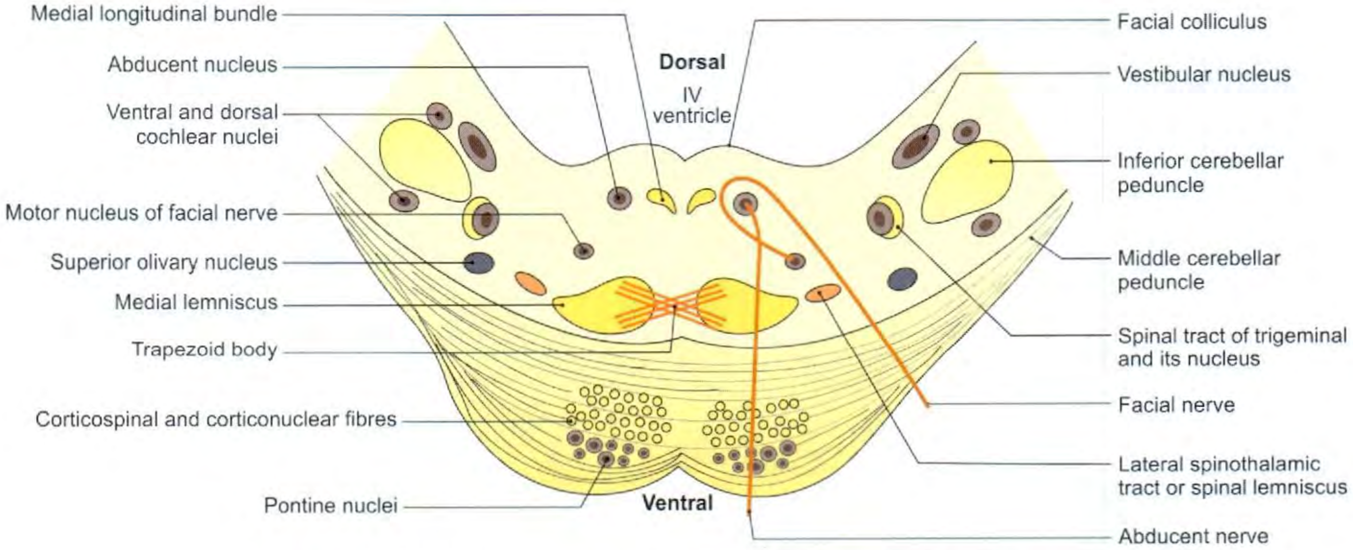


Fig. 5.9: TS of lower part of pons or TS at the level of facial colliculus

3 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, partly in the medulla and partly in the pons. They are divisible into four parts, superior, inferior, medial and lateral. They receive the fibres of the vestibular nerve, and give efferents to the cerebellum (vestibulocerebellar), the medial longitudinal bundle, the spinal cord (vestibulospinal tract arising in the lateral vestibular nucleus) and the lateral lemniscus.

The dorsal and ventral *cochlear nuclei* are situated dorsal and ventral to the inferior cerebellar peduncle. They receive the fibres of the cochlear nerve, and give efferents mostly to the superior olivary nucleus and partly to nuclei of the corpus trapezoideum, and to nuclei of the lateral lemniscus. These fibres form the trapezoid body.

4 The spinal nucleus of the trigeminal nerve lies in the lateral part.

5 Other nuclei present include the salivatory and lacrimatory nuclei.

White Matter

1 The *trapezoid body* or corpus trapezoideum is a transverse band of fibres lying just behind the ventral part of the pons. It consists of fibres that arise in the cochlear nuclei of both sides. It is a part of the auditory pathway.

2 The medial lemniscus forms a transverse band on either side of the midline, just behind the trapezoid body. It is joined by anterior spinothalamic tract.

3 The lateral spinothalamic tract (spinal lemniscus) lies lateral to the medial lemniscus.

4 The trigeminal lemniscus conveys fibres of second sensory neurons from the opposite spinal and sensory nuclei of trigeminal nerve.

5 The inferior cerebellar peduncle lies lateral to the floor of the fourth ventricle.

6 The fibres of the facial nerve follow a peculiar course. They first pass backwards and medially to reach the medial side of the abducent nucleus. They then form a loop dorsal to the abducent nucleus. This loop is responsible for producing an elevation, the *facial colliculus*, in the floor of the fourth ventricle.

Tegmentum in the Upper Part of Pons

Identify the following features as shown in Fig. 25.10.

Grey Matter

The special features are the *motor, and superior sensory nuclei of the trigeminal nerve.* The motor nucleus is medial to the superior sensory nucleus.

White Matter

1 Immediately behind the ventral part of the pons we see bands of fibres made up (from medial to lateral side) of the medial lemniscus, the trigeminal lemniscus, the spinal lemniscus (spinothalamic tracts consist of two adjacent pathways: Anterior and lateral. The anterior spinothalamic tract carries information about crude touch and crude pressure. The lateral spinothalamic tract conveys sensations pain and temperature) and the lateral lemniscus.

The trigeminal lemniscus contains fibres arising in the spinal nucleus of the trigeminal nerve and travelling to the thalamus. The lateral lemniscus is a part of the auditory pathway. It is formed by fibres arising in nuclei lying in close relation to the trapezoid body (superior olivary nucleus and nucleus of trapezoid body).

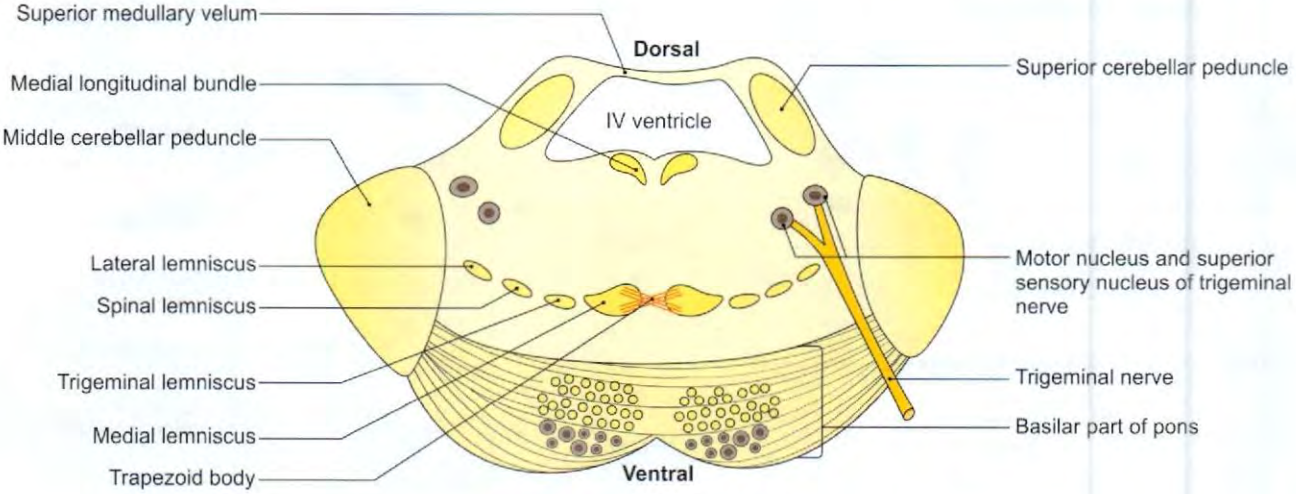


Fig. 5.10: TS of upper pons

2 The superior cerebellar peduncles lie dorsolateral to the fourth ventricle (replacing the inferior peduncle seen in the lower part of the pons).

3 The medial longitudinal bundle is made up of fibres that interconnect the nuclei of the cranial nerves III, IV, VI and VIII and the spinal root of the XI. It coordinates movements of the head and neck in response to stimulation of the cranial nerve VIII. However, the majority of fibres in the medial longitudinal bundle arise in the vestibular nuclei (Fig. 5.16).

BLOOD SUPPLY

The pontine arteries are a number of small vessels which come off at right angles from either side of the basilar artery and supply the pons and adjacent parts of the brain.

DEVELOPMENT

From cranial metencephalic part of rhombencephalic vesicle. Cells of alar lamina migrate to form the pontine nuclei, cochlear and vestibular nuclei, trigeminal sensory nucleus. Basal plate neuroblasts give rise to abducens nucleus, facial nucleus, motor nucleus of trigeminal and superior salivatory nucleus.

CLINICAL ANATOMY

- *Pontine haemorrhage:* This entity has following features:
  a. Bilateral paralysis of face and limbs due to involvement of VII nerve nucleus and all corticospinal fibres.
  b. Deep coma due to damage to the reticular formation.
  c. Hyperpyrexia due to cutting off of the temperature regulating fibres from the hypothalamus.
  d. Pin point pupil due to damage to sympathetic ocular fibres. Pontine haemorrhage is usually fatal.
- *Cerebellopontine angle* (Fig. 5.11): The anatomical structures located in the cerebellopontine angle include choroid plexuses of IV ventricle, flocculus, VII and VIII cranial nerves. A tumour, acoustic neuroma, in this angle arises usually in relation to VIII nerve. Features are:
  a. Ipsilateral facial paralysis and loss of taste in anterior two-thirds of tongue and hyperacussis due to damage to fibres of facial nerve.
  b. Deafness and vertigo due to damage to both the parts of VIII nerve.
  c. Ataxia on the affected side due to involvement of the flocculus.
  d. Absence of corneal reflex on the side of lesion due to damage to nucleus of V nerve including its spinal tract.
- *Millard-Gubler's syndrome* (Fig. 5.11): In this condition, there is damage to fibres of VI and VII nerves along with pyramidal fibres. Features are:
  a. Ipsilateral facial paralysis due to damage to VII nerve; there is paralysis of facial muscles on the same side.
  b. Ipsilateral loss of abduction of the eye due to damage to VI nerve.
  c. Contralateral hemiplegia due to lesion of the pyramidal fibres.
- *Tumours of pons:* Astrocytoma is the most common tumour of brain stem, usually in childhood. Signs and symptoms vary according to area of origin of tumour.

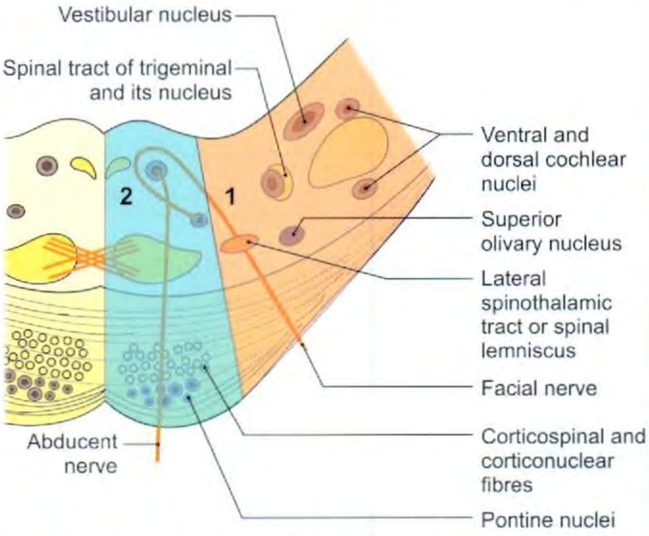
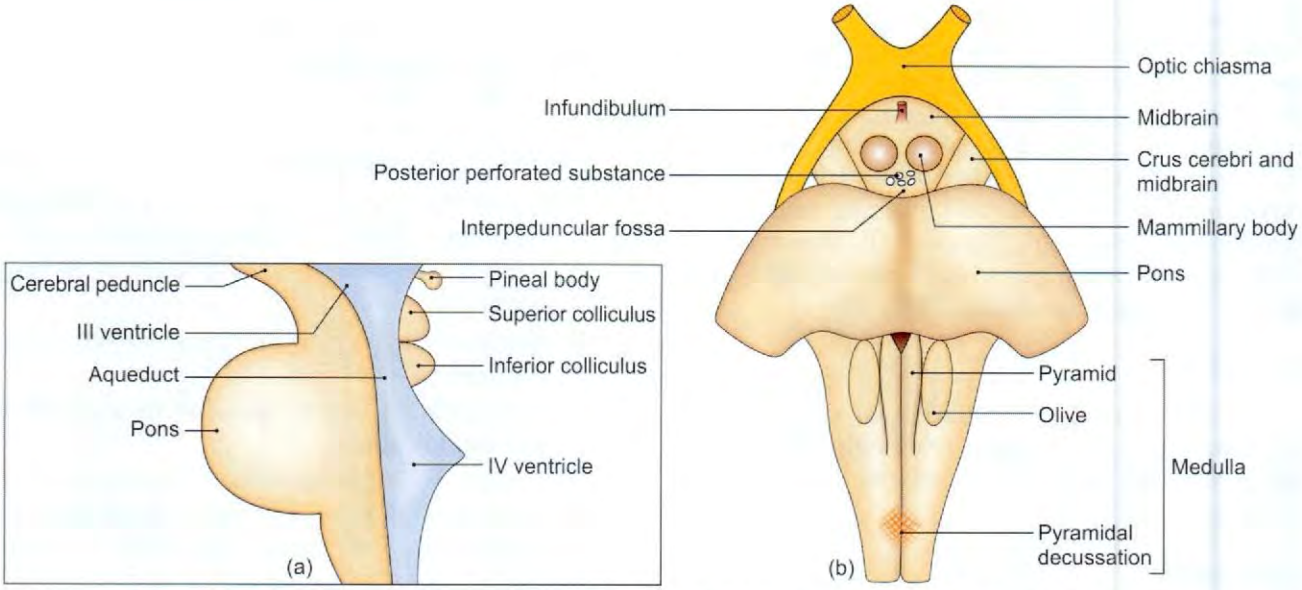


Fig. 5.11: Lesion of pons. (1) Cerebellopontine angle tumour and (brown area) (2) Millard-Gubler's syndrome (blue area)

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 5.12a and b).

The midbrain passes through the tentorial notch, and is related on each side to the parahippocampal gyri, the optic tracts, the posterior cerebral artery, the basal vein, the trochlear nerve, and the geniculate bodies. Anteriorly, it is related to the interpeduncular structures, and posteriorly to the splenium of the corpus callosum, the great cerebral vein, the pineal body, and the posterior ends of the right and left thalami (*see* Fig. 6.8).



Figs 5.12a and b: (a) Sagittal section of midbrain with pons, and (b) ventral aspect of midbrain

SUBDIVISIONS

The major subdivisions of midbrain are as follows:

1. The *tectum* is the part posterior to aqueduct. It is made up of the right and left superior and inferior colliculi (Fig. 5.13).
2. Each half of the midbrain anterior to the aqueduct is called the *cerebral peduncle.* Each cerebral peduncle is subdivided into:
   a. Crus cerebri, anteriorly.
   b. Substantia nigra, in the middle.
   c. Tegmentum, posteriorly (Fig. 5.13).

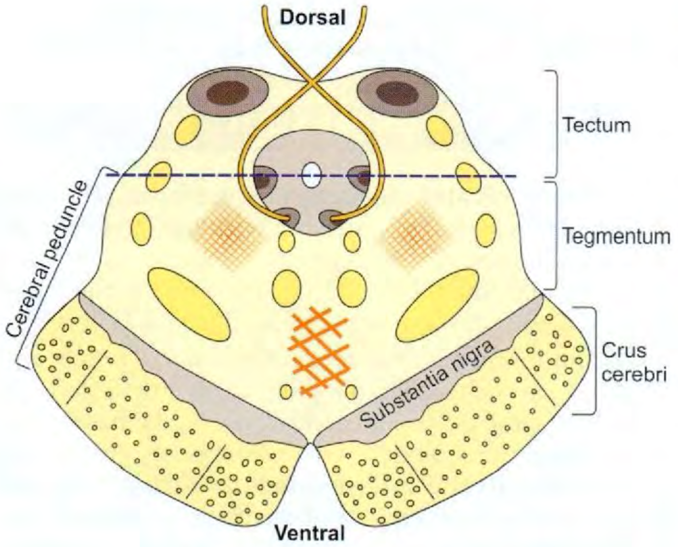


Fig. 5.13: Parts of midbrain

EXTERNAL FEATURES

Ventral surface presents crus cerebri. It is crossed by optic tract, basal vein, posterior cerebral and superior cerebellar arteries from the medial side of this oculomotor nerve and from lateral side trochlear nerve emerges.

On the dorsal aspects superior and inferior colliculi are present. They are called together as corpora quadrigemina (quadruplet bodies). The superior colliculus is connected to the lateral geniculate body by the superior brachium (*see* Fig. 6.8).

Likewise, the inferior colliculus is connected to the medial geniculate body by the inferior brachium (*see* Fig. 6.8) III and IV cranial nerves are attached to midbrain (Fig. 5.12b).

INTERNAL STRUCTURE OF MIDBRAIN

It is studied conveniently by examining sections, at the level of the inferior colliculi and at the level of the superior colliculi.

Transverse Section of Midbrain at the Level of Inferior Colliculi

Grey Matter

1. The central (periaqueductal) grey matter contains:
   a. The *nucleus of the trochlear nerve* in the ventromedial part.
   b. 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 (Fig. 5.14) and temporomandibular joint.

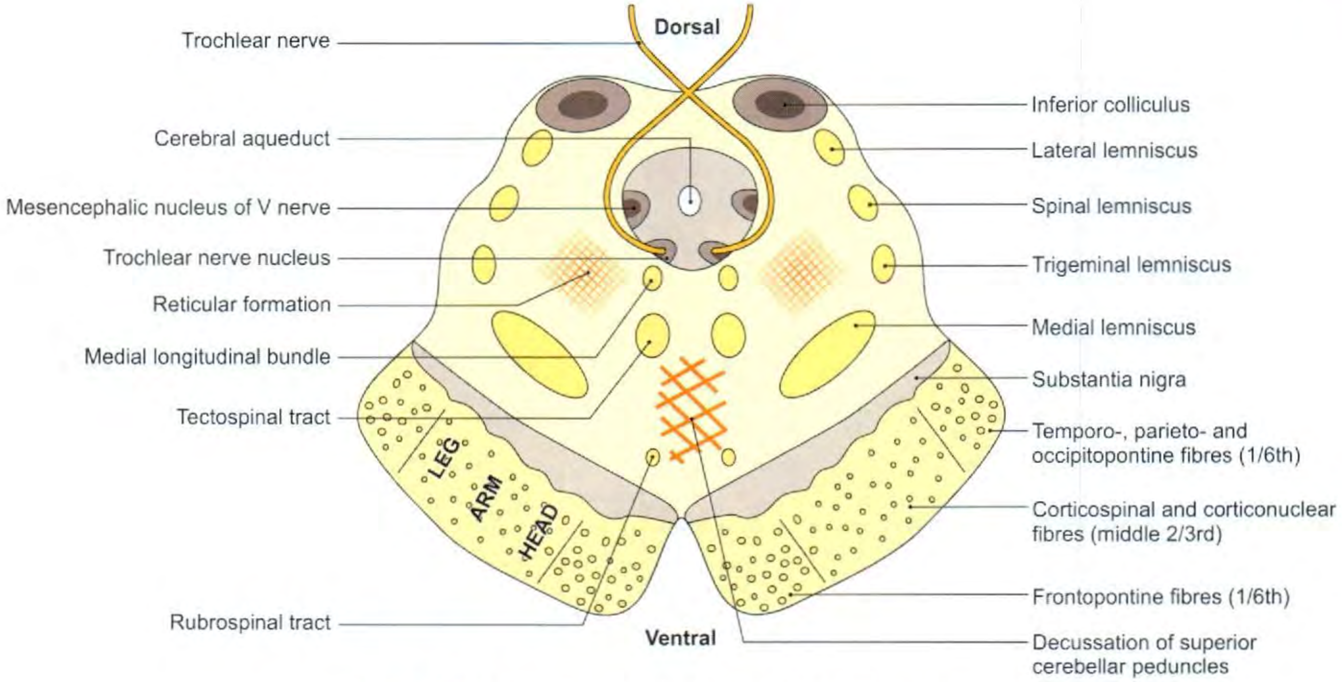


Fig. 5.14: TS of midbrain at the level of inferior colliculus

2 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 centre for auditory reflexes, but the available evidence indicates that it helps in localizing the source of sounds.

3 The *substantia nigra* is a lamina of grey matter made up of deeply pigmented nerve cells. It is concerned with muscle tone (Fig. 5.14).

White Matter

1 The *crus cerebri* contains:
   a. The corticospinal tract in the middle.
   b. Frontopontine fibres in the medial one-sixth.
   c. Temporopontine, parietopontine and occipitopontine fibres in the lateral one-sixth.

2 The *tegmentum* contains ascending tracts as follows.
   a. 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.
   b. The *decussation of the superior cerebellar peduncles* is seen in the median plane.
   c. The *medial longitudinal bundle* lies in close relation to the trochlear nucleus (somatic efferent column).
   d. The tectospinal tract and the rubrospinal tract are present.

3 The trochlear nerve passes laterally and dorsally round the central grey matter. It decussates in the superior medullary velum, and emerges lateral to the frenulum veli.

Transverse Section of Midbrain at the Level of Superior Colliculi

Grey Matter

1 The central grey matter contains:
   a. Nucleus of *oculomotor nerve* with Edinger-Westphal nucleus in the ventromedial part.
   b. *Mesencephalic nucleus* of the trigeminal nerve in the lateral part. The oculomotor nuclei of the two sides are very close to each other (Fig. 5.15).

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

3 *Pretectal nucleus* lies deep to the superolateral part of the superior colliculus. It receives afferents from the lateral roots of the optic tract. It gives efferents to the Edinger-Westphal nuclei of both sides.

The pretectal nucleus is an important part of the pathway for light reflex and the consensual reflex. Its lesion causes Argyll Robertson pupil in which the light reflex is lost but accommodation reflex remains intact.

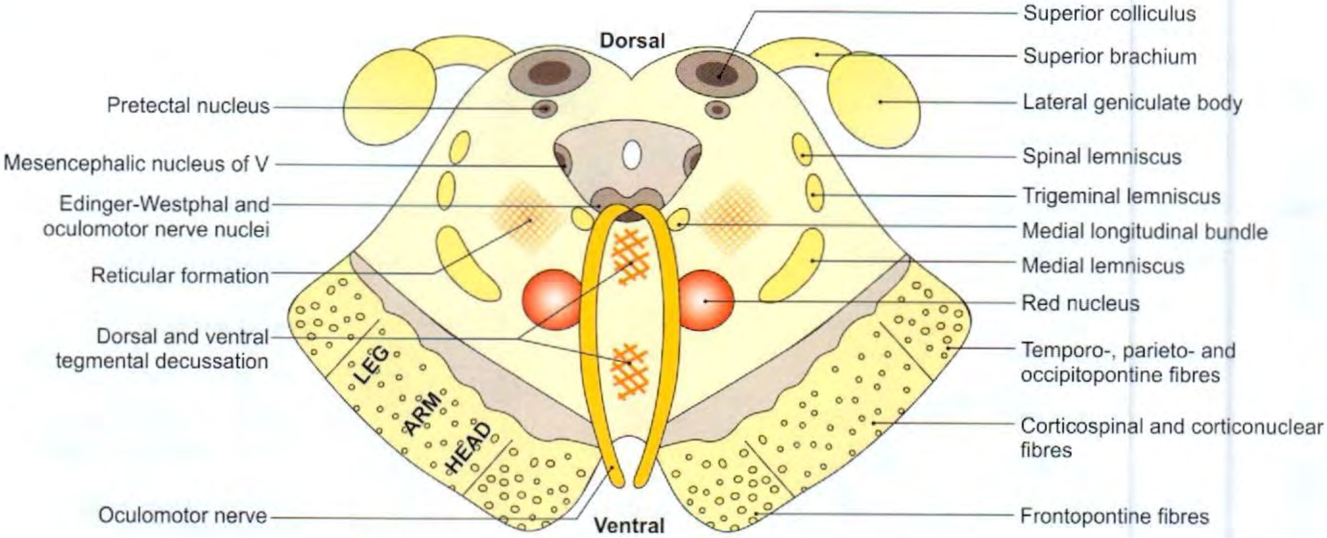


Fig. 5.15: TS of midbrain at the level of superior colliculus

4 *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.

5 *Substantia nigra* has already been described.

White Matter

1 The *crus cerebri* has the same tracts as described above.

2 The *tegmentum* contains the following:

  a. The same lemnisci as seen in the lower part except for the lateral lemniscus which has terminated in the inferior colliculus.

  b. The decussation of the tectospinal and tectobulbar tracts forms the *dorsal tegmental decussation*.

  c. The decussation of the rubrospinal tracts forms the *ventral tegmental decussation*.

  d. Medial longitudinal bundle.

  e. Emerging fibres of oculomotor nerve.

3 The *tectum* shows the posterior commissure connecting the two superior colliculi.

BLOOD SUPPLY

Most of the blood supply is derived from branches of the basilar artery. Besides this it also receives from

1. Posterior cerebral
2. Superior cerebellar
3. Posterior communicating
4. Anterior choroidal

MEDIAL LONGITUDINAL BUNDLE

Main constituent fibres of medial longitudinal bundle (Fig. 5.16) are the fibres from left and right medial vestibular nuclei. These fibres reach up to interstitial nucleus of Cajal at the upper end of aqueduct. The lower end of the fibres reaches up to cervical segments of spinal cord.

The bundle connects the cranial nerve nuclei of III, IV, VI, VIII and spinal root of XI nerves. It is also connected to the anterior horn cells which supply muscles of the neck.

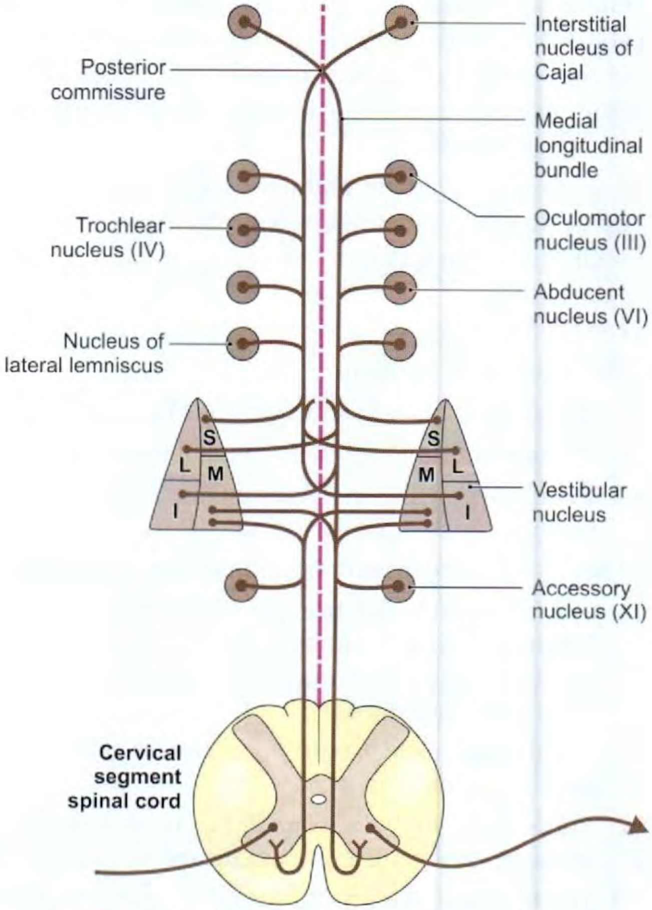


Fig. 5.16: Connections of medial longitudinal bundle

This bundle integrates movements of eyes, and neck. It also maintains equilibrium.

DEVELOPMENT

From middle vesicle or the mesencephalon. Alar lamina cells multiply and fuse to form 4 colliculi. These cells also migrate ventrally to form red nucleus and substantia nigra. The basal lamina forms the crus cerebri.

CLINICAL ANATOMY

- Weber's syndrome (Fig. 5.17): This syndrome involves III nerve nucleus and corticospinal fibres. Features are:
  - a. Hemiplegia on the opposite side due to involvement of corticospinal fibres.
  - b. Pupil points downwards and laterally due to paralysis of III nerve.
- *Benedikt's syndrome* (Fig. 5.17): In this condition, most of the tegmentum of midbrain is damaged. Lesion includes loss of medial lemniscus, red nucleus, superior cerebellar peduncle and fibres of III nerve. Features are:
  - a. Loss of proprioception due to lesion of medial lemniscus.
  - b. Pupil points downwards and laterally due to injury to III nerve.
  - c. Tremors and twitching of opposite side due to damage to red nucleus and superior cerebellar peduncle.
- *Parinaud's syndrome* (Fig. 5.17): Lesion of superior colliculi leads to this syndrome. Features include weakness of upward gaze and vertical nystagmus due to lesion of superior colliculus.
- *Argyll Robertson pupil:* In this condition, light reflex is lost but accommodation reflex is retained due to lesion in the vicinity of pretectal nucleus (Fig. 5.17).

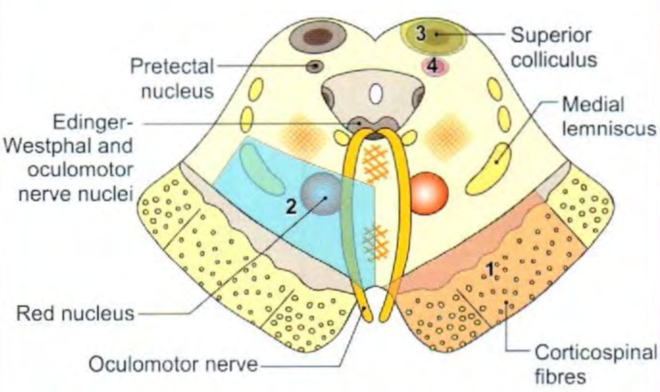


Fig. 5.17: Lesion of midbrain. (1) Weber's syndrome, (2) Benedikt's syndrome, (3) Parinaud's syndrome and (4) Argyll Robertson pupil

Mnemonics

Mahanagar Telephone Sitam (Nigam) Limited (MTSL) (from medial to lateral)

M – *Medial lemniscus*
T – *Trigeminal lemniscus*
S – *Spinal lemniscus*
L – Lateral lemniscus

FACTS TO REMEMBER

- Pyramidal decussation cuts off the anterior horn which forms nucleus of 1st cervical nerve and nucleus of spinal accessory nerve.
- Nucleus gracilis and nucleus cuneatus are equivalent of the nuclei in the posterior horn of spinal cord. These are present in the medulla oblongata. Fasciculus gracilis and fasciculus cuneatus relay in their respective nuclei.
- At the lower section of pons, fibres of cochlear nuclei form trapezoid body which forms lateral lemniscus. Nuclei of VI, VII and VIII cranial nerves are present here.
- At the upper section of pons some of the nuclei forming trigeminal nerve are situated. The nerve lies at the junction of pons with the middle cerebellar peduncle.
- Section, at the level of inferior colliculus shows 4 lemnisci: Medial, trigeminal, spinal and lateral (MTSL) from medial to lateral side. It also shows nucleus of IV nerve, the delicate cranial nerve.
- Section at the level of superior colliculus shows prominent red nucleus. It also shows III nerve nucleus with Edinger-Westphal nucleus.

CLINICOANATOMICAL PROBLEM

A person suffering from syphilis complains of inability to see in response to light thrown in the eyes, whereas he can read and see nearby things:

- Where is the lesion?
- What is such a lesion called?

Ans: In such cases, the light reflex is lost, whereas accommodation reflex is retained. It is due to result of lesion in the vicinity of pretectal nucleus. Such a condition is called Argyll Robertson pupil. The fibres of light reflex take following course:

Retina → optic nerve → optic chiasma → optic tract → some fibres to pretectal nucleus of both sides → Edinger-Westphal nucleus → 3rd nerve nucleus and 3rd nerve → ciliary ganglion → short ciliary nerves → pupil constricts. The lesion in syphilis involves the pretectal nucleus, so light reflex is lost.

FREQUENTLY ASKED QUESTIONS

1. Draw a labeled diagram of transverse section of medulla oblongata at the level of sensory decussation.
2. Draw a labeled diagram of midbrain at the level of superior colliculus.
3. Write short notes on:
   a. Medial lemniscus
   b. Nuclei of trigeminal nerve
   c. Lateral lemniscus
   d. Pontine nuclei

MULTIPLE CHOICE QUESTIONS

1. The pontine nuclei form an important part of:
   a. Corticorubral pathway
   b. Cortico-ponto-cerebellar pathway
   c. Vestibulocerebellar pathway
   d. Olivocerebellar pathway
2. Which of these fasciculus lies most medially?
   a. Fasciculus cuneatus
   b. Fasciculus gracilis
   c. Inferior cerebellar peduncle
   d. None of the above
3. Which is the content of central grey matter in section of lower part of medulla?
   a. Hypoglossal nucleus
   b. Nucleus of spinal tract of trigeminal nerve
   c. Nucleus ambiguus
   d. Spinal nucleus of XI nerve
4. What is true about crus cerebri?
   a. The corticospinal tract is in its middle part
   b. Frontopontine fibres in medial one-sixth part
   c. Temporopontine, parietopontine and occipitopontine fibres in lateral one-sixth part
   d. All of the above
5. Pons contains which of the following set of nuclei?
   a. IX, X, XI, XII
   b. V, VI, VII, VIII
   c. III, IV
   d. IV, V, VI, VII

ANSWERS

1. b **2.** b **3.** a **4.** d **5.** b

CHAPTER

6

Cerebellum

The brain is a wonderful organ. It starts working the moment we get up in the morning and does not stop until you get into the office
—R Frost

INTRODUCTION

Cerebellum (Latin *small brain*) though small in size (weighs about 150 grams), subserves important functions for maintaining tone, posture, and equilibrium of the body. It is the largest part of the hindbrain and 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. 6.1).

Relations

Anteriorly: Fourth ventricle, pons and medulla.

Posteroinferiorly: Squamous occipital bone.

Superiorly: Tentorium cerebelli (Fig. 6.2).

EXTERNAL FEATURES

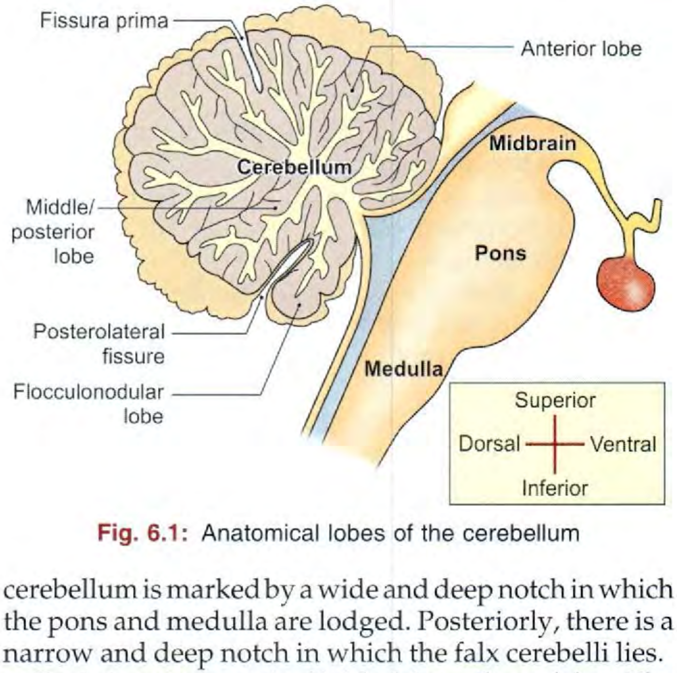


Fig. 6.1: Anatomical lobes of the cerebellum

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 (Fig. 6.3a). The inferior surface shows a deep median notch called the *vallecula* which separates the right and left convex hemispheres (Fig. 6.3b). 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.

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. 6.4).

PARTS OF CEREBELLUM

The cerebellum is subdivided into numerous small parts by fissures. Each fissure cuts the vermis and both hemispheres. Out of the numerous fissures, however, only the following are worth remembering.

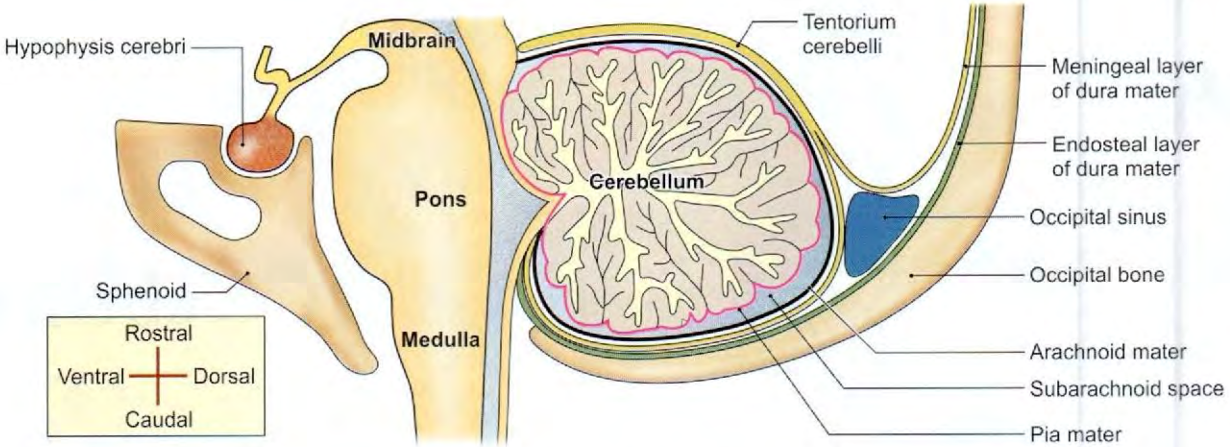


Fig. 6.2: Relations of cerebellum

1 The *horizontal fissure* separates the superior surface from the inferior surface (Fig. 6.4).
2 The *primary fissure (fissura prima)* separates the anterior lobe from the middle lobe on the superior surface of the cerebellum.
3 The *posterolateral fissure* separates the middle lobe from the flocculonodular lobe on the inferior surface.

The various parts of cerebellum are shown in Fig. 6.4. Where both the superior and inferior surfaces of the cerebellum are drawn in one plane. The upper part of the diagram, above the horizontal fissure represents the superior surface; and the lower part, below the horizontal fissure represents the inferior surface.

Parts of vermis	*Subdivisions of the cerebellar hemisphere*
1. Lingula	—
2. Central lobule	Ala
3. Culmen	Quadrangular lobule
4. Declive	Simple lobule
5. Folium	Superior semilunar lobule
6. Tuber	Inferior semilunar lobule
7. Pyramid	Biventral lobule
8. Uvula	Tonsil
9. Nodule	Flocculus

In Fig. 26.4, note that each part of the vermis has a lateral extension. However, the *lingula* does not have any lateral extension.

MORPHOLOGICAL AND FUNCTIONAL DIVISIONS OF CEREBELLUM

1 The *archicerebellum* phylogenetically is the oldest part of the cerebellum to appear in evolution in aquatic vertebrates. It includes of 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 (Fig. 6.5).
2 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.
3 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 (Table 6.1).

FUNCTIONALLY

The anterior and posterior lobes are organized into 3 longitudinal zones—lateral, intermediate and vermis (Fig. 6.6).

Lateral Zone

Connected with association areas of the brain and is involved in planning, programming and coordination muscular activities of distal parts of limbs. It is done through dentate rubrothalamocortical tract, descending corticospinal and rubrospinal tracts.

Intermediate Zone

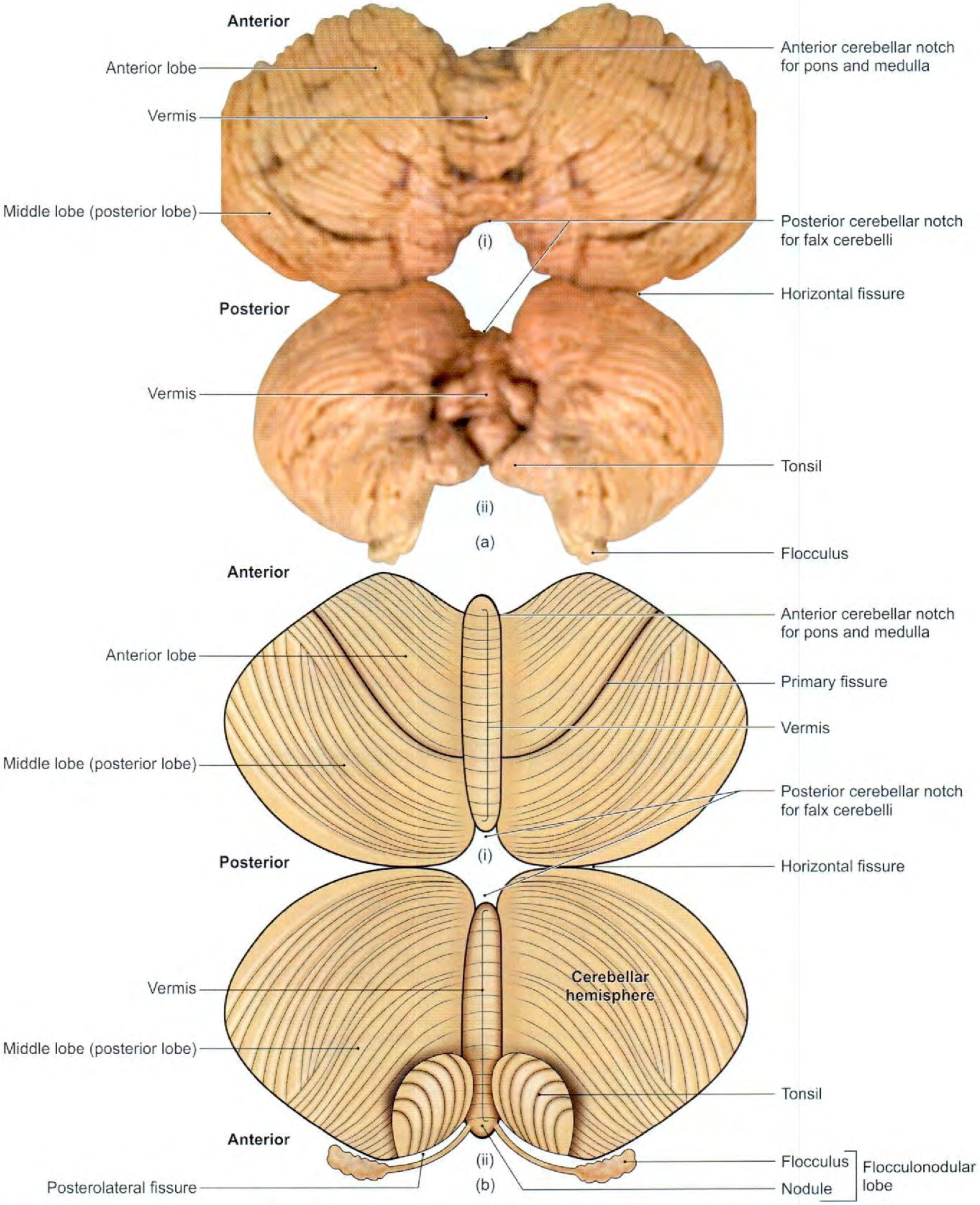
Concerned with control of muscles of flexor group via rubrospinal tract.

Median Zone/Vermis

Concerned with control of extensor muscles 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.



Figs 6.3a and b: (a) (i) Superior, (ii) inferior surface of cerebellum (gross), and (b) (i) superior, (ii) inferior surface of cerebellum (diagrammatic)

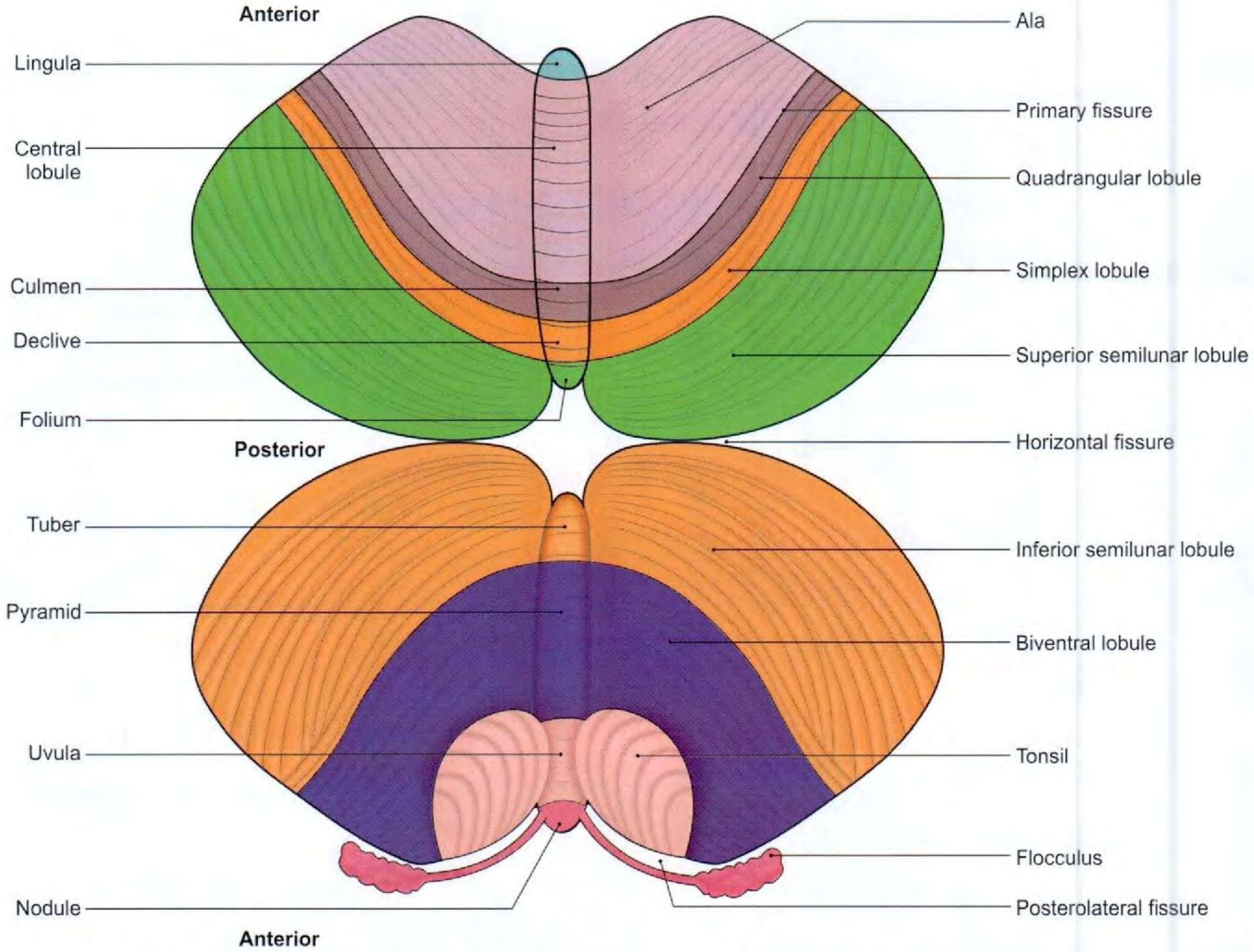


Fig. 6.4: Lobes and morphological subdivisions of cerebellum. Area above horizontal fissure represents superior surface and area below the fissure shows inferior surface

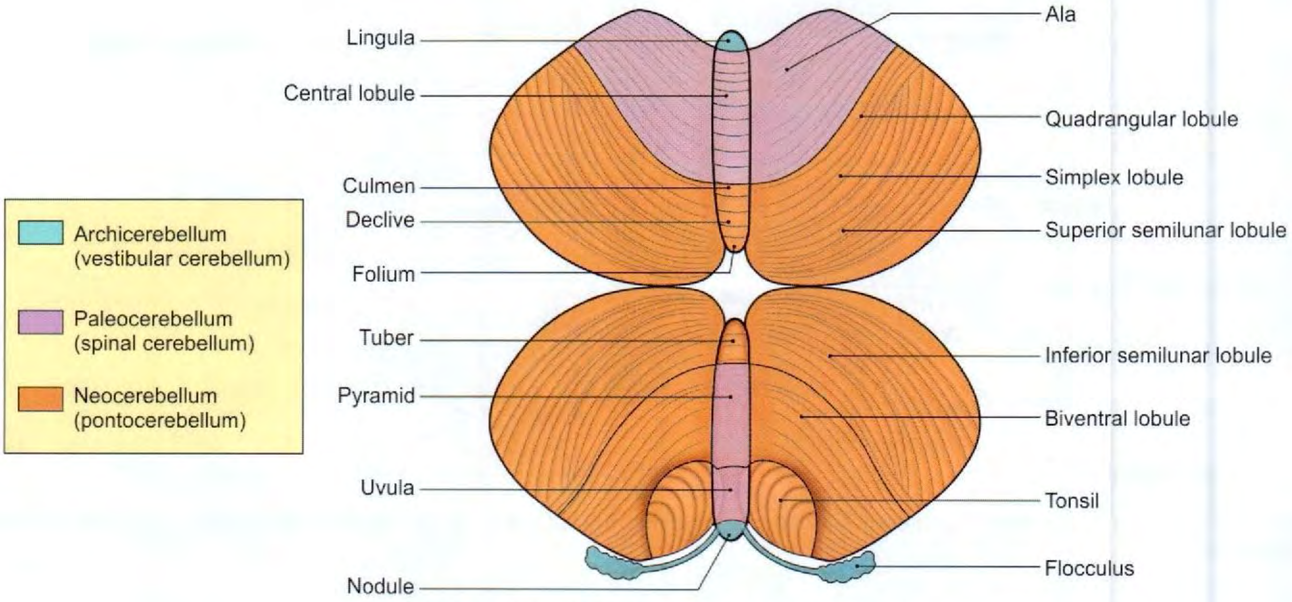


Fig. 6.5: Functional subdivisions of cerebellum

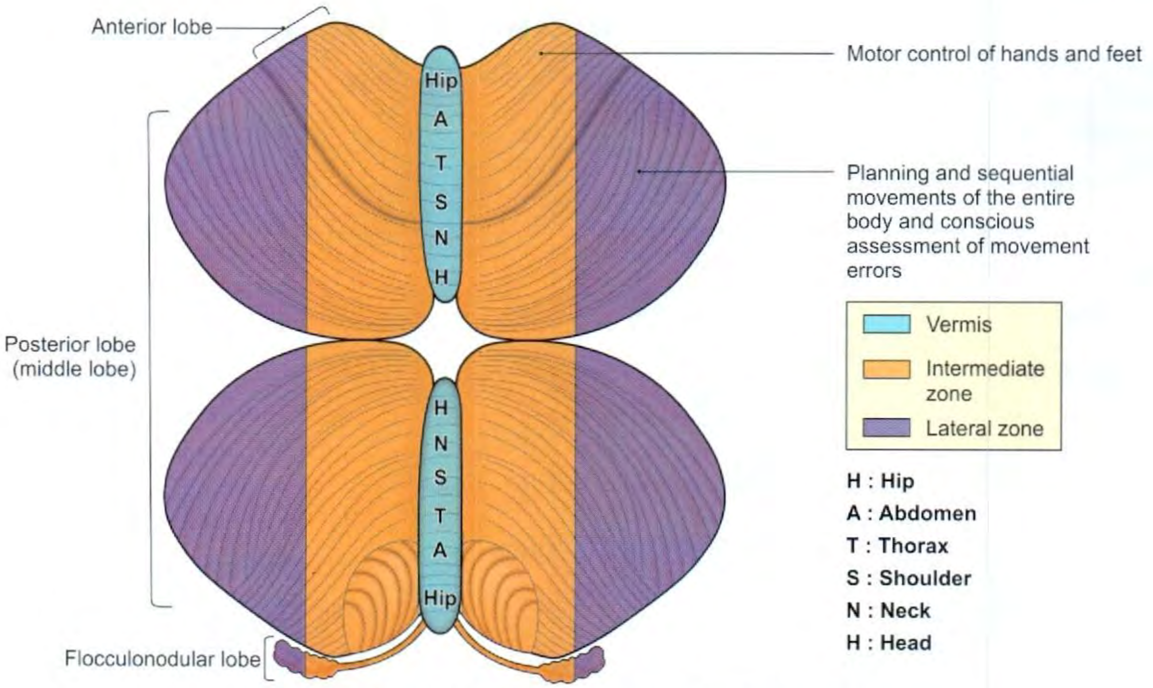


Fig. 6.6: Functions of cerebellum according to the zones

Table 6.1: 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 Olivocerebellar 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 centre between cerebral cortex and peripheral motor movements

CONNECTIONS OF CEREBELLUM

The fibres entering or leaving the cerebellum are grouped to form three peduncles (Latin *small foot*) which connect the cerebellum to the midbrain, the pons and the medulla (Fig. 6.2). The constituent fibres in them are given in Table 6.2 and Figs 6.7 and 6.8.

It is clear from Table 6.2 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. There are four pairs of nuclei:

1 *Nucleus dentatus* is neocerebellar.
2 *Nucleus globosus*

Table 6.2: Constituents of the cerebellar peduncles

Peduncle	*Afferent tracts*	*Efferent tracts*
A. Superior cerebellar peduncle (connects cerebellum to midbrain)	1. Anterior spinocerebellar 2. Tectocerebellar	1. Cerebellorubral 2. Dentatothalamic 3. Dentato-olivary 4. Fastigioreticular
B. Middle cerebellar peduncle (connects cerebellum to pons)	Pontocerebellar (part of the corticopontocerebellar pathway)	
C. Inferior cerebellar peduncle (connects cerebellum to medulla oblongata)	1. Posterior spinocerebellar 2. Cuneocerebellar (posterior external arcuate fibres) 3. Olivocerebellar 4. Parolivocerebellar 5. Reticulocerebellar 6. Vestibulocerebellar 7. Anterior external arcuate fibres 8. Striae medullaris 9. Trigeminocerebellar	1. Cerebellovestibular 2. Cerebello-olivary 3. Cerebelloreticular

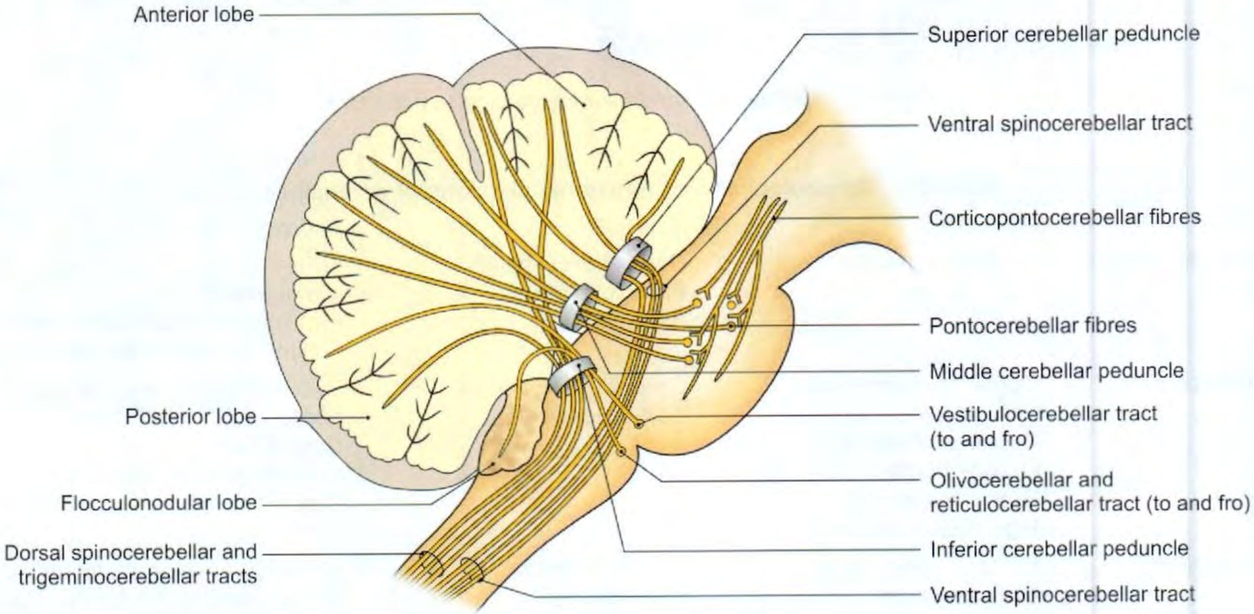


Fig. 6.7: Connections of cerebellum

3 *Nucleus emboliformis* is paleocerebellar.
4 *Nucleus fastigii* is archicerebellar (Fig. 6.9).

HISTOLOGICAL STRUCTURE

The structure of cerebellum is uniform throughout, i.e. is 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 cell which inhibits dendrites of Purkinje cell (Figs 6.10a and b).

The cortex contains 3 layers as follows:

1 *Molecular layer*: It consists of unmyelinated nerve fibres which are derived from the parallel fibres of axons of granule cells, axons of stellate and basket cells, sensory climbing fibres, dendrites of Purkinje and Golgi cells. It also contains stellate and basket cells.

2 *Intermediate layer*: It contains single layer of cell bodies of Purkinje cells.

3 *Inner layer*: Made up of cell bodies and dendrites of granule cell, Golgi cells.

Neurons of Cerebellum

They are 5 types in which four types of, i.e. Purkinje, basket, stellate, and Golgi are inhibitory. Only the granular cells are excitatory.

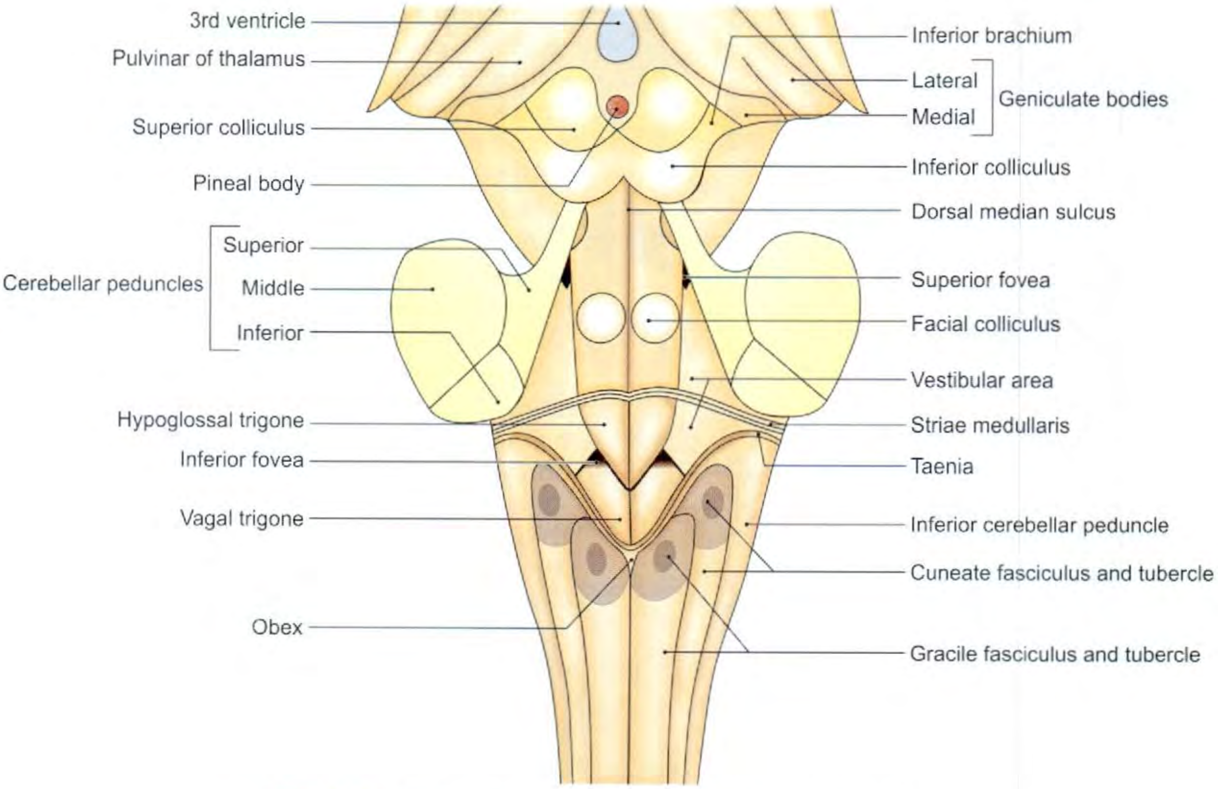
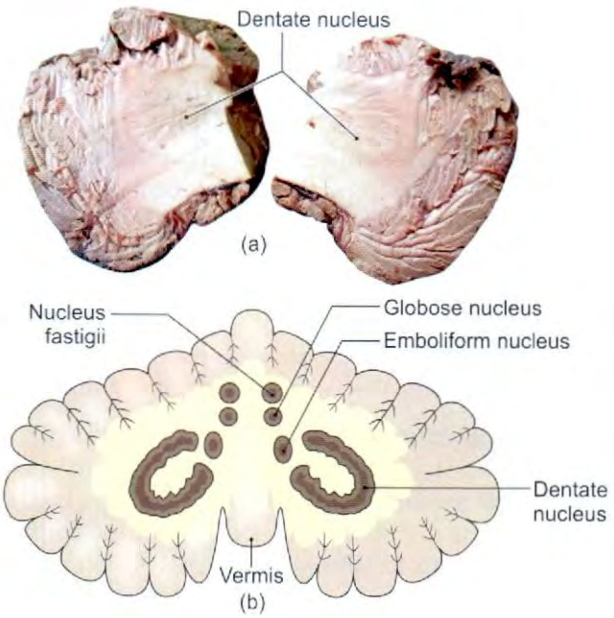


Fig. 6.8: Position of cerebellar peduncles (in posterior view)



Figs 6.9a and b: Positions of intracerebellar nuclei

Purkinje cell: It is the characteristic cell of cerebellum. It is a large cell with flask shape. It gets stimulated by climbing fibres coming from inferior olivary nucleus. The main output of this cell is to cerebellar nuclei and is inhibitory in nature. These are the main output neurons.

Granule cell: It is a small rounded cell with dendrites. the axons of these cells form parallel fibres which are connected to other cells.

Stellate cell and basket cell: Their cell bodies are at right angles to the long axis of the folium.

Golgi cells: They are the largest neurons. They receive input from parallel fibres, climbing fibres and mossy fibres and output to granule cells.

Sensory Fibres of Cerebellum

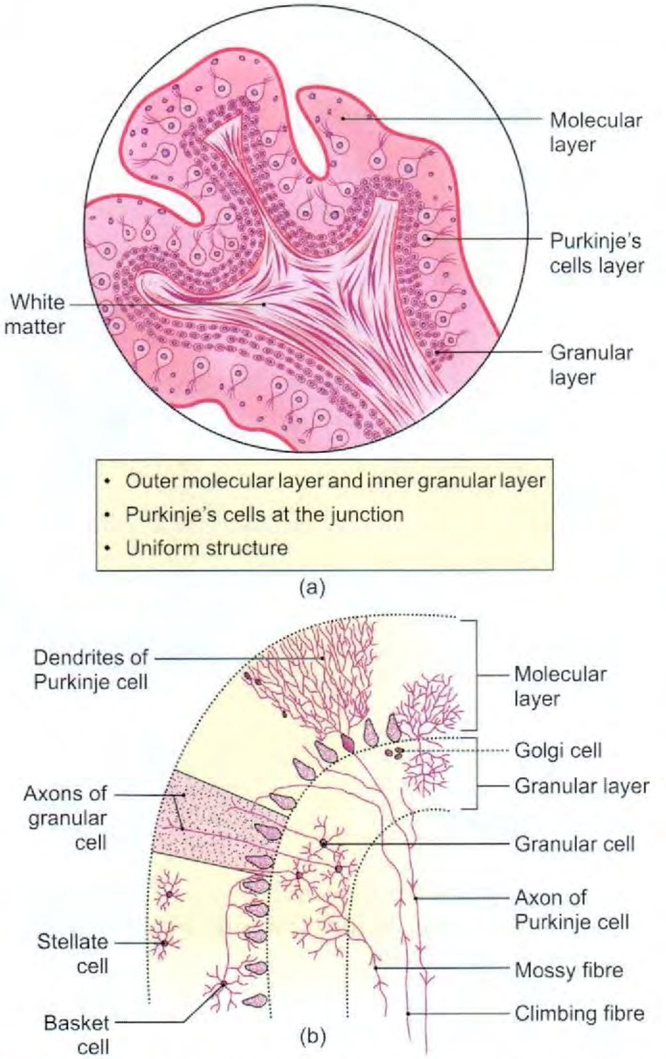
The afferent connections of cerebellum are through **mossy** and **climbing** fibres. Mossy fibres constitute all the afferents except those of olivo-cerebellar fibres. Mossy fibres synapse with granule and Golgi cells (Table 6.5). These fibres release neurotransmitter and glutamate. Climbing fibres start from inferior olivary nucleus. These olivo-cerebellar fibres climb up and make synaptic connection with dendrites of Purkinje's cells (Fig. 6.11). These fibres release neurotransmitter aspartate.

BLOOD SUPPLY

Cerebellum is supplied by two superior cerebellar arteries, two anterior inferior cerebellar arteries and two posterior inferior cerebellar arteries.

Superior cerebellar is a branch of basilar artery.

Anterior inferior cerebellar is a branch of basilar artery.



- Outer molecular layer and inner granular layer
- Purkinje's cells at the junction
- Uniform structure

Figs 6.10a and b: (a) Histology of cerebellum, and (b) histological connections of cerebellar neurons

Posterior inferior cerebellar is a branch of vertebral artery.

Veins drain into neighbouring venous sinuses.

FUNCTIONS OF CEREBELLUM

Cerebellum controls the same side of the body. Its influence is ipsilateral. This is in marked contrast to which control the opposite half of the body.

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 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 fibres.

All sensory information of muscles, joints, cutaneous, auditory and visual parts are relayed here. Spinocerebellar tracts carry information from the same side (Fig. 6.6).

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

Cerebellum functions as "comparator". It receives information from cerebrum and spinal cord. It corrects and modifies ongoing movements through thalamocortical projections, reticulospinal and rubrospinal tracts.

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

DEVELOPMENT

Cerebellum develops from the neurons of alar lamina of metencephalic part of the rhombencephalic vesicle. These neurons migrate dorsally and form the rhombic lip which forms the cerebellum. The earliest part to develop is the archicerebellum. In its centre, the paleocerebellum develops, splitting the archicerebellar parts into two parts, the lingula and flocculonodular lobe. Lastly, the paleocerebellar part is also split by the development of neocerebellum in its centre into two parts, the anterior lobe except lingula and pyramid with uvula.

CLINICAL ANATOMY

Cerebellar Dysfunction

- Vermis lesions lead to truncal ataxia as connection of vermis to the vestibular nuclei are involved.
- Nystagmus is due to loss of labyrinthine connections of vermis to labyrinth. Vermis is also related to emotions.
- *Anterior lobe lesion:* Lesion of anterior lobe causes gait ataxia. There is incoordination of the lower limbs resulting in staggering gait and inability to walk in a straight line. It is also seen in alcoholics.
- *Neocerebellar lesions:* These lesions cause incoordination of voluntary movements of the upper limbs. It results in intention tremor, action tremor and overshoot movements.

- Speech is also defective. Phonation is defective due to loss of smoothness in expiratory muscles. Articulation is defective as there is less coordination between muscles of lip, tongue and palate.
- If there is thrombosis of one of six arteries nurturing cerebellum, "cerebellum cognitive affective syndrome" develops. These patients show in attention, grammatical errors in speech and patchy memory loss. Involvement of vermis results in dulling of emotional response. It is characterised by:
  a. Muscular hypotonia
  b. Intention tremors (tremors only during movements) tested by finger-nose and heel-knee tests.
  c. Adiadochokinesia which is inability to perform rapid and regular alternating movements, like pronation and supination.
  d. Nystagmus is to and fro oscillatory movements of the eyeballs while looking to either side.
  e. Scanning speech is jerky and explosive speech.
  f. Ataxic or unsteady gait.

SUMMARY

Three parts:	• Archicerebellum • Paleocerebellum • Neocerebellum
Three lobes:	• Anterior lobe • Middle or posterior lobe • Flocculonodular lobe
Three fissures:	• Fissura prima • Horizontal fissure • Posterolateral fissure
Three functional zones:	• Vermal zone for trunk and girdle movement • Intermediate zone for hands/feet • Lateral zone for planning and programming movement
Three histological layers of grey matter:	• Molecular layer • Purkinje cell layer • Granular cell layer
Three peduncles	• Superior cerebellar peduncle to midbrain • Middle cerebellar peduncle to pons • Inferior cerebellar peduncle to medulla oblongata
Three deeper nuclei:	• Nucleus dentate with neocerebellum • Nucleus emboliformis and nucleus globose with paleocerebellum • Nucleus fastigii with flocculonodular lobe
Three arteries for each hemisphere:	• Superior cerebellar • Anterior inferior cerebellar • Posterior inferior cerebellar
Three functions:	• Tone, posture equilibrium by flocculonodular lobe • Tone posture and crude movements by anterior lobe • Smooth, accurate and balanced movements by middle lobe
Three main symptoms (one for each lobe):	• Truncal ataxia in flocculonodular lobe defect • Staggering gait in anterior lobe defect • Defective speech in middle lobe defect

FACTS TO REMEMBER

- Cerebellum or a little brain acts like younger sibling of the large cerebrum. It controls tone, posture, equilibrium and fine movements of the body. It cannot initiate the movement.
- It is connected to medulla oblongata by inferior cerebellar peduncle.
- It is connected to pons by middle cerebellar peduncle
- It is connected to midbrain by superior cerebellar peduncle.
- Number of neurons are about half of the cerebrum, though it is much smaller than the cerebrum.
- Its structure is uniform throughout, i.e. homotypical.
- Its control is ipsilateral.

CLINICOANATOMICAL PROBLEM

A 40-year-old female complained of inability to work properly with her right hand. She would sway to right side while walking. She could not do rapid pronation and supination of her right forearm. Magnetic resonance imaging showed a tumour in her right lobe of the cerebellum

- Which cerebellar functions have been lost to give rise to above symptoms?
- Name the peduncles of the cerebellum.

Ans: The cerebellum controls tone, posture, equilibrium and control of fine movements of the body. The tumour has disrupted these functions, giving rise to symptoms from which she is suffering.

Cerebellum is connected to medulla oblongata by inferior cerebellar peduncle.

It is connected to pons by middle cerebellar peduncle.

It is also connected to midbrain by superior cerebellar peduncle.

FREQUENTLY ASKED QUESTIONS

1. Name the afferent and efferent fibers of the three cerebellar peduncles.

2. Discuss the functions and clinical anatomy of cerebellum.

3. Write short notes on:
   a. Dental nucleus
   b. Parts of vermis and subdivision of cerebelllar hemisphere
   c. Histology of cerebellar cortex

MULTIPLE CHOICE QUESTIONS

1. The ratio of cerebellum to cerebrum in an adult is:
   a. 1 : 8
   b. 1 : 16
   c. 1 : 4
   d. 1 : 20

2. Purkinje cells are situated in:
   a. Cerebral cortex
   b. Junction of molecular and granular layers of cerebellum
   c. Granular layer of cerebellum
   d. Nucleus emboliformis

3. What is the true about cerebellum?
   a. It is situated in posterior cranial fossa behind pons and medulla oblongata
   b. It is an infratentorial structure that coordinate voluntary movements of body
   c. Its structure is homotypical
   d. All of the above

4. Which lobe is smallest in cerebellum?
   a. Flocculonodular
   b. Middle
   c. Anterior
   d. Posterior

5. Which of the following regions of cerebellum is concerned with planning and programming muscular activities?
   a. Intermediate zone
   b. Vermis
   c. Lateral zone
   d. Flocculonodular zone

6. Which is the afferent tract of superior cerebellar peduncle?
   a. Reticulocerebellar
   b. Frontocerebellar
   c. Tectocerebellar
   d. Striae medullaris

7. Which function of cerebellum is not true?
   a. Its function as comparator
   b. Vermis controls axial muscle and thus maintains posture
   c. Archicerebellum and paleocerebellum controls muscles of hand, finger, feet and toes
   d. Flocculonodular lobe is connected to vestibular nuclei. It maintains posture of the body

8. Superior cerebellar peduncle contains which of the following fibres?
   a. Posterior spinocerebellar
   b. Olivocerebellar
   c. Vestibulocerebellar
   d. Anterior spinocerebellar

ANSWERS

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

CHAPTER

7

Fourth Ventricle

Man's mind, once stretched by a new idea, never regains its original dimensions

—Bovee

INTRODUCTION

The cavity of hindbrain is called the fourth ventricle. It is a tent-shaped space situated between the pons and upper part of medulla oblongata in front and cerebellum behind. So it lies dorsal to pons and upper part of medulla oblongata and ventral to cerebellum.

It has lateral boundaries, floor, roof and a cavity (Figs 7.1 to 7.4).

LATERAL BOUNDARIES

On each side, fourth ventricle is bounded (Fig. 7.1):

1 Inferolaterally by gracile, cuneate tubercles and inferior cerebellar peduncles.
2 Superolaterally by the superior cerebellar peduncles.

FLOOR

It is also called 'rhomboid fossa' because of its rhomboidal shape. The floor is formed by:

1 Posterior (dorsal) surface of lower or closed part of pons (Fig. 7.1).
2 Posterior (dorsal) surface of open or upper part of medulla oblongata.

Structural Layers

The floor is lined by

1 Ependyma.
2 A thin layer of the neuroglia beneath the ependyma.
3 A layer of grey matter, forming the various nuclei deep to neuroglia.

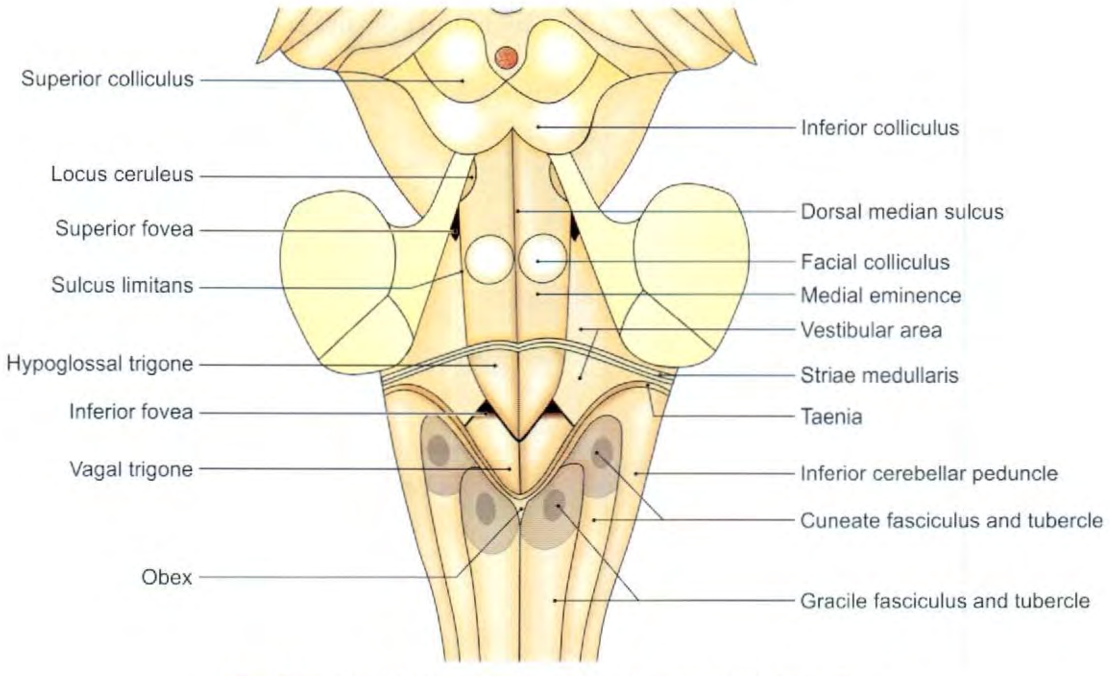


Fig. 7.1: Boundaries of IV ventricle and structures in its floor

Parts

It is divisible into:

1 An upper triangular part formed by dorsal surface of pons.
2 A lower triangular part formed by dorsal surface of medulla.
3 The intermediate part is at the junction of pons and medulla. The intermediate part is prolonged laterally over the inferior cerebellar peduncle as the floor of lateral recess. This part is marked by transversely running fibres which are fibres of *stria medullaris*. These fibres represent fibres from arcuate nucleus to the opposite cerebellum.

Features of the Floor

1 Dorsal median sulcus divides the floor into two symmetrical halves (Fig. 7.1).
2 Sulcus limitans divides each half into median eminence and lateral vestibular area. The sulcus limitans presents depression at the cranial end called superior fovea and towards caudal part called inferior fovea.
3 Medial eminence: The eminence is wider above and narrow below. It presents facial colliculus just opposite and medial to superior fovea. Deep to the colliculus is the genu of the facial nerve formed by this nerve looping around the abducent nucleus.
4 In the uppermost part (pontine part) the sulcus limitans overlies an area that is bluish in colour and is called locus coeruleus. The colour is due to presence of pigmented neurons which constitute substantia ferruginea. These neurons belong to the reticular formation. They are rich in noradrenaline and help in paradoxical sleep.
5 Descending from the inferior fovea, there is a sulcus that runs obliquely towards midline. This sulcus divides medial eminence into two triangles. These are hypoglossal triangle medially and vagal triangle laterally. These overlie the hypoglossal nerve nucleus and of vagus nerve, respectively.
6 Between the vagal triangle above and gracile tubercle below there is small area called the area postrema which may function as chemoreceptor. An ependymal thickening called funiculus seperans separates both. This area is devoid of blood–brain barrier.
7 Vestibular area: This lies lateral to the inferior fovea (sulcus limitans) which overlies the vestibular nuclei. This area is partly in the pons and partly in the medulla.

The lowest part of the floor resembles the pointed nib of writing pen so it is described as calamus scriptorius.

ROOF

The roof of the ventricle is diamond-shaped and can be divided into superior and inferior parts (Fig. 7.2). The superior or cranial part of roof is formed by superior cerebellar peduncles and superior medullary velum. The superior cerebellar peduncles on emerging from central white matter of cerebellum pass first cranially and ventrally forming at first lateral boundaries of ventricles. On approaching the inferior colliculi, they converge and then intermingle over the ventricles and form part of the roof. The superior medullary velum which is made up of nervous tissue fills the angular interval between the two superior cerebellar peduncles. It is covered on the dorsal surface by lingula of superior vermis.

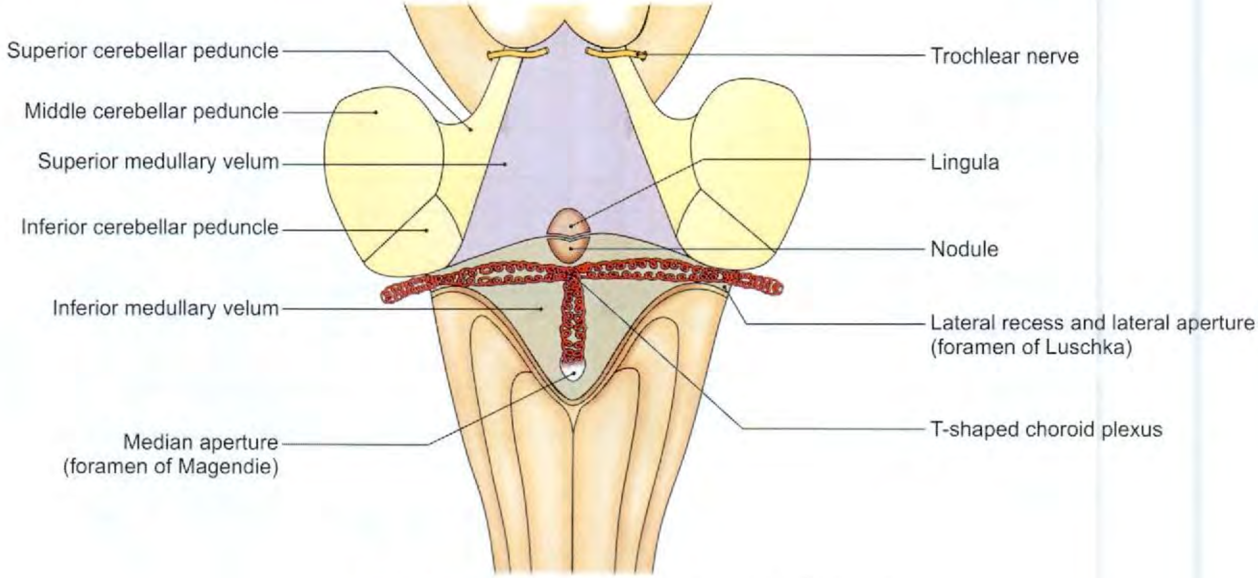


Fig. 7.2: Schematic diagram of roof of IV ventricle

The caudal inferior part of roof in most of its extent consists of an exceedingly thin sheet, entirely devoid of nervous tissue and formed by the ventricular ependyma and double fold of pia mater or the tela choroidea of the fourth ventricle which covers it posteriorly. Caudally, the continuity of sheet is broken by a gap termed the *median aperture* through which the cavity of ventricle communicates freely with the subarachnoid space in the region of the cerebellomedullary cistern. The inferior medullary velum forms a small part of roof in the region lateral to the nodule of cerebellum.

Superior to the region of inferior medullary velum on each side, the layer of tela choroidea in contact with the ependyma of caudal part of roof reaches the inferolateral boundary of ventricular floor, which is marked by a narrow, white ridge termed *taenia*. The two taeniae are continuous below with a small curved margin, the *obex* often used to denote the inferior angle itself.

Tela Choroidea of Fourth Ventricle

It is a double layer of pia mater which occupies the interval between the cerebellum and the lower part of the ventricle. Its posterior layer provides a covering of pia mater to the inferior vermis, and after covering the nodule, is reflected ventrally, and caudally in immediate contact with ependyma. The tela choroidea with vascular fringes covered by secretory ependyma form the choroid plexuses of fourth ventricle. These project into lower part of roof of fourth ventricle. Each plexus (left or right) consists of a vertical limb lying next to midline and a horizontal limb extending into lateral recesses. The vertical limb of the two plexuses lie side by side so that whole structure is T-shaped. The vertical limbs of the T-shaped structure reach the median aperture and project into the subarachnoid space through it. The lateral ends of horizontal limbs reach the lateral apertures. The arterial supply of these plexuses is from the posterior inferior cerebellar arteries (Fig. 7.2).

Communication

The cavity of the fourth ventricle communicates inferiorly with the central canal and superiorly with cerebral aqueduct (Fig. 7.3a).

Openings in the Roof

In the caudal part of roof of fourth ventricle there are three openings, one median and two lateral (Fig. 7.3a).

The median aperture of fourth ventricle alternatively known as *foramen of Magendie* is a large opening situated caudal to nodule. This opening provides the principal communication between ventricular system and subarachnoid space. The lateral apertures, also known as *foramina of Luschka*, are situated at the ends of lateral

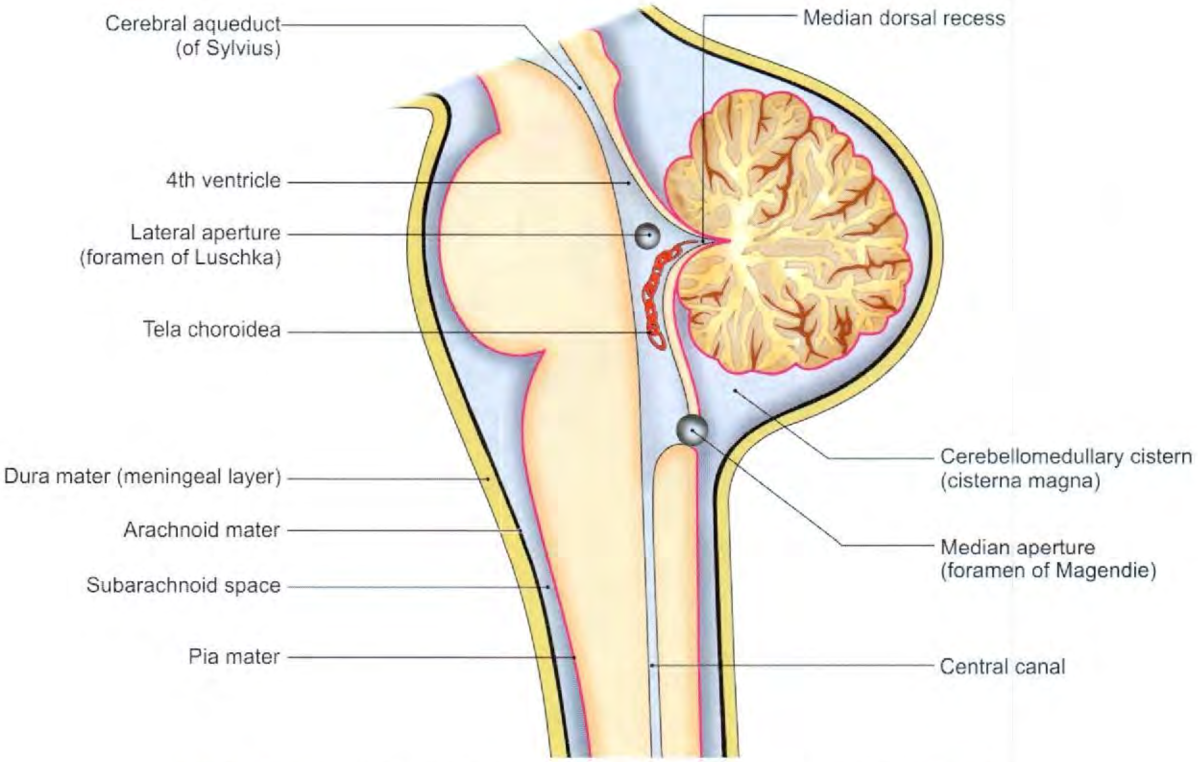


Fig. 7.3a: Sagittal section of brain stem and cerebellum to show IV ventricle

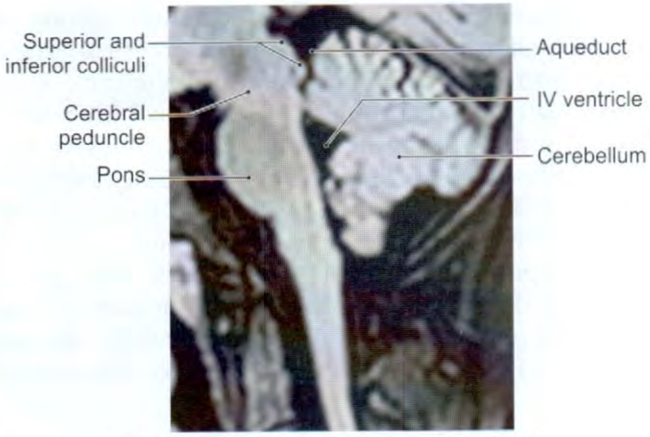


Fig. 7.3b: MRI showing fourth ventricle

recesses and are partly occupied by parts of choroid plexuses which protrude into subarachnoid space. Through these also fourth ventricle communicates with subarachnoid space.

ANGLES

Superior angle: Continuous with cerebral aqueduct.

Inferior angle: Continuous below with central canal of spinal cord (Fig. 7.3b).

Lateral angles: One on each side towards the inferior cerebellar peduncles.

RECESSES OF FOURTH VENTRICLE

These are extensions of the main cavity of ventricle. Fine recesses have been identified (Fig. 7.4).

1. Two lateral recesses one on each side. Each lateral recess passes laterally in the interval between the inferior cerebellar peduncle (ventrally) and the peduncle of flocculus dorsally reaching as far as the medial part of flocculus.
2. One recess present in the median plane, is known as median dorsal recess. It extends dorsally into white core of cerebellum and lies cranial to nodule.
3. Two lateral dorsal recesses, one on each side. Each lateral dorsal recess extend dorsally lateral to the nodule and cranial to the inferior medullary velum. These lie on either side of median dorsal recess.

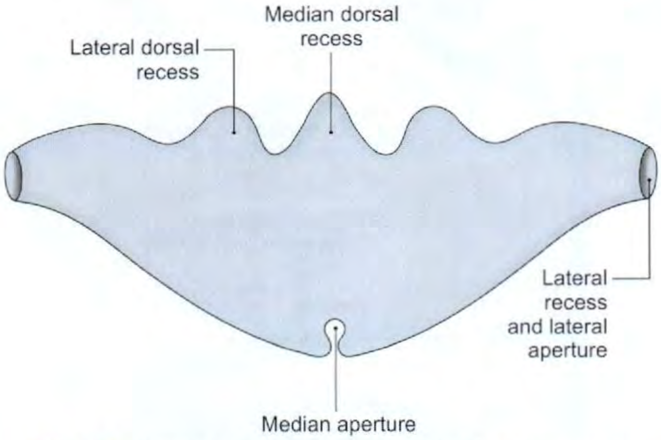


Fig. 7.4: Recesses and apertures of the fourth ventricle

CLINICAL ANATOMY

- Vital centres are situated in the vicinity of vagal triangle. An injury to this area, therefore, would prove fatal.
- Infratentorial brain tumours block the foramina of Luschka and Magendie situated in the roof of fourth ventricle. This results in marked early rise of intracranial pressure which causes headache, vomiting, papilloedema, etc.

FACTS TO REMEMBER

- Vital centres like respiratory and cardiovascular are situated in the floor of IV ventricle.
- Fourth ventricle has 3 openings, one foramen of Magendie and two foramina of Luschka for the exit of used CSF into the subarachnoid space for absorption in the superior sagittal venous sinus.
- It also has 5 recesses to keep the CSF
- In its floor are nuclei of VI, VII, VIII, X and XII cranial nerves.

CLINICOANATOMICAL PROBLEM

A criminal was hanged to death

- How does death occur in hanging?
- Name the ligaments related to atlanto-occipital, atlantoaxial joints and ligaments between axis and occipital condyles.

Ans: The death during hanging occurs due to injury to transverse ligament of the atlas providing freedom to the bound dens of axis. The freed dens hits backwards on the vital centres in floor of fourth ventricle, resulting in immediate death.

Ligaments in this region are:

- Membrana tectoria
- Vertical band of cruciate ligament
- Apical ligament
- Alar ligament
- Anterior atlanto-occipital membrane
- Posterior atlanto-occipital membrane

FREQUENTLY ASKED QUESTIONS

1. Name the lateral boundaries, structure in the floor and roof of the fourth ventricle.
2. Name the recesses of 4th ventricle
3. Name the openings in the roof of 4th ventricle.

MULTIPLE CHOICE QUESTIONS

1. What is situated in the vicinity of vagal triangle?
   a. Vital centres
   b. Respiratory centre
   c. Cardiovascular centre
   d. Vasomotor centre
2. Inferolaterally IV ventricle is not bounded by:
   a. Gracile tubercles
   b. Cuneate tubercles
   c. Inferior cerebellar peduncles
   d. Superior cerebellar peduncles
3. Which of the following nuclei is related to IV ventricle?
   a. Facial nerve nucleus
   b. Hypoglossal nucleus
   c. Vestibular nuclei
   d. All of the above
4. Area postrema functions as:
   a. Chemoreceptor
   b. Osmoreceptor
   c. Nocireceptor
   d. None of the above
5. Which structure form choroid plexus?
   a. Tela choroidea with secretory ependyma
   b. Obex
   c. Lateral recess
   d. Secretory ependyma

ANSWERS

1. a **2.** d **3.** d **4.** a **5.** a

CHAPTER

8

Cerebrum

Knowledge is better than wealth. You have to look after wealth, knowledge looks after you.
Our life is what our thoughts make it
—M Aurelius

INTRODUCTION

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 (Figs 8.1a, b; 8.2 to 8.5). It is made up of outer grey matter and inner white matter and some neuronal masses called basal ganglia within the white matter. Besides this each hemisphere contains a cavity called lateral ventricle.

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

DISSECTION

Keep the cerebrum in a position so that the longitudinal fissure faces superiorly. Identify the convex strong band of white matter, the corpus callosum, binding parts of the medial surfaces of the two cerebral hemispheres. Define splenium as the thick rounded part of corpus callosum (Fig. 8.3).

Divide the corpus callosum in the median plane starting from the splenium towards the trunk, genu and rostrum. Inferior to the trunk of corpus callosum extend the incision into the tela choroidea of the lateral and third ventricles, and the interthalamic adhesion connecting the medial surfaces of two thalami.

Identify the thin septum pellucidum connecting the inferior surfaces of corpus callosum to a curved band of white matter—anterior column of the fornix. Look for the anterior commissure just at the anterior end of the anterior column of fornix.

Turn the brain upside down and identify optic chiasma (Fig. 8.4). Divide the optic chiasma, anterior communicating artery, infundibulum and a thin groove between the adjacent mammillary bodies, posterior cerebral artery close to its origin. Carry the line of division around the midbrain to join the two ends of the median cut. Separate the right and the left cerebral hemispheres.

In the two hemisphere, identify the three surfaces, four borders, three poles. Identify the central sulcus, posterior ramus of lateral sulcus, parieto-occipital sulcus and preoccipital notch. Join parieto-occipital sulcus to preoccipital notch. Extend the line of posterior ramus of lateral sulcus till the previous line. Now demarcate the four lobes of the superolateral surface of each cerebral hemisphere (Figs 8.1a and b).

Strip the meninges from the surfaces. Identify the vessels on the surfaces of hemisphere. Demarcate the main sulci and gyri on the superolateral surface, medial surface and inferior surface of hemisphere (*refer to BDC App*).

Make thin slice through the part of the calcarine sulcus, posterior to its junction with the parieto-occipital sulcus. Identify the stria running through it. On cutting series of thin slices try to trace the extent of visual stria.

Features

The cerebrum is made 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 Sulci and Gyri

Cerebral cortex is folded into gyri (Greek *circle*) which are separated from each other by sulci. This pattern increases the surface area of the cortex. In human brain, the total area of the cortex is estimated to be more than 2000 cm^2, and approximately two-thirds of this area is hidden from the surface within the sulci. The pattern of folding of the cortex is not entirely haphazard. It is largely determined by the differential growth of specific functional areas of the cortex, because many of the sulci bear a definite topographical relation to these areas. The formation of sulci in the intrauterine life begins from 5th–6th month and ends almost at the end of ninth month.

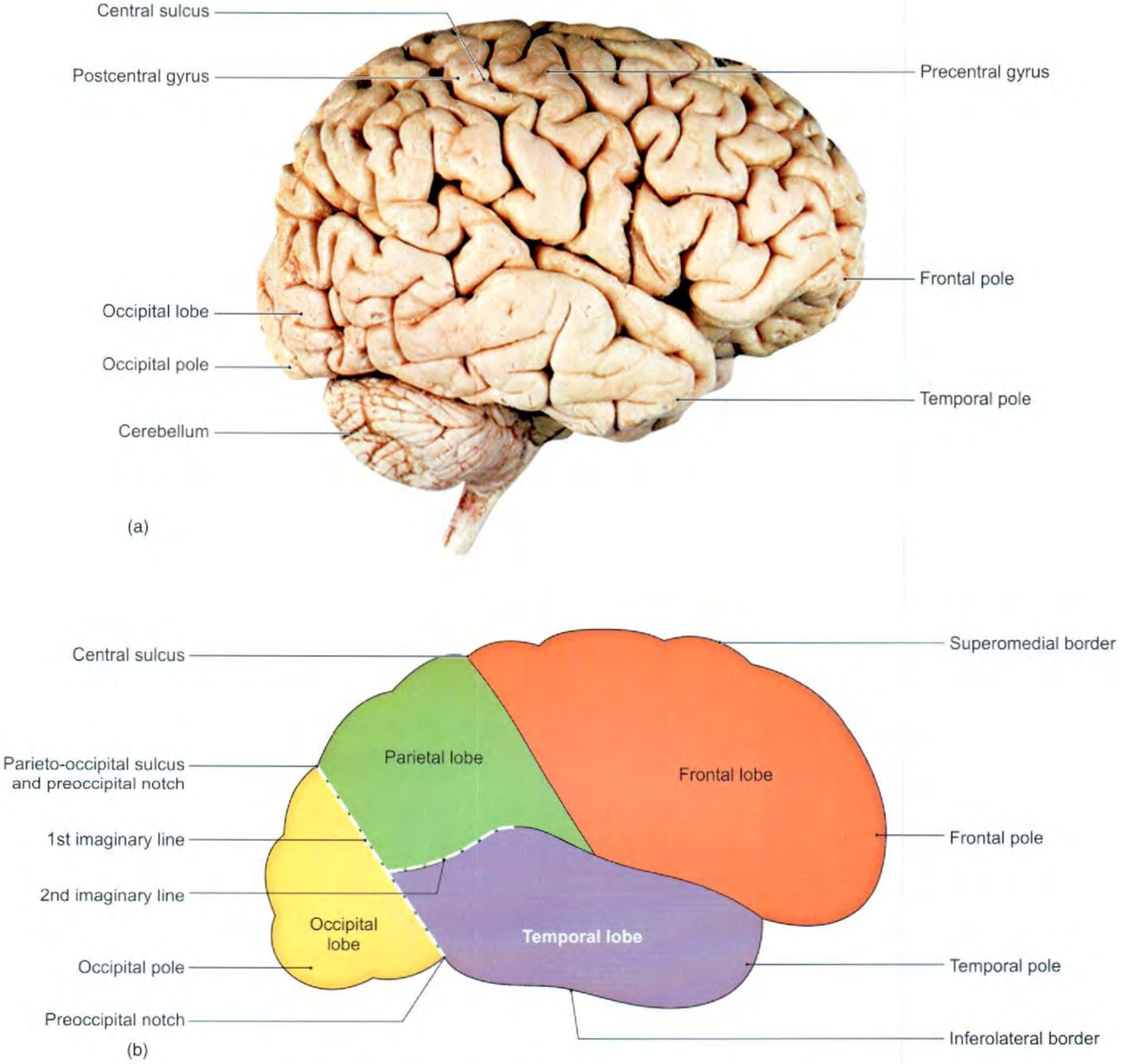
CEREBRAL HEMISPHERE

EXTERNAL FEATURES

Each hemisphere has the following features:

Three Surfaces

1 The *superolateral surface* is convex and is related to the cranial vault (Figs 8.1a and 8.2).



Figs 8.1a and b: Superolateral surface of cerebral hemisphere

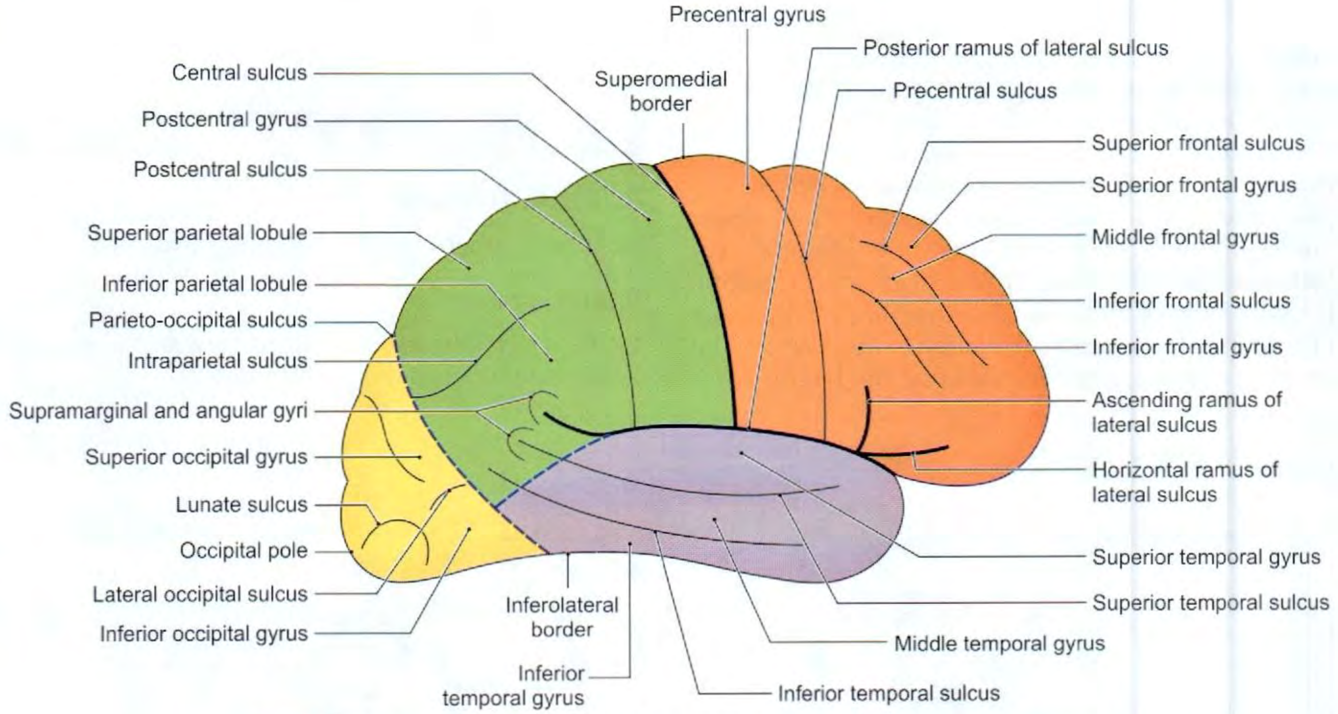


Fig. 8.2: Sulci and gyri on superolateral surface of right cerebral hemisphere

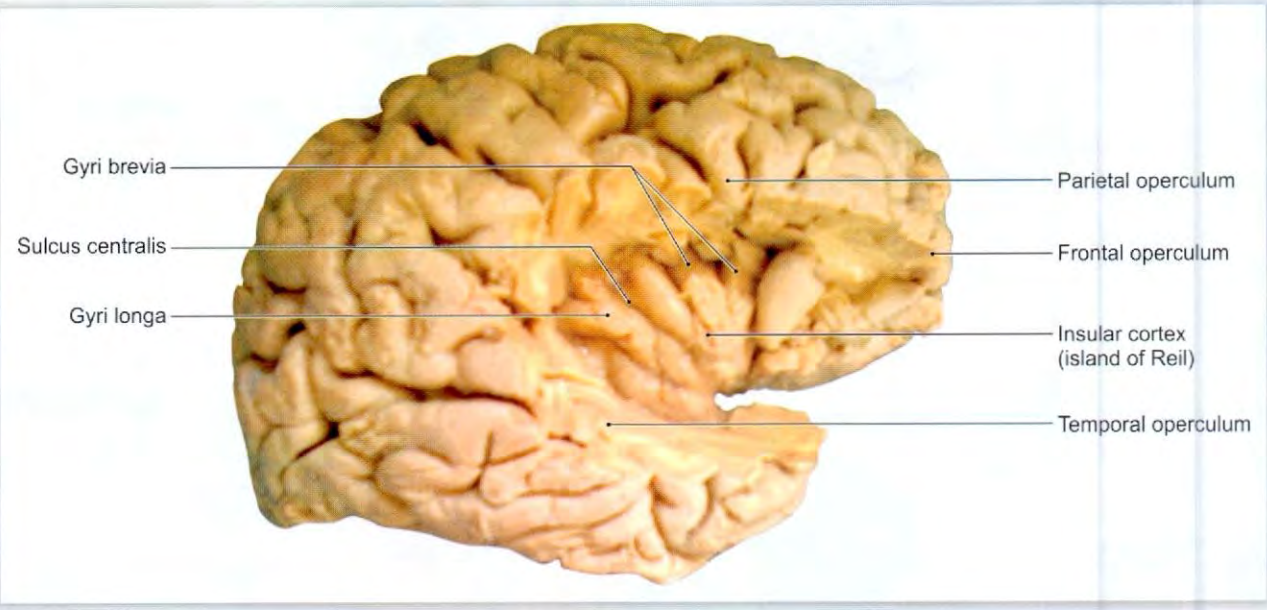


Fig. 8.3: The region of insula

2 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. 8.3).

3 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.

Four Borders

1 *Superomedial border* separates the superolateral surface from the medial surface (Fig. 8.1).

2 *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

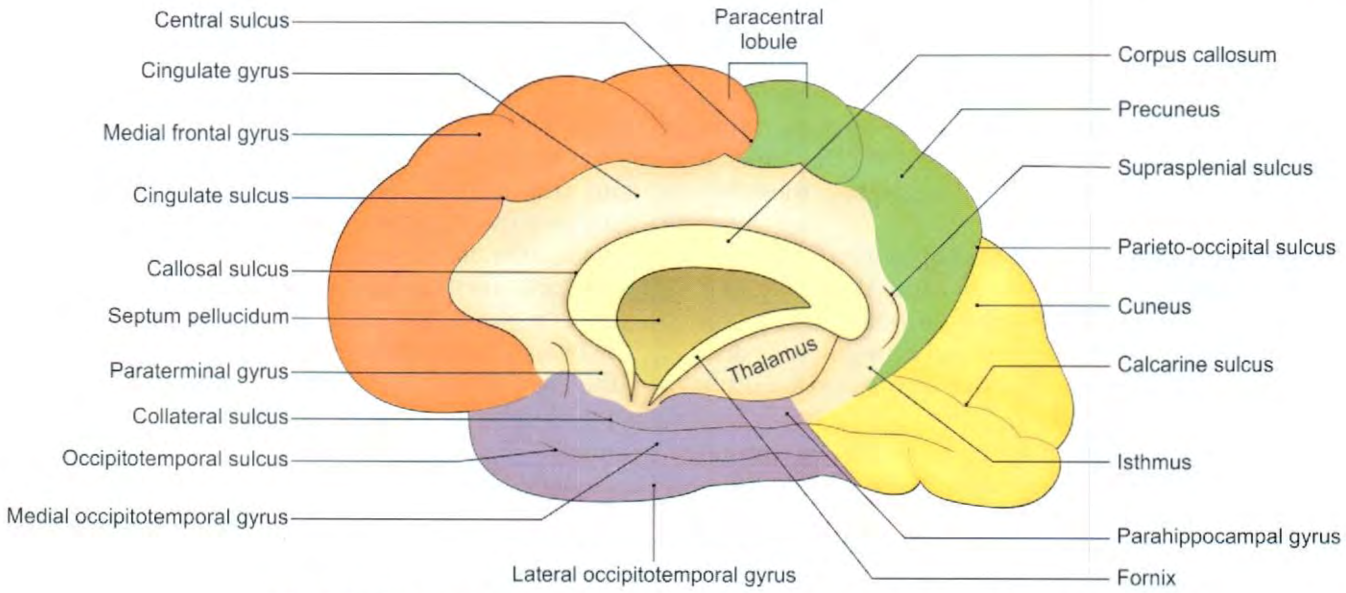


Fig. 8.4: Sulci and gyri on the medial surface of right cerebral hemisphere

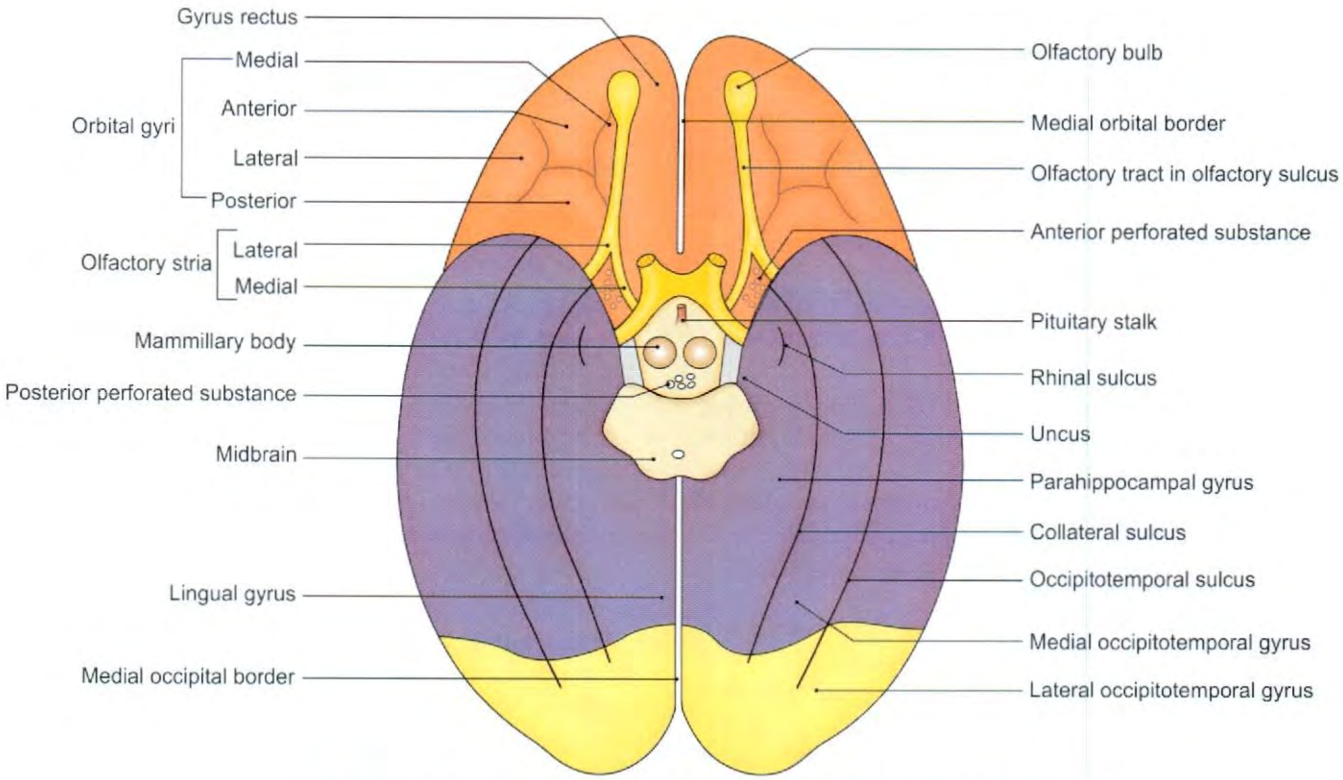


Fig. 8.5: Gyri and sulci on the inferior aspect of cerebral hemisphere

5 cm in front of the occipital pole, it is called the preoccipital notch (Fig. 8.1).

3 *Medial orbital border* separates the medial surface from the orbital surface (Fig. 8.4).
4 *Medial occipital border* separates the medial surface from the tentorial surface (Fig. 8.4).

Three Poles

1 *Frontal pole,* at the anterior end.
2 *Occipital pole,* at the posterior end.
3 *Temporal pole,* at the anterior end of the temporal lobe (Fig. 8.1).

Lobes of Cerebral Hemisphere

Each cerebral hemisphere is divided into four lobes—frontal, parietal, occipital and temporal. Their positions correspond, very roughly, to that of the corresponding bones. The lobes are best appreciated on the superolateral surface (Fig. 8.2). The sulci separating the lobes on this surface are as follows:

1. The *central sulcus* begins at the superomedial border of the hemisphere a little behind the midpoint between the frontal and occipital poles. It runs on the superolateral surface obliquely downwards and forwards and ends a little above the posterior ramus of the lateral sulcus (Fig. 8.2).
2. It is seen that the *lateral sulcus* separates the orbital and tentorial parts of the inferior surface. Laterally, this sulcus reaches the superolateral surface where it divides into anterior, ascending and posterior branches. The largest of these, the *posterior ramus of the lateral sulcus* passes backwards and slightly upwards over the superolateral surface.
3. The *parieto-occipital* sulcus is a sulcus of the medial surface. Its upper end cuts off the superomedial border about 5 cm in front of the occipital pole.
4. The *preoccipital notch* is an indentation on the inferolateral border, about 5 cm in front of the occipital pole.

The division is completed by drawing one line joining the parieto-occipital sulcus to the preoccipital notch; and another line continuing backwards from the posterior ramus of the lateral sulcus to meet the first line. The boundaries of each lobe will now be clear from Fig. 8.1b.

Insula

Insula lies deep in floor of lateral fissure surrounded by a circular sulcus and overlapped by adjacent cortical areas, the opercula (Fig. 8.3).

Insula comprises frontal operculum between anterior and ascending rami of lateral sulcus.

Parietal operculum lies between ascending and posterior rami of lateral sulcus.

The temporal opercula below posterior ramus of lateral sulcus formed by superior temporal gyri.

Insula is a pyramidal area, apex near anterior perforated substance.

Three zones are seen here—afferents reach from ventral posterior nucleus of the thalamus, medial geniculate body and part of pulvinar.

Efferents reach from areas 5, 7, olfactory, limbic system and amygdala.

Role of anterior insular cortex is in olfaction and taste.

Role of posterior insular cortex is in language function.

Sulci and Gyri on Superolateral Surface

These are shown in Fig. 8.2 and Table 8.1.

1. The *central sulcus* (Latin *furrow)* has been described earlier. The upper end of the sulcus extends for a short distance on to the medial surface (where it will be examined later).
2. We have seen that the *lateral sulcus* begins on the inferior surface. On reaching the lateral surface, it divides into three rami. The largest of these is the *posterior ramus*. The posterior end of this ramus turns upwards into the temporal lobe. The other rami of the lateral sulcus are the *anterior horizontal and anterior ascending rami*. They extend into the lower part of the frontal lobe.
3. The frontal lobe is further divided by the following sulci.
    a. The *precentral sulcus* runs parallel to the central sulcus, a little in front of it. The *precentral gyrus* lies between the two sulci (Table 8.1).
    b. The area in front of the precentral sulcus is divided into *superior, middle and inferior frontal gyri by the superior and inferior frontal sulci.*
    c. The anterior horizontal and anterior ascending rami of the lateral sulcus subdivide the inferior frontal gyrus into three parts *pars orbitalis, pars triangularis, and pars opercularis.*
4. The parietal lobe is further subdivided by the following sulci:
    a. The *postcentral sulcus* runs parallel to the central sulcus, a little behind it. The postcentral gyrus *lies between the two sulci.*
    b. *The area behind the postcentral gyrus is divided into the superior and inferior parietal lobules* by the *intraparietal sulcus.*
    c. The inferior parietal lobule is invaded by the upturned ends of the posterior ramus of the lateral sulcus, and of the superior and inferior temporal sulci. They divide the inferior parietal lobule into anterior, middle and posterior parts. The anterior part is called the *supramarginal gyrus*, and the middle part is called the *angular gyrus.*
5. The *superior and inferior temporal sulci* divide the temporal lobe into *superior, middle and inferior temporal gyri.*
6. The occipital lobe is further subdivided by the following sulci.
    a. The *lateral occipital sulcus* divides this lobe into the *superior and inferior occipital gyri.*
    b. The *lunate sulcus* separates these gyri from the occipital pole.
    c. The area around the parieto-occipital sulcus is the *arcus parieto-occipitalis.* It is separated from the superior occipital gyrus by the *transverse occipital sulcus.*

Table 8.1: Sulci and gyri of the cerebrum

Surface/Lobe	*Sulci*	*Gyri*
I. Superolateral surface (*refer to BDC App*)		
1. Frontal lobe	A. Precentral B. Superior frontal C. Inferior frontal	a. Precentral b. Superior frontal c. Middle frontal d. Inferior frontal which also contains anterior horizontal and anterior ascending rami of the lateral sulcus, and the pars orbitalis, pars triangularis and pars opercularis
2. Parietal lobe	A. Postcentral B. Intraparietal	a. Postcentral b. Superior parietal lobule c. Inferior parietal lobule, which is divided into 3 parts: i. The anterior, supramarginal ii. The middle, angular iii. The posterior, over the upturned end of inferior temporal sulcus
3. Temporal lobe	A. Superior temporal B. Inferior temporal	a. Superior temporal b. Middle temporal c. Inferior temporal
4. Occipital lobe	A. Transverse occipital B. Lateral occipital C. Lunate D. Superior and inferior polar E. Calcarine	a. Arcus parieto-occipitalis b. Superior occipital c. Inferior occipital d. Gyrus descendens
II. Medial surface (*refer to BDC App*)	A. Anterior parolfactory B. Posterior parolfactory C. Cingulate D. Callosal E. Suprasplenial or subparietal F. Parieto-occipital G. Calcarine	a. Paraterminal b. Paraolfactory (subcallosal area) c. Medial frontal d. Paracentral lobule e. Cingulate f. Cuneus g. Precuneus
III. Inferior surface (*refer to BDC App*)	A. Olfactory B. H-shaped orbital sulci C. Collateral D. Rhinal E. Occipitotemporal	a. Gyrus rectus b. Anterior orbital c. Posterior orbital d. Medial orbital e. Lateral orbital f. Lingual g. Uncus h. Parahippocampal i. Medial occipitotemporal j. Lateral occipitotemporal

Sulci and Gyri on Medial Surface

Confirm the following facts by examining (Fig. 8.3).

The central part of the medial aspect of the hemisphere is occupied by the *corpus callosum*. The corpus callosum is divisible into the *genu* (anterior end), the *body*, and the *splenium* (posterior end). It is made up of nerve fibres connecting the two cerebral hemispheres. Below the corpus callosum, there are the *septum pellucidum*, the *fornix* and the *thalamus*. In the remaining part of the medial surface, identify the following sulci.

1. The *cingulate sulcus* starts in front of the genu and runs backwards parallel to the upper margin of the corpus callosum. Its posterior end reaches the superomedial border a little behind the upper end of the central sulcus (Table 8.1).
2. The *suprasplenial sulcus* lies above and behind the splenium.
3. The *calcarine sulcus* begins a little below the splenium and runs towards the occipital pole. It gives off the *parieto-occipital sulcus* which reaches the superolateral surface.
4. A little below the genu, there are two small anterior and posterior *paraolfactory sulci*.

The following gyri can now be identified.

1. The *cingulate gyrus* lies between the corpus callosum and the cingulate sulcus. Its posterior part is bounded

above by the *suprasplenial sulcus* and is divided into anterior and posterior parts.

2. The U-shaped gyrus around the end of the central sulcus is the *paracentral lobule.* It is usually divided into anterior and posterior parts.
3. The area between the cingulate gyrus and the superomedial border in front of the paracentral lobule is called the *medial frontal gyrus.*
4. The quadrangular area between the suprasplenial sulcus and the superomedial border is called the *precuneus.*
5. The triangular area between the parieto-occipital sulcus (above) and the calcarine sulcus (below) is called the *cuneus.*
6. A narrow strip between the splenium and the stem of the calcarine sulcus is the *isthmus.*
7. The *paraterminal gyrus* lies just in front of the lamina terminalis.
8. The *paraolfactory gyrus* lies between the anterior and posterior parolfactory sulci.

Sulci and Gyri on the Orbital Surface

1. Parallel to the medial orbital border there is the *olfactory sulcus;* between these two there is the *gyrus rectus.* The rest of the orbital surface is subdivided by an H-shaped sulcus into *anterior, posterior, medial and lateral orbital gyri.*
2. The stem of the lateral sulcus lies deep between the temporal pole and orbital surface (Fig. 8.4).

Sulci and Gyri on the Tentorial Surface

This area presents two sulci running anteroposteriorly. The medial one is the *collateral sulcus,* and the lateral is the *occipitotemporal sulcus.* On the medial side of the temporal pole, there is the *rhinal sulcus.*

The gyri are as follows:

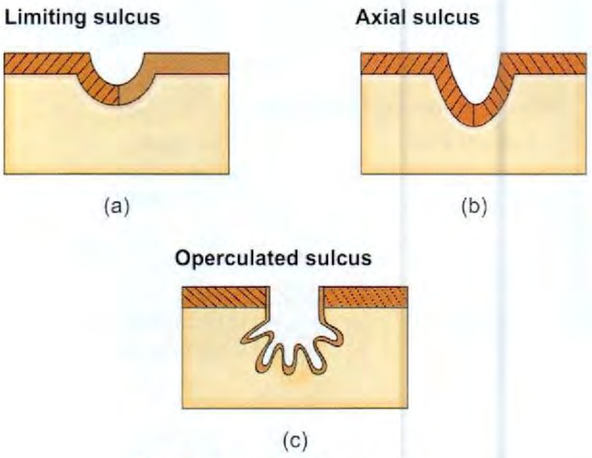
1. The part medial to the rhinal sulcus is the *uncus.*
2. The part medial to the collateral sulcus is the *parahippocampal gyrus.* Its posterior part is limited medially by the calcarine sulcus. It is joined to the cingulate gyrus through the isthmus (Fig. 8.3).
3. The part lateral to the collateral sulcus is divided into *medial and lateral occipitotemporal gyri* by the *occipitotemporal sulcus.*
4. The part medial and above parahippocampal gyrus contains dentate gyrus which is continuous in front with uncus.

Types of Sulci

According to Function

1. Limiting sulcus separates at its floor two areas which are different functionally and structurally.

   For example, the central sulcus between the motor and sensory areas (Fig. 8.6a).
2. Axial sulcus develops in the long axis of a rapidly growing homogeneous area.



Figs 8.6a to c: Types of sulci

   For example, the postcalcarine sulcus in the long axis of the striate area (Fig. 8.6b).
3. Operculated sulcus separated by its lips in two areas, and contains a third area in the walls of the sulcus. For example, the lunate sulcus (Fig. 8.6c).

According to Formation

1. Primary sulci formed before birth, independently. Example is central sulcus.
2. Secondary sulcus is produced by factors other than the exuberant growth in the adjoining areas of the cortex. Examples are the lateral and parieto-occipital sulci.

According to Depth

1. Complete sulcus is very deep so as to cause elevation in the walls of the lateral ventricle. Examples are the collateral and calcarine sulci.
2. Incomplete sulci are superficially situated and are not very deep, e.g. precentral sulcus.

Structural and Functional Types of the Cortex

1. *Allocortex (archipallium):* It is the original olfactory cortex, and is represented by rhinencephalon (piriform area and hippocampal formation). Structurally, it is simple and is made up of only three layers.
2. *Isocortex (neopallium):* It is the lately acquired cortex, containing various centres other than those for smell. Structurally, it is thick and six layered. It is subdivided into the following.
   a. Granular cortex (koniocortex or dust cortex). It is basically a sensory cortex.
   b. Agranular cortex. This is the motor cortex.

FUNCTIONAL OR CORTICAL AREAS OF CEREBRAL CORTEX

Functionally, the cortex is divided into number of areas by many neurobiologists. Brodmann's areas are taken normally according to whom there are 200 areas. There are three basic functional divisions of cerebral cortex:

1. *Motor areas:* The primary motor area has been identified on the basis of elicitation of motor responses at a low threshold of electric stimulation which gives rise to contraction of skeletal musculature. These areas give origin to corticospinal and corticonuclear fibres (Figs 8.7 and 8.8).
2. *Sensory areas:* In these areas, electrical activity can be recorded if appropriate sensory stimulus is applied to a particular part of the body (Fig. 8.8).

   The ventral posterior nucleus of thalamus is main source of afferent fibres for the first sensory area. This thalamic nucleus is the site of termination of all the fibres of the medial lemniscus and of most of the spinothalamic and trigeminothalamic tracts.
3. *Association areas:* In these regions, the direct sensory or motor responses are not elicited. These areas integrate and analyse the responses from various sources. Many such areas are known to have motor or sensory functions.

   The motor and sensory functions also overlap in the same region of cortex. If the motor function is predominant, it is known as motor-sensory (Ms) and where sensory function is predominant, it is called sensorimotor (Sm).

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.

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. The pharyngeal region, tongue are represented in the most ventral and lower part of precentral gyrus, followed by the face, hand, arm, trunk and thigh. The remainder of leg, foot and perineum is on the medial surface of hemisphere in the paracentral lobule (Fig. 8.7).

Another significant feature in this area is that the size of the cortical area for a particular part of the body is determined by the functional importance of the part and its need for sensitivity and intricacy of the movements of that region. The area for the face, especially the *larynx and lips*, is therefore disproportionately large and a large area is assigned to the hand particularly the thumb and index finger. Movements of joints are represented rather than individual muscles (Table 8.2).

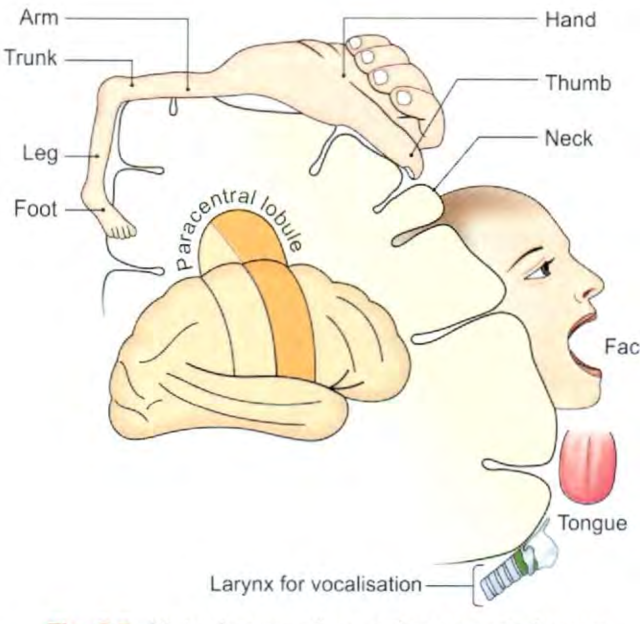


Fig. 8.7: Motor homunculus on the precentral gyrus

Connections of motor area:

Afferents:

- From the ventral nucleus of thalamus and contralateral cerebellar hemispheres
- From the opposite hemispheric cortical areas.

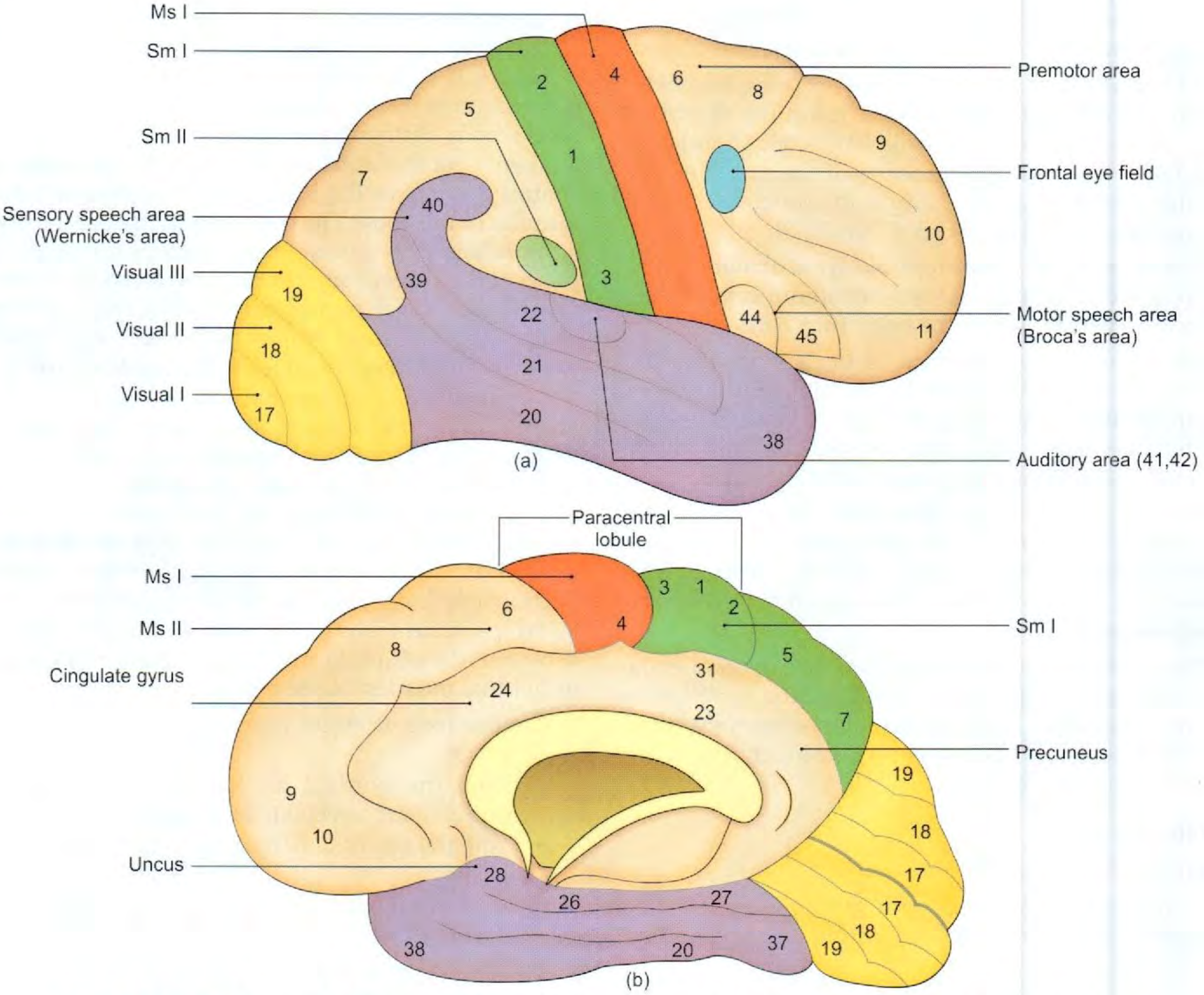
Efferents:

- Corticonuclear, corticobulbar and corticospinal tracts
- Frontopontine fibres
- Projection fibres to basal ganglia

Premotor Area *(refer to BDC App)*

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 (Fig. 8.8).

In general, the primary motor area is the cortex in which execution of movements originates and relatively simple movements are maintained. In contrast, the premotor area programmes skilled motor activity and thus directs the primary motor area in its execution. The premotor and primary motor areas are together referred to as the primary somatomotor area (Ms I). Both these areas give origin to corticospinal and corticonuclear fibres and receive fibres from cerebellum after relay in ventral intermediate nucleus of thalamus. It has same connections as motor area.



Figs 8.8a and b: Functional areas: (a) Superolateral surface, and (b) medial surface of cerebral hemisphere

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. Different parts of body are represented within this area. It differs from the main motor area in that its stimulation produces bilateral movements (Fig. 8.8). Its function is to control complex movements which require sequential organisation.

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 30%, it is situated in right hemisphere (Fig. 8.8).

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

Table 8.2: 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 judgement	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 colour, size, form, motion, illumination and transparency	Homonymous hemianopia with macular sparing
	Visuopsychic area, parastriate 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

inferior frontal gyri, medial frontal gyrus, 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 judgement. It has reciprocal connections with thalamic dorsomedial nucleus, hypothalamus, and limbic system.

CLINICAL ANATOMY

Motor areas

- Destructive lesion of primary motor area 4 results in voluntary paresis of the affected part of body. Spastic voluntary paralysis of the opposite side of body characteristically follows if the lesion spreads beyond area 4 or that interrupts projection fibres in the medullary centre or internal capsule. Irritative lesion of the motor area leads to focal convulsive movements of the corresponding part of body, referred to as *Jacksonian epilepsy*.
- Lesion of supplementary motor area 6 leads to apraxia and akinesia. This is the condition which involves difficulty in performing the skilled movements once learnt, in absence of paralysis, ataxia or sensory loss. When the disability affects writing, it is called *agraphia*.
- Frontal eye field: Destruction of this area causes conjugate deviation of the eyes towards the side of lesion. The patient cannot voluntarily move his eyes in the opposite direction, but this movement occurs involuntarily when he observes an object moving across the field of vision.
- Speech area: Lesion of Broca' s area on the dominant side of hemisphere causes expressive aphasia. It is characterised by hesitant and distorted speech with relatively good comprehension.
- A lesion involving language areas *(Wernicke's area* and *Broca's area)* leads to receptive aphasia. In this condition, auditory and visual comprehension of language that is naming of objects and repetition of a sentence spoken by the examiner are all defective (Fig. 8.8a).
- A lesion involving Wernicke's area and superior longitudinal fasciculus or arcuate fasciculus results in *jargon aphasia* in which speech is fluent but unintelligible jargon.
- Voluntary smile in a stroke patient will accentuate the asymmetry. A genuine smile which uses only extrapyramidal pathways, will be symmetrical and there will be no asymmetry for the duration of the smile. One needs to remember that motor cortex is required only for voluntary moment.

Sensory Areas

First Somesthetic Area

First somesthetic (general sensory) area is also called *first somatosensory area* (Sm I). It occupies postcentral gyrus on the superolateral surface of the cerebral hemisphere and posterior part of paracentral lobule on the medial surface. It corresponds to areas 3, 1 and 2 of Brodmann (Figs 8.8 and 8.9).

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. The area of the cortex that receives sensations from a particular part of body is not proportional to the size of that part, but rather to the intricacy of sensations received from it. Thus, the thumb, fingers, lips and tongue have a disproportionately large representation. The different sensations, i.e. cutaneous and proprioceptive are represented in different parts within sensory area.

The ventral posterior nucleus of thalamus is the main source of afferent fibres for the sensory area. This thalamic nucleus is the site of termination of all the fibres of the medial lemniscus. Most of the fibres of the spinothalamic and trigeminothalamic tracts carrying fibres for cutaneous sensibility end in anterior part of the area and those for deep sensibility end in the posterior part.

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 (Fig. 8.8).

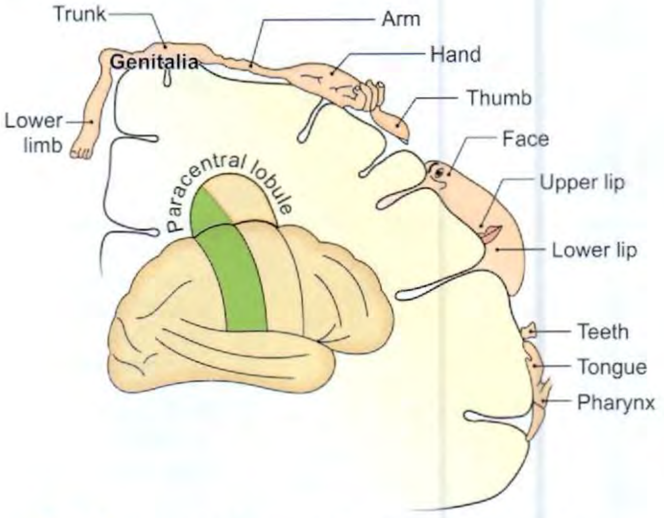


Fig. 8.9: Sensory homonculus of the postcentral gyrus

Somesthetic Association Cortex

Somesthetic association cortex is mainly in the superior parietal lobule on the superolateral surface of the 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 (Fig. 8.8).

CLINICAL ANATOMY

Sensory areas

- First somesthetic or general sensory area (areas 3, 1 and 2 of Brodmann). When this part of cortex is the site of destructive lesion, a crude form of awareness persists for the sensation of pain, heat and cold on the opposite side of lesion. There is poor localization of stimulus. There is loss of discriminative sensations of fine touch, movements and position of part of the body.
- Somesthetic association cortex (superior parietal lobule) areas 5 and 7 of Brodmann: A lesion in this area leads to defect in understanding the significance of sensory information, which is called *agnosia*. A lesion that destroys a large portion of this association cortex causes tactile agnosia and *astereognosis* which are closely related. This is the condition when a person is unable to recognize the objects held in the hand, while the eyes are closed. He is unable to correlate the surface, texture, shape, size and weight of the object or to compare the sensations with previous experience.

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. The visual area is also called the striate area because the cortex here contains the *line of Gennari*, which is just visible to the unaided eye.

The chief source of afferent fibres to area 17 is the *lateral geniculate nucleus* of thalamus by way of geniculocalcarine tract. Area 17 constitutes the first visual area. 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. Since fibres of geniculocalcarine tract (optic radiation) terminate in these regions also, therefore, these areas are regarded as second and the third visual areas respectively (Fig. 8.8).

The role of the second and third visual areas includes among other complex aspects of vision, the relating of present to past visual experience, with recognition of what is seen and appreciation of its significance. The three areas are linked together by association fibres. The visual areas give efferent fibres which reach frontal eye field.

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 *medial geniculate* body of the thalamus is the principal source of fibres ending in the auditory cortex with these fibres constituting the auditory radiation. There is spatial representation in the auditory area with respect to pitch of sounds. Impulses of low frequencies impinge on anterolateral part of area and impulses of high frequencies get heard on the posteromedial part.

Cortex gets afferents from both ears. Body receives information that originates mainly in the organ of Corti of opposite side, the incomplete decussation of ascending pathways ensures a substantial input from the ear of same side as well (Fig. 8.8).

The auditory radiation does not only end in first auditory area but extends to neighbouring 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. This region of the cortex is also known as *Wernicke's area* and is of major importance in language functions.

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*. It places the taste area adjacent to first sensory area of cortex for tongue and pharynx. Its location is similar to second somesthetic area.

Smell

Ends in pyriform lobe.

CLINICAL ANATOMY

Special sensory areas

a. Primary visual area 17: Lesion of this area, leads to loss of vision in the visual field of the opposite side—homonymous hemianopia.

b. Auditory area:
  - Primary auditory areas 41 and 42: A unilateral lesion involving the auditory area causes diminution in the acuity of hearing in both ears and the loss is greater in the opposite ear. However, the impairment is slight because of the bilateral projection to the cortex and the deficit is difficult to detect by clinical tests.
  - Auditory association cortex or secondary area 22. In lesions of this area, interpretation of the sounds is lost.

Functions of Cerebral Cortex

1 *Cerebral dominance:* One cerebral hemisphere dominates the other one in relation to handedness, speech, perception of language and spatial judgement. In 80–95% subjects, the left hemisphere dominates the right one. The dominant lobe contains the Broca's motor speech area. Since left hemisphere controls the right half of the body, all these subjects are right-handed. The left hemisphere is verbal, mathematical, analytical, scientific, calculative and has direct link to consciousness.

The right hemisphere is active in understanding geometrical figures imaginative, artistic, religious, and important for temporal synthesis and spatial comprehension. It helps in recognition of faces, figures and appreciating music.

Localisation of speech on left side in 70% of left handed and 98% of right handed is well known. Association of negative emotions with right prefrontal activity and of positive emotions with left prefrontal activity is also known. Mahatma Gandhi, father of the nation, Bill Clinton, Bill Gates, Amitabh Bachchan and Abhishek Bachchan, are all left handed. Functional asymmetry in a structurally symmetrical structure is a great and ingenious way of economising on neural tissue. It practically doubles the capabilities of the brain. Women mostly operate through right hemisphere while men mostly use their dominant left hemisphere.

2 *Discriminatory aspects:* Sensory cortex is not concerned with recognition only, but is also involved with discrimination of sensory function as:

a. Recognition of spatial relationship

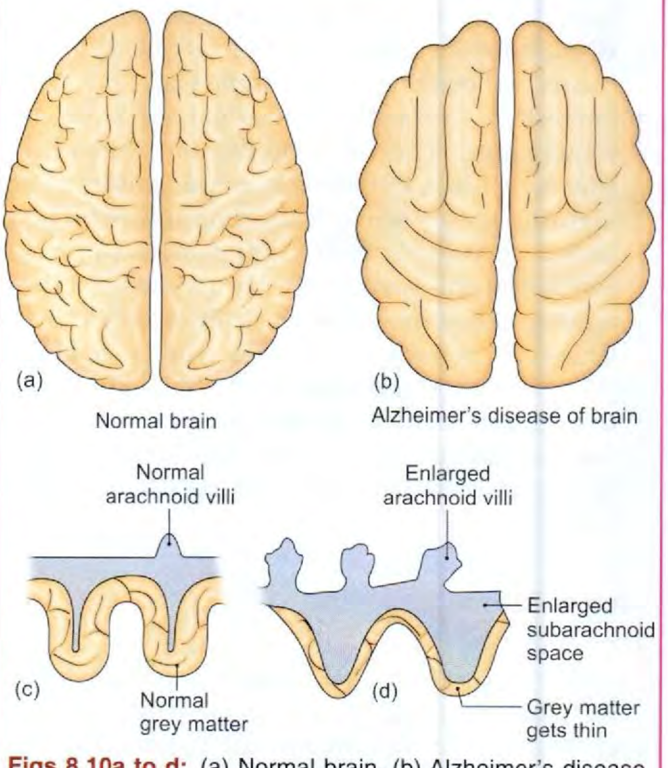
b. Graded response to stimuli of different intensities

c. Appreciation of similarities and differences in external objects, brought into contact with surface of body.

3 *Associative functions:* The information thus discriminated and classified is correlated with previous experience. This association forms the basis of memory patterns. These are transmitted to frontal cortex which synthesize it and forms basis of thinking and related intellectual activities.

CLINICAL ANATOMY

- Table 8.3 depicts summary of functions and effects of damage of lobes of brain. Figures 8.10a and c show normal brain.
- *Ageing:* Usually after 60–70 years or so there are changes in the brain. These are:
  a. Prominence of sulci due to cortical shrinkage (Fig. 8.10b).
  b. The gyri get narrow and sulci get broad (Fig. 8.10d).
  c. The subarachnoid space becomes wider.
  d. There is enlargement of the ventricles.
- *Dementia:* In this condition, there is slow and progressive loss of memory, intellect and personality. The consciousness of the subject is normal. Dementia usually occurs due to Alzheimer's disease.
- *Alzheimer's disease:* The changes of normal ageing are more pronounced in the parietal lobe, temporal lobe, and in the hippocampus.



Figs 8.10a to d: (a) Normal brain, (b) Alzheimer's disease of brain, (c) normal grey matter and arachnoid villi, and (d) changes in the elderly brain

Table 8.3: Summary of functions and effects of damage of lobes of brain (Fig. 8.1)

Lobes of brain	*Functions*	*Effects of damage*
Frontal	Personality, emotional control, social behaviour, contralateral motor control, language and micturition	Lack of initiation, antisocial behaviour, impaired memory and incontinence
Parietal (non-dominant)	Spatial orientation, recognition of faces, appreciation of music and figures	Spatial disorientation, non-recognition of faces
Parietal (dominant)	Language, calculation, analytical, logical, and geometrical	Dyscalculia, dyslexia, apraxia (inability to do complex movements) and agnosia (inability to recognize)
Temporal (non-dominant)	Auditory perception, pitch perception, non-verbal memory, smell and balance	Reception aphasia and impaired musical skills
Temporal (dominant)	Language, verbal memory and auditory perception	Dyslexia, verbal memory impaired and receptive aphasia
Occipital	Visual processing	Visual loss and visual agnosia

HUMAN SPEECH

There have been many evolutionary changes in human for the purpose of articulation. These are

i. Bipedal position
ii. Flexed skull
iii. Increased growth of prefrontal part of brain
iv. Receding of the lower jaw
v. Decreased distance between posterior border of hard palate and anterior margin of foramen magnum
vi. Larynx pulled downwards
vii. Posterior one-third of tongue pulled downwards and facing backwards forming the anterior wall of the laryngopharynx
viii. Cavity of mouth and of pharynx being at right angle to each other
ix. Anterior two-thirds of tongue being thin and more agile, voice produced due to tongue touching the palate was clear and sharp.

Before the origin of language was the evolution of music. Music is in biology of all living beings; it generates different emotions and is universal. Music was the only way to communicate with or attract the female. Language generates much less or no emotions and is not universal.

Broca's area on left side is related to speech; on the right side is related to music, poetic expressions, figures, faces, etc. Broca's area: Neural circuits are formed for articulation of different phenomes.

The temporal lobe contains auditory area which receives the sound waves. Above and behind auditory area is Wernicke's area. This area is responsible for comprehension of stimuli received by auditory area. It is seven times larger in human than in a chimpanzee. Wernicke's area organizes the matter to be uttered by articulatory system. This area also makes complex sentences. A bundle of fibres, arcuate fibers connect Wernicke's and Broca's areas. This bundle carries the organized and composed speech of Wernicke's area to the Broca's area for speaking.

Temporal lobe on its inner aspect contains hippocampus and globular amygdala on its anterior aspect. Hippocampus area stores long-term memories. Amygdala is concerned with primary emotions. It receives as well as initiates emotions and recognizes faces. Limbic system comprises hippocampus, amygdala, cingulate gyrus and basal nuclei.

Frontal lobe's functions are intelligence and cognitive ability.

In modern human, inferior parietal lobule area is considerably enlarged. The gyri are supramarginal and angular gyri.

Supramarginal gyrus is used for fine finger movement, tongue movement, fine facial movement. In this area, visual perception, perception of auditory sense, and knowledge of position of joints come together. Inferior parietal lobule is important for speech.

Phenome is the smallest unit of speech.

Word is the smallest unit of language. Words are composed of phenomes.

Prosodic functions (high and low of voice) are related to thalamus and basal ganglia. Prosodic aspect of speech is less in parkinsonism wherein the speech gets monotonous without any prosodic effects as there is lack of dopamine.

Source: Lele, DN: The Evolutions of Speech and Language, CBS Publishers & Distributors, New Delhi, 2016. (Dr DN Lele, Director, Lele Hospital and Research Centre, Nashik, Maharashtra, is an otolaryngologist of international repute).

DIENCEPHALON

The diencephalon is a middle structure which is largely embedded in the cerebrum, and therefore hidden from surface view (Figs 8.11a and b). Its cavity forms the greater part of the third ventricle. The hypothalamic sulcus, extending from the interventricular foramen to the cerebral aqueduct, divides each half of the diencephalon into dorsal and ventral parts. Further subdivisions are given below.

DORSAL PART OF DIENCEPHALON

1 Thalamus (dorsal thalamus).
2 Metathalamus, including the medial and lateral geniculate bodies, described with thalamus.
3 Epithalamus, including the pineal body and habenula.

VENTRAL PART OF DIENCEPHALON

1 Hypothalamus, and
2 Subthalamus (ventral thalamus).

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.

Measurements:

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

It has anterior and posterior ends; superior, inferior, medial and lateral surfaces.

The *anterior end* with anterior nucleus is narrow and forms the posterior boundary of the interventricular foramen (Figs 8.11a 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. 8.11a).

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 by the free margin of body of fornix. It is limited laterally by the caudate nucleus, the stria terminalis and the thalamostriate vein, and medially by the habenular stria (stria medullaris thalami) (Fig. 8.17).

The *inferior surface* rests on the subthalamus and the hypothalamus (Fig. 8.18).

The *medial surface* forms the posterosuperior part of the lateral wall of the third ventricle (*see* Fig. 9.3). The medial surfaces of two thalami are interconnected by an interthalamic adhesion (Fig. 8.12).

The *lateral surface* forms the medial boundary of the posterior limb of the internal capsule (Fig. 8.20).

Structure and Nuclei of Thalamus

White matter

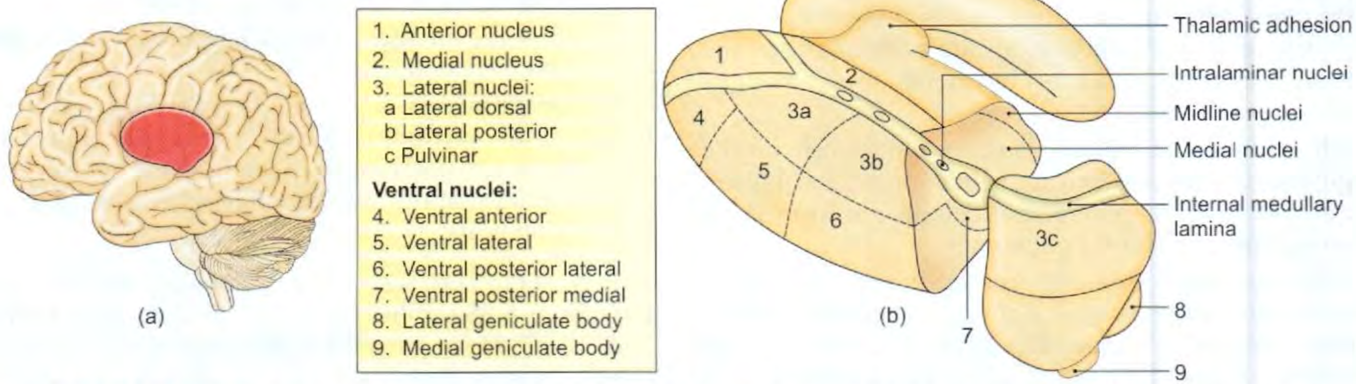
The *external medullary lamina* covers the lateral surface.

The *internal medullary lamina* divides the thalamus into three parts—anterior, medial and lateral.

Grey matter

The grey matter is divided to form several nuclei.

1 *Anterior nucleus* in the anterior part (Fig. 8.13).
2 *Medial nucleus* in the medial part.
3 The lateral part of the thalamus is largest and represents the *neothalamus*. It is divided into the *lateral 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.



Figs 8.11a and b: (a) Location of thalamus in the cerebral hemisphere, and (b) three-dimensional view of thalamus

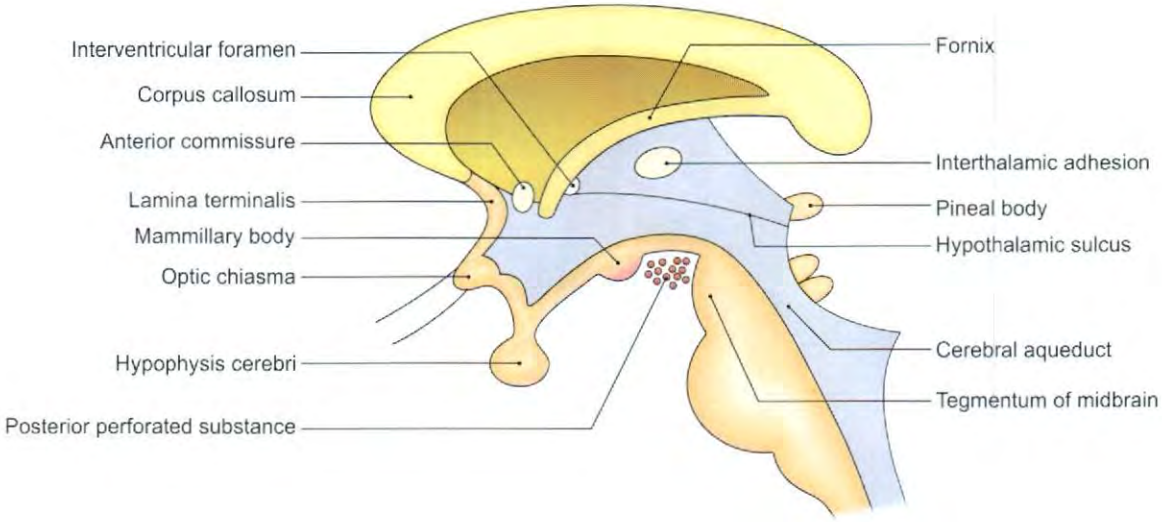


Fig. 8.12: Thalamus and hypothalamus as seen in sagittal section

Table 8.4: Connection of thalamus

Name	*Afferents*	*Efferents*	*Functions*
Anterior nucleus (Fig. 8.13)	Mammillothalamic tract	To cingulate gyrus (Fig. 8.15)	Relay station for hippocampal impulses
Medial nucleus	From hypothalamus, frontal lobe in front of area 6, corpus striatum, and other thalamic nuclei	To same parts from which the afferents are received	Relay station for visceral impulses
Lateral nuclei: Lateral dorsal, lateral posterior and pulvinar	From precuneus and superior parietal lobule; also from ventral and medial nuclei Temporal and occipital lobes	To precuneus and superior parietal lobule Temporal and occipital lobes	Correlative in function
Ventral nuclei: Ventral anterior	From globus pallidus (subthalamic fasciculus)	To areas 6 and 8 of cortex (Fig. 8.18)	Relay station for striatal impulses
Ventral lateral	From cerebellum (dentatothalamic fibres) and red nucleus	To motor areas 4 and 6	Relay station for cerebellar impulses
Ventral posterolateral (Figs 8.14 and 8.15)	Spinal and medial lemnisci	To postcentral gyrus (areas 3, 1, 2)	Relay station for exteroceptive (touch, pain and temperature) and proprioceptive impulses from body, except face and head
Ventral posteromedial (Fig. 8.15)	Trigeminal and solitariothalamic lemnisci	To postcentral gyrus (areas 3, 1, 2)	Relay station for impulses from the face, head and taste impulses
Intralaminar, midline, and reticular nuclei (Fig. 8.11)	Reticular formation of brain stem	To all parts of cerebral cortex	Participate in arousal reactions/ascending reticular activating system (ARAS)
Centromedian nucleus (Fig. 8.13)	From parts of corpus striatum; collaterals from spinal, medial, trigeminal lemnisci, ascending reticulothalamic fibres. Impulses from areas 4, 6 of cerebral cortex	Not connected to cerebral cortex, connected to other thalamic nuclei, corpus striatum	Receive pain fibres
Medial geniculate body	Auditory fibres from inferior colliculus	Primary auditory areas 41, 42 (Fig. 8.18)	Relay station for auditory impulses and perception of painful and nociceptive stimuli
Lateral geniculate body	Optic tract	Primary visual cortex area 17	Relay station for visual impulses

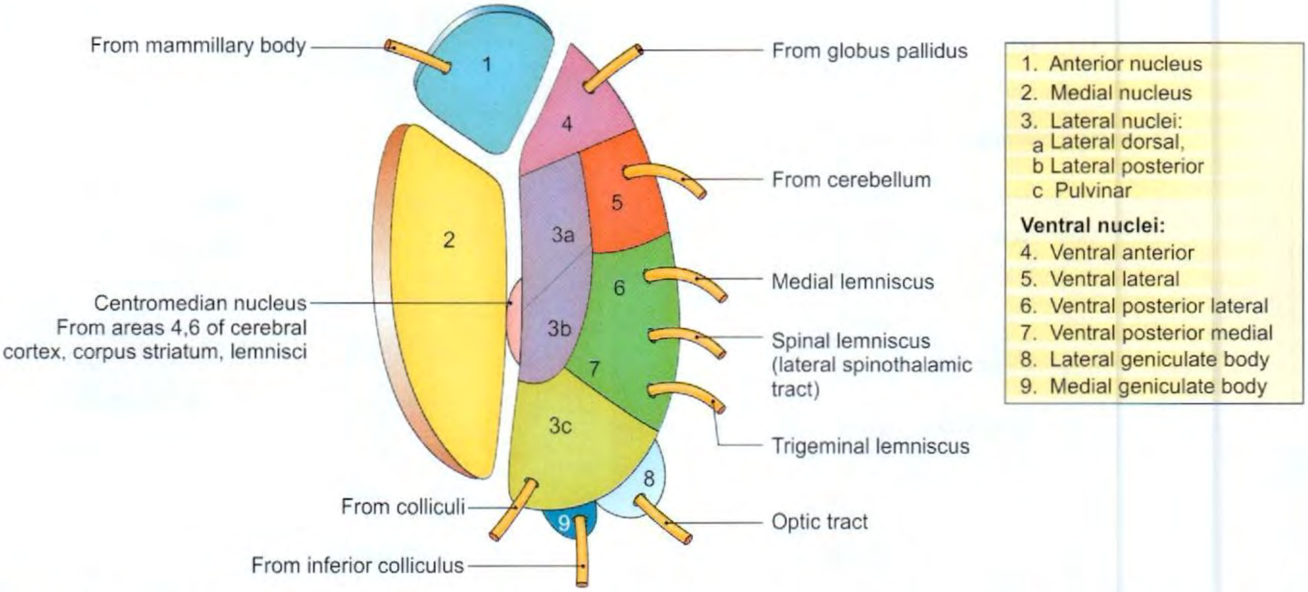


Fig. 8.13: Parts of the thalamus. The afferents to the nuclei of thalamus are also indicated (colour coding in Figs 8.14 to 8.16 is same)

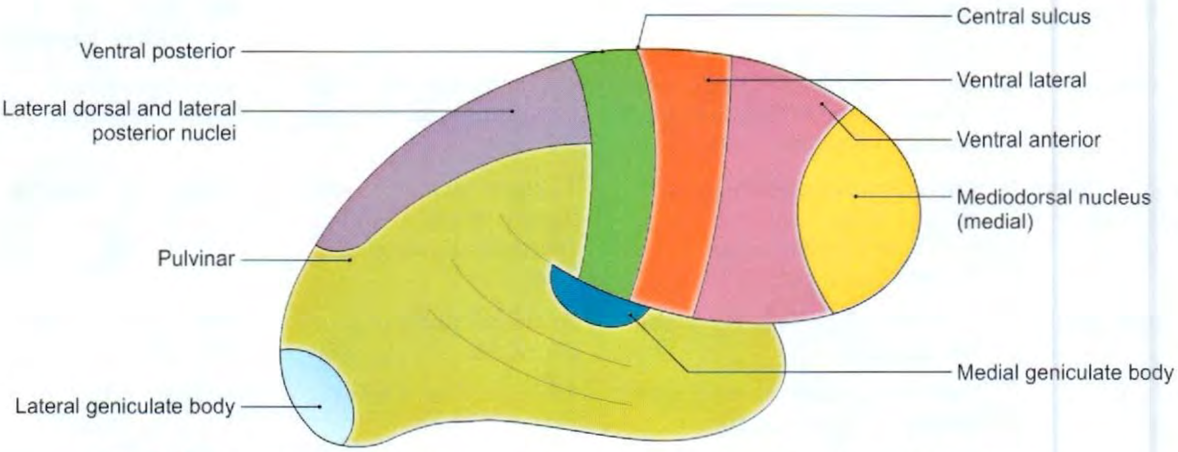


Fig. 8.14: Projection from thalamic nuclei to superolateral surface of cerebral hemisphere

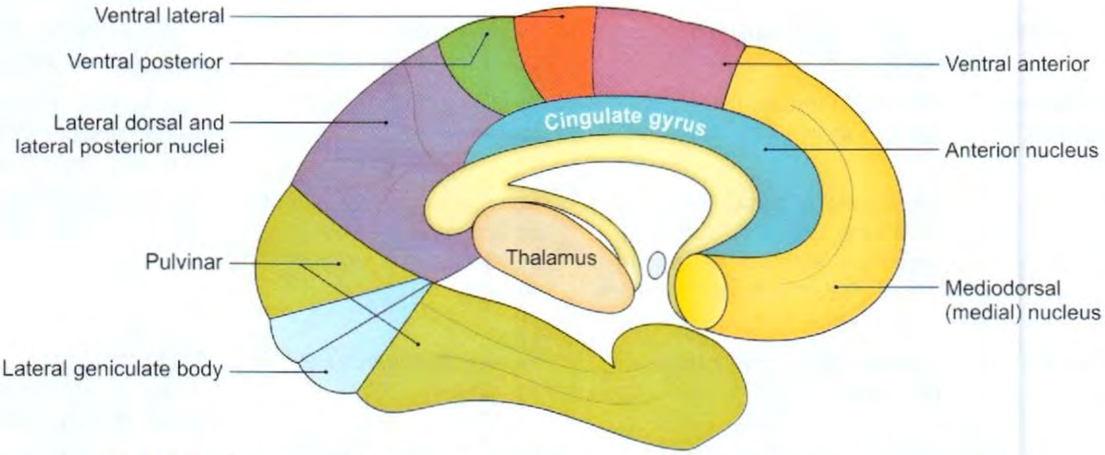


Fig. 8.15: Projection from thalamic nuclei to medial surface of cerebral hemisphere

4 *Intralaminar nuclei* including *centromedian nucleus* (located in the internal medullary lamina), midline nuclei (periventricular grey on the medial surface) and reticular nuclei (on the lateral surface) are also present.

Connections and functions of thalamus

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

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

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

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 centre* 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 8.4.

Metathalamus (Part of Thalamus)

The metathalamus consists of the medial and lateral geniculate bodies, which are situated on each side of the midbrain, below the thalamus.

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 (*see* Fig. 6.8).

Afferents

(1) Lateral lemniscus, (2) fibres from both inferior colliculi, and (3) ascending reticular pathway and perception of painful and nociceptive stimuli.

Efferents

1 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.
2 To secondary somatosensory area.

Function

Medial geniculate body is the last relay station on the pathway of auditory impulses to the cerebral cortex.

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 (*see* Fig. 6.8).

Structure

It is six-layered structure. Layers 1, 4 and 6 (blue) receive contralateral optic fibres, and layers 2, 3 and 5 (pink) receive ipsilateral optic fibres (Fig. 8.16).

Connections

Afferents: Optic tract (lateral root).

Efferents: It gives rise to optic radiations going to the visual area of cortex through retrolentiform part of internal capsule.

Function

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

CLINICAL ANATOMY

- Lesions of the thalamus cause impairment of all types of sensibilities; joint sense (posture and passive movements) being the most affected.
- The thalamic syndrome (occurs due to vascular impairment) is characterized by disturbances of sensations, hemiplegia, or hemiparesis together with hyperaesthesia and severe spontaneous pain. Pleasant as well as unpleasant sensations or feelings are exaggerated. It is associated with abnormal movements like choreoathetosis.
- Damage to medial nucleus of thalamus results in decrease in tension aggression and anxiety. It increases forgetfulness.

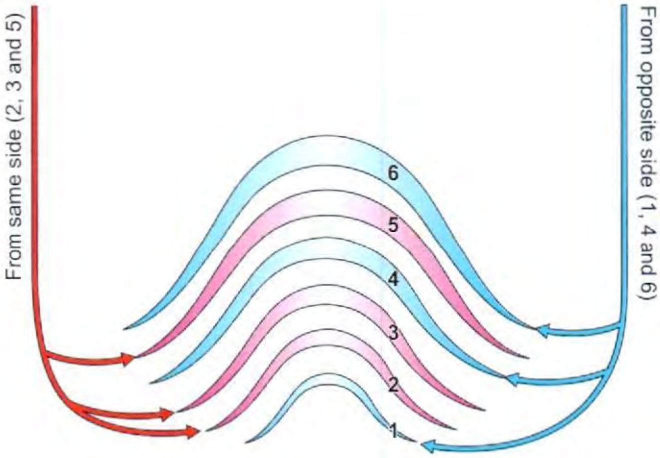


Fig. 8.16: Six layers of lateral geniculate body

Epithalamus

The epithalamus (Fig. 8.17) occupies the caudal part of the roof of the diencephalon and consists of:

1 The right and left habenular nuclei, each situated beneath the floor of the corresponding habenular trigone.
2 The pineal body or epiphysis cerebri.
3 The habenular commissure.
4 The posterior commissure.

Habenular Nucleus

The nucleus lies beneath the floor of the habenular trigone. The trigone is a small, depressed triangular area, situated above the superior colliculus and medial to the pulvinar of the thalamus. Medially, it is bounded by the stria medullaris thalami and stalk of the pineal body. The habenular nucleus forms a part of the limbic system.

Afferents

- Hypothalamus
- Amygdaloid body
- Hippocampus

Efferents: To interpeduncular nucleus

Functions: Acts as nodal point for convergence of basic emotional drives.

Pineal Body/Pineal Gland

The pineal (Latin *pine, cone*) body is a small, conical organ, projecting backwards and downwards between the two superior colliculi. It is placed below the splenium of the corpus callosum, but is separated from it by the tela choroidea of the third ventricle.

It consists of a conical *body* about 8 mm long, and a *stalk* or *peduncle* which divides anteriorly into two laminae separated by the pineal recess of the third ventricle. The superior lamina of the stalk contains the habenular commissure; and the inferior lamina contains the posterior commissure (Fig. 8.17).

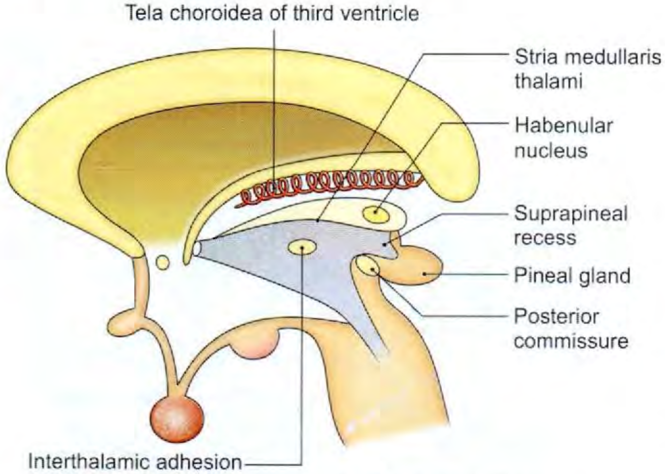


Fig. 8.17: Components of the epithalamus

Morphological Significance

In many reptiles, the epiphysis cerebri is represented by a double structure. The anterior part *(parapineal organ)* develops into the pineal or parietal eye. The posterior part is glandular in nature. The human pineal body represents the persistent posterior glandular part only. The parietal eye has disappeared.

Structure

The pineal gland is composed of two types of cells, pinealocytes and neuroglial cells, with a rich network of blood vessels and sympathetic fibres. The vessels and nerves enter the gland through the connective tissue septa which partly separate the lobules. Sympathetic ganglion cells may be present.

Calcareous concretions are constantly present in the pineal after the 17th year of life and may form aggregations *(brain sand)*. Spaces or cysts may also be present. Pineal gland has no neural tissue in it.

Functions

The pineal body has for long been regarded as a vestigial organ of no importance. Recent investigations have shown that, it is an endocrine gland of great importance. It produces hormones that may have an important regulatory influence on many other endocrine organs (including the adenohypophysis, the neurohypophysis, the thyroid, the parathyroids, the adrenal cortex and medulla, and the gonads). The best known hormone is melatonin which causes changes in skin colour in some species. The synthesis and discharge of melatonin is remarkably influenced by exposure of the animal to light and is more during dark period.

Hypothalamus

The hypothalamus is a part of the diencephalon (Fig. 8.18). It lies in the floor and lateral wall of the third ventricle. It has been designated as the head ganglion of the autonomic nervous system because it takes part in the control of many visceral and metabolic activities of the body.

Anatomically, it includes:

a. The floor of the third ventricle, or structures in the interpeduncular fossa.
b. The lateral wall of the third ventricle below the hypothalamic sulcus.

Boundaries

As seen on the base of the brain, the hypothalamus is bounded *anteriorly* by the posterior perforated substance; and *on each side* by the optic tract and crus cerebri (Fig. 8.4).

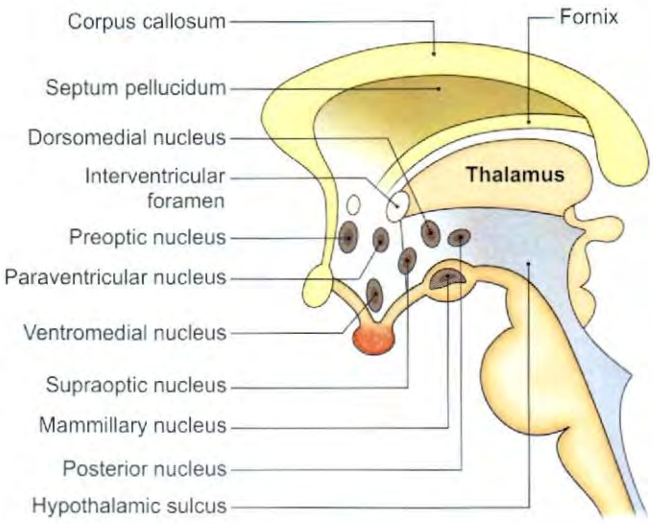


Fig. 8.18: Nuclei of medial zone of hypothalamus

As seen in a sagittal section of the brain, it is bounded *anteriorly* by the lamina terminalis; *inferiorly* by the floor of the third ventricle (from the optic chiasma to the posterior perforated substance); and *posterosuperiorly* by the hypothalamic sulcus.

Parts of the Hypothalamus

The hypothalamus is subdivided into optic, tuberal and mammillary parts. The nuclei present in each part are as follows:

Optic part

1 Preoptic and supraoptic nuclei.
2 Paraventricular nucleus, just above the supraoptic nucleus and lateral nucleus in lateral zone.
3 Suprachiasmatic nucleus—above the optic chiasma.

Tuberal part

4 Ventromedial nucleus.
5 Dorsomedial nucleus.
6 Tuberal nucleus, lateral to the ventromedial nucleus.
7 Arcuate nucleus—in floor of third ventricle.

Mammillary part

8 Posterior nucleus, caudal to the ventromedial and dorsomedial nuclei and mammillary nucleus.
9 Lateral nucleus, lateral to the posterior nucleus.

The nuclei 3, 4 and 6 (medial) are separated from nuclei 5 and 7 (lateral) by the column of the fornix, the mammillothalamic tract and the fasciculus retroflexus.

Important Connections

Afferents

The hypothalamus receives visceral sensations through the spinal cord and brain stem (reticular formation). It is also connected to several centres associated with olfactory pathways, including the piriform cortex, cerebellum; and retina.

Efferents

1 Supraoptico-hypophyseal tract from the optic nuclei to the pars posterior, the pars tuberalis and the pars intermedia of the hypophysis cerebri.
2 Mammillothalamic tract.
3 Mammillotegmental tract (periventricular system of fibres).
4 Tubero-infundibular tract.

Functions of Hypothalamus

The hypothalamus is a complex neuroglandular mechanism concerned with regulation of visceral and vasomotor activities of the body. Its functions are as follows:

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.

General autonomic effect

The anterior parts of the hypothalamus chiefly mediate parasympathetic activity; and the posterior parts, chiefly mediate sympathetic activity, but the effects often overlap. Thus the hypothalamus controls cardiovascular, respiratory and alimentary functions.

Temperature regulation

The hypothalamus maintains a balance between heat production and heat loss of the body. Raised body temperature is decreased through vasodilation, sweating, panting and reduced heat production. Lowered body temperature is elevated by shivering and in prolonged cases by hyperactivity of the thyroid.

Regulation of food and water intake

The *hunger* or *feeding centre* is placed laterally, the *satiety centre,* medially. Stimulation of the feeding centre or damage of the satiety centre causes hyperphagia (overeating) leading to obesity. Stimulation of the satiety centre or damage of the feeding centre causes hypophagia or even aphagia and death from starvation.

The *thirst or drinking centre* is situated in the lateral part of the hypothalamus. Its stimulation causes copious drinking and overhydration.

Sexual behaviour 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.* Sleep is produced by the *hypnogenic zones,* mainly of the thalamus and hypothalamus and partly by the brain stem. 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.

CLINICAL ANATOMY

Lesions of the hypothalamus give rise to one of the following syndromes.

- Obesity: Frolich's syndrome, or Laurence-Moon-Biedl syndrome.
- Diabetes insipidus.
- Diencephalic autonomic epilepsy. This is characterized by flushing, sweating, salivation, lacrimation, tachycardia, retardation of respiratory rate, unconsciousness, etc.
- Sexual disturbance. Either precocity or impotence.
- Disturbance of sleep. Somnolence (persistent sleep), or narcolepsy (paroxysmal sleep).
- Hyperglycaemia and glycosuria.
- Acute ulcerations in the upper part of the gastrointestinal tract.

Subthalamus

The subthalamus lies between the midbrain and thalamus, medial to internal capsule and the globus pallidus (Fig. 8.19). It consists of the following:

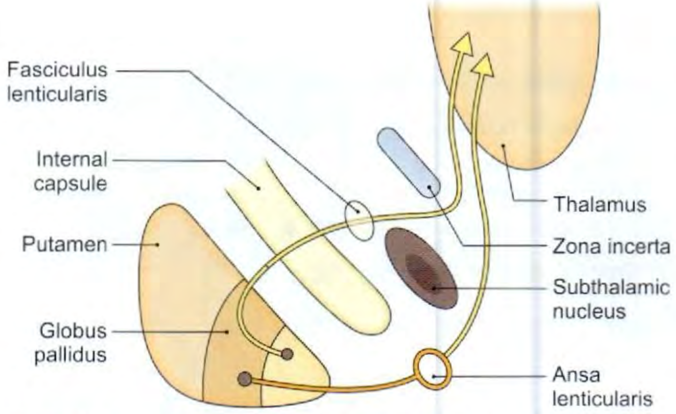


Fig. 8.19: Important fibre bundle running through subthalamic region

Grey Matter

1. The cranial ends of the red nucleus and substantia nigra extend into it.
2. Subthalamic nucleus.
3. Zona incerta.

White Matter

1. Cranial ends of lemnisci, lateral to the red nucleus.
2. Dentatothalamic tract along with the rubrothalamic fibres.
3. Ansa lenticularis (ventral) (Fig. 8.22).
4. Fasciculus lenticularis (dorsal).
5. Subthalamic fasciculus (intermediate fibres).

The *subthalamic nucleus* is biconvex (in coronal section) and is situated dorsolateral to the red nucleus and ventral to the zona incerta. From its connections, it appears to be an important site for integration of a number of motor centres.

The *zona incerta* is a thin lamina of grey matter situated between the thalamus and the subthalamic nucleus. Laterally, it is continuous with the reticular nucleus of the thalamus. Its activity influences drinking of water.

CLINICAL ANATOMY

Discrete lesions of the subthalamic nucleus result in *hemiballismus* characterised by involuntary choreiform movements on the opposite side of the body. The condition is abolished by ablation of the globus pallidus or of its efferent tracts, the anterior ventral nucleus of the thalamus, area 4 of the cerebral cortex, or of the corticospinal tract. From these facts, it appears that the subthalamic nucleus has an inhibitory control on the globus pallidus and on the cerebral cortex.

BASAL NUCLEI

DISSECTION

Raise the lower border of the insula, stripping a thin layer of grey matter situated deep to the white matter of insula. This grey matter is known as the claustrum. As the insula is gradually raised, the external capsule and on a deeper plane, a fan-shaped layer of white matter, the corona radiata, is identifiable. Its fibres pass on a deeper plane than that of superior longitudinal fasciculus.

To explore the lentiform nucleus, strip the external capsule and identify rounded lentiform nucleus. Dissect the striate branches of the middle cerebral artery on the lateral surface of the lentiform nucleus (Fig. 8.20).

Remove the genu and rostrum of corpus callosum from the cerebral hemisphere, identify the head of the caudate nucleus and the anterior part of the corona radiata emerging from between the caudate and the lentiform nuclei. Identify the anterior commissure and trace its fibres reaching till the temporal lobe.

Internal Capsule

To expose the internal capsule, remove the lentiform nucleus as it forms the lateral boundary of the internal capsule. It is difficult to separate as many fibres of internal capsule enter the lentiform nucleus. Some fibres form two medullary laminae and divide the lentiform nucleus into outer dark part—the putamen and two paler inner parts—the globus pallidus. Putamen is continuous with the caudate nucleus. Trace the continuity of the corona radiata with the internal capsule and of the internal capsule with the crus cerebri. The latter part is visible after stripping the optic tract from the lateral side of the internal capsule.

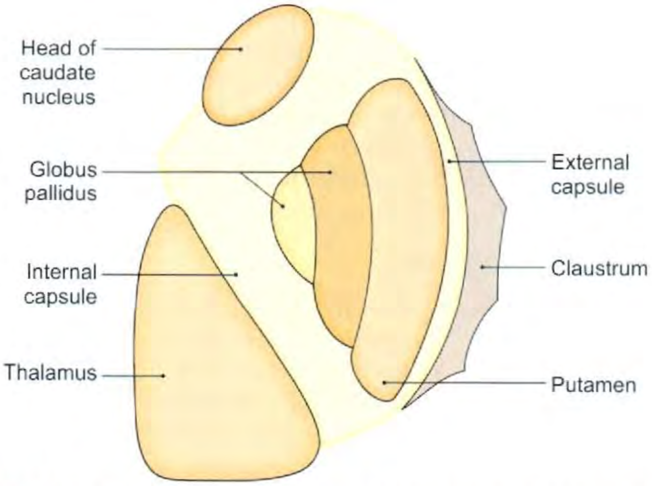


Fig. 8.20: Horizontal section through corpus striatum, thalamus and internal capsule

Features

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

1 The *corpus striatum* (Fig. 8.20), which is partially divided by the internal capsule into two nuclei:
   a. The *caudate nucleus*.
   b. The *lentiform nucleus*.

   These two nuclei are interconnected by a few bands of grey matter below the anterior limb of the internal capsule. The bands give it a striped appearance, hence the name. The lentiform nucleus is divided into a lateral part, the *putamen* and a medial part, the *globus pallidus*. The caudate nucleus and putamen (neostriatum) are often grouped as the *striatum*, whereas the globus pallidus (paleostriatum) is the *pallidum*.
2 The *amygdaloid body* forms a part of the limbic system.
3 *Claustrum*.

The four nuclei (caudate, lentiform, amygdaloid and claustrum) are joined to the cortex at the anterior perforated substance.

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 (Fig. 8.21).

The nucleus has a head, a body, and a tail.

The *head* forms the floor of the anterior horn of the lateral ventricle, and the medial wall of the anterior limb of the internal capsule. Bands of grey matter connect it to the putamen across the anterior limb of the internal capsule near the anterior perforated substance.

The *body* forms the floor of the central part of the lateral ventricle, and lies medial to the posterior limb

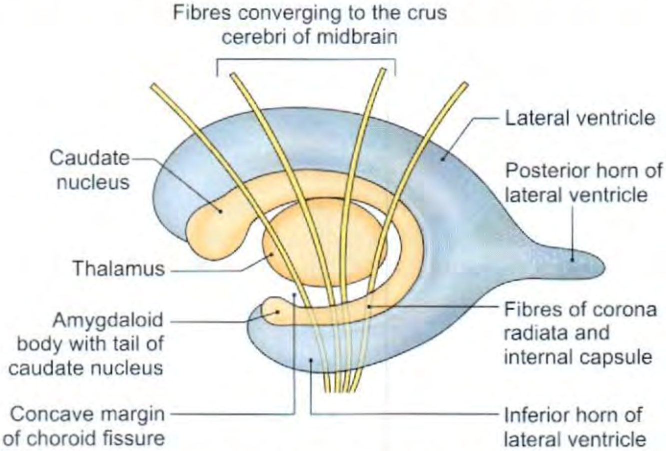


Fig. 8.21: Relations of caudate nucleus to lateral ventricle, thalamus and internal capsule

of the internal capsule. It is separated from the thalamus by the stria terminalis and the thalamostriate vein. Superiorly, it is related to the fronto-occipital bundle and the corpus callosum.

The tail forms the roof of the inferior horn of the lateral ventricle, and ends by joining the amygdaloid body at the temporal pole. It is related medially to the stria terminalis, laterally to the tapetum, and superiorly to the sublentiform part of the internal capsule and to the globus pallidus.

Lentiform Nucleus

This is a large lens-shaped (biconvex) nucleus, forming the lateral boundary of the internal capsule. It lies beneath the insula and the claustrum.

The lentiform nucleus has three surfaces:

a. The *lateral surface* is convex. It is related to the external capsule, the claustrum, the outermost capsule, insula, and is grooved by the *lateral striate arteries*.
b. The *medial surface* is more convex. It is related to the internal capsule, the caudate nucleus and the thalamus (Fig. 8.22).
c. The *inferior surface* is related to the sublentiform part of the internal capsule which separates it from the optic tract, the tail of the caudate nucleus, and the inferior horn of the lateral ventricle. The surface is grooved by the anterior commissure just behind the anterior perforated substance.

The lentiform nucleus is divided into two parts by a thin lamina of white matter.

The larger lateral part is called the *putamen (*Latin *to cut).* Structurally, it is similar to the caudate nucleus and contains small cells.

The smaller medial part is called the *globus pallidus.* It is made up of large (motor) cells.

Morphological Divisions of Corpus Striatum

1 The *paleostriatum* is the older and primitive part. It is represented by the globus pallidus (pallidum).
2 The *neostriatum* is more recent in development. It is represented by the caudate nucleus and the putamen of the lentiform nucleus. The neostriatum is often called the striatum.

Connections of Corpus Striatum

The caudate nucleus and putamen are afferent nuclei, while the globus pallidus is the efferent nucleus, of the corpus striatum (Fig. 8.22). The connections are shown in Table 8.5.

Functions of Corpus Striatum

1 The corpus striatum regulates muscle tone and thus helps in smoothening voluntary movements.
2 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.
3 It influences the precentral motor cortex which is supposed to control the extrapyramidal activities of the body.
4 These do not receive any sensory input from spinal cord unlike the cerebellum. Basal ganglia contribute to cognitive function of the brain.
5 These help cortex in execution of learned patterns of movements subconsciously.
6 Corpus striatum, cerebellum and motor areas of cerebrum jointly are responsible for planning, execution and control of movements.
7 Corpus striatum and cerebellum without sending fibres to spinal cord modify the effect on spinal cord through projections to motor cortex and extrapyramidal fibres.
8 Basal ganglia and cerebellum do not initiate movements but are able to adjust motor commands.

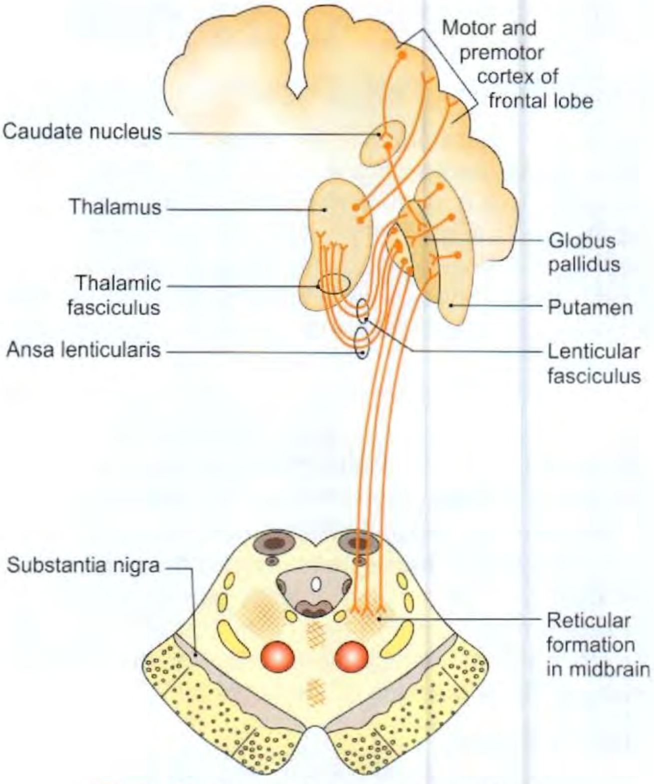


Fig. 8.22: Connections of corpus striatum

AMYGDALOID BODY

This is a nuclear mass in the temporal lobe, lying anterosuperior 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 (Fig. 8.22).

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

Afferents: From the olfactory tract.

Table 8.5: Connections of the corpus striatum

Nucleus	*Afferents*	*Efferents*
A. Caudate nucleus and putamen	From: 1. Cerebral cortex (areas 4 and 6) 2. Thalamus (medial, intralaminar and midline nuclei) 3. Substantia nigra	Chiefly to globus pallidus, but also to substantia nigra and thalamus
B. Globus pallidus	Mainly from: 1. Caudate nucleus 2. Putamen Also from: 1. Thalamus 2. Subthalamic nucleus 3. Substantia nigra	Efferents form three bundles, namely: 1. Ansa lenticularis, ventrally (Fig. 8.22) 2. Fasciculus lenticularis, dorsally 3. Subthalamic fasciculus from the middle part of the globus pallidus These bundles terminate in the following: 1. Thalamus 2. Hypothalamus 3. Subthalamic nucleus 4. Red nucleus 5. Olivary nucleus 6. Substantia nigra 7. Reticular nuclei

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

CLAUSTRUM

It is saucer-shaped nucleus situated between the putamen and the insula, with which it is coextensive. Inferiorly, it is thickest and continuous with the anterior perforated substance.

CLINICAL ANATOMY

- Lesions of basal ganglia and cerebellum do not cause paralysis. These produce abnormal movements or posture or changes in tone.
- *Parkinsonism:* Lesions of corpus striatum leads to parkinsonism (Fig. 8.23). Its features are:
  a. Hypertonicity or lead pipe rigidity.
  b. Loss of automatic associated movements and also of facial expression.
  c. Involuntary movements like tremors, choreiform movements, athetoid movements.
  d. Continuous writhing movements of trunk and limbs may continue even in sleep. Voluntary movements may be impossible.
- *Chorea:* Chorea means dancing. Chorea is form of involuntary movement characterised by fine random movements of hands and feet. These movements are rather disorganized.
  This occurs due to disease of caudate nucleus.
- *Athetosis:* It is a form of movement which is slow repetitive and writhing in nature. It is due to lesion of putamen.
- *Ballismus:* This is characterized by irregular movements of trunk, girdles and both the limbs. It is due to disease of subthalamic nucleus.
- L-dopa (a precursor of dopamine) is used as a replacement therapy in parkinsonism because dopamine the normal neurotransmitter in the striatum, is reduced in these cases. The nigrostriate fibres are considered important in the genesis of parkinsonism tremor, since its neurons utilize dopamine in the neurotransmission.

Neurosurgically, pallidectomy and thalamodectomy have been used with success to control the contralateral tremors in different types of disease of corpus striatum.

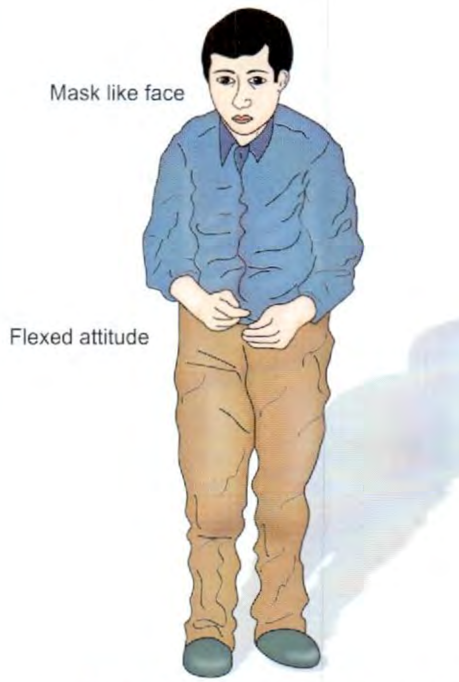


Fig. 8.23: Posture in parkinsonism

WHITE MATTER OF CEREBRUM

DISSECTION

Scrape the grey matter between adjacent gyri till the white matter connecting the adjacent gyri is visible. This will expose the short association fibres. Identify the cingulate gyrus on the medial surface of the left hemisphere. Scrape the grey matter of this gyrus till a band of white matter—the cingulum is exposed. Define the extent of cingulum from the anterior end of corpus callosum, around its convex trunk and splenium into the parahippocampal gyrus (Fig. 8.24).

Similarly scrape the cortex between temporal pole, motor speech area and the orbital cortex to expose uncinate fasciculus. Also expose superior longitudinal fasciculus joining the frontal lobe to the occipital and temporal lobes. Lastly, scrape the grey matter between occipital and temporal lobes to expose the inferior longitudinal fasciculus (*refer to BDC App*).

Identify the various parts of the corpus callosum. Remove the fibres of the cingulum and identify the superficial fibres of the genu of corpus callosum passing into the medial aspect of hemisphere. Such fibres of the two sides form the forceps minor.

Expose the band of fibres passing from splenium of corpus callosum towards the superior part of occipital lobe. Trace the fibres of tapetum arising from the trunk and splenium of corpus callosum curving to reach the inferior parts of the occipital and temporal lobes.

Identify the anterior commissure lying just anterior to column of fornix and the interventricular foramen. Examine the posterior commissure situated dorsal to the upper part of aqueduct and inferior to the root of the pineal body. Look for habenular commissure present at the root of the pineal body. Lastly, identify the commissure of the fornix and the hypothalamic commissures.

Lift up a strip of superficial fibres of the genu of corpus callosum and tear these laterally. Identify the intersectioning fibres of corpus callosum and those of the vertically disposed fibres of the corona radiata.

SUBDIVISIONS

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

ASSOCIATION (ARCUATE) FIBRES

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

Short Association Fibres

These fibres connect adjacent gyri to one another (Fig. 8.24).

Long Association Fibres

These fibres connect more widely separated gyri to one another. Some examples are:

1 The *uncinate fasciculus,* connecting the temporal pole to the motor speech area and to the orbital cortex.
2 The *cingulum,* connecting the cingulate gyrus to the parahippocampal gyrus seen on the medial surface.
3 The *superior longitudinal fasciculus,* connecting the frontal lobe to occipital and temporal lobes.
4 The *inferior longitudinal fasciculus,* connecting the occipital and temporal lobes (Fig. 8.24, inset).
5 Fronto-occipital fasciculus seen on the medial surface

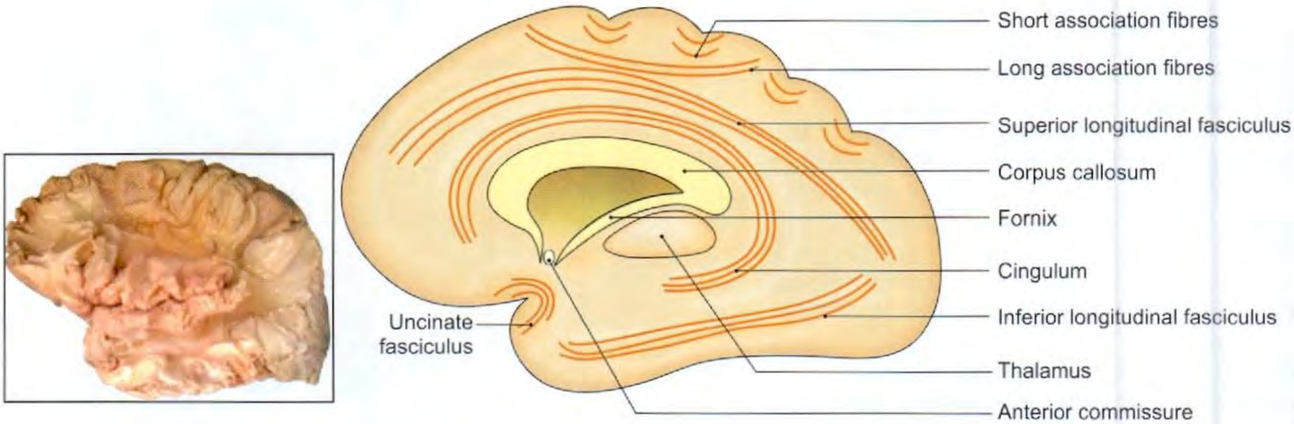


Fig. 8.24: Association fibres of cerebrum

COMMISSURAL FIBRES

These are the fibres which connect corresponding parts of the two hemispheres. They constitute the commissures of the cerebrum. They are:

1. The *corpus callosum* connecting the cerebral cortex of the two sides (Fig. 8.25).
2. The *anterior commissure,* connecting the archipallia (olfactory bulbs, piriform area and anterior parts of temporal lobes) of the two sides (Fig. 8.12).
3. The *posterior commissure,* connecting the superior colliculi, and also transmitting corticotectal fibres and fibres from the pretectal nucleus to the Edinger-Westphal nucleus of the opposite side.
4. The *commissure of the fornix (hippocampal commissure),* connecting the crura of the fornix and thus the hippocampal formations of the two sides.
5. The *habenular commissure,* connecting the habenular nuclei.
6. The *hypothalamic commissures,* including the anterior hypothalamic commissure of Ganser, the ventral supraoptic commissure of Gudden and the dorsal supraoptic commissure of Meynert.

Corpus Callosum

The corpus callosum is the largest commissure of the brain. It connects the two cerebral hemispheres. Since it is the neopallial commissure, it attains enormous size in man (10 cm long).

Parts of Brain Connected

The corpus callosum connects all parts of the cerebral cortex of the two sides, except the lower and anterior parts of the temporal lobes which are connected by the anterior commissure.

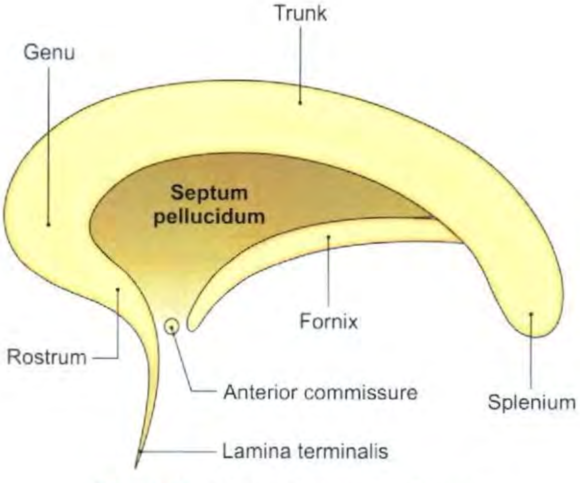


Fig. 8.25: Parts of corpus callosum

Parts of Corpus Callosum

1. The *genu* is the anterior end. It lies 4 cm behind the frontal pole. It is related anteriorly to the anterior cerebral arteries, and posteriorly to the anterior horn of the lateral ventricle (Fig. 8.25, also *see* Fig. 11.5).
2. The *rostrum* is directed downwards and backwards from the genu, and ends by joining the lamina terminalis, in front of the anterior commissure. It is related superiorly to the anterior horn of the lateral ventricle, and inferiorly to the indusium griseum and the longitudinal striae.
3. The *trunk* or body is the middle part, between the genu and the splenium. Its *superior surface* is convex from before backwards and concave from side to side. It is related to the anterior cerebral arteries (*see* Fig. 11.5) and to the lower border of the falx cerebri. It is overlapped by the cingulate gyrus and is covered by the indusium griseum and the longitudinal striae. The *inferior surface* is concave from before backwards and convex from side to side. It provides attachment to the septum pellucidum and the fornix, and forms the roof of the central part of the lateral ventricle.
4. The *splenium* is the posterior end forming the thickest part of the corpus callosum. It lies 6 cm in front of the occipital pole. Its *inferior surface* is related to the tela choroidea of the third ventricle (*see* Fig. 9.1), the pulvinar, the pineal body, and the tectum of the midbrain. The *superior surface* is related to the inferior sagittal sinus and the falx cerebri. *Posteriorly,* it is related to the great cerebral vein, the straight sinus and the free margin on the tentorium cerebelli.

Fibres of Corpus Callosum

1. The *rostrum* connects the orbital surfaces of the two frontal lobes.
2. The *forceps minor* is made up of fibres of the genu that connect the two frontal lobes (Figs 8.26a and b).
3. The *forceps major* is made up of fibres of the splenium connecting the two occipital lobes.
4. The *tapetum* is formed by some fibres from the trunk and splenium of the corpus callosum. The tapetum forms the roof and lateral wall of the posterior horn, and the lateral wall of the inferior horn of the lateral ventricle (Figs 8.26a and b).

Functional Significance

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

PROJECTION FIBRES

These are fibres which connect the cerebral cortex to other parts of the CNS, e.g. the brain stem and spinal cord. Many important *tracts,* e.g. corticospinal and corticopontine, are made up of projection fibres.

Examples: (a) Corona radiata and (b) internal capsule.

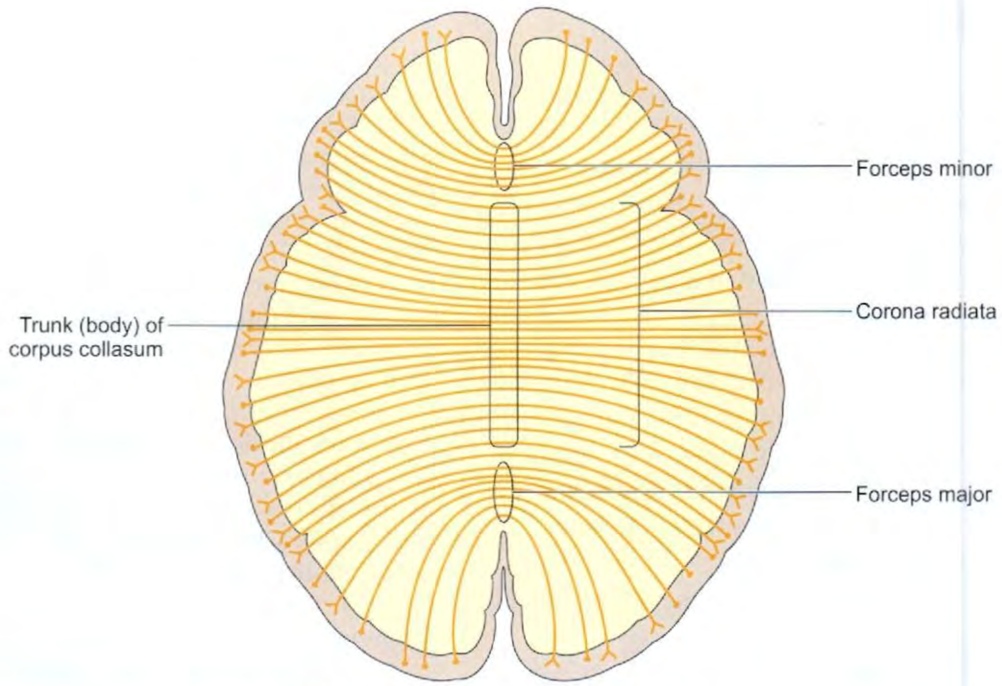


Fig. 8.26: Fibres of corpus collosum

Internal Capsule

Gross Anatomy

The internal capsule is a large band of fibres, 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. 8.27).

The internal capsule contains fibres going to and coming from the cerebral cortex. It can be compared to a narrow gate where the fibres are densely crowded. Small lesions of the capsule can give rise to widespread derangements of the body.

When traced *upwards,* the fibres of the capsule diverge and are continuous with the corona radiata. When traced *downwards*, its fibres converge and many of them are continuous with the crus cerebri of the midbrain.

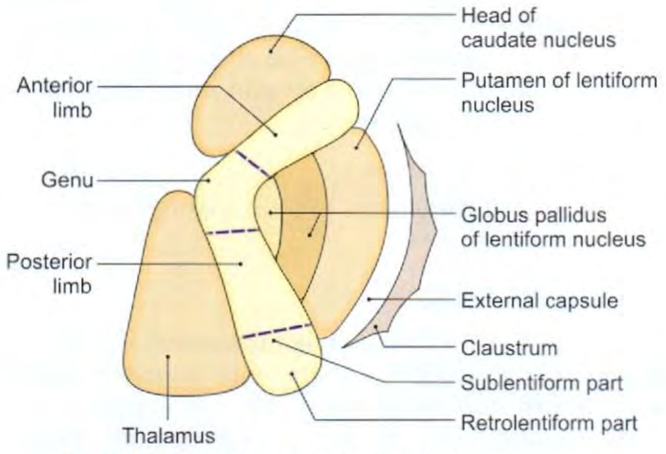


Fig. 8.27: Boundaries and parts of internal capsule

The internal capsule is divided into the following parts.

a. The *anterior limb* lies between the head of the caudate nucleus and the lentiform nucleus (Figs 8.27 and 8.28).
b. The *genu* is the bend between the anterior and posterior limbs.
c. The *posterior limb* lies between the thalamus and the lentiform nucleus.
d. 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.
e. The *retrolentiform part* lies behind the lentiform nucleus.

Relations

Medially: Head of caudate nucleus and thalamus

Laterally: Lentiform nucleus

Fibres of Internal Capsule

Motor fibres

Corticopontine lie in anterior limb, genu and posterior limb (Fig. 8.29).

Frontopontine start from frontal lobe to reach the pontine nuclei where these relay to reach opposite cerebellar hemisphere. These are called corticopontocerebellar fibres.

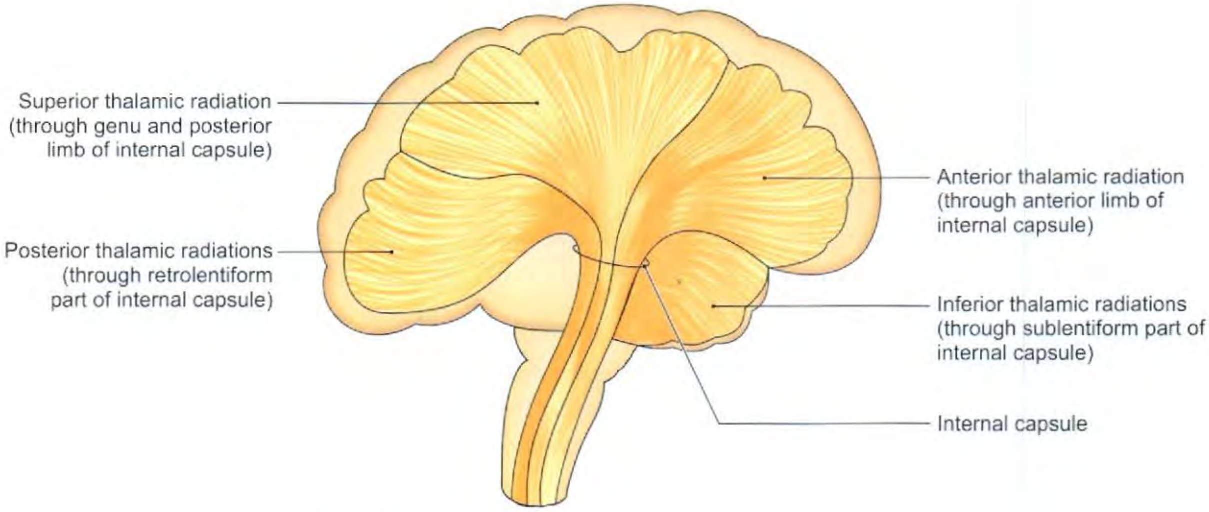


Fig. 8.28: Fibres of various parts of internal capsule

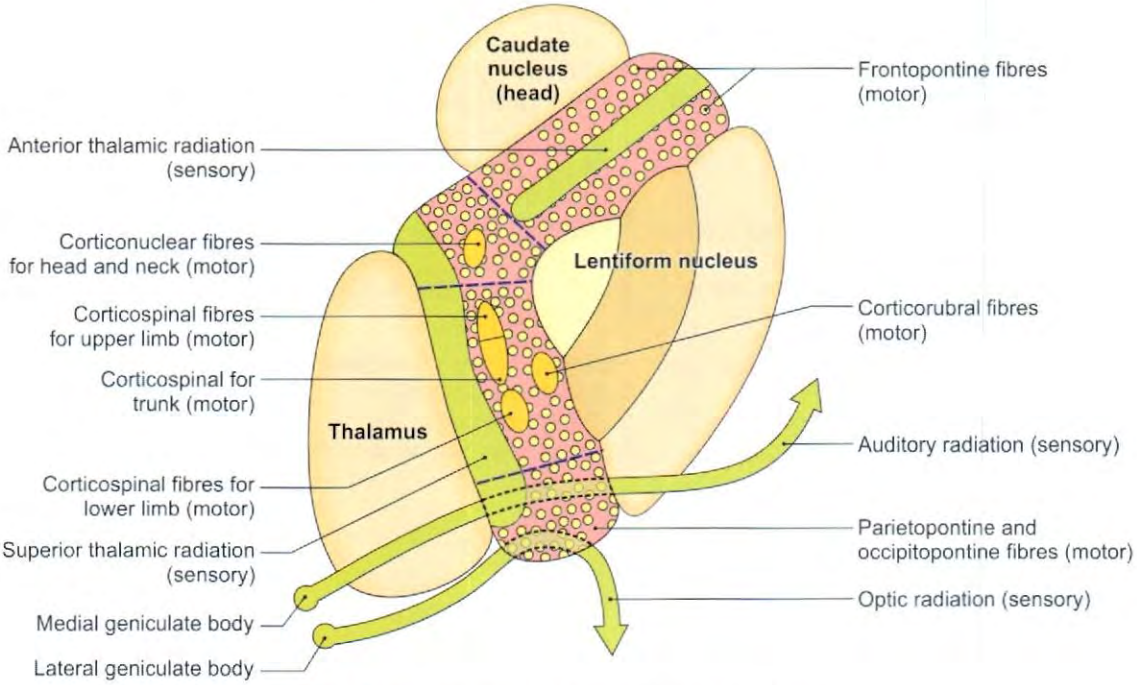


Fig. 8.29: Fibre components of internal capsule

Parietopontine and occipitopontine lie in retrolentiform part of internal capsule.

Temporopontine lie in sublentiform part of internal capsule.

Pyramidal fibres

Corticonuclear to nuclei of III, IV, V, VI, VII, XII and nucleus ambiguus for IX, X, XI nerves of opposite side.

Corticospinal: Fibres for anterior horn cells of muscles of head and neck lie in genu.

Fibres for upper limb, trunk and lower limb lie in posterior limb of internal capsule in sequential order (Fig. 8.29).

Extrapyramidal fibres

These fibres start from cerebral cortex as corticostriate and corticorubral fibres and reach corpus striatum and red nucleus.

Sensory fibres

Thalamocortical fibres form thalamic radiations (3rd order neuron fibres):

1 Anterior thalamic radiation: Fibres from anterior and dorsomedial nuclei of thalamus terminate in cortex frontal lobe.

2. Superior thalamic radiation: Fibres of ventral group of nuclei of thalamus reach sensory areas of frontal and parietal lobes.
3. Inferior thalamic radiation: Connect medial geniculate body with primary auditory cortex.
4. Posterior thalamic radiation: These fibres connect lateral geniculate body to area 17 forming optic radiation.

Constituent fibres

The fibres of internal capsule are shown in Fig. 8.30 and presented in Table 8.6.

Blood Supply

The arteries supplying different parts of the internal capsule are shown in Fig. 8.30.

Table 8.6: Fibres in the internal capsule

Part	*Descending tracts*	*Ascending tracts*	*Arterial supply*
Anterior limb (Fig. 8.29)	Frontopontine fibres (a part of the cortico-pontocerebellar pathway)	Anterior thalamic radiation (fibres from anterior and medial nuclei of thalamus)	1. Recurrent branch of anterior cerebral 2. Direct branches from anterior cerebral
Genu	Corticonuclear fibres (a part of the pyramidal tract going to motor nuclei of cranial nerves and forming their supranuclear pathway	Anterior part of the superior thalamic radiation (fibres from posterior ventral nucleus of thalamus)	1. Direct branches from internal carotid 2. Posterior communicating
Posterior limb	1. Corticospinal tract (pyramidal tract for the upper limb, trunk and lower limb) 2. Corticopontine fibres 3. Corticorubral fibres	1. Superior thalamic radiation 2. Fibres from globus pallidus to subthalamic nucleus	1. Lateral striate branches of middle cerebral 2. Medial striate branches of middle cerebral 3. Anterior choroidal
Sublentiform part	1. Parietopontine and temporopontine fibres 2. Fibres between temporal lobe and thalamus	1. Auditory radiation 2. Fibres connecting thalamus to temporal lobe	1. Branches of posterior cerebral 2. Anterior choroidal
Retrolentiform part	1. Parietopontine and occipitopontine fibres 2. Fibres from occipital cortex to superior colliculus and pretectal region	Posterior thalamic radiation made up of: 1. Mainly optic radiation 2. Partly fibres connecting thalamus to the parietal and occipital lobes	Branches of posterior cerebral

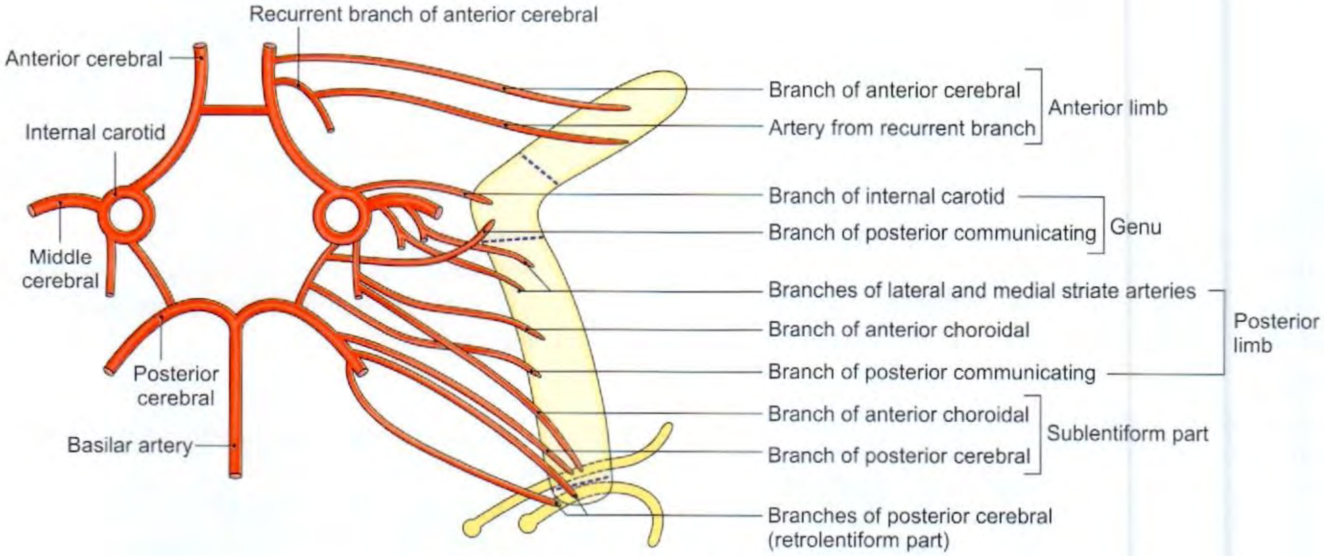


Fig. 8.30: Arteries supplying the internal capsule

CLINICAL ANATOMY

- Lesions of the internal capsule are usually vascular, due to involvement of the medial and lateral striate branches of the middle cerebral artery. They give rise to hemiplegia on the opposite half of the body (paralysis of one-half of the body, including the face).

  It is an upper motor neuron type of paralysis (Fig. 8.31). The larger lateral striate artery is called, "Charcot's artery of cerebral haemorrhage".
- Thrombosis of the recurrent branch of the anterior cerebral artery gives rise to an upper motor neuron type of paralysis of the opposite upper limb and of the face.
- A lesion in the genu of the internal capsule would produce sensory and motor loss in the contralateral side of the head. This may not be complete since there is bilateral cortical innervation of most cranial nerve nuclei.

Fig. 8.31: Posture in left-sided hemiplegia

DEVELOPMENT

Cerebral hemispheres arise as outgrowths from the lateral wall of prosencephalon during 5–6 weeks. These gradually enlarge to cover thalamus, midbrain and pons. Further growth results in formation of lobes and poles. Increased growth in a limited area result in formation of sulci and gyri. The basal part of the hemisphere increases in size to form two big nuclei connected together by fibres. These nuclei are the caudate and lentiform nuclei. Both ascending and descending fibres pass. These form internal capsule (projection fibres). The commissural fibres develop in the lamina terminalis.

FACTS TO REMEMBER

- Human's status as the most highly evolved animal so far is due to larger size of the cerebrum, especially the frontal lobes.
- Cerebrum comprises 3 borders: superomedial, inferolateral and medial; 3 surfaces: superolateral, medial and inferior; 3 poles: frontal, occipital and temporal and 4 lobes: frontal, parietal, temporal and occipital.
- Cerebrum receives sensations from the opposite side of body. It controls the movements of the opposite side of body, a few structures are controlled by both sides.
- Body is represented upside down, only the face and area of vocalization is represented straight.
- Thalamus is the inner chamber receiving and coordinating motor, sensory, visceral, visual, auditory and emotional impulses.
  - Commissural fibre components are anterior commissure, posterior commissure, habenular commissure. The largest is the corpus callosum. These connect identical areas of 2 hemispheres.
  - Association fibres connect different areas of same hemisphere
  - Projection fibres connect upper areas of brain with lower ones.
- Internal capsule is the most typical example of projection fibres.
- Its posterior limb is supplied by lateral and medial striate arteries. These are end arteries. Blockage or haemorrhage of these arteries causes upper motor neuron type of paralysis on the opposite side of the body.

CLINICOANATOMICAL PROBLEMS

Case 1

A hypertensive old lady of 88 years complained of severe headache on her right side. After two hours she could not move her left upper and left lower limbs. Her voice was also altered. CT scan showed bleeding in the area of internal capsule.

- Where is the lesion in brain responsible for her symptoms?
- What are the differences between central and cortical branches?

Ans: There has been a haemorrhage in the area of internal capsule on right side of the cerebrum, leading to upper motor neuron paralysis of her left upper and lower limbs. The lateral striate branches, the central branches of middle cerebral artery are most vulnerable to injury.

Differences between central and cortical branches:

Central branch	Cortical branch
1. Thin, long, arise in groups	Arise singly, thicker in size and shorter
2. These do not anastomose and are end arteries	These anastomose freely on the surface
3. If these get blocked, there is large infarct	If these get blocked, there is small infarct

Case 2

A 65-year-old person developed tremors in his hands. He cannot eat his food comfortably. His movements have slowed down, and walks by bending forwards. There is mostly a stare in his eyes with no emotional expression.

- What is the likely diagnosis?
- What is the line of treatment?

Ans: The likely diagnosis is parkinsonism. In this condition, there is paucity of movements with lead-pipe rigidity. These are also associated with involuntary movements like tremors.

The line of treatment is "L-dopa", given as a replacement therapy, because dopamine the normal neurotransmitter in globus pallidus is reduced in these conditions. Surgical treatment include pallidectomy to control tremors.

Case 3

A 45-year-old officer complained of resting tremors of his hands, with inability to eat his food. He would walk with a forward bend as it trying to catch centre of gravity.

- What is the diagnosis and what neurotransmitter is deficient in such a case?
- What are the other features?

Ans: The patient is suffering from 'parkinsonism'. It occurs due to degeneration of nigrostriate fibres. Patient has pill-rolling movements of hands including resting tremors, and mask like face.

FREQUENTLY ASKED QUESTIONS

1. Describe the superolateral surface of the cerebral hemisphere under the following headings: Sulci, gyri and functional areas.
2. Describe the connections of the various including the nuclei of thalamus. What are their functions?
3. Write short notes on:
   a. Corpus callosum
   b. Motor speech area
   c. Lateral geniculate body
   d. Components of basal ganglia and their functions
   e. Interpenduncular fossa
   f. Association fibers
4. Describe the parts of internal capsule. Name their component fibres. Enumerate its arteries. Add a note on its clinical importance.

MULTIPLE CHOICE QUESTIONS

1. Anterior limit of forebrain is represented by:
a. Stria medullaris b. Stria terminalis
c. Lamina terminalis d. Stria medullaris thalami

2. Broca's area is located in which lobe?
a. Parietal b. Frontal
c. Temporal d. Occipital

3. All of following are parts of basal ganglia *except*:
a. Caudate nucleus b. Thalamus
c. Putamen d. Globus pallidus

4. Which of the following structures is related to auditory pathway?
a. Lateral geniculate body
b. Trapezoid body
c. Medial lemniscus
d. Spinal lemniscus

5. Brodmann's number given to auditosensory area is:
a. 41, 42 b. 44, 45
c. 3, 1, 2 d. 18, 19

6. Afferents to lateral geniculate body is:
a. Optic tract
b. Globus pallidus
c. Auditory fibres from inferior colliculus
d. Reticular formation of brain stem

7. A saucer-shaped nucleus situated between putamen and insula is:
a. Claustrum b. Globus pallidus
c. Zona incerta d. Subthalamic nuclei

8. Parkinsonism is due to lesion in:
a. Corpus luteum b. Corpus striatum
c. Corpus callosum d. Substantia gelatinosa

ANSWERS

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

CHAPTER

9

Third Ventricle, Lateral Ventricle and Limbic System

Genius is one percent inspiration and ninety-nine percent perspiration
—Thomas

INTRODUCTION

Third and lateral ventricles of brain secrete the cerebrospinal fluid with the help of their choroid plexuses. Rhinencephalon and limbic system are related to smell and various visceral activities.

THIRD VENTRICLE

DISSECTION

Identify the extent of the third ventricle from the lamina terminalis anteriorly to the upper end of the aqueduct and root of pineal body posteriorly. Examine its anterior wall, posterior wall, roof, floor and lateral walls (*refer to BDC App*).

FEATURES

The third ventricle is a median cleft between the two thalami. Developmentally, it represents the cavity of the diencephalon, except for the area in front of the interventricular foramen which is derived from the median part of the telencephalon. The cavity is lined by ependyma (Fig. 9.1).

COMMUNICATIONS

Anterosuperiorly, on each side, it communicates with the lateral ventricle through the interventricular foramen (foramen of Monro). This foramen is bounded anteriorly by the column of the fornix, and posteriorly by the tubercle of the thalamus.

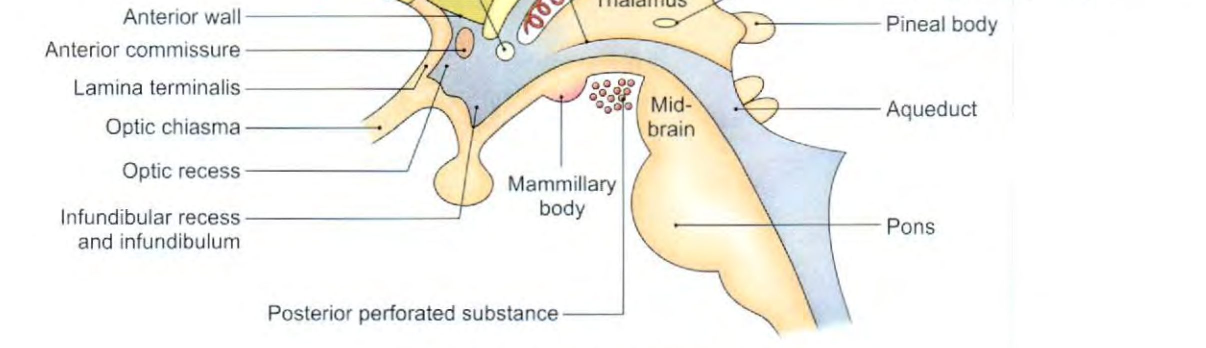


Fig. 9.1: Boundaries of third ventricle

Posteroinferiorly, in the median plane, it communicates with the fourth ventricle through the cerebral aqueduct (Fig. 9.1).

RECESSES

Recesses are extensions of the cavity. These are:

1 Suprapineal.
2 Pineal—upper lamina of the recess is traversed by habenular commissure and lower lamina by the posterior commissure.
3 Infundibular (Latin *funnel*).
4 Optic (Fig. 9.1).
5 Vulva—between the diverging columns of fornix.

BOUNDARIES

Anterior Wall

1 Lamina terminalis.
2 Anterior commissure.
3 Anterior columns of fornix. The two columns of the fornix diverge, pass downwards and backwards, and sink into the lateral wall of the third ventricle to reach the mammillary body.

Posterior Wall

1 Pineal body.
2 Posterior commissure (in the lower lamina of the pineal stalk).
3 Cerebral aqueduct.

Roof

It is formed by body of fornix and the ependyma lining the under surface of the tela choroidea of the third ventricle. The choroid plexus of the third ventricle projects downwards from the roof.

At the junction of the roof with the anterior and lateral walls, there are the interventricular foramina.

Floor

It is formed by hypothalamic structures:

1 Optic chiasma.
2 Tubercinerium.
3 Infundibulum (pituitary stalk).
4 Mammillary bodies.
5 Posterior perforated substance.
6 Tegmentum of the midbrain.

At the junction of the floor with the anterior wall, there is the optic recess (Fig. 9.1).

Lateral Wall

It is formed by the following:

1 Medial surface of thalamus (in its posterosuperior part).
2 Hypothalamus (in its anteroinferior part).
3 The hypothalamic sulcus which separates the thalamus from the hypothalamus. The sulcus extends from the interventricular foramen to the cerebral aqueduct.

Note that

a. The interthalamic adhesion connects the medial surfaces of the two thalami and crosses the ventricular cavity.
b. The habenular stria lies at the junction of the roof and the lateral wall. The two striae join posteriorly at the habenular commissure.
c. The columns of the fornix, as already indicated, run downwards and backwards to reach the mammillary bodies. The columns lie beneath the lateral wall of the ventricle.

CLINICAL ANATOMY

- The third ventricle is a narrow space which is easily obstructed by local brain tumours or by developmental defects. The obstruction leads to raised intracranial pressure in adults and hydrocephalus in infants.
- Tumours in the lower part of the third ventricle give rise to hypothalamic symptoms, like diabetes insipidus, obesity, sexual disturbance, disturbance of sleep, hyperglycaemia and glycosuria.
- The site of obstruction can be found out by CT scan/MRI (magnetic resonance imaging) scans, where, the third ventricle is seen, normally, as a narrow, vertical midline shadow. Dilatation of the third ventricle would indicate obstruction at a lower level, e.g. the cerebral aqueduct. If the obstruction is in the third ventricle, both the lateral ventricles are dilated symmetrically. Obstruction at an interventricular foramen causes unilateral dilatation of the lateral ventricle of that side.

LATERAL VENTRICLE

DISSECTION

Take the right hemisphere and put the tip of the knife at the interventricular foramen. Give a vertical incision through the fornix, septum pellucidum, body of corpus callosum, the medial surface of the hemisphere till the superomedial border (Fig. 9.2a).

Turn the brain so that superolateral surface points towards you. Continue the previous incision on this surface for 2 cm. Carry the incision posteriorly and then curve it downwards till the end of the posterior ramus of the lateral sulcus (Fig. 9.2b).

Expose the insula by depressing the temporal lobe. Cut through the medial part of the gyri situated on the superior surface of the temporal lobe till the stem of the lateral sulcus (Fig. 9.2c).

Now try to separate the frontal lobe from the temporal lobe, and open up the stem of the lateral sulcus. Put the knife in the anterior part of stem of the lateral sulcus and extend the incision medially to the inferior part of stem of the lateral sulcus. Keep on opening the cut while making it and identify the choroid plexus entering the inferior horn of the lateral ventricle from its medial side.

Now brain is easily separable into an upper frontal part and a lower occipitotemporal part. Lift the fornix from the thalamus, separating the fornix from the choroid plexus. Identify the choroidal branches of the posterior cerebral artery.

Identify structures in all horns of lateral ventricle with the help of the two parts, i.e. frontal and occipitotemporal parts of the cerebral hemisphere.

Expose the anterior column of fornix by scraping the ependyma of anterior part of third ventricle. Trace the anterior column of fornix till the mammillary body. Trace another bundle, the mammillothalamic tract till the anterior nucleus of the thalamus.

FEATURES

The lateral ventricles are two irregular cavities situated one in each cerebral hemisphere. Each lateral ventricle communicates with the third ventricle through an interventricular foramen (foramen of Monro). Each lateral ventricle consists of:

1 A central part.
2 Three horns: Anterior, posterior and inferior (Figs 9.3 and 9.4).

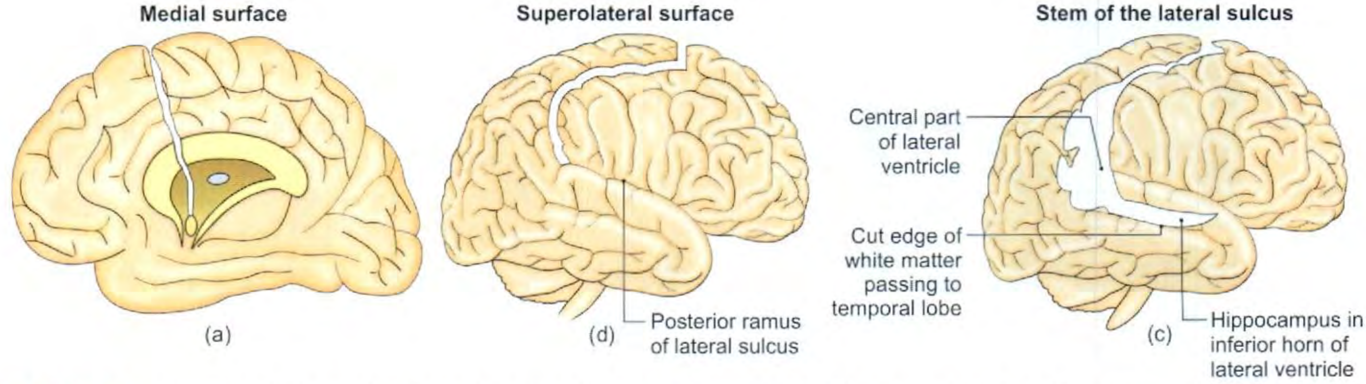
Central Part

This part of the lateral ventricle extends from the interventricular foramen in front to the splenium of the corpus callosum behind (Fig. 9.1).

Boundaries

Roof

It is formed by the undersurface of the corpus callosum (Fig. 9.5a).



Figs 9.2a to c: Drawing to show: (a) The first incision to be made in the dissection to expose the lateral ventricle, (b) the second part of the incision to be made in the dissection to expose the lateral ventricle, and (c) the third part of the incision to complete the exposure of the lateral ventricle

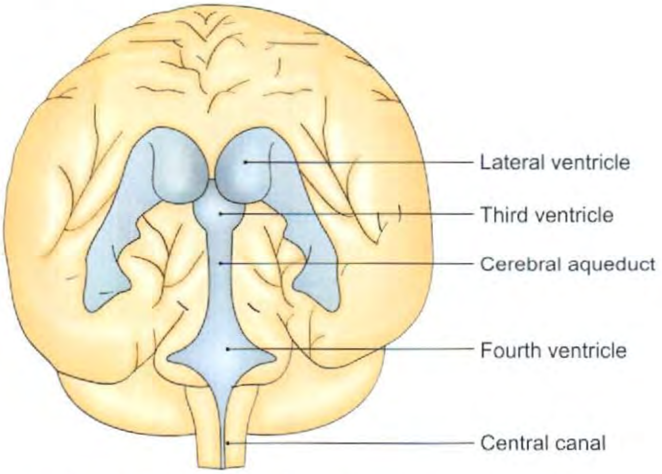


Fig. 9.3: Ventricles seen from the ventral surface

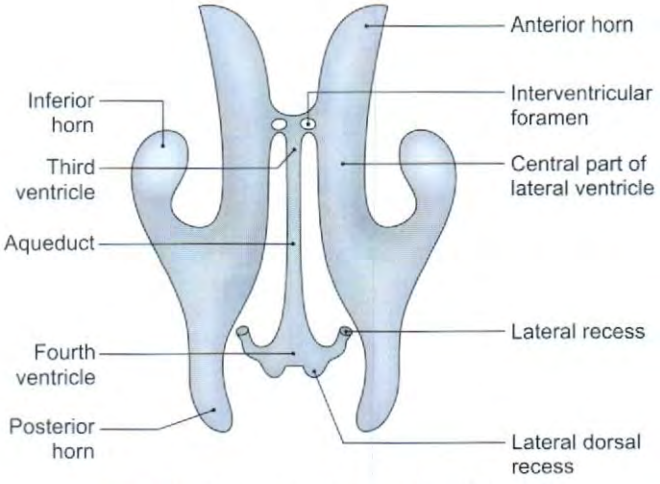


Fig. 9.4: Ventricles of brain (superior view)

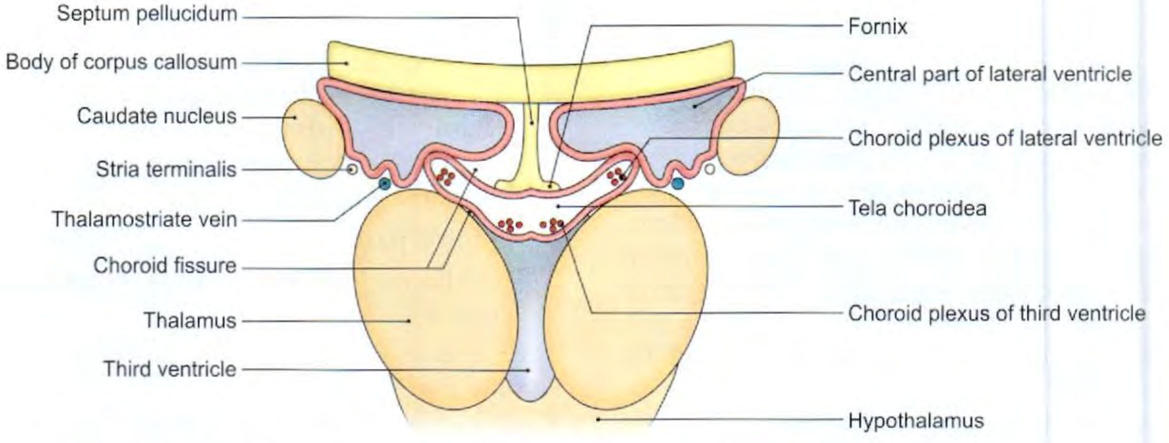


Fig. 9.5a: Boundaries of third ventricle and central part of lateral ventricle (coronal section)

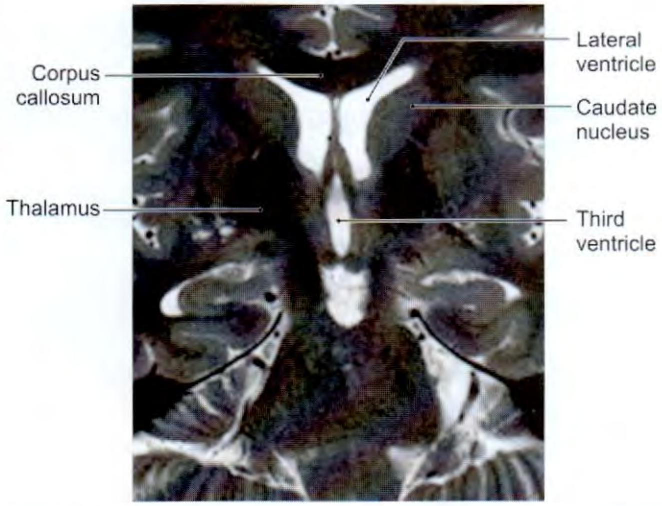


Fig. 9.5b: MRI showing third ventricle and part of lateral ventricle

Floor

It is formed (from lateral to medial side) by:

1 Body of caudate nucleus (Fig. 9.5b).
2 Stria terminalis.
3 Thalamostriate vein.
4 Lateral portion of the upper surface of the thalamus.
5 Choroid plexus.
6 Upper surface of symmetric half of body of fornix.

Medial wall

It is formed by:

1 Septum pellucidum.
2 Body of fornix (Fig. 9.5).

Choroid fissure

The line along which the choroid plexus invaginates into the lateral ventricle is called the choroid fissure. It is a C-shaped slit in the medial wall of the cerebral hemisphere. It starts at the interventricular foramen (above and in front) and passes around the thalamus and cerebral peduncle to the uncus (in the temporal lobe). Thus, it is present only in relation to the central part and inferior horn of the lateral ventricle. Its convex margin is bounded by the fornix (body and crus), the fimbria and the hippocampus (Fig. 9.6) and the concave margin is bounded by the thalamus (superior and posterior surfaces), the tail of the caudate nucleus and the stria terminalis (Fig. 9.5a). At the fissure, the pia mater and ependyma come into contact with each other and both are invaginated into the ventricle by the choroid plexus.

In the central part of lateral ventricle, the choroid fissure is a narrow gap between the edge of the fornix and the upper surface of the thalamus. The gap is invaginated by the choroid plexus (Fig. 9.5).

Anterior Horn

This is the part of the lateral ventricle which lies in front of the interventricular foramen and extends into the

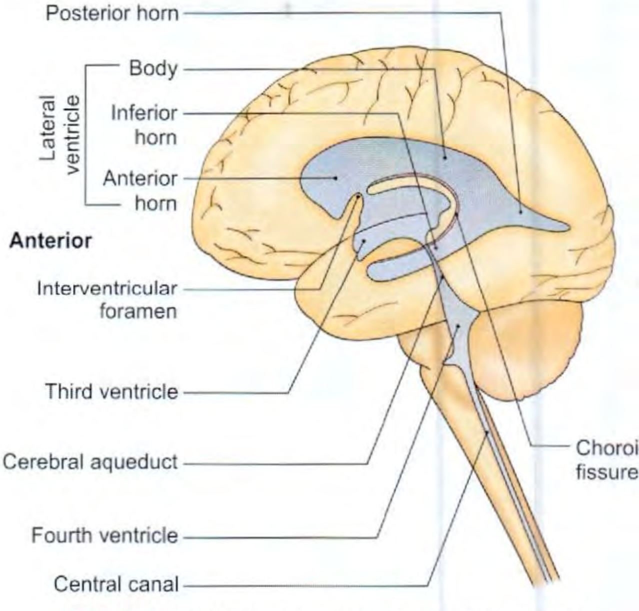


Fig. 9.6: Ventricle seen from the lateral surface

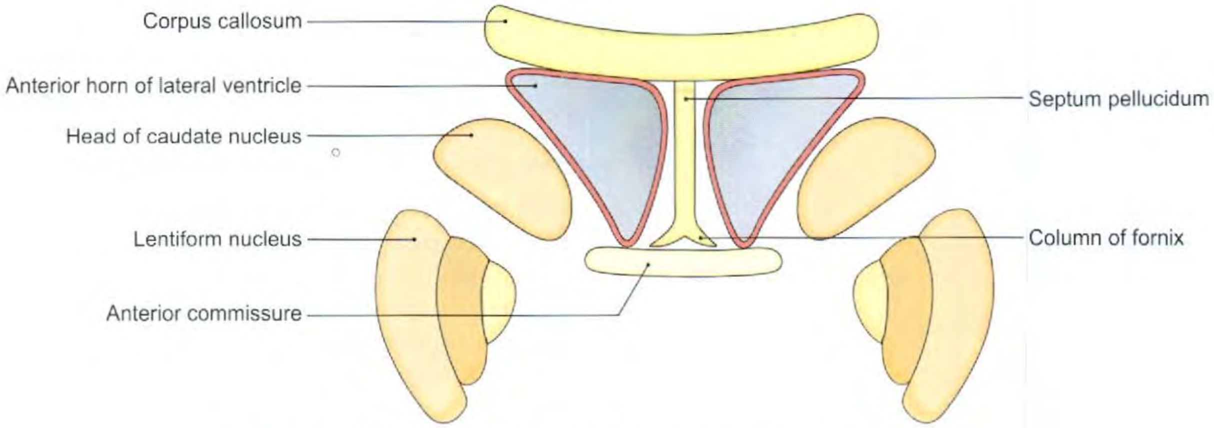


Fig. 9.7a: Boundaries of anterior horn of lateral ventricle (coronal section)

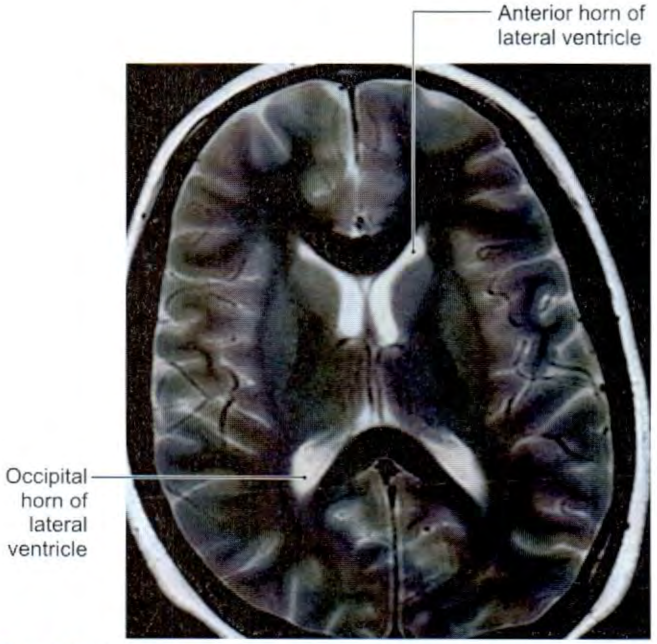


Fig. 9.7b: MRI of anterior and occipital horns of lateral ventricles

frontal lobe. It is directed forwards, laterally and downwards, and is triangular on cross-section (Fig. 9.7).

Boundaries

Anterior

Posterior surface of genu and rostrum of the corpus callosum.

Roof

Anterior part of the trunk of the corpus callosum.

Floor

1 Head of the caudate nucleus.
2 Upper surface of the rostrum of the corpus callosum.

Medial

1 Septum pellucidum.
2 Column of fornix.

Posterior Horn

This is the part of the lateral ventricle which lies behind the splenium of the corpus callosum and extends into the occipital lobe. It is directed backwards and medially (Fig. 9.8).

Boundaries

Floor and medial wall

1 Bulb of the posterior horn raised by the forceps major.
2 Calcar avis raised by the anterior part of the calcarine sulcus.

Roof and lateral wall

Tapetum fibres of optic radiation.

Inferior Horn

This is the largest horn of the lateral ventricle. It begins at the junction of the central part with the posterior horn of the lateral ventricle; and extends into the temporal lobe (Fig. 9.9).

Boundaries

Roof and lateral wall

1 Chiefly the tapetum.
2 Tail of caudate nucleus.

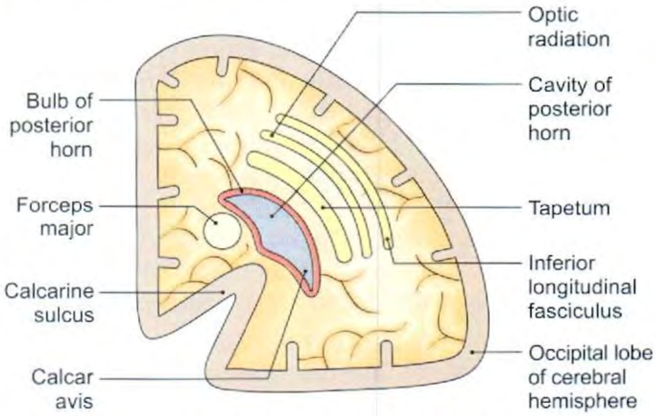


Fig. 9.8: Boundaries of posterior horn of lateral ventricle

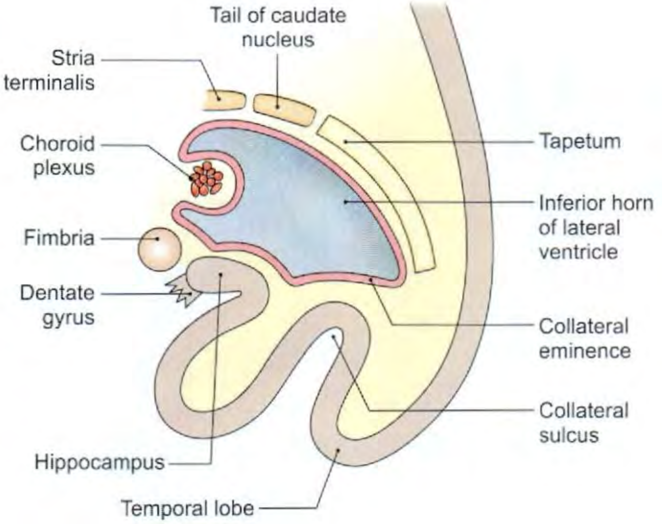


Fig. 9.9: Boundaries of inferior horn of lateral ventricle

3 Stria terminalis.
4 Amygdaloid body.

Floor

1 Collateral eminence raised by the collateral sulcus (Fig. 9.10).
2 Hippocampus, medially.

In the inferior horn, the line of ependymal invagination by the choroid plexus (i.e. the choroid fissure) lies between the stria terminalis and the fimbria.

LIMBIC SYSTEM

The main objects of primitive life are food and sex. Food is necessary for survival of the individual, and sex, for survival of the species. The primitive brain is, therefore, adapted to control and regulate behaviour of the animal with regards to seeking and procuring of food, courtship, mating, housing, rearing of young, rage, aggression and emotions.

The parts of the human brain controlling such behavioural patterns constitute the limbic system. These parts represent the phylogenetically older areas of the cortex (archipallium and paleopallium) which have been grouped in the past with the rhinencephalon and were earlier considered to be predominantly olfactory in function. However, their important role in controlling the behaviour patterns is now increasingly realized.

Structures comprising limbic system form a ring along medial wall of cerebral hemisphere. These are interposed between hypothalamus and the neocortex.

Limbic structures process and monitor emotional aspects of experience and direct emotional responses. These aid in understanding the behavioural consequences of our deeds with the help of frontal lobe.

This system helps us to select various events which we need to remember. Lesions of limbic system cause disturbances of motivation, memory and emotions as occurs in schizophrenia.

CONSTITUENT PARTS

1 Olfactory nerves, bulb, tract, striae and trigone.
2 Anterior perforated substance (Fig. 9.11).
3 Pyriform lobe, consisting of the uncus, the anterior part of the parahippocampal gyrus, and a few small areas in the region.
4 Posterior part of the parahippocampal and cingulate gyri.
5 Hippocampal formation, including the hippocampus, the dentate gyrus, indusium griseum and longitudinal striae (Fig. 9.12).
6 *Amygdaloid nuclei:* It is a part of limbic system. Amygdala evokes anxiety and rage. Its afferents are from olfactory area and from cerebral cortex. Its efferent pass via stria terminalis and also go to uncus. Injury to amygdala causes placity, orality and hypersexuality (Fig. 9.13).
7 Septal region
8 Fornix, stria terminalis, stria habenularis, and anterior commissure.

FUNCTIONS

1 It controls food habits necessary for survival of the individual. Regulates autonomic functions and endocrine glands.
2 It controls sex behaviour necessary for survival of the species. Controls endocrine glands.
3 It controls emotional behaviour expressed in form of joy and sorrow, fear, fight and friendship, liking and disliking, associated with a variety of somatic and autonomic bodily alterations. This requires integration of olfactory, somatic and visceral impulses related to memory and learning.

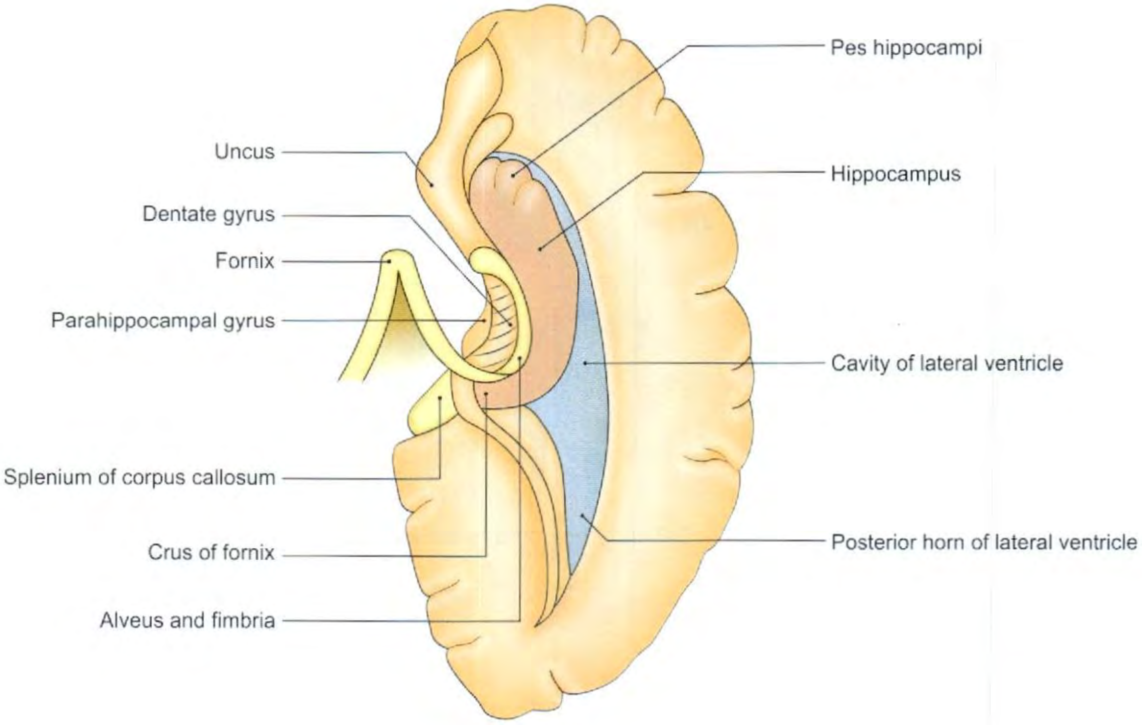
TERMS

Following are the terms with their components related to limbic system.

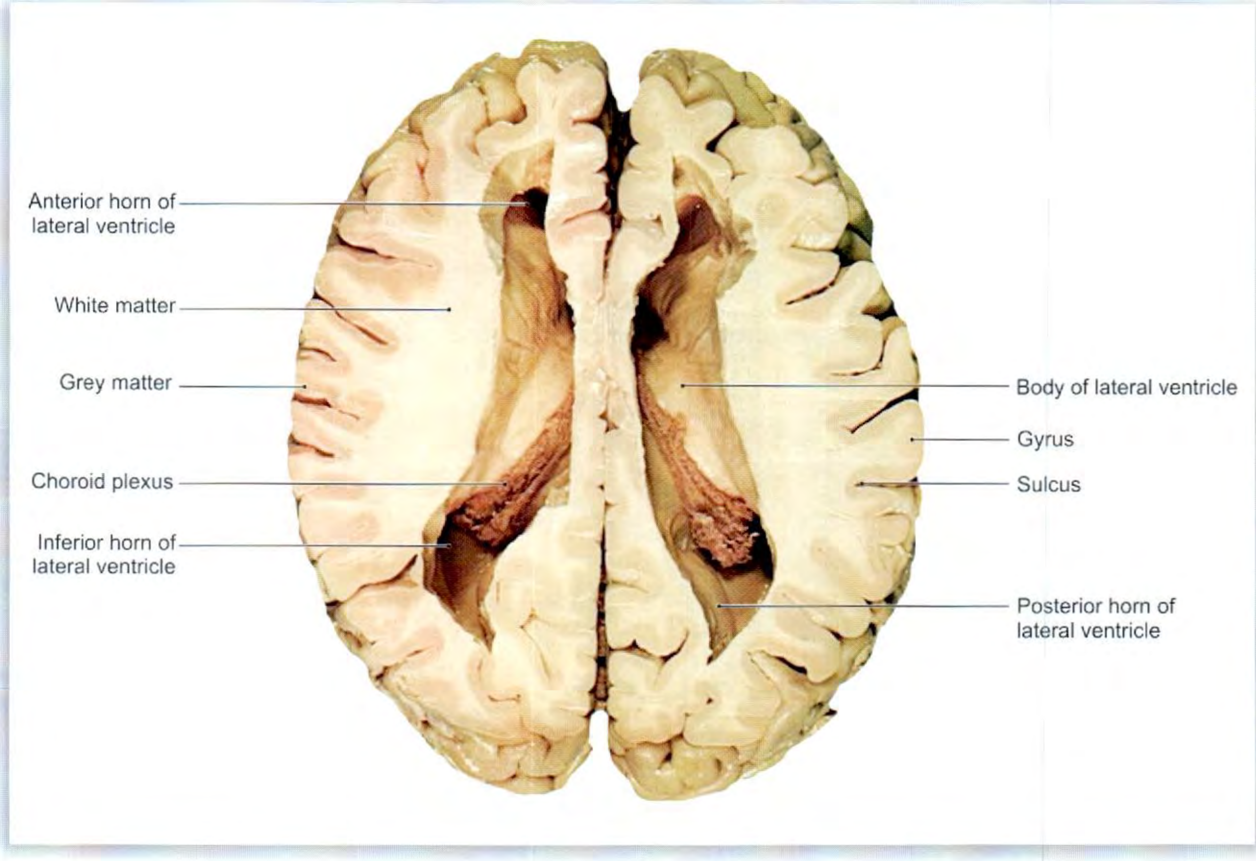
Rhinencephalon

Rhinencephalon comprises the following:

1 Olfactory mucosa
2 Olfactory bulb
3 Olfactory tract—3 roots:
   a. Medial root ends in subcallosal or parolfactory gyrus (Flowchart 9.1a).
   b. Intermediate root ends in anterior perforated substance and diagonal band of Broca (Fig. 9.11).
   c. Lateral olfactory root ends in pyriform lobe (uncus, anterior part of parahippocampal gyrus, cortex in region of limen insulae, dorsomedial part of amygdaloid nucleus) (Fig. 9.12 and Flowchart 9.1a).



(a)



(b)

Figs 9.10a and b: Cavity of lateral ventricle including its anterior horn, body, inferior and posterior horns

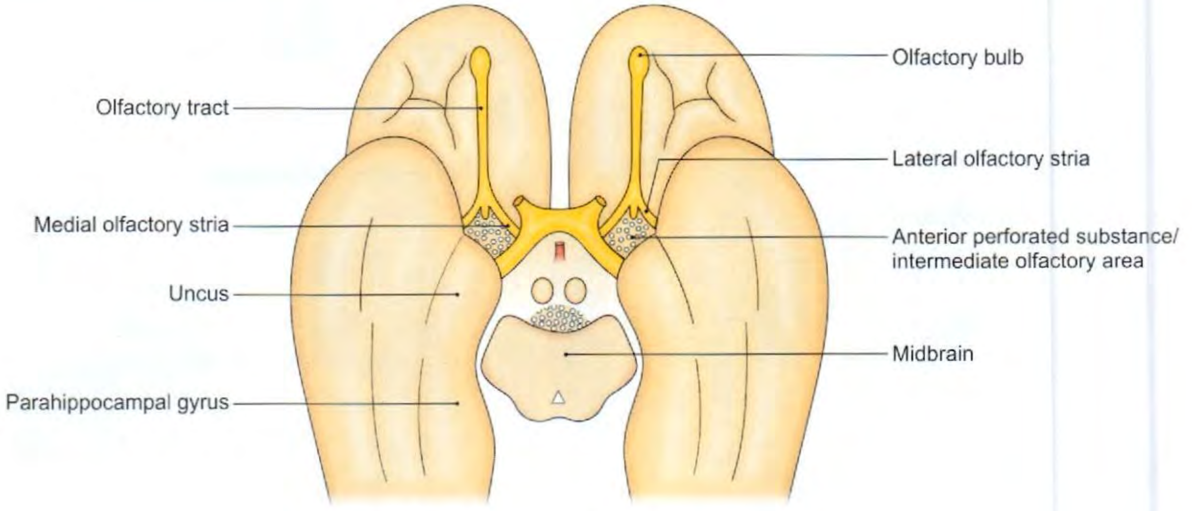


Fig. 9.11: Olfactory bulb and olfactory stria

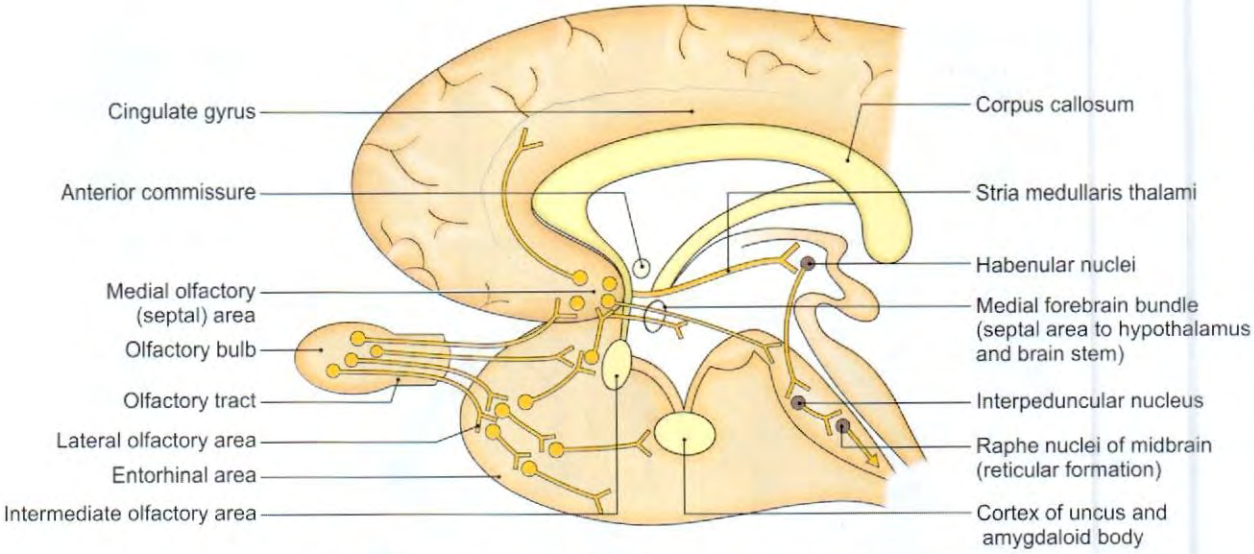


Fig. 9.12: Some connections of the olfactory cortical areas

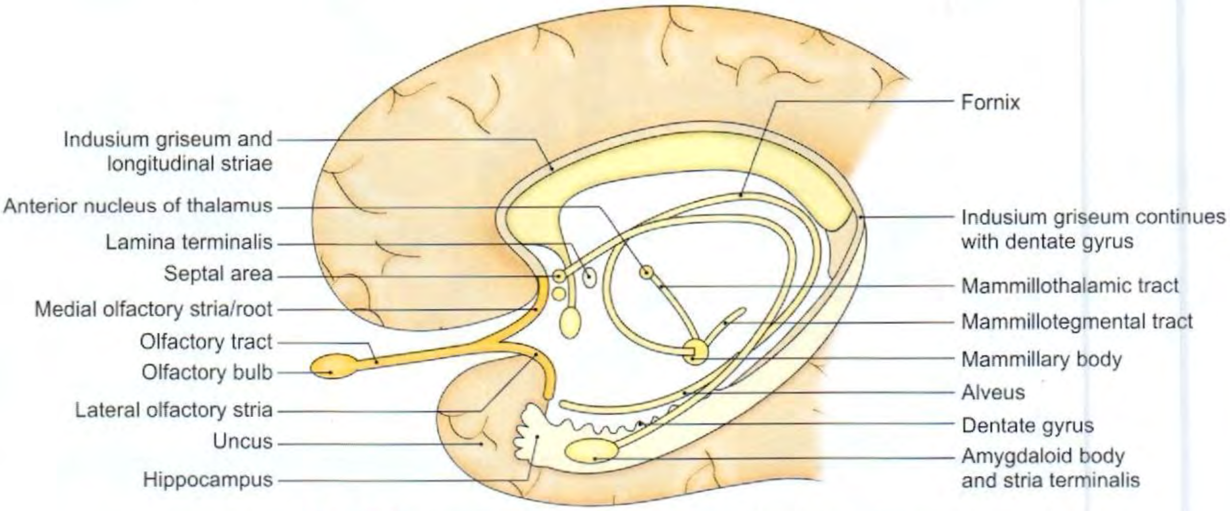
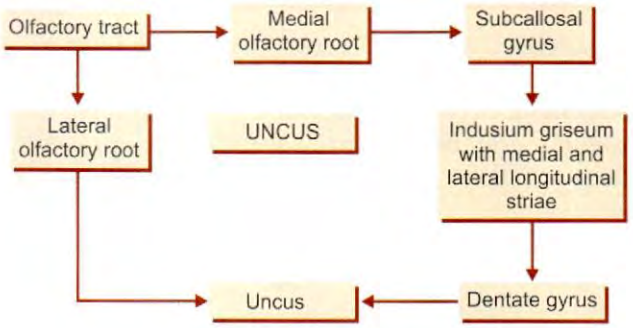
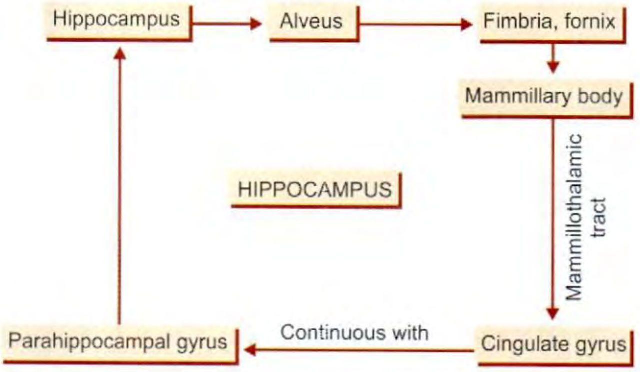


Fig. 9.13: Fornix and related pathways of limbic system

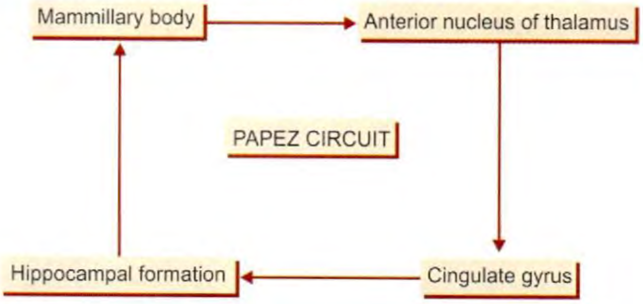
Flowchart 9.1a: Olfactory tracts



Flowchart 9.1b: Hippocampus



Flowchart 9.1c: Papez circuit



Connecting Pathways

Alveus, fimbria, fornix, mammillary body, mammillothalamic tract, and stria terminalis (Fig. 9.13).

Limbic Lobe

Hippocampus, parahippocampal gyrus, cingulate gyrus, subcallosal gyrus, and amygdala. These are non-neocortical structures (Fig. 9.14).

Hippocampal Formation

Hippocampus, dentate gyrus, and part of parahippocampal gyrus (Flowchart 9.1b).

Limbic System

This is a functioning group. It includes hypothalamus, some nuclei of thalamus, tectum of midbrain, frontal lobe, insular cortex. These are all concerned with emotional states and behaviour.

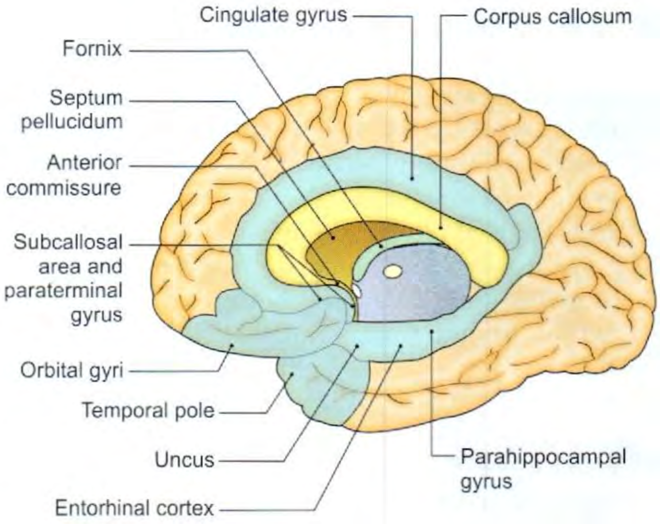


Fig. 9.14: Parts of limbic system

Papez Circuit

It interconnects limbic structures, hippocampus, fornix, mammillary body, mammillothalamic tract, anterior nucleus of thalamus, cingulate gyrus, cingulum, parahippocampal gyrus (Fig. 9.15 and Flowchart 9.1c). It is important for long-term permanent memory.

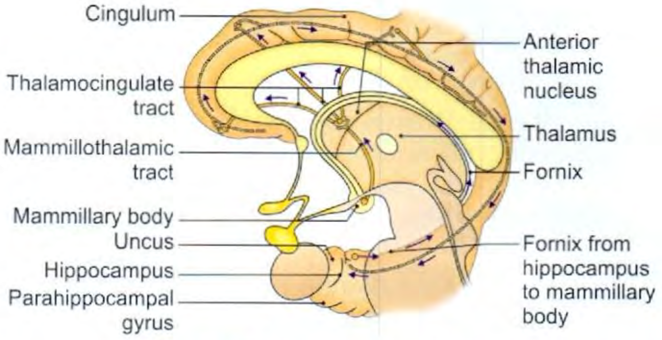


Fig. 9.15: Uncus and Papez circuit

CLINICAL ANATOMY

- Hippocampus can be regarded as the cortical centre for autonomic reflexes. Hippocampal-amygdala complex is related to the memory of recent events. Lesions of this complex are associated with a loss of memory for recent events only. Patient is unable to commit any new facts to memory and does not remember recent events. In spite of this, his general intelligence remains unaltered.
- Destruction of olfactory nerves results in loss of the sense of smell (anosmia).

- A tumour, usually a meningioma, in the floor of anterior cranial fossa may interfere with the sense of smell because of pressure on olfactory bulb and the olfactory tract. It is necessary to test each nostril separately because the olfactory loss is likely to be unilateral.
- A lesion that affects the uncus and amygdaloid body may cause, "uncinate fits" characterised by an imaginary disagreeable odour, by movements of lips and tongue, and often by a "dreamy state".

FACTS TO REMEMBER

- The right and left lateral ventricles communicate with the single third ventricle through the interventricular foramen.
- Third ventricle is a slit-like ventricle in between the two thalami.
- Aqueduct is the narrow duct connecting 3rd ventricle above with the fourth ventricle below.
- Limbic system comprises connections of fornix and Papez circuits. These are mostly present on the flat medial surface of cerebral hemisphere.

CLINICOANATOMICAL PROBLEM

A patient complained of severe headache and vomiting off and on for a few months. Later these became persistent. On examination and investigations, there was a tumour below third ventricle which prevented the normal flow of CSF. He also showed papilloedema.

- Which organ would usually be involved in tumour?
- Name the nuclei of thalamus.

Ans: Mostly the thalamus is involved in this case. Since third ventricle is a very narrow space between the two thalami, it gets blocked easily causing headache and vomiting. The meninges and CSF travel along the optic nerve till the optic disc. The raised intracranial pressure is projected at the optic disc in the form of papilloedema.

Nuclei of thalamus: Anterior, medial and lateral groups.

Group lateral is divided into:

- Dorsolateral which comprises—lateral dorsal, lateral posterior and pulvinar.
- Ventromedial which comprises—anterior, intermediate and posterior.

FREQUENTLY ASKED QUESTIONS

1. Write an essay on third ventricle of brain.
2. Describe the structures seen in the body and inferior horn of lateral ventricle.
3. Write short notes on:
   a. Papez circuit
   b. Limbic system

MULTIPLE CHOICE QUESTIONS

1. Foramen of Monro connects:
   a. Lateral ventricle to 4th ventricle
   b. 3rd ventricle to 4th ventricle
   c. 3rd ventricle to aqueduct
   d. Lateral ventricle to 3rd ventricle
2. Which of the following is largest horn of lateral ventricle?
   a. Posterior horn b. Inferior horn
   c. Anterior horn d. Central part
3. Which is not a part of limbic system?
   a. Hypophysis cerebri
   b. Amygdaloid nuclei
   c. Olfactory nerve, bulbs, tracts and stria
   d. Fornix
4. What is correct form of Papez circuit?
   a. Mammillary body–anterior nucleus of thalamus–cingulate gyrus–hippocampal formation
   b. Mammillary body–cingulate gyrus–anterior nucleus of thalamus–hippocampal formation
   c. Mammillary body–hippocampal formation–anterior nucleus of thalamus–cingulate gyrus
   d. Anterior nucleus of thalamus–mammillary body–cingulate gyrus–hippocampal formation
5. Hippocampal amygdala is related to:
   a. Memory for recent events
   b. Movements
   c. Emotional behaviour
   d. None of the above

ANSWERS

1. d **2.** b **3.** a **4.** a **5.** a

CHAPTER

10

Some Neural Pathways and Reticular Formation

Life is a constant struggle to keep up appearances and keep down expenses
—P Syrcus

INTRODUCTION

Course of pyramidal tracts responsible for voluntary movements is described here. The sensory pathways for exteroceptive, unconscious and conscious proprioceptive are outlined.

PYRAMIDAL TRACT: CORTICOSPINAL AND CORTICONUCLEAR TRACTS

This is a descending tract, extending from the cerebral cortex to various motor nuclei of the cranial and spinal nerves. It constitutes the upper motor neuron in the motor pathway from the cortex to voluntary muscles.

Corticonuclear fibres reach the nuclei of cranial nerves (Fig. 10.1).

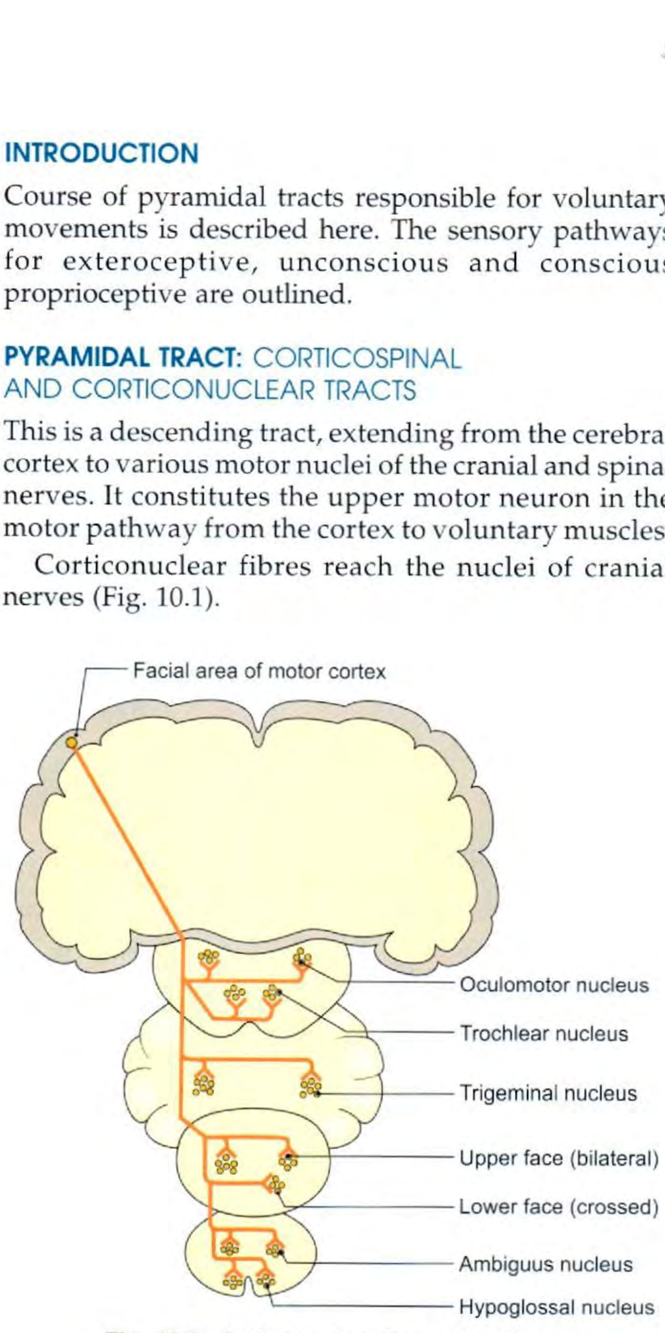


Fig. 10.1: Pathway of corticonuclear fibres

Origin

Each pyramidal tract contains about one million fibres which originate from:

1 The motor area 4 of the cortex
2 Premotor area 6 and also
3 The somesthetic areas 3, 2, 1.

Certain notable features of the motor cortex are given.

1 The body is represented upside down. The areas for the legs and perineum lie in the paracentral lobule.
2 The angle of mouth, tongue, larynx, the thumb and the great toe are represented by relatively large areas.
3 It is the movements which are represented in the cortex rather than the individual muscles.

Course

The tract passes through the following parts of the CNS.

1 Corona radiata.
2 Internal capsule, occupying the genu and the posterior limb.
3 Middle two-thirds of the crus cerebri of the midbrain.
4 Basilar part of the pons.
5 Pyramid of the medulla. In the lower part of the medulla, about 75 to 80% of the fibres cross to opposite side and descend as the lateral (crossed) corticospinal tract. About 20% fibres remain uncrossed and run down as the anterior (uncrossed) corticospinal tract (*see* Fig. 3.11).
6 Thus, in the spinal cord, there are two corticospinal tracts: Lateral (crossed) and anterior (uncrossed). Ultimately most of the uncrossed fibres also cross to the opposite side before termination (*see* Fig. 3.12).

Termination

Before termination, all fibres of the pyramidal tract cross to opposite side. They terminate, mostly through an interneuron, in the motor nuclei of cranial nerves and in relation to the anterior horn cells of the spinal cord. The fibres which terminate in the motor nuclei of the cranial nerves collectively form the corticonuclear tract.

Functions

1. The pyramidal tract is concerned with voluntary movements of the body.
2. Possibly, it is also the pathway for superficial reflexes.

CLINICAL ANATOMY

- Effects of lesion of the pyramidal tract:
  Lesions above the level of decussation cause contralateral paralysis (Fig. 10.2), while lesions below the decussation cause ipsilateral paralysis. It is an upper motor neuron type of paralysis which is characterized by the following.
  a. Loss of the power of voluntary movements.
  b. Clasp-knife type of rigidity (hypertonia).
  c. Tendon reflexes are exaggerated.
  d. Superficial reflexes are lost.
  e. Babinski's sign is positive.
  f. Reaction of degeneration is absent.

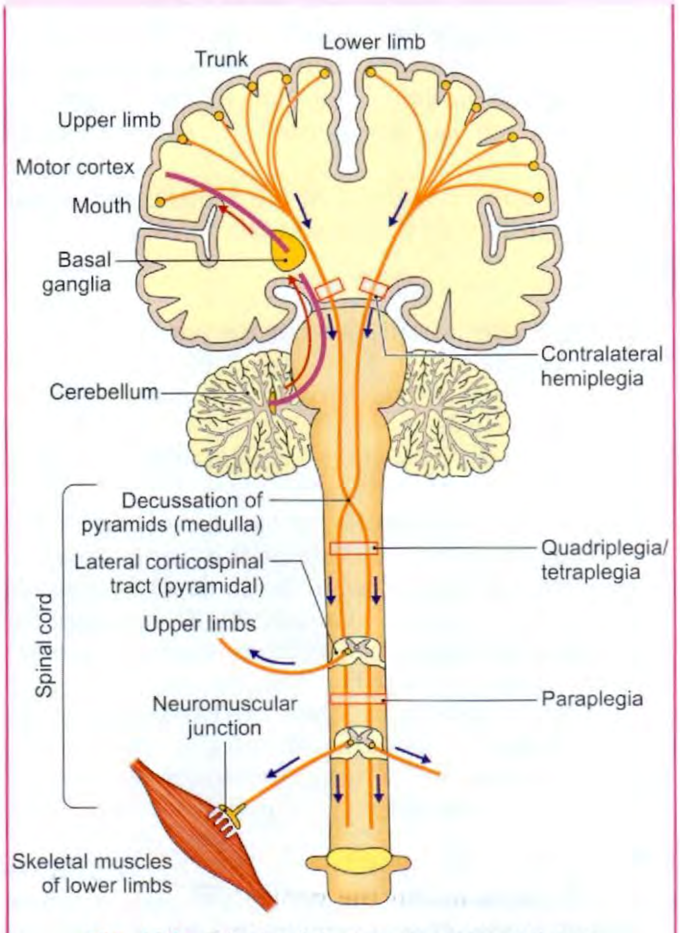


Fig. 10.2: Effects of damage to motor pathway

PATHWAY OF PAIN AND TEMPERATURE

Receptors

1. Free nerve endings for pain.
2. End bulbs of Krause for cold.
3. Organs of Ruffini for warmth, and of Golgi-Mazzoni for heat.

First Neuron

First neuron is located in the dorsal root ganglia. Peripheral processes of neurons in the ganglia constitute the sensory nerves. These processes end in relation to the receptors. The central processes of the neurons pass through the dorsal nerve roots to enter the spinal cord, where they synapse with the second neuron.

Second Neuron

Second neuron is located in the grey matter of the spinal cord. Their axons form the lateral spinothalamic tract. This tract is crossed. It ascends through the lateral white column of the spinal cord to enter the brain stem. In the brain stem, this tract is referred to as the spinal lemniscus to end in the thalamus (Figs 10.3a and b).

Third Neuron

Third neuron lies in the posterolateral ventral nucleus of the thalamus. Fibres arising in this nucleus pass through the internal capsule and the corona radiata to reach the somatosensory areas 3, 1, 2 of cerebral cortex.

PATHWAY OF TOUCH

Receptors

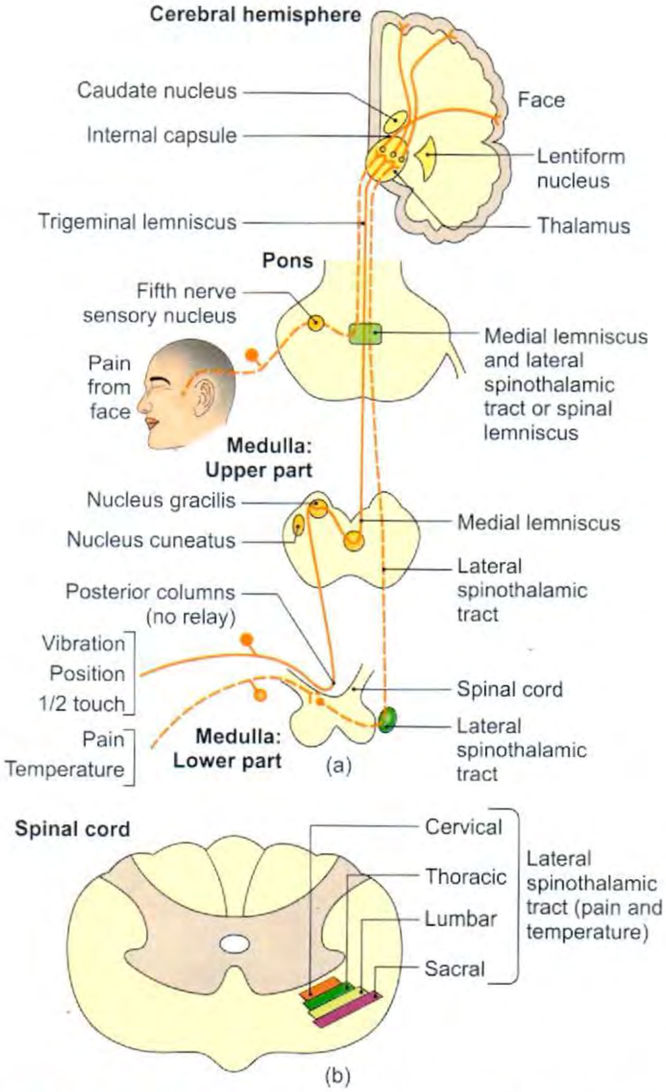
1. Tactile (Messiner's) corpuscles.
2. Merkel's discs.
3. Free nerve endings around the hair follicles.

First Neuron

First neuron is similar to that for pain and temperature pathway. The 2nd neuron is different for fine touch and for crude touch.

PATHWAY OF FINE TOUCH

1. The central processes of the neurons in the dorsal nerve root ganglia enter the posterior white column of the spinal cord and form the fasciculus gracilis and the fasciculus cuneatus. These are uncrossed tracts.
2. The second neuron lies in the nucleus gracilis or nucleus cuneatus. It gives off the internal arcuate fibres which cross to the opposite side through the sensory decussation. Reaching the other side they run upwards as the medial lemniscus. The medial lemniscus ends in the posterolateral ventral nucleus of the thalamus.



Figs 10.3a and b: Pathway of: (a) Posterior column, and (b) pain and temperature impulses

3 Fibres starting in the thalamus pass through the internal capsule and the corona radiata and end in the somatosensory area of the cerebral cortex (areas 3, 1, 2).

PATHWAY OF CRUDE TOUCH

1 The central processes of neurons in the dorsal nerve root ganglia terminate in the grey matter of the spinal cord.
2 The second neuron lies in the spinal cord (mainly the posterior grey column). Axons of those neurons cross the midline and form the anterior spinothalamic tract. In the brain stem, this tract merges with the medial lemniscus.
3 The third neuron and termination of the pathway are the same as for fine touch.

PATHWAY OF PROPRIOCEPTIVE (KINAESTHETIC) IMPULSES

Receptors

1 Muscle spindles
2 Golgi tendon organs
3 Pacinian corpuscles
4 Uncapsulated nerve endings.

First Neuron

First neuron is similar to that for pain and temperature.

In their further course, the proprioceptive pathways are different for conscious and unconscious impulses.

PATHWAY OF CONSCIOUS PROPRIOCEPTIVE IMPULSES

Their course is similar to that for fine touch described earlier.

PATHWAY OF UNCONSCIOUS PROPRIOCEPTIVE IMPULSES

These impulses end in the cerebellum (*see* Figs 3.16 and 3.17).

1 The first neuron has been described above.
2 The *second neuron* fibres are represented by three tracts, namely the posterior and anterior spinocerebellar tracts (from the lower limb and trunk) and the cuneocerebellar tract (posterior external arcuate fibres) from the upper limb.

The *posterior spinocerebellar tract* contains ipsilateral fibres arising in dorsal (thoracic) nucleus of the spinal cord. It enters the ipsilateral cerebellar hemisphere through the inferior cerebellar peduncle.

The *anterior spinocerebellar tract* is made up mainly of crossed fibres arising from the spinal grey matter (posterior grey column). The fibres ascend to the upper part of pons and then turn down into the superior cerebellar peduncle to reach the cerebellum of same side.

The *cuneocerebellar tract (posterior external arcuate fibres),* is functionally similar to the posterior spinocerebellar tract. It arises from the accessory (external) cuneate nucleus which receives afferents from the fasciculus cuneatus. The tract enters the ipsilateral cerebellar hemisphere through the inferior cerebellar peduncle.

TASTE PATHWAY

1 The taste from anterior two-thirds of tongue except from vallate papillae is carried by chorda tympani branch of facial till the geniculate ganglion. The central processes go to the tractus solitarius in the medulla (Fig. 10.4).

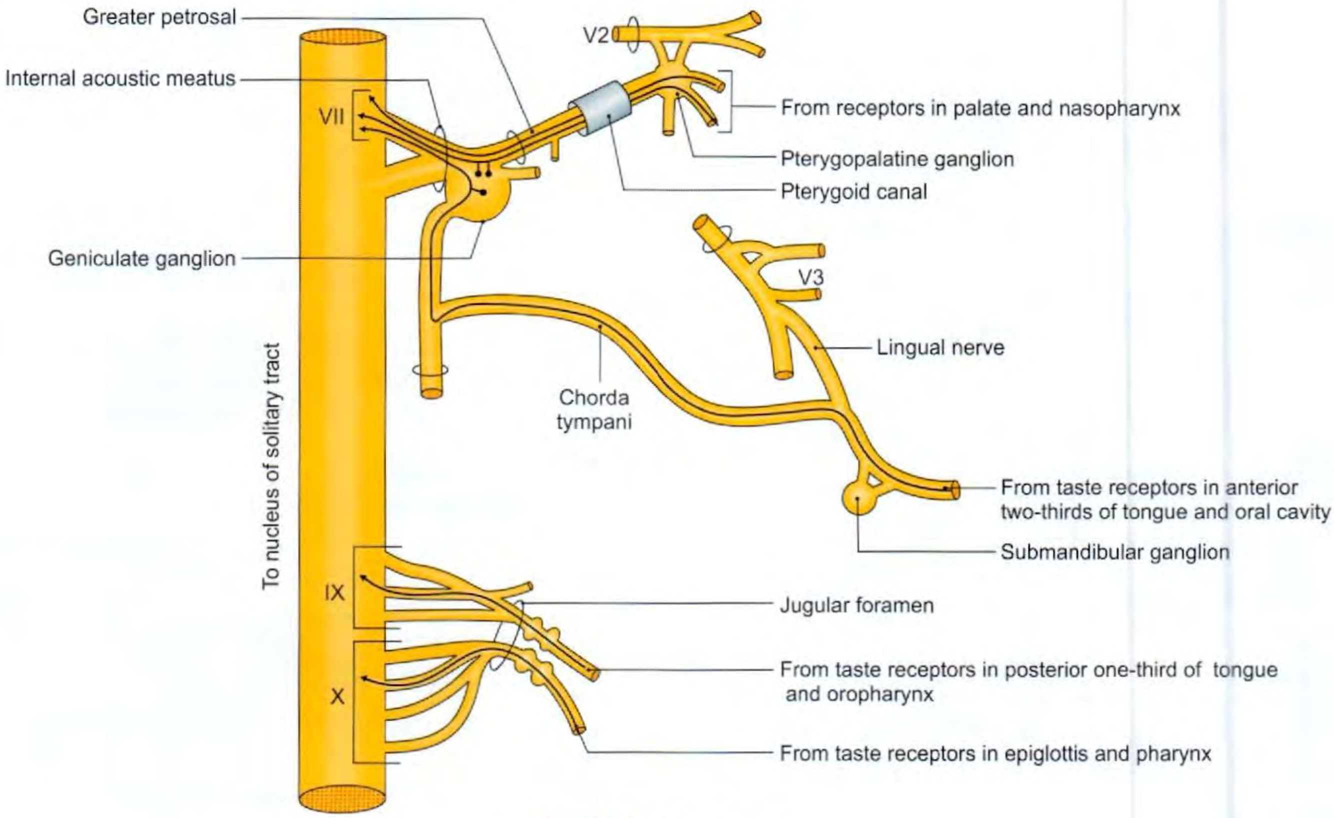


Fig. 10.4: Taste pathway

2 Taste from posterior one-third of tongue including the vallate papillae is carried by cranial nerve IX till the inferior ganglion. The central processes also reach the tractus solitarius.

3 Taste from posteriormost part of tongue and epiglottis travel through vagus nerve till the inferior ganglion of vagus. These central processes also reach tractus solitarius.

4 After a relay in tractus solitarius, the solitario-thalamic tract is formed which becomes a part of trigeminal lemniscus and reaches the ventro-posteromedial nucleus of thalamus of opposite side. Another relay here takes the fibres to lowest part of postcentral gyrus, which is the area for taste.

RETICULAR FORMATION

The reticular formation is a diffuse network of fine nerve fibres 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 brain stem, although it can be traced to all levels of the CNS.

LOCATION AND IDENTITY

1 The reticular formation, in general, is placed in the deep and dorsal parts of the neural axis.

2 It is very diffuse in its distribution, and has ill-defined boundaries.

3 It is better defined physiologically than anatomically (*see* Figs 5.5, 5.12 and 5.13).

CONNECTIONS

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

1 The *motor neurons* of the cerebral cortex, the basal ganglia, the cerebellum, various masses of grey matter in the brain stem including the nuclei of cranial and spinal nerves.

2 The *sensory neurons* of the somesthetic pathways (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.

3 The *autonomic neurons* of the hypothalamus, limbic system and the general visceral efferent columns.

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 areas facilitate them.

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 anaesthetics produce their effects by acting on this system.

Autonomic Influences

Through its autonomic connections and certain specific centres, 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, behavioural and visceral activities. It also takes part in neuroendocrine regulation and the development of conditioned and learned reflexes.

ACTION OF DRUGS

1 Narcotics act more on nonspecific sensory system and less on the specific sensory system. Their main action is depression of reticular-activating system, precise effects of which depend upon the type of narcotics used and its dosage. Narcotics depress the diffuse thalamocortical system as well.

2 Barbiturates depress the afferent impulses reaching the reticular-activating pathways.

3 Analgesics act by suppression of reactions concerned with activation of reticular-activating pathways.

4 Morphine suppresses the corticoreticular pathways, and stimulates the nonspecific thalamic system, rhinencephalon and its projections. It also depresses conduction along specific sensory pathways.

FACTS TO REMEMBER

- Corticonuclear fibres give fibres to cranial nerve nuclei.
- The corticonuclear fibres of one side of cortex reach VII nerve nucleus of both sides which supply the muscles of upper half of face on both sides. It also gives fibres to nucleus of VII and supply to lower half of facial muscles only on the contralateral side.
- Unconscious impulses reach ipsilateral cerebellum, while conscious impulses reach the contralateral cerebrum.
- Anterior spinothalamic carrying crude touch and pressure joins the medial lemniscus during its upward journey through the brain stem. Thus, medial lemniscus carries conscious proprioceptive sensations, i.e. movement, vibration and position including whole touch and pressure to the thalamus.
- Nucleus of tractus solitarius receives impulses of taste through chorda tympani, branch of VII from most of anterior two-thirds of tongue; through glossopharyngeal from circumvallate papillae and posterior one-third of tongue. It also receives impulses from posterior most part of tongue and vallecula via internal laryngeal branch of vagus nerve.

FREQUENTLY ASKED QUESTIONS

1. Describe the pyramidal tract under the following headings:
   a. Origin
   b. Course
   c. Termination and functions
2. Describe the pathway of crude touch and fine touch.
3. Write short notes on:
   a. Pathway of unconscious propriocptive impulses
   b. Pathway of taste
   c. Location and main connections of reticular formation

MULTIPLE CHOICE QUESTIONS

1. Nucleus receiving impulses of taste:

a. Dorsal nucleus of vagus
b. Spinal nucleus of trigeminal nerve
c. Nucleus ambiguus
d. Tractus solitarius

2. Action of barbiturates is:

a. Suppress the corticoreticular pathways
b. Increase the activity of reticular-activating system
c. Depress the afferent impulses reaching reticular-activating pathway
d. None of these

3. Ascending reticular-activating system is formed by:

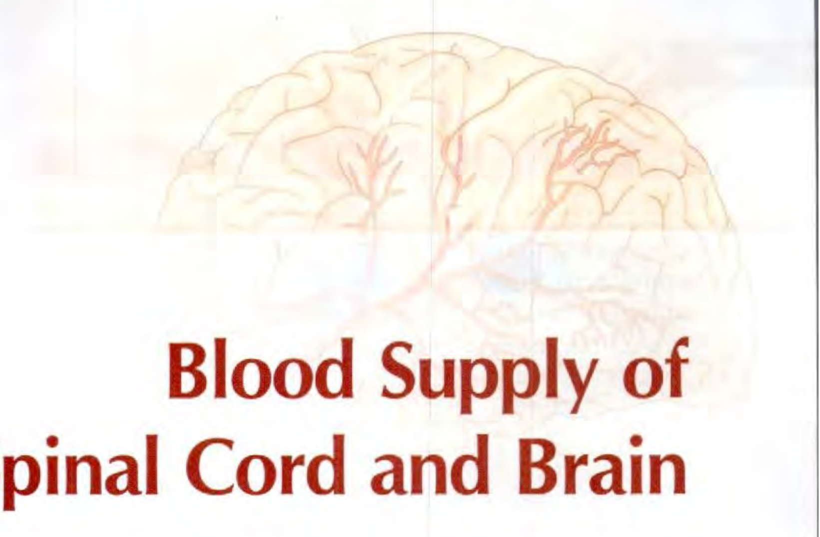
a. Great number of collaterals from spinothalamic tract
b. Trigeminal lemniscus
c. Auditory pathway
d. All of these

4. Upper motor neuron type of paralysis is characterised by:

a. Clasp knife type of rigidity
b. Tendon reflexes are exaggerated
c. Babinski's sign positive
d. All of these

ANSWERS

1. d **2.** c **3.** d **4.** d



CHAPTER

11

Blood Supply of Spinal Cord and Brain

The only weapon with which the unconscious patient can immediately retaliate upon the incompetent surgeon is haemorrhage

—William S Halsted

INTRODUCTION

The nervous tissue is too delicate to bear anoxia beyond three minutes. The blood supply to nervous tissue per unit tissue is maximum in the body. It shows the importance of the grey matter. The blood supply may be erratic due to haemorrhage, thrombosis or embolism of the arteries supplying the nervous tissue. Further the arteries are "end arteries" once these reach the deeper level. Neurons die, in bits and pieces; an individual also walks slowly and steadily towards death, and that is the end of this physical life.

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). In addition to these channels, the pia mater covering the spinal cord has an arterial plexus (called the *arteria vasocorona)* which also sends branches into the substance of the cord (Fig. 11.1).

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.

Many of these radicular branches are small and end by supplying the nerve roots. A few of them, which are larger, contribute blood to the spinal arteries. Frequently, one of the anterior radicular branches is very large and is called the *arteria radicularis magna.* Its position is variable. This artery may be responsible for supplying blood to as much as the lower two-thirds of the spinal cord.

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.

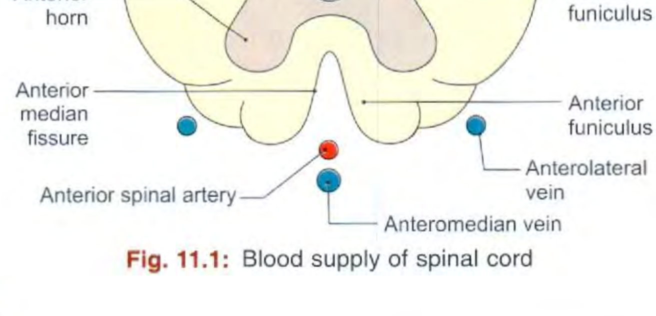


Fig. 11.1: Blood supply of spinal cord

CLINICAL ANATOMY

Anterior spinal artery supplies anterior two-thirds while posterior spinal artery supplies posterior one-third of spinal cord. Posterior column gets affected in posterior spinal artery thrombosis. Anterolateral columns get affected in anterior spinal artery thrombosis (Fig. 11.2).

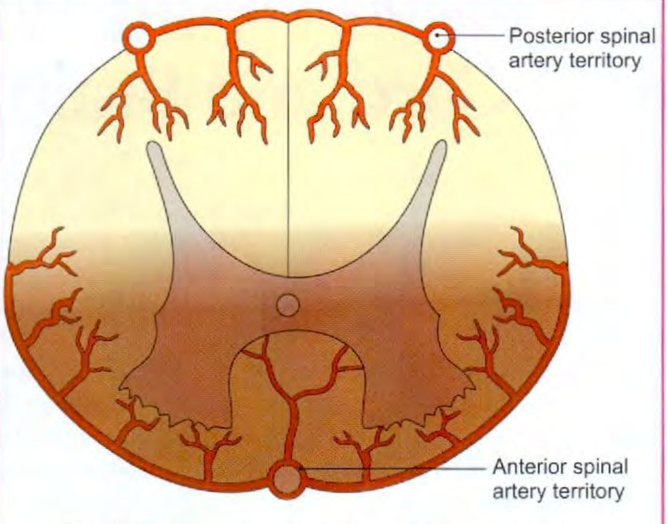


Fig. 11.2: Thrombosis of the anterior spinal artery

ARTERIES OF BRAIN

Two vertebral and two internal carotid arteries carry the total arterial supply to the brain (*refer to BDC App*).

VERTEBRAL ARTERIES

The vertebral artery on each side is a branch of first part of subclavian artery. Its course is divided into four parts:

- 1st part lies from its origin to the foramen transversarium of 6th cervical vertebra.
- 2nd part courses through foramen transversaria of 6th to 1st cervical vertebrae (Fig. 11.3).
- 3rd part lies on the posterior arch of atlas vertebra in the suboccipital triangle.
- 4th part of the vertebral artery enters the cranium through foramen magnum under the free margin of posterior atlanto-occipital membrane.

It enters the subarachnoid space in the upper part of vertebral canal after piercing the dura mater and arachnoid mater. Then it curves round the ventrolateral aspect of the medulla oblongata between the rootlets of hypoglossal nerve, to unite with its fellow at the lower border of pons and forms the median basilar artery.

Intracranial Branches

Posterior Spinal Artery

It is the first intracranial branch. It passes inferiorly on the spinal medulla among dorsal roots of spinal nerves (Fig. 11.4).

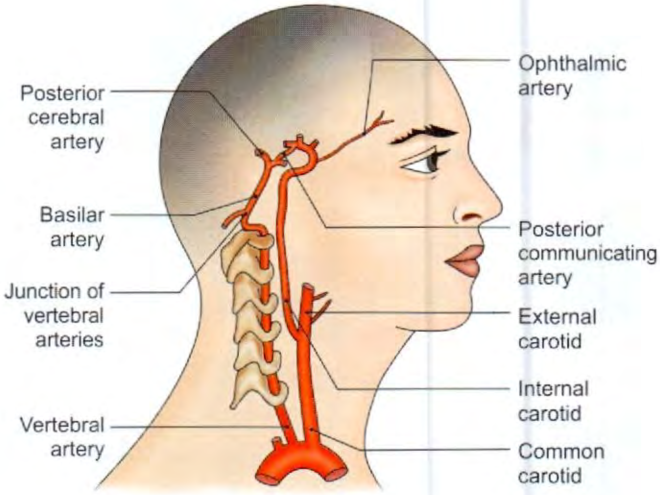


Fig. 11.3: Carotid and vertebral arteries

Posterior Inferior Cerebellar Artery

It is the largest branch which arises from vertebral artery after it pierces the meninges. It pursues a tortuous course, passes between rootlets of hypoglossal, vagus and glossopharyngeal nerves supplies almost lateral half of medulla as far as the lower border of pons, reaches its posterior aspect between the thin roof of cavity of fourth ventricle and cerebellum, gives a choroidal branch to the choroid plexus of fourth ventricle and turns downwards on the cerebellum supplying it.

Anterior Spinal Artery

It is formed by the union of a branch from each vertebral artery on ventral surface of medulla oblongata close to the pons. It supplies the median part of medulla oblongata and continues inferiorly throughout the length of spinal medulla/cord (Fig. 11.1).

Medullary Branches

As vertebral artery ascends along medulla oblongata, it gives number of branches to the medulla oblongata.

Meningeal Branches

A few meningeal branches are given.

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

1 *Anterior inferior cerebellar artery:* It arises at the lower border of pons, and passes laterally, supplying the sixth, seventh and eighth cranial nerves. It then loops over the flocculus of cerebellum and supplies anteroinferior aspect of cerebellum.

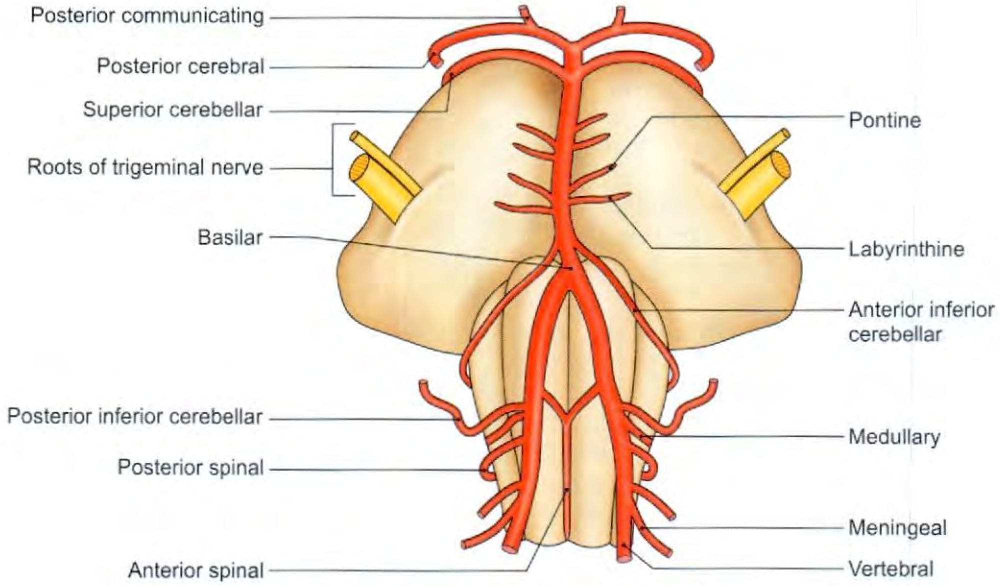


Fig. 11.4: Arteries related to brain stem

2 *Labyrinthine artery:* It accompanies the vestibulocochlear nerve and enters the internal auditory meatus to supply the internal ear. It is an end artery.

3 *Pontine branches:* These are numerous slender branches which pierce the pons both in the medial and lateral parts (Fig. 11.4).

4 *Superior cerebellar artery:* It arises close to superior border of pons. It winds posteriorly along the superior border of pons and middle cerebellar peduncle supplying both. It sends many branches to the superior surface of cerebellum.

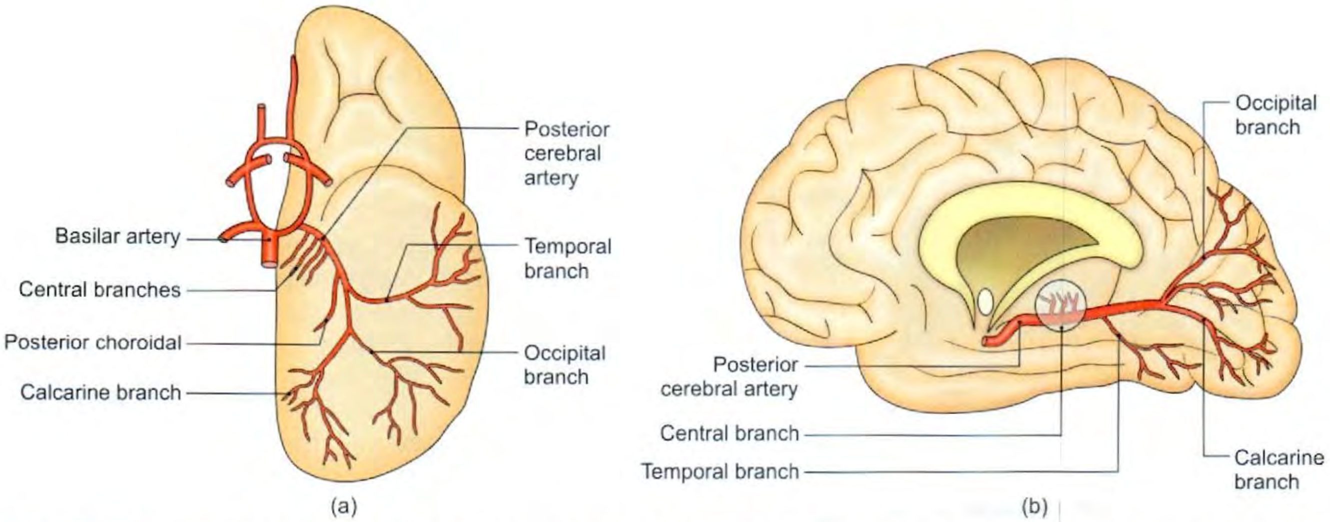
5 *Two terminal posterior cerebral branches diverge at upper border of pons:* These give rise to number of central (posteromedial group) branches into the ventral surface of midbrain and then curve posterolateral to midbrain at inferomedial surface of corresponding hemisphere supplying it with cortical branches.

Branches of posterior cerebral arteries

1 *Posteromedial central branches:* These pierce ventral surface of base of brain thus forming the *posterior perforated substance* in the interpeduncular fossa. These supply midbrain and caudal part of diencephalon.

2 *Posterior choroidal artery:* Arises on the lateral aspect of central branches, supplies choroid plexus of the lateral ventricle and the third ventricle.

3 *Cortical branches,* namely temporal branches, parieto-occipital branch and occipital branch to cerebral cortex as shown in Figs 11.5a and b.



Figs 11.5a and b: Posterior cerebral artery on: (a) Inferior surface of left cerebral hemisphere, and (b) medial surface of right cerebral hemisphere

CLINICAL ANATOMY

- Thrombosis of posterior cerebral artery results in homonymous hemianopia on the opposite side.
- Thrombosis of superior cerebellar artery results in Fig. 11.6.
  a. Cerebellum: Disturbed gait, limb ataxia.
  b. Brain stem: Ipsilateral Horner's syndrome. Contralateral sensory loss—pain and temperature (including face).
- Damage to anterior inferior cerebellar artery results in Fig. 11.7.
  a. Cerebellum: Ipsilateral limb ataxia.
  b Brain stem: Ipsilateral—Horner's syndrome. Sensory loss—pain and temperature of face. Facial weakness and paralysis of lateral gaze. Contralateral sensory loss—pain and temperature of limbs and trunk.
- Thrombosis of posterior inferior cerebellar artery causes damage as given in Fig. 11.8:
  a. Cerebellum: Dysarthria, ipsilateral limb ataxia, vertigo and nystagmus (due to damage to vestibulo-floccular connections).
  b. Brain stem: Ipsilateral—Horner's syndrome. Sensory loss—pain and temperature of face. Pharyngeal and laryngeal paralysis. Contralateral sensory loss—pain and temperature of limbs and trunk.

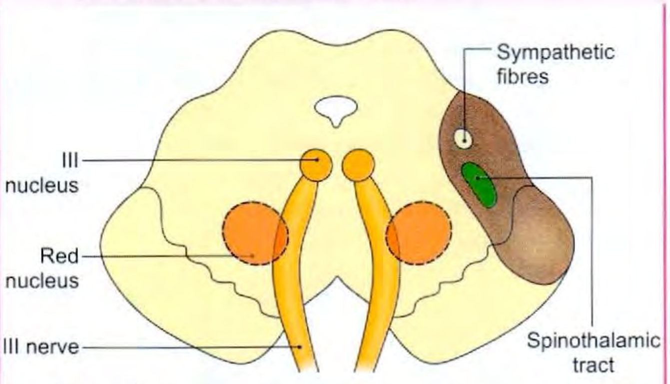


Fig. 11.6: Effects due to thrombosis of superior cerebellar artery

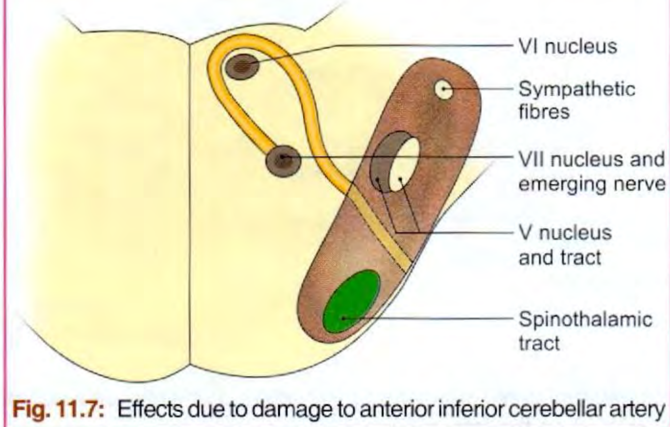


Fig. 11.7: Effects due to damage to anterior inferior cerebellar artery

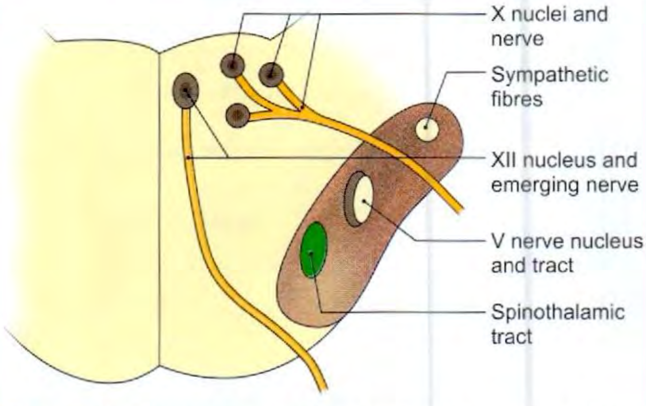


Fig. 11.8: Effects due to thrombosis of posterior inferior cerebellar artery

INTERNAL CAROTID ARTERY

Each internal carotid artery 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 divides into middle and anterior cerebral arteries.

Branches

1. *Ophthalmic artery* for the contents of orbit (*see* Chapter 13, Volume 3).
2. *Posterior communicating artery:* It passes posteriorly across the crus cerebri to join the posterior cerebral artery and helps to complete the arterial circle. It gives branches to the crus cerebri, optic tract, hypophysis and hypothalamus.
3. *Anterior choroidal artery:* It passes posterolaterally, supplies crus cerebri and turns laterally to the medial aspect of temporal lobe to supply choroid plexus of inferior horn of lateral ventricle.
4. *Anterior cerebral artery:* It is a terminal branch of internal carotid artery and runs above the optic nerve to follow the curve of corpus callosum. Close to its origin, this artery is joined by anterior communicating artery. Deep branches of anterior cerebral supply part of internal capsule and the basal nuclei. Cortical branches supply the medial surface of hemisphere by giving:
   a. Orbital
   b. Frontal
   c. Parietal branches (Fig. 11.9).
5. *Middle cerebral artery:* It is the larger terminal branch of internal carotid artery that lies in line with the internal carotid artery (Figs 11.10a and b). It runs laterally in the stem of lateral sulcus. It gives off:

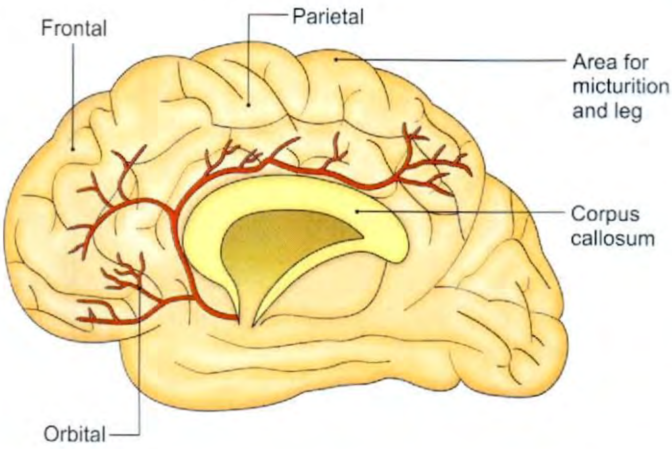
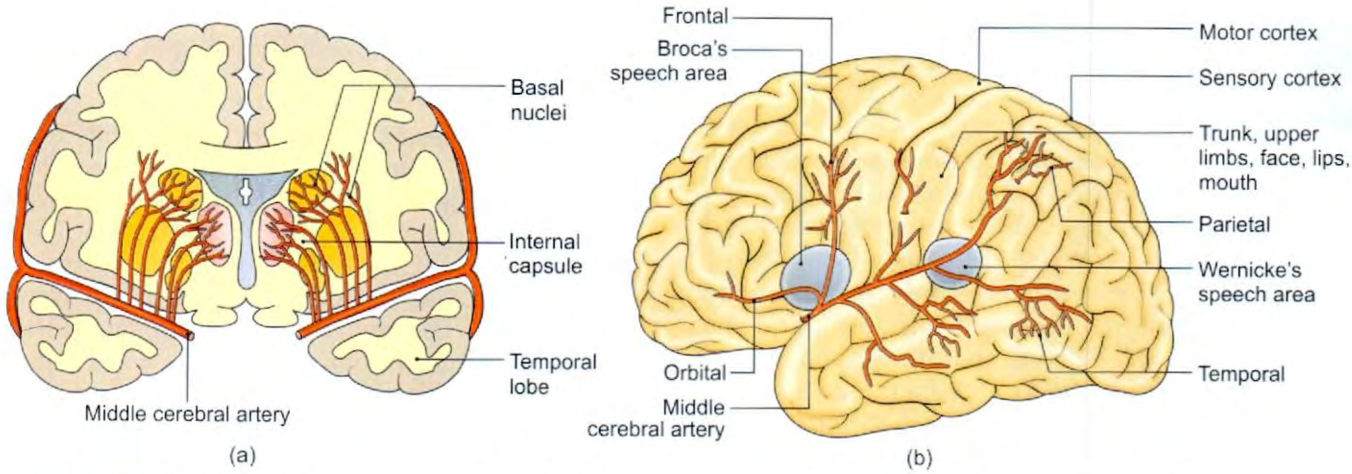


Fig. 11.9: Medial surface of right cerebral hemisphere with anterior cerebral artery

a. Deep or perforating branches which supply anterior limb of internal capsule and part of basal nuclei. The artery then passes out to the lateral surface of hemisphere at the insula of the lateral sulcus. It ends by giving cortical branches.
b. Temporal (Fig. 11.11)
c. Frontal
d. Parietal branches.

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 of internal carotid, terminal parts of internal carotid arteries and the posterior cerebral branches of basilar artery (*refer to BDC App*).



Figs 11.10a and b: (a) Deep branches of middle cerebral artery, and (b) cortical branches of middle cerebral artery

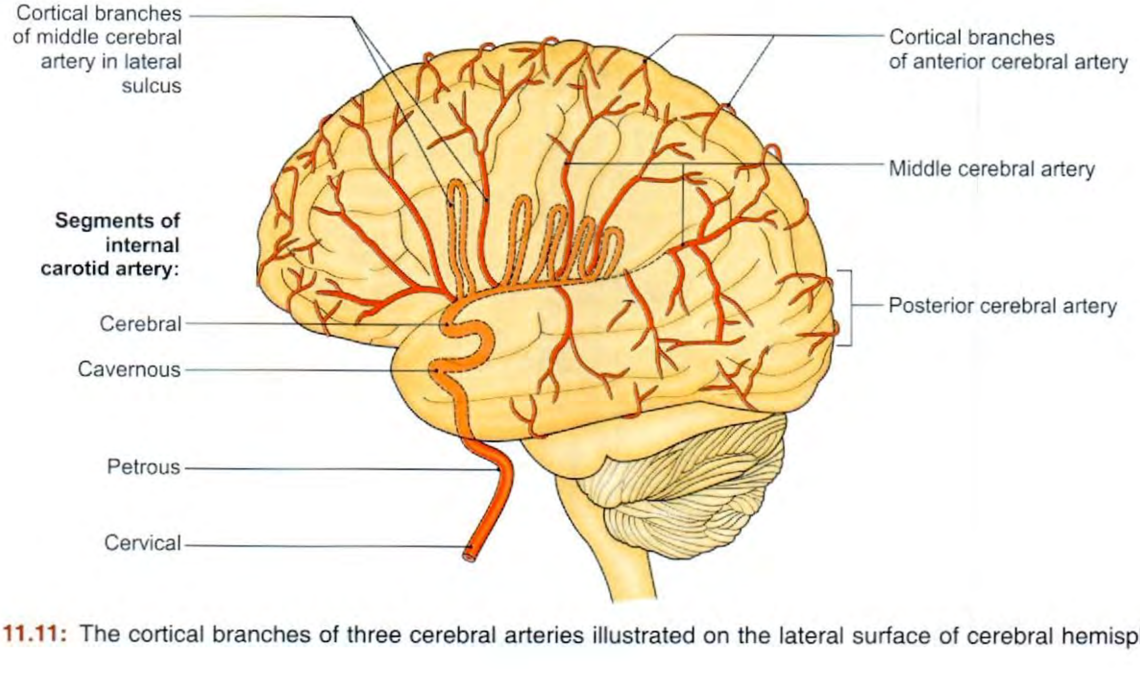


Fig. 11.11: The cortical branches of three cerebral arteries illustrated on the lateral surface of cerebral hemisphere

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.

FORMATION

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

Anterolaterally: Anterior cerebral arteries.

Laterally: Internal carotid arteries (Figs 11.12 and 11.13a, b).

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 blood streams on right and left sides of the circulus arteriosus. Middle cerebral artery is not forming the circle of Willis.

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 11.1.

Cerebral Cortex

Cerebral cortex is 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:
   i. A strip of about 2 cm wide along the superomedial border extending from frontal pole to the parietooccipital sulcus is supplied by anterior cerebral artery (Fig. 11.14).
   ii. Area of occipital lobe is supplied by posterior cerebral artery.
   iii. Inferior temporal gyrus excluding the part of the temporal pole is also supplied by posterior cerebral artery.
2. *Medial and tentorial sufaces*: 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. 11.15).
3. *Inferior surface*: Medial one-third of orbital surface is supplied by anterior cerebral, while lateral two-thirds, including the temporal pole area and anterior most part of tentorial surface is vascularised by middle cerebral. Rest of the tentorial surface is supplied by the posterior cerebral artery (Fig. 11.16).

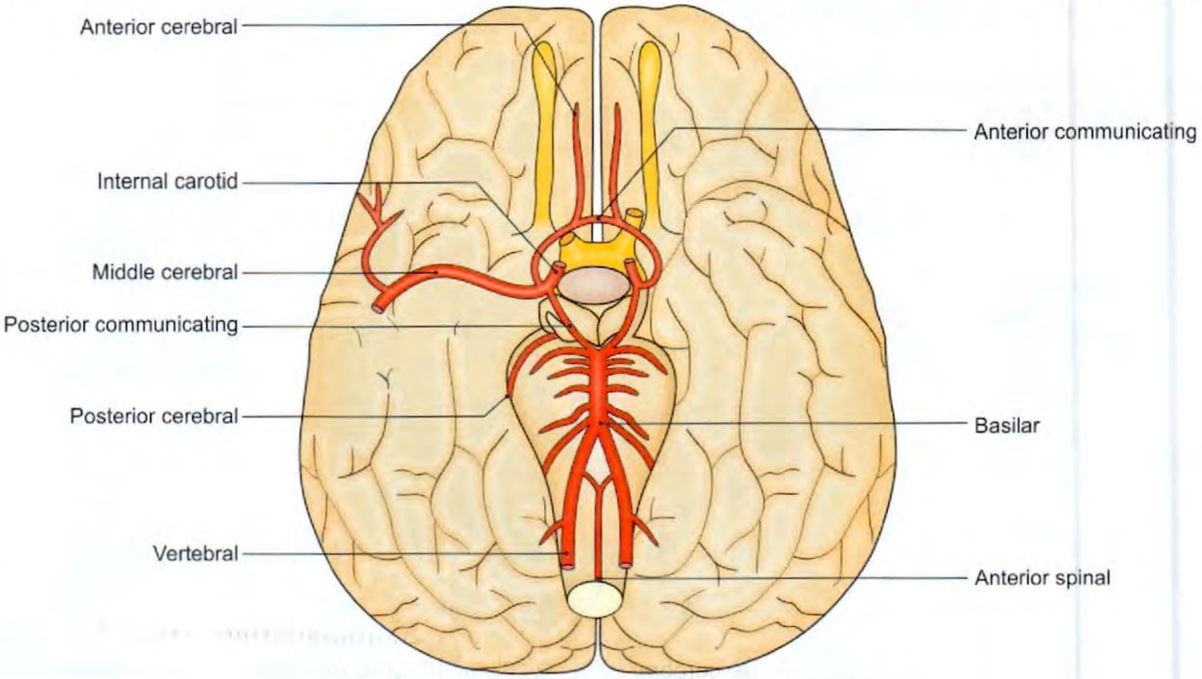


Fig. 11.12: Arteries seen on the inferior surface of brain

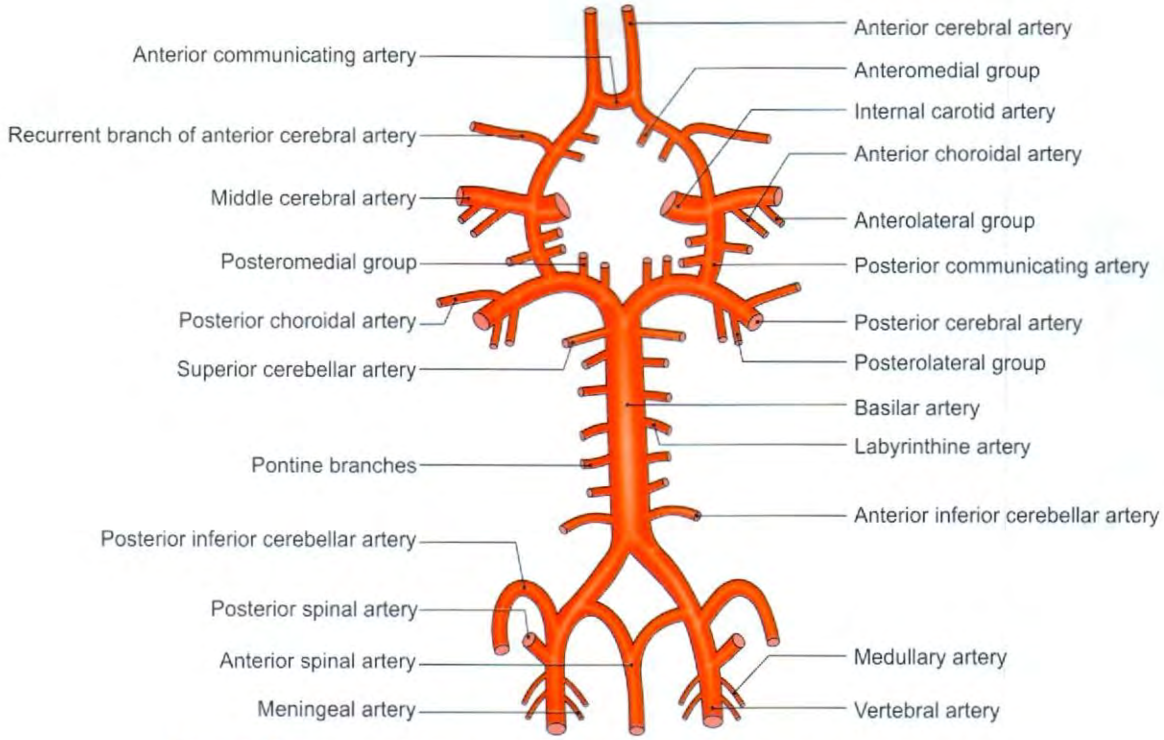


Fig. 11.13a: Circle of Willis and the branches of arteries supplying the brain

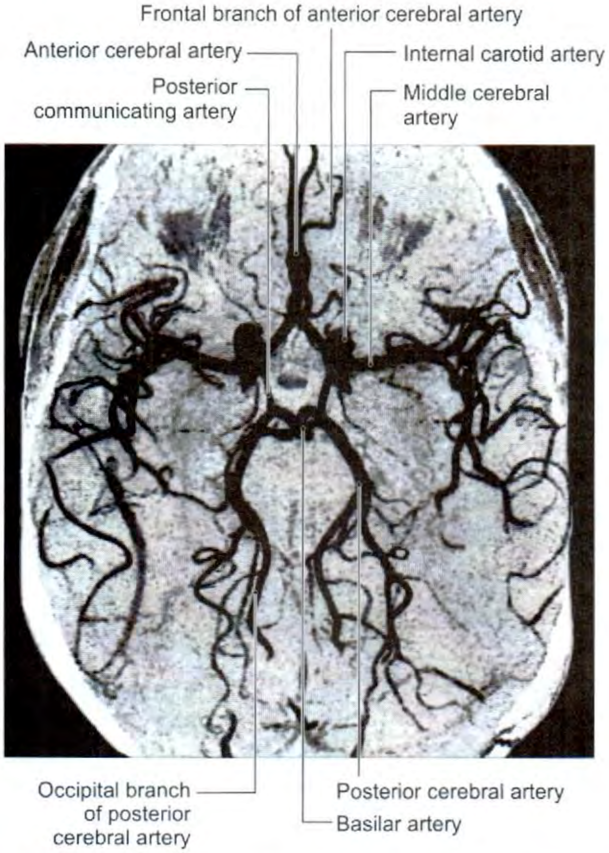


Fig. 11.13b: Magnetic resonance angiogram of the cerebral blood vessels

Central Branches

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

1. Anteromedial arise as one group from both anterior cerebral and anterior communicating artery. These enter the medialmost part of anterior perforated substance.
2. Anterolateral group arise in *two groups* one from each middle cerebral artery. These divide in two sets: Mediate striate ascend through lentiform nucleus to supply this nucleus including caudate nucleus and internal capsule. The lateral striate arise ascend lateral to lentiform nucleus, turn medially, pass through the substance of this nucleus to enter internal capsule. One of the lateral striate branch is larger than the others and is called Charcot's artery of cerebral haemorrhage.
3. The posteromedial arise as *one group* from posterior communicating and posterior cerebral arteries.
4. Posterolateral arise as *two groups* from the lateral parts of each posterior cerebral artery. These are also in two sets.

Choroidal Branches

1. The anterior choroidal is a branch of internal carotid artery. It supplies blood to choroid plexus of inferior horn of lateral ventricle.
2. Posterior choroidal artery arises from posterior cerebral to give branches for the choroid plexus of rest of lateral ventricle including third ventricle.

Table 11.1: Important arteries of brain

Artery	*Origin*	*Course*	*Cortical branches*
Middle cerebral (Figs 11.10 and 11.14)	Largest and direct branch of ICA	In the lateral sulcus and on the insula	1. Orbital 2. Frontal 3. Parietal 4. Temporal
Anterior cerebral (Figs 11.9 and 11.15)	Smaller terminal branch of ICA	Coextensive with corpus callosum. Two arteries are connected by the anterior communicating artery	1. Orbital 2. Frontal 3. Parietal, including paracentral artery
Posterior cerebral (Fig. 11.16)	Terminal branch of basilar artery	Winds round cerebral peduncle to reach the tentorial surface of cerebruma	1. Temporal 2. Occipital 3. Parieto-occipital

* AL: Anterolateral; AM: Anteromedial; PM: Posteromedial; PL: Posterolateral

3. Posterior inferior cerebellar artery supplies the choroid plexus of the fourth ventricle.

Important arteries of the brain are shown in Table 11.1.

ARTERIAL SUPPLY OF DIFFERENT AREAS

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. 11.14).

Anterior cerebral artery is chief artery on medial surface (Fig. 11.15).

Posterior cerebral is principal artery on inferior surface (Fig. 11.16).

Cerebellum

The little brain is supplied by following arteries:

- Superior cerebellar
- Anterior inferior cerebellar
- Posterior inferior cerebellar

BLOOD-BRAIN BARRIER

The constituents of CSF are not exactly same as those of extracellular fluid (ECF) elsewhere in the body. Many large molecular substances hardly pass from blood to CSF or interstitial fluids of brain even though these can pass to ECF of the body thereby reflecting the existence of BBB.

The existence of a 'blood–brain barrier' (BBB or haematoencephalic barrier) is due to the fact that the endothelial cells of brain capillaries are held to each other by tight junctions. The BBB is formed by structures between the blood and nerve cells of brain. The blood in the lumen of the capillary is separated from the neurons by:

a. Capillary endothelium.
b. Basement membrane of endothelium.
c. Intimately applied to the capillaries there are numerous processes of astrocytes and it has been

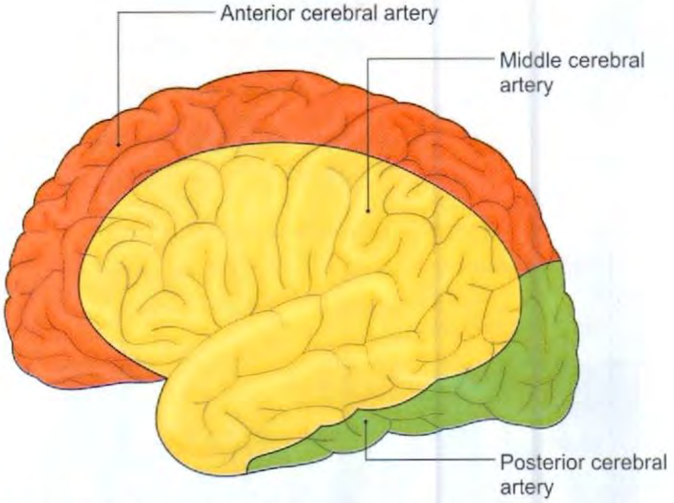


Fig. 11.14: Arterial supply of superolateral surface of cerebral hemisphere

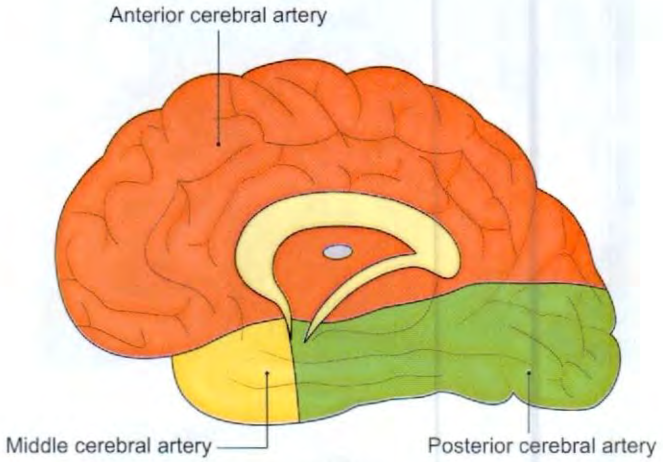


Fig. 11.15: Arterial supply of medial and tentorial surfaces of cerebral hemisphere

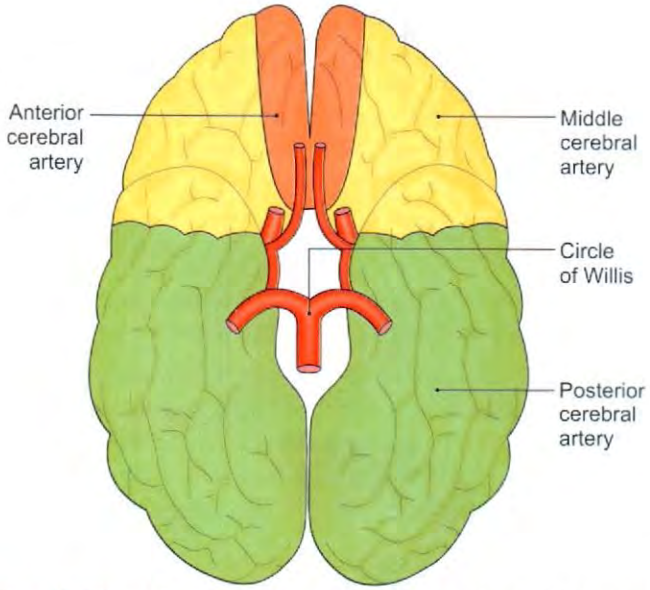


Fig. 11.16: Arterial supply of inferior surface of cerebral hemisphere

estimated that these processes cover about 80% of the capillary surface.

Some areas of brain are devoid of blood–brain barrier. These include pineal body, hypophysis cerebri, choroid plexuses and area postrema in fourth ventricle of brain. BBB exists in newborn but is more permeable to certain substances than it is in adult.

Functions of Blood–Brain Barrier

1. To modulate entry of metabolic substrates notably glucose.
2. It allows entry of gases, water, electrolytes, amino acids and lipid-soluble substances.
3. It restricts entry of macromolecules that is lipid insoluble substances and thus blocks entry of toxins as either these are bound to the plasma albumin or their solubilities are inappropriate.
4. It blocks entry of transmitters from blood, notably of epinephrine.
5. The drugs like penicillin, noradrenaline and thiopentone cannot cross it.
6. Some drugs like atropine, chloramphenicol, tetracycline and sulfas cross the barrier easily.
7. Its other important function is to pump ions—notably potassium into and out of the blood.
8. Entry of hormones is restricted to certain places only, so that normal biological rhythm of the body is maintained.

PERIVASCULAR SPACES

The perivascular spaces (Virchow-Robin) are extensions of subarachnoid space around vessels penetrating the brain surface. The spaces taper progressively. Although these are inward extensions in anatomical sense. The subarachnoid and perivascular spaces are separated a thin layer of pia mater. The flow of extracellular fluid is outward into the subarachnoid space.

The perivascular spaces are involved in autoregulation of brain arterioles which regulates the blood supply to tissues.

The chief internal source of autoregulation is the adjustment of arterial muscle tone in response to intraluminal pressure changes. Cerebral blood flow remains at 60–70 ml/100 g/min during systemic blood pressure; changes ranging from 80 to 180 mm Hg. This is achieved by a direct myogenic response to distension produced by rising intraluminal pressure.

The H^+ ion concentration in the perivascular space is the chief external source of autoregulation of cerebral blood vessels. A rising H^+ (usually following hypercapnia—excess plasma CO_2) travels along perivascular space from the capillary bed and it inhibits vascular muscle, perhaps by reducing ionized calcium level. On the other hand, hypocapnia causes vasoconstriction.

CLINICAL ANATOMY

- Thrombosis of lateral striate branches of middle cerebral artery causes motor and sensory loss to most of the opposite side of body except lower limb.
- Hemiplegia is a common condition. It is an upper motor neuron type of paralysis of one-half of the body, including the face. It is usually due to an internal capsule lesion caused by thrombosis of one of the lenticulostriate branches of middle cerebral artery (cerebral thrombosis) (Fig. 11.17). One of the lenticulostriate branches is most frequently ruptured (cerebral haemorrhage); it is known as Charcot's artery of cerebral haemorrhage. This lesion also produces hemiplegia with deep coma, and is ultimately fatal.
- Thrombosis of Heubner's recurrent branch of the anterior cerebral artery causes contralateral upper monoplegia.
- Occlusion proximal to the anterior communicating artery is normally well tolerated because of the cross flow (Fig. 11.18a).

  Distal occlusion results in weakness and cortical sensory loss in the contralateral lower limb with associated incontinence (Fig. 11.18b).
- Thrombosis of the paracentral artery (terminal cortical branch of the anterior cerebral artery) causes contralateral lower limb monoplegia.

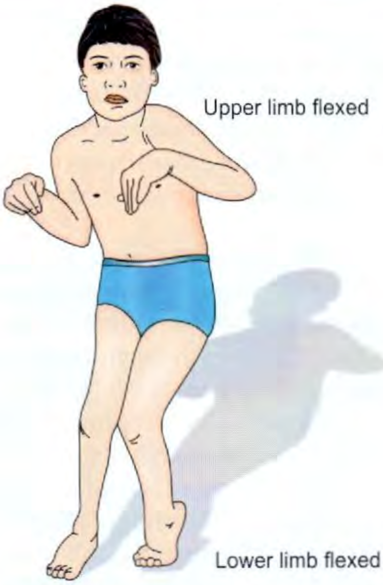
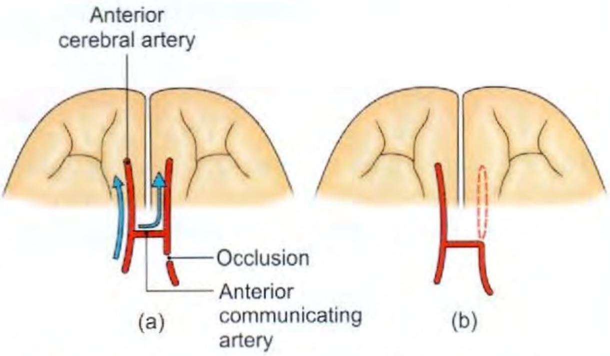


Fig. 11.17: Posture of hemiplegic person



Figs 11.18a and b: Effects of occlusion of anterior cerebral artery

VEINS OF THE CEREBRUM

CHARACTERISTICS OF THE VEINS

1. The walls are devoid of muscle.
2. The veins have no valves.
3. 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

1. *Superior cerebral veins:* These are 6 to 12 in number. They drain the superolateral surface of the hemisphere. They terminate in the superior sagittal sinus (Fig. 11.19).
2. *Superficial middle cerebral vein:* This drains the area round the posterior ramus of the lateral sulcus. It terminates in the cavernous sinus, or at times into the sphenoparietal sinus. Through the superior and inferior anastomotic veins, it communicates with the superior sagittal and transverse sinuses. It also communicates with the deep middle cerebral vein.
3. *Deep middle cerebral vein:* This drains the surface of the insula and terminates in the basal vein.
4. *Inferior cerebral veins:* These are several in number. They are divided into orbital and tentorial veins. The orbital veins terminate in the superior cerebral veins or in the superior sagittal sinus. The tentorial veins terminate in the cavernous or any other surrounding sinus.
5. *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 (Fig. 11.20).

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 run posteriorly parallel to each other in the tela choroidea, and unite together to form the great cerebral vein below the splenium of the corpus callosum (Fig. 11.21).

Terminal Veins

1. *Great cerebral vein:* This is a single median vein. It is formed by union of the two internal cerebral veins. It terminates in the straight sinus. Its tributaries include the basal veins, and veins from the pineal body, the colliculi, the cerebellum and the adjoining part of the occipital lobes of the cerebrum.
2. *Basal vein:* There is one vein on each side. It is formed at the anterior perforated substance by the union of the deep middle cerebral vein, the anterior cerebral veins, and the striate veins. It runs posteriorly, winds round the cerebral peduncle, and terminates by joining the great cerebral vein. Its tributaries include (apart from the veins forming it) small veins from the cerebral peduncle, interpeduncular structures, the tectum of the midbrain, and the parahippocampal gyrus.

Ultimately, all veins drain into the various cranial venous sinuses which, in turn, drain into the internal jugular vein.

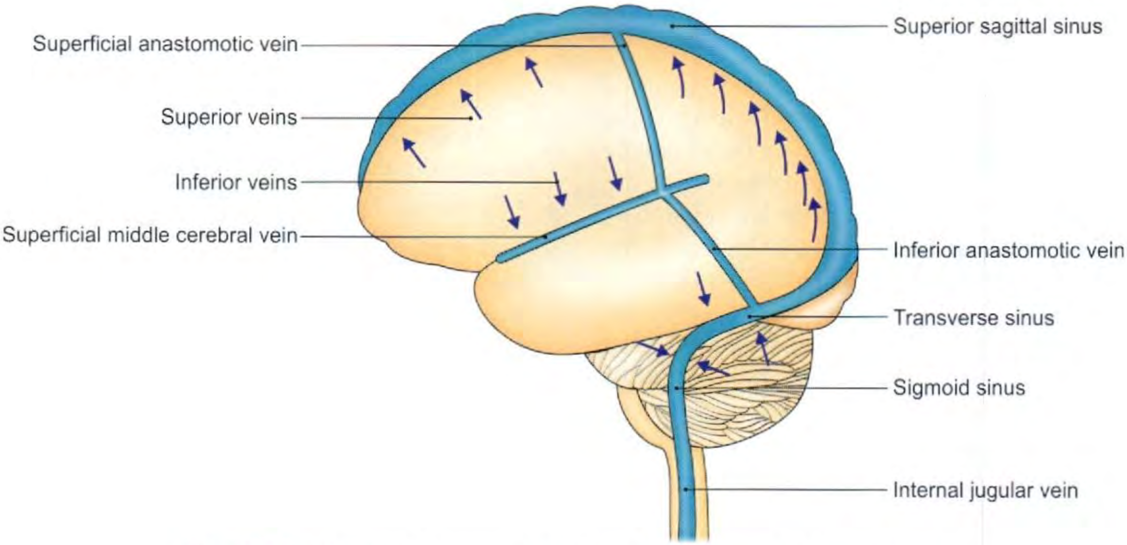


Fig. 11.19: Veins on the superolateral surface of cerebral hemisphere

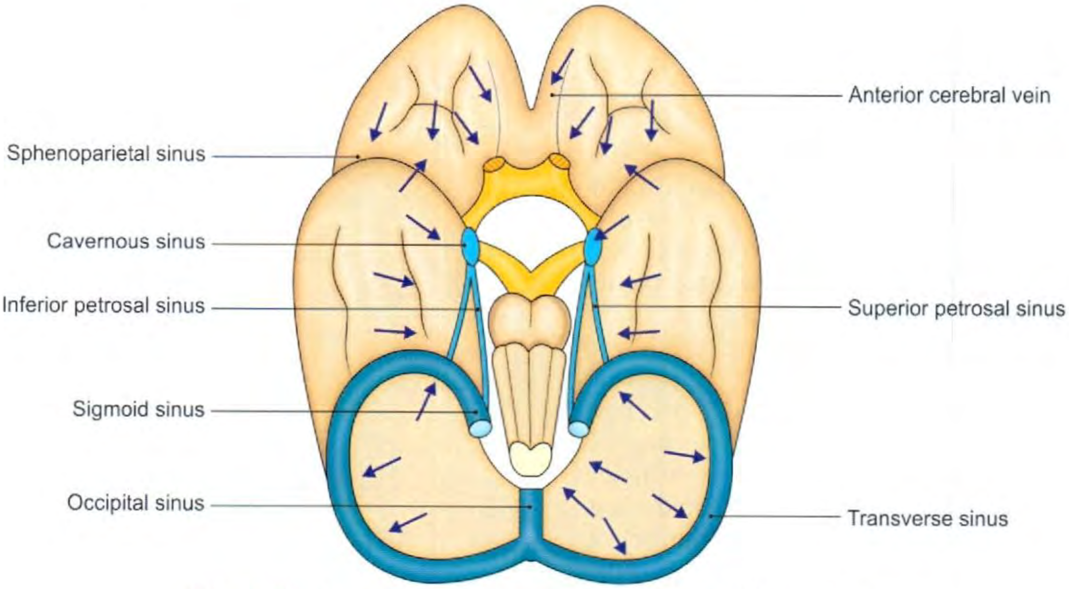


Fig. 11.20: Veins on the inferior surface of cerebral hemisphere

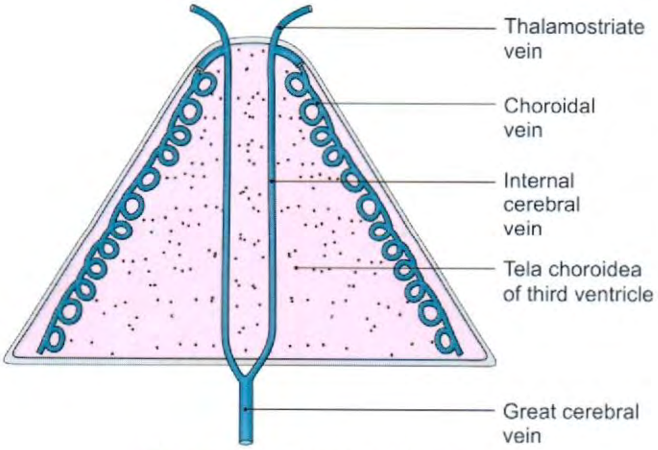


Fig. 11.21: Internal cerebral veins

BLOOD SUPPLY OF THE BRAIN STEM

The *midbrain* is supplied by branches from the posterior cerebral arteries, including their central branches, both posteromedial and posterolateral.

The *pons* is supplied by the pontine branches of basilar artery.

The *medulla* is supplied by:

a. The medullary branches of the vertebral artery.

b. Branches from the posterior inferior cerebellar artery.

The veins of the brain stem drain into neighbouring venous sinuses.

CLINICAL ANATOMY

- Anastomotic and end arteries: In the circle of Willis, the blood in the three communicating arteries is normally static. Following occlusion of one of the three large arteries contributing to the circle, the other two compensate more or less completely, via communicating arteries. With occlusion of one internal carotid, the other internal carotid may perfuse both anterior cerebral arteries. With occlusion of basilar, each posterior cerebral artery may be perfused by the internal carotid of its own side.

  Further anastomosis occurs between cortical branches of cerebral arteries, prior to perforation of the branches into brain substance. Once the cortical and central branches perforate, they become end arteries hardly communicating at capillary level.
- Cerebral vascular disease is quite common in old age and manifest in different ways.
  a. Haemorrhage—cortical or subcortical
  b. Thrombosis
  c. Embolism.
- Hypertensive encephalopathy is a manifestation of sustained elevation of diastolic blood pressure in the form of multiple diffuse small lesions distributed all over, result in a variegated picture of the circle of Willis (Berry's aneurysm).
- The arteries of the brain are supplied with sympathetic nerves which run on to them from carotid and vertebral plexuses. They are extremely sensitive to injury and readily react by passing into prolonged spasms. This by itself may be sufficient to cause damage to brain tissue since even the least sensitive neurons cannot withstand absolute loss of blood supply for a period more than 3–7 minutes.

Mnemonics

Cell is Clearly Circulating

C – *Cortical branches*
C – *Central branches*
C – *Choroidal branches*

FACTS TO REMEMBER

- Posterior inferior cerebellar artery is the largest branch of vertebral artery. It supplies posterolateral part of medulla oblongata, lower part of pons, inferior surface of cerebellum including choroidal branches to 4th ventricle.
- Posterior cerebral arteries are the terminal branches of the basilar artery and suppy the visual cortex.
- Middle cerebral artery is the larger terminal branch of internal carotid and supplies most of the superolateral surface of the cerebral cortex.
- Anterior cerebral artery is the smaller terminal branch of the internal carotid artery. It runs along the corpus callosum supplying maximum area on the medial surface of the cerebral hemisphere.
- Two lobes of the cerebellum are supplied by 3 pairs of cerebellar arteries. These are superior cerebellar, anterior inferior cerebellar and posterior inferior cerebellar arteries.
- Anterior two-thirds of spinal cord is supplied by larger anterior spinal artery. Only posterior one-third of the cord is supplied by posterior spinal arteries.

CLINICOANATOMICAL PROBLEMS

Case 1

A 40-year-old obese man complains of nausea, vomiting, hoarseness of voice for 15 days, difficulty in walking on the right side, with inability to feel pain, hot and cold sensations from the limbs and trunk.

- Where is the lesion?
- Which nuclei and fibres are involved?

Ans: The symptoms in the present case are due to thrombosis of the largest branch of fourth part of vertebral artery, the posterior inferior cerebellar artery. The various nuclei involved are vestibular nuclei, inferior cerebellar peduncle, nucleus ambiguus and lateral spinothalamic tract of the opposite side.

Case 2

A hypertensive patient aged 60 years was taking the treatment very erratically. One night he felt severe headache and soon paralysis of both his right-sided limbs.

- Where is the lesion?
- Explain the genesis of his symptoms.

Ans: The hypertension should have been treated properly. Since the treatment was not done along the right lines, he suffered from haemorrhage of the left lateral striate arteries which supply the internal capsule. This leads to paralysis of his right half of the body. This is an upper motor neuron type of paralysis with exaggerated reflexes, increased tone of the muscles, etc. It is quite a serious condition and is called "cerebral stroke".

FREQUENTLY ASKED QUESTIONS

1. Describe the intracranical course of vertebral, basilar and internal carotid arteries including the formation of circle of Willis.
2. Enumerate the branches of anterior, middle and posterior cerebral arteries.
3. Write short notes on:
    a. Blood supply of spinal cord
    b. Blood supply of cerebellum
    c. Blood–brain barrier
    d. Blood supply of brain stem
    e. Name the external cerebral, internal cerebral and the terminal veins

MULTIPLE CHOICE QUESTIONS

1. Labyrinthine artery is a branch of:
    a. Basilar
    b. Vertebral
    c. Internal carotid
    d. Posterior inferior cerebellar
2. Vein of Galen or great cerebral vein is formed by union of:
    a. Right and left internal cerebral veins
    b. Occipital and transverse sinuses
    c. Inferior sagittal and straight sinuses
    d. Occipital and petrosal sinuses
3. Which of the following arteries supply visual fibres?
    a. Anterior and middle cerebral
    b. Middle cerebral
    c. Middle and posterior cerebral
    d. Posterior cerebral
4. Anterior spinal artery is a branch of:
    a. Vertebral
    b. Internal carotid
    c. Basilar
    d. Labyrinthine
5. Which is the largest direct branch of internal carotid artery?
    a. Middle cerebral
    b. Anterior cerebral
    c. Posterior cerebral
    d. Posterior inferior cerebellar
6. What is not true about BBB (blood–brain barrier)?
    a. Many larger molecular substances hardly pass from blood to CSF
    b. Formed by structure between blood and nerve cells of brain
    c. The constitution of CSF is exactly same as those of extracellular fluid elsewhere in body
    d. Pineal body, hypophysis cerebri, choroid plexus, area postrema, IV ventricle are devoid of BBB

ANSWERS

1. a **2.** a **3.** c **4.** a **5.** a **6.** c

CHAPTER

12

Investigations of a Neurological Case, Surface and Radiological Anatomy and Evolution of Head

Let us respect grey hairs, especially our own
—JP Senn

INTRODUCTION

A neurological case needs to have a detailed clinical history, family history, and clinical examination besides the investigations.

INVESTIGATIONS REQUIRED IN A NEUROLOGICAL CASE

Study of brain is of importance in localising the lesion. Besides detailed history and clinical examination, the following investigations may have to be done according to the need of each case.

1 *X-ray skull:* Anteroposterior and lateral views (Fig. 12.1).
2 *Lumbar puncture:* It is done between third and fourth lumbar spines. This is clinically useful for diagnostic and prognostic purposes. It is also used for giving spinal anaesthesia.
3 *Computerised tomography or CT scan:* In this procedure, X-ray beam traces an arc at multiple angles around a section of the body. The resulting transverse section is reproduced by the computer on its monitor screen (Fig. 12.2).
4 *Magnetic resonance imaging (MRI):* The body is exposed to high energy magnetic field, which permits protons in tissues to arrange themselves in relation to the field. Then a pulse of radiowaves 'reads' these ion patterns and a colour-coded image is reproduced on the computer screen (Fig. 12.3).
5 *Sonography:* High frequency sound waves produced by wand (held in hand) get reflected off body tissues and are detected by the same instrument. The image, the *sonogram*, is reproduced on the computer screen. It is used to diagnose hydrocephaly or anencephaly during intrauterine life.

Fig. 12.1: Lateral view of skull and cervical vertebrae

Fig. 12.2: Computerised tomography (CT) scan

Fig. 12.3: Magnetic resonance imaging (MRI)

Fig. 12.4: Angiography

6 *Positron emission tomography (PET):* Substance emitting positrons are injected into the body which are taken up by tissues. Collision of positrons with electrons of body tissues produces gamma rays, detected by gamma cameras, put around the patient. Thus, PET scan is seen on computer screen. Activity of different areas of brain is visualised.

7 *Angiography*

   a. *MR angiography*: This technique employs modification so that blood vessels can be visualised without injecting the dye. The conventional angiography is still preferred.

   b. *Angiography:* The contrast medium is injected into the common carotid or vertebral arteries. X-ray pictures taken immediately show the arterial pattern. The capillary and venous pattern is seen after a little time (Fig. 12.4).

   c. *Digital subtraction angiography (DSA):* In this procedure, low concentrations of contrast media are used. Bones and muscles are removed with the help of the computer. Ideal method is arterial DSA wherein diluted contrast medium is injected into the artery to see its course, branches and their diseases.

Because of these modern and safe procedures, the older techniques—pneumoencephalography, ventriculography and myelography have become obsolete.

8 *Electrophysiological methods*

   a. *Electromyography (EMG):* This is the study of electrical activity accompanying the muscle contraction. It is also used to study the action of various muscles.

   b. *Electroencephalography (EEG):* The pattern of electrical activity of brain is analysed by putting electrodes in the scalp at different points and recording it in the machine.

   c. Nerve conduction studies done to estimate the rate of conduction through the nerve fibres.

These procedures may be used according to the requirement of the patient.

SURFACE ANATOMY

Borders of Cerebral Hemisphere

Mark the following points (Fig. 12.5).

- Point 1, just superolateral to the inion
- Point 2, just superolateral to the nasion
- Point 3, at the zygomatic process of the frontal bone just above the eyebrow
- Point 4 at the pterion
- Point 5 at the middle of the upper border of the zygomatic arch.

The *superomedial border* is marked by joining points 1 and 2 by a paramedian line.

The *superciliary border* is marked by first joining points 2 and 3 by a line arching upwards just above the eyebrow, and then extending this line to point 4.

The *inferolateral border* is marked by first joining points 4 and 5 by a line convex forwards (temporal pole), and by then joining points 5 and 1 by a line convex upwards, passing just above the external acoustic meatus.

Central Sulcus

- Point 6 is taken 1.2 cm behind the midpoint of a line joining the nasion with the inion.

- Point 7, 5 cm above the preauricular point. The sulcus is marked by joining these points by a sinuously curved line running downwards and forwards making an angle of 70 degrees with the median plane

Lateral Sulcus

The following points are used to mark the lateral sulcus and its posterior ramus.

- Point 4 at the pterion
- Point 8 is taken 2 cm below the parietal eminence.

Point 4 (pterion) is also called the *sylvian point*. It is the stem of the lateral sulcus.

The posterior ramus of the lateral sulcus is about 7 cm long and can be marked by joining points 4 and 8.

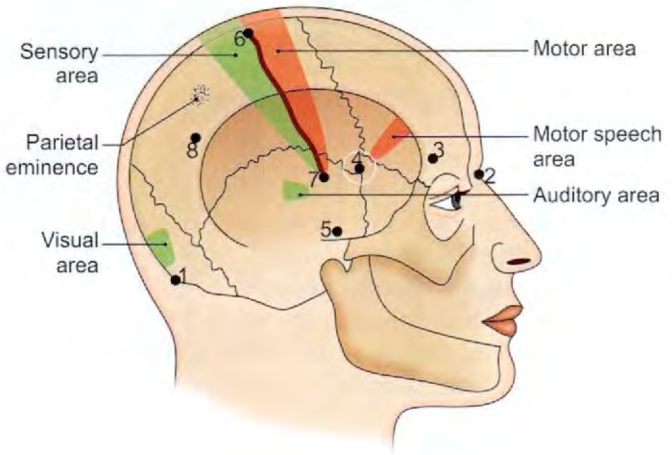


Fig. 12.5: Surface marking of borders of cerebral hemisphere and of lateral sulcus

Superior Temporal Sulcus

This is marked by a line parallel and 1 cm below the posterior ramus of the lateral sulcus.

Functional Areas of Cerebral Cortex

1. The *motor area* is marked by a strip about 1 cm broad in front of the central sulcus.
2. The *sensory area* is marked by a strip about 1 cm broad, behind the central sulcus.
3. The *auditory area* is marked between the superior temporal sulcus and the posterior ramus of the lateral sulcus, immediately below the lower end of the central sulcus.
4. *The visual area* (the part extending onto the supero-lateral surface) is marked immediately in front of the occipital pole.
5. Motor speech area is marked by an area above and anterior to pterion. It is mostly present in the left hemisphere.

Cerebellum

It is marked behind the auricle, immediately below the marking for the transverse sinus lying between inion and base of mastoid process.

RADIOLOGICAL ANATOMY OF THE BRAIN

Cerebral Angiography

Cerebral angiography is a radiological technique by which cerebral vessels can be visualized. The arterial system is visualized by carotid angiography, and the vertebral system by vertebral angiography.

Dye: About 10 to 12 ml of 30% pyelocil or diodone.

Technique: For carotid angiography, the common carotid artery is located at the carotid tubercle and the dye is injected percutaneously. A series of skiagrams are taken rapidly at intervals of 1 second. Within 2 seconds after the commencement of injection, the dye reaches the cerebral arteries, and after 2 seconds it is in the veins. After another two seconds or so, the dye passes into the intracranial venous sinuses. The skiagrams taken at different intervals provide arteriograms, venograms (or phlebograms) and sinograms.

Similarly for vertebral angiography, the dye is injected into the vertebral artery and skiagrams are taken as described above.

Indications: Cerebral angiography is helpful in diagnosis of intracranial tumours, haematomas, aneurysms and angiomas.

EVOLUTION OF THE HEAD

The head forms the *fore-end* of the body where all the special sense organs (eyes, ears, nose and tongue) are concentrated in and around the face. It is at this end of the body that the central nervous system shows its greatest development leading to the formation of the brain. The various sense organs keep the individual informed about the surroundings so that he can better adjust and sustain himself. The continuous inflow of information collected by the sense organs is processed and stored in the form of memory which forms the basis of all knowledge and experience.

Photosensitivity is one of the fundamental properties of protoplasm. This has resulted in evolution of the eyes which serve to determine the direction of movement with reference to light even in prevertebrate forms of life. In most mammals, however, vision appears to be dominated (in importance) by the sense of smell. In primates, including man, there is a progressive reduction in the importance of the sense of smell, with a concomitant increase in the importance of vision associated with the ability to perform skilled acts of a wide variety.

Fig. 12.6: Size of the jaws relative to the size of the head during evolution

The evolution of the sense of *hearing* took place only when water dwelling species evolved into those with a terrestrial mode of life. This becomes obvious when we remember that the production and transmission of sound requires air. The sense of hearing greatly helped the animal in detecting hostile sounds made by enemies. In man, hearing assumed increasing importance in receiving sounds of articulate speech. Homologous with the ear there are lateral-line organs found in water dwelling vertebrates like fishes and amphibia. These organs are sensitive to vibration produced by water currents and help their owners in judging the depth and direction of movement of water, and also in detecting the presence of other animals in the neighbourhood.

The *sense of smell* (*olfactory sense*) is one of the oldest sensibilities which made its appearance first in aquatic vertebrates, and was the first to receive cortical representation. Most of the primitive mammals are guided primarily and predominantly by their sense of smell; the other senses of touch, hearing and vision being merely accessory to the dominating influence of smell. Man has freely exploited this uncanny endowment of a sharp sense of smell in domesticated animals, especially in dogs.

The sense of smell played a significant role in the animals search for food; and for sex. With the adoption of an arboreal (tree dwelling) mode of life by primates (monkeys and apes), the sense of smell became less important. This mode of life favoured a higher development of visual, tactile, acoustic, kinaesthetic, and motor functions in association with increasing intelligence. The reduced importance of the sense of smell has been associated with the loss of a projecting snout (the region of the mouth and nose) that is so typical of lower mammals. However, it is believed that the tactile function of the snout is more important than its olfactory function.

The most important factor in the disappearance of the snout in primates and man appears to be the adoption of an erect posture in which the forelimbs are no longer required to support body weight, and are, therefore, free to perform various functions. (This is often referred to, by anthropologists as *emancipation of the forelimbs*.)

Thus, it would appear that the whole spectrum of human sensibilities is acquired by man from his animal ancestors. In fact man is inferior to many animals (dogs, cattle, etc.) in his acuity of the senses of smell, vision and hearing. However, the supremacy of man in the animal kingdom is due to the large relative size of his brain which has given him unlimited powers of thought, of reason and of judgement, highly developed speech and hands that can achieve perfection at craftsmanship.

The anatomical features of the *human face* are a result of a series of changes that have occurred during evolution. The many changes observed are a result of two main factors. These are the progressive reduction in the size of the jaws; and a concomitant increase in the size of the cranial cavity in association with the increasing size of the brain. The alterations in the face and head are by-products of a change in posture from pronograde (four-footed), through orthograde to a plantigrade (two-footed) one. A pronograde animal (dog, cow) has large jaws and a small head. An orthograde animal (ape or monkey) has smaller jaws and a larger head than in pronograde animals. Plantigrade man has the smallest jaws and the largest head. Thus, the size of the jaws is inversely proportional to that of the head (Fig. 12.6).

Reduction in jaw size is attributable to the liberty of movements of the upper limbs, and also to changed habit of eating cooked food, both of which have greatly relieved the jaws of their diverse functions (tactile feeling, holding, sorting, breaking, biting, tearing, chewing, piercing, fighting, etc.) seen in lower animals. The muscles acting on the jaws have obviously become smaller and weaker.

The same is also true of muscles on the back of the neck. In pronograde animals, these muscles support the weight of the head. In order to permit freedom of mobility to the tongue for articular speech in man, the alveolar arches are broadened and the chin is pushed forwards, making the mouth cavity more roomy. With recession of the jaws, the oral aperture is reduced in size, and the lips are supported by a much better developed orbicularis oris.

The distinctive external nose, with exuberant growth of cartilages forming the prominent dorsum, tip and alae is a characteristic human feature, although it appears to serve no special function. The eyes are directed forwards and not laterally as in lower mammals. This change in direction of the eyes enables stereoscopic vision. The palpebral fissures are larger in man than in any other primate, and the bony orbits are decidedly smaller than in the great apes. Further, the interorbital distance is greater in man than in apes in whom the nasal root is greatly constricted.

The supraorbital margins of man are markedly reduced remnants of the highly developed brow ridges of other primates. The diminution in man is partly due to the receding jaws which relieve the ridges of their function as buttresses, and partly to the development of a prominent forehead because of increase in the size of the cranial cavity. The forehead protects the eyes from above, a similar function being performed by the brow ridges in apes.

FREQUENTLY ASKED QUESTIONS

1. Name the investigations required in a neurological case.
2. Name the functional areas of cerebral cortex and their location.
3. Write an essay on evolution of head.

CHAPTER

13

Autonomic Nervous System

Delay in the best remedy for anger. Hunger is the best sauce in the world

Autonomic nervous system comprises sympathetic and parasympathetic components. Sympathetic is active during fright, flight or fight. During any of these activities, the pupils dilate, skin gets pale, blood pressure rises, blood vessels of skeletal muscles, heart, lungs and brain dilate. There is hardly any activity in the digestive tract due to which the individual does not feel hungry. The person is tense and gets tired soon.

Parasympathetic has the opposite effects of sympathetic. This component is sympathetic (kind) to the digestive tract. In its activity, digestion and metabolism of food occurs. Heart beats normally. Person is relaxed and can do creative work.

Autonomic nervous system is controlled by brain stem and cerebral hemispheres. These include reticular formation of brain stem, thalamic and hypothalamic nuclei, limbic lobe and prefrontal cortex including the ascending and descending tracts interconnecting these regions.

SYMPATHETIC NERVOUS SYSTEM: THORACOLUMBAR OUTFLOW

This is the larger of the two components of autonomic nervous system. It consists of two ganglionated trunks, their branches, prevertebral ganglia, plexuses. It supplies all the viscera of thorax, abdomen and pelvis, including the blood vessels of head and neck, brain, limbs, skin and the sweat glands as well as arrector pilorum muscle of skin.

The preganglionic fibres are axons of neurons situated in the lateral horns of T1–L2 segments of spinal cord. They leave spinal cord through their respective ventral roots, to reach sympathetic ganglia and beginning of ventral rami via white rami communicantes (wrc) [singular: ramus communicans]. There are 14 wrc on each side. These fibres can have following alternative routes:

- They relay in the ganglion of the sympathetic trunk, postganglionic fibres pass via the grey rami communicantes (grc) and get distributed to the blood vessels of skin, sweat glands and to arrector pili muscles (Figs 13.1 and 13.2).
- These may pass through the corresponding ganglion and ascend to a ganglion higher before terminating in the above manner.
- These may pass through the corresponding ganglia and descend to a ganglion lower and then terminate in the above manner.
- Postganglionic fibres from upper thoracic ganglia supply the thoracic viscera.
- Some preganglionic fibres pass to corresponding ganglia and emerge from these (unrelayed) in the from of splanchnic nerves to supply the abdominal and pelvic viscera after synapsing in the ganglia situated in the abdominal cavity.
- Few fibres of splanchnic nerves reach the medulla of the suprarenal gland.

Sympathetic trunks on either side of the body extend from cervical region to the coccygeal region where both trunks fuse to form a single *ganglion impar*. Sympathetic trunk has cervical, thoracic, lumbar, sacral and coccygeal parts. The branches of each part are discussed below.

Cervical Part of Sympathetic Trunk

It extends from base of skull to neck of 1st rib. It has 3 ganglia namely superior, middle and inferior cervical ganglia. Branches of these ganglia are tabulated in Table 13.1.

Thoracic Part of Sympathetic Trunk

There are usually 11 ganglia on the sympathetic trunk of thoracic part. 1st ganglion lies on neck of 1st rib and is usually fused with inferior cervical ganglion and forms stellate ganglion. The lower ones lie on the head of the ribs. The sympathetic trunk continues with its abdominal part by passing behind the medial arcuate ligament.

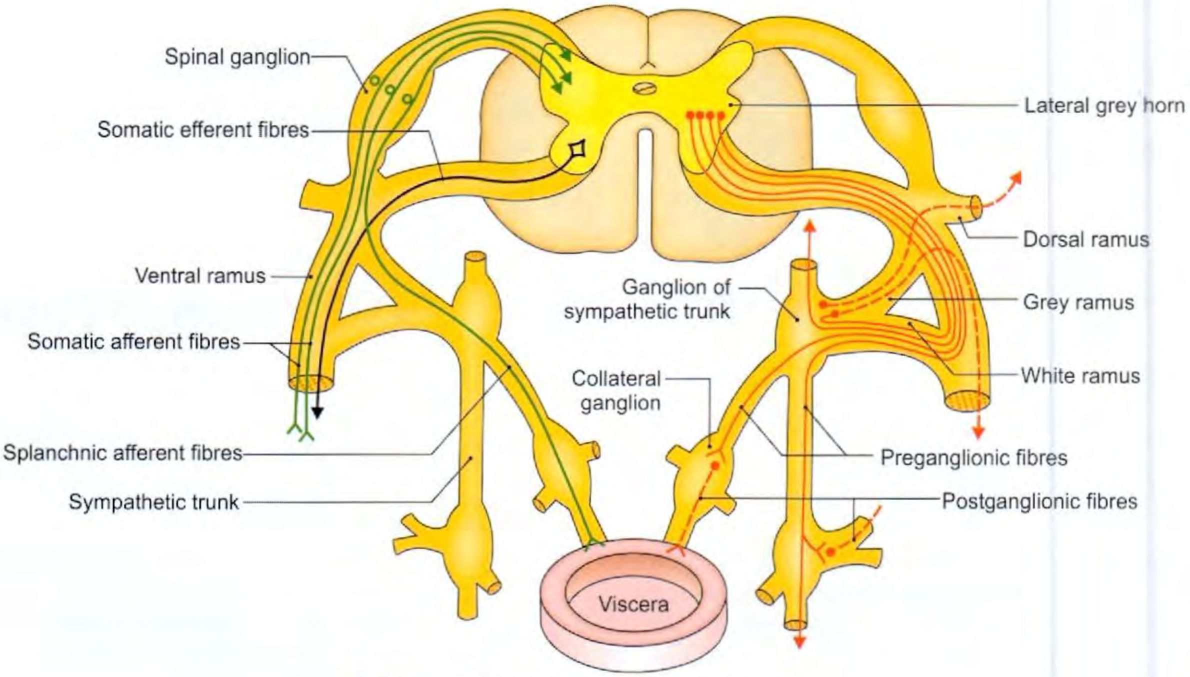


Fig. 13.1: Components of a typical spinal nerve

The ganglia are connected with the respective spinal nerves via the white ramus communicans (from the spinal nerve to the ganglion) and the grey ramus communicans (from the ganglion to the spinal nerve, i.e. ganglion gives grey, ggg).

Branches

1. Grey rami communicantes to all the spinal nerves of thorax, i.e. T1–T12. The postganglionic fibres pass along the spinal nerves to supply cutaneous blood vessels, sweat glands and arrector pili muscles.
2. White rami communicantes from upper 4–6 ganglia travel up the cervical part of sympathetic trunk to relay in the three cervical ganglia. Fibres from the lower thoracic ganglia T10–L2 pass down as preganglionic fibres to relay in the lumbar or sacral ganglia.
3. Second to fifth ganglia give postganglionic fibres to heart, lungs, aorta and oesophagus.
4. Lower eight ganglia give fibres which are preganglionic (unrelayed) for the supply of abdominal viscera. These are called as splanchnic (visceral) nerves.
    - Ganglia 5–9 give fibres which constitute greater splanchnic nerve.
    - Ganglia 9–10 give fibres that constitute lesser splanchnic nerve.
    - Ganglion 11 gives fibres that constitute lowest splanchnic nerve.

Abdominal Part of Sympathetic Trunk

It runs along the medial border of psoas major muscle. It is continuous with the pelvic part by passing behind the common iliac vessels. There are 4 ganglia in the lumbar or abdominal part. Only upper two ganglia receive white ramus communicans from the ventral primary rami of first and second lumbar nerves.

Branches

1. Grey rami communicantes to the L1–L5 spinal nerves. These pass along the spinal nerves to be distributed to the sweat glands, cutaneous blood vessels and arrector pili muscles (sudomotor, vasomotor and pilomotor).
2. Postganglionic fibres pass medially to the aortic plexus.
3. Postganglionic fibres pass in front of common iliac vessels to form hypogastric plexus, which is also supplemented by branches of aortic plexus.

Aortic plexus: This plexus is formed by preganglionic sympathetic, postganglionic sympathetic, preganglionic parasympathetic and visceral afferent fibres around the abdominal aorta. This plexus is concentrated around the origin of ventral and lateral branches of abdominal aorta. These are known as coeliac plexus, superior mesenteric plexus, inferior mesenteric plexus and renal plexus.

Pelvic Part of Sympathetic Trunk

Pelvic part runs in front of sacrum, medial to ventral sacral foramina. Caudally, the two trunks unite and fuse

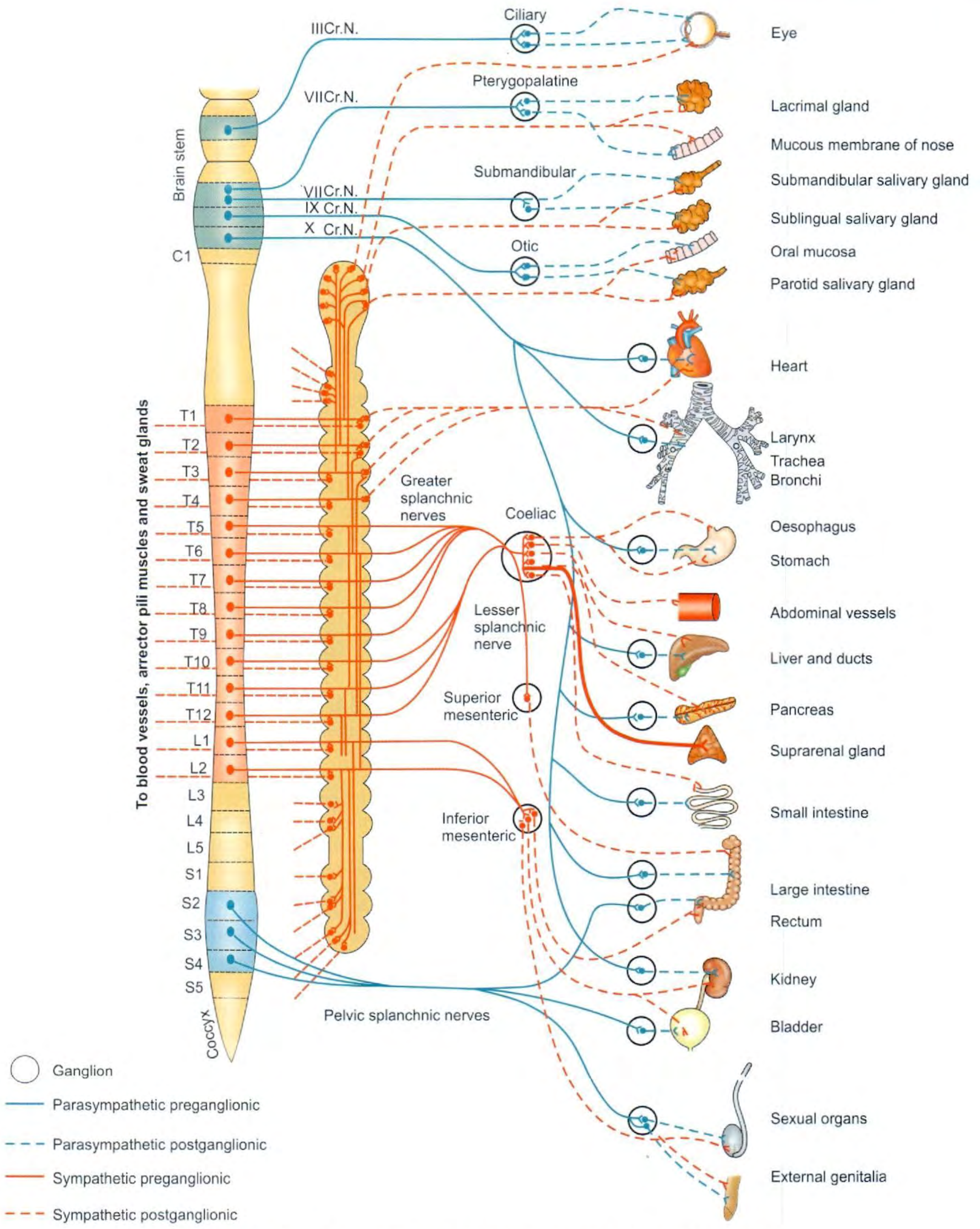


Fig. 13.2: Distribution of sympathetic and parasympathetic nervous systems

Table 13.1: Branches of superior, middle and inferior cervical ganglia

	Superior cervical ganglion	*Middle cervical ganglion*	*Inferior cervical ganglion*
Arterial branches	(i) Along internal carotid artery as internal carotid nerve (ii) Along common carotid and external carotid arteries	Along inferior thyroid artery	Along subclavian and vertebral arteries
Grey rami communicantes	Along cervical 1–4 nerves	Along 5 and 6 cervical nerves	Along 7 and 8 cervical nerves
Along cranial nerves	Along IX, X, XI, XII cranial nerves	—	—
Visceral branches	Pharynx thyroid, cardiac	Cardiac	Cardiac

into a single ganglion impar in front of coccyx. There are 4 ganglia in this part of sympathetic trunk. Their branches are:

1. Grey rami communicantes to the sacral and coccygeal nerves.
2. Branches to the pelvic plexuses.

Collateral/Prevertebral Ganglia and Plexuses

Coeliac Plexus

Coeliac plexus is the largest of the three autonomic plexuses, e.g. coeliac, superior mesenteric and inferior mesenteric plexuses. It is a dense network of nerve fibres which unite the two coeliac ganglia. The ganglia receive the greater splanchnic nerves, lesser splanchnic nerves of both sides including some filaments of vagi and phrenic nerves.

Coeliac ganglia are two irregularly shaped ganglia. Each ganglion receives greater splanchnic nerve. The lower part of the ganglion receives lesser splanchnic nerve and is also called as aorticorenal ganglion. The aorticorenal ganglion gives off the renal plexus which accompanies the renal vessels.

Secondary plexuses arising from coeliac and aorticorenal plexus are distributed along the branches of the aorta, namely phrenic, splenic, left gastric, hepatic, intermesenteric, suprarenal, renal, gonadal, superior and inferior mesenteric plexuses.

Superior Hypogastric Plexus

This plexus lies between the two common iliac arteries and is formed by: (i) aortic plexus, (ii) branches from lumbar sympathetic ganglia. It divides into right and left inferior hypogastric plexus (pelvic plexus); which runs on the medial side of internal iliac artery and is supplemented by pelvic splanchnic nerves (parasympathetic nerves). Thus, inferior hypogastric plexus contains both sympathetic and parasympathetic nerves. These are for the supply of the pelvic viscera along the branches of the arteries.

PARASYMPATHETIC NERVOUS SYSTEM

Craniosacral Outflow

Preganglionic parasympathetic fibres are present in 4 cranial nerves, e.g. III, VII, IX, and X cranial nerves and also along S2, S3, and S4 spinal nerves. Four ganglia namely ciliary, pterygopalatine, submandibular and otic are concerned with efferent parasympathetic fibres of III, VII and IX nerves. Their pathways are shown in Appendix, Table A.2, Volume 3.

1. Oculomotor parasympathetic fibres arise in midbrain, from the Edinger-Westphal nucleus. Preganglionic fibres pass through the III nerve and leave as motor root along the nerve to inferior oblique muscle to enter the *ciliary ganglion.* These fibres are relayed in the ciliary ganglion, and the postganglionic fibres pass via the short ciliary nerves to be distributed to ciliaris and sphincter pupillae muscles.
2. Facial nerve contains efferent parasympathetic fibres. These are the axons of neurons of superior salivatory nucleus. These fibres leave the brain as nervus intermedius, and form part of the facial nerve and pass along its chorda tympani branch. Chorda tympani nerve joins the lingual nerve in the infratemporal fossa. These fibres travel with the lingual nerve to reach submandibular ganglion. Fibres of chorda tympani nerve relay in this ganglion from where postganglionic fibres supply the submandibular and sublingual salivary glands.

   Greater petrosal branch of facial nerve joins the deep petrosal (sympathetic fibres) to form the *nerve of pterygoid canal.* Only greater petrosal nerve fibres relay in the *pterygopalatine ganglion.* These postganglionic fibres supply lacrimal gland, glands of nose, pharynx and palate.
3. Glossopharyngeal nerve contains the axons of the inferior salivatory nucleus. They travel through IX nerve and are given off in its tympanic branch which forms tympanic plexus from where the lesser petrosal nerve starts. The lesser petrosal nerve relays in the otic ganglion. The postganglionic fibres are

given to the auriculotemporal nerve to reach the parotid salivary gland.

4 Vagus or X cranial nerve contains efferent parasympathetic fibres. They have their origin in the dorsal nucleus of vagus and pass along its pulmonary, cardiac, oesophageal, gastric and intestinal branches.

Sacral Outflow

Pelvic Splanchnic Nerves

These are the preganglionic fibres constituting the sacral component of the craniosacral outflow of the parasympathetic nervous system. These arise from lateral horn cell of S2–S4 segments of spinal cord. The axons of these neurons pass along the ventral rami of S2–S4 nerves to join the inferior hypogastric plexus to be distributed to the pelvic viscera.

Some of the parasympathetic fibres ascend from inferior hypogastric plexus to reach superior hypogastric plexus and finally the inferior mesenteric plexus. Thereafter, these fibres are distributed along the branches of inferior mesenteric artery to supply left one-third of transverse colon, descending colon and pelvic colon. These preganglionic fibers relay in the neurons situated in the wall of the viscera.

NERVE SUPPLY OF THE VISCERA

Heart

Preganglionic sympathetic neurons are located in lateral horns T1–T5 segments of spinal cord. These fibres pass along the respective ventral roots of thoracic nerves to synapse with the respective ganglia of the sympathetic trunk. After relay, the postganglionic fibres form thoracic branches which intermingle with the vagal fibers, to form cardiac plexus.

Some fibres from T1–T5 segments of spinal cord reach their respective ganglia. These fibres then travel up the cervical part of the sympathetic chain and relay in superior, middle and inferior cervical ganglia. After relay, the postganglionic fibres form the three cervical cardiac nerves. Preganglionic parasympathetic neurons for the supply of heart are situated in the dorsal nucleus of vagus nerve.

Sympathetic activity increases the heart rate. Larger branches of coronary arteries are mainly supplied by sympathetic. It causes vasodilation of coronary arteries. Impulses of pain travel along sympathetic fibres. These fibres pass through sympathetic trunk and reach the spinal cord via T1–T5 spinal nerves. Thus, the pain may be referred to the area of skin supplied by T1–T5 nerves, i.e. retrosternal, medial side of the left upper limb. Since one is more conscious of impulses coming from skin than the viscera one feels as if the pain is in the skin. This is the basis of the referred pain.

Smaller branches of coronary arteries are supplied by parasympathetic nerves. These nerves are concerned with slowing of the cardiac cycle. The nerves reach the heart by two plexuses—superficial and deep cardiac plexuses.

Superficial Cardiac Plexus

- Superior cervical cardiac branch of left sympathetic trunk.
- Inferior cervical cardiac branch of left vagus nerve.

Deep Cardiac Plexus

It consists of two halves which are interconnected and lie anterior to bifurcation of trachea.

Right half	*Left half*
• Superior, middle, inferior cervical cardiac branches of right sympathetic trunk	Only middle and inferior branches of left sympathetic trunk
• Cardiac branches of T2–T4 ganglia of right side	Same
• Three cervical cardiac branches of right vagus	Two cervical cardiac branches of left vagus
• Two branches of right recurrent laryngeal nerve arising from neck region	Same, but coming from thoracic region

Branches from the plexus give extensive branches to pulmonary plexuses, right and left coronary plexuses. Branches from the coronary plexuses supply both the atria and the ventricles. Left ventricle receives richer nerve supply because of its larger size.

Lungs

The lungs are supplied from the anterior and posterior pulmonary plexuses. The anterior plexus is an extension of deep cardiac plexus. The posterior plexus is formed from branches of vagus and T2–T5 sympathetic ganglia. Small ganglia are found on these nerves for the relay of parasympathetic (brought via vagus neve) fibres. Parasympathetic is bronchoconstrictor (motor) whereas sympathetic is inhibitory. Sympathetic stimulation causes relaxation of smooth muscles of bronchial tubes (bronchodilator). The pressure of inspired air also causes bronchodilation.

Gastrointestinal Tract

Oesophagus

- Cervical part of oesophagus receives branches from recurrent laryngeal nerve and middle cervical ganglion of sympathetic trunk.
- Thoracic part gets branches from vagal trunks and oesophageal plexus as well as from sympathetic trunks and greater splanchnic nerves.

- Abdominal part receives fibres from vagal trunks (i.e. anterior and posterior gastric nerves), thoracic part of sympathetic trunks, greater splanchnic nerves and plexus around left gastric artery. The nerves form a plexus called myenteric plexus between two layers of the muscularis externa and another one in the submucous layer.

Stomach

Sympathetic supply reaches from coeliac plexus along gastric and gastroepiploic arteries. A few branches also reach from thoracic and lumbar sympathetic trunks. Parasympathetic supply is derived from vagus nerves. The left vagus forms anterior gastric, while right vagus comprises posterior gastric nerve. The anterior gastric nerve supplies cardiac orifice, anterior surface of body as well as fundus of stomach and pylorus.

Posterior gastric nerve supplies posterior surface of body and fundus till pyloric antrum. It gives number of coeliac branches which form part of the coeliac plexus.

Vagus is secretomotor to stomach. Its stimulation causes secretion which is rich in pepsin. Sympathetic inhibits peristalsis and is motor to the pyloric sphincter. It also carries pain fibres from stomach.

Small Intestine

The nerves of this part of the gut are derived from coeliac ganglia formed by posterior gastric nerve (vagus) and splanchnic nerves (sympathetic) and the plexus around superior mesenteric artery. These nerves form myenteric plexus and submucous plexus. Parasympathetic fibres relay in the ganglion cells present in these plexuses. Parasympathetic system is secretomotor to the intestines and inhibits the sphincters. Sympathetic fibres inhibits the peristaltic movements of intestine but stimulates the sphincters. The autonomic nerves in the intestine form enteric nervous system.

Large Intestine

Large intestine, except the lower half of anal canal, is supplied by both components of autonomic nervous system. The derivatives of midgut, i.e. caecum, vermiform appendix, ascending colon and right two-thirds of transverse colon receive their sympathetic nerve supply from coeliac and superior mesenteric ganglia and parasympathetic from vagus nerve.

Left one-third of transverse colon, descending colon, sigmoid colon, rectum and upper half of anal canal (developed from hind gut) receive their sympathetic nerve supply from lumbar part of sympathetic trunk and superior hypogastric plexus through the plexuses on the branches of inferior mesenteric artery. Its effect is chiefly vasomotor. Parasympathetic supply of colon is received from pelvic splanchnic nerves S2–S4. Pelvic splanchnic nerves give fibres to inferior hypogastric plexuses to supply rectum and upper half of anal canal. Some of inferior hypogastric plexuses pass up through superior hypogastric plexus and get distributed along the branches of inferior mesenteric artery to the left third of transverse colon, descending and sigmoid colons.

Rectum and Anal Canal

Sympathetic fibres pass along inferior mesenteric and superior rectal arteries and also via superior and inferior hypogastric plexuses.

Parasympathetic supply is from pelvic splanchnic nerves, which join inferior hypogastric plexus. This supply is motor to muscles of rectum and inhibitory to internal sphincter.

The external anal sphincter is supplied by inferior rectal branch of pudendal nerve. Afferent impulses of physiological distension of rectum and sigmoid colon are carried by parasympathetic, whereas pain impulses are conveyed both by the sympathetic and parasympathetic nerves.

Pancreas

Branches of coeliac plexus pass along the arteries. Effect of sympathetic is vasomotor. The nerve fibres make synaptic contact with acinar cells before innervating the islets. The parasympathetic ganglia lie in sparse connective tissue of the gland and the islet cells.

Liver

Nerves of the liver are derived from hepatic plexus which is an offshoot of coeliac plexus. This contains both sympathetic and parasympathetic fibres. These accompany the blood vessels and bile duct. Both types of nerve fibres also reach the liver through various peritoneal folds.

Gallbladder

Parasympathetic and sympathetic nerves of gallbladder are derived from coeliac plexus, along the hepatic artery (hepatic plexus) and its branches. Fibres from the right phrenic nerve (C4) through the communication of coeliac and phrenic plexus also reach gallbladder in the hepatic plexus. Thus, the reason of pain in the right shoulder (from where impulses are carried by lateral supraclavicular nerve C4) in cholecystitis is the stimulation of phrenic nerve fibres (C4) due to the communication between phrenic plexus and hepatic plexus via coeliac plexus. Coeliac plexus gets fibres from thoracic 7 ganglia. Thoracic 7 nerve supplies skin over inferior angle of scapula. Hepatic plexus, an offshoot of coeliac plexus supplies gallbladder. So pain of gallbladder is also referred to inferior angle of scapula.

Kidneys

The kidneys are supplied by renal plexus formed from coeliac ganglion, coeliac plexus, lowest thoracic splanchnic nerve, and first lumbar splanchnic nerve. The plexus runs along the branches of renal artery to supply the vessels, renal glomeruli and tubules. These are chiefly vasomotor in function.

Ureter is supplied in its upper part from renal and aortic plexus, middle part from superior hypogastric plexus and lower part from hypogastric nerve and inferior hypogastric plexus.

Vesical Plexus

Sympathetic fibres arise from T11–12 segments and lumbar 1–2 segments of spinal cord. Parasympathetic fibres arise from sacral 2, 3, 4 segments of spinal cord, which relay in the neurons present in and near the wall of urinary bladder. Parasympathetic system is motor to the muscular coat and inhibitory to the sphincter; sympathetic system is chiefly vasomotor. Emptying and filling of urinary bladder is normally controlled by parasympathetic system only.

Male Reproductive Organs

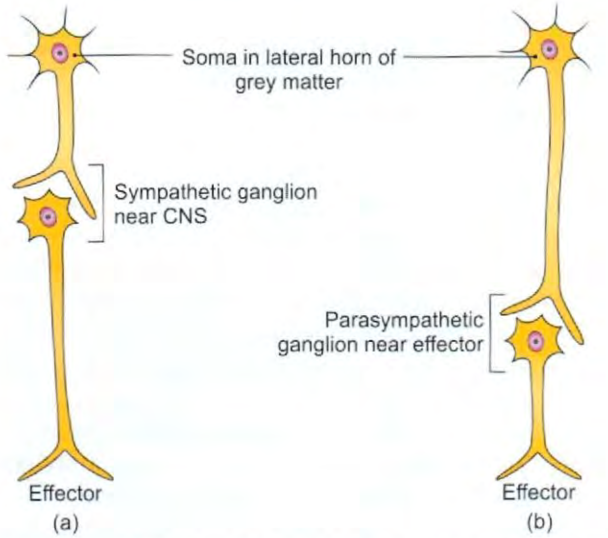
Testicular plexus accompanies the testicular artery to reach the testis. It is formed by renal and aortic plexus, and also from superior and inferior hypogastric plexuses. This plexus supplies the epididymis and ductus deferens.

Prostatic plexus is formed from inferior hypogastric plexus and branches are distributed to prostate, seminal vesicle, prostatic urethra, ejaculatory ducts, erectile tissue of penis, penile part of urethra and bulbourethral glands. Sympathetic nerves cause vasoconstriction, parasympathetic nerves cause vasodilatation.

Comparison of parasympathetic and sympathetic nervous systems is tabulated in Table 13.2.

Table 13.2: Comparison of parasympathetic and sympathetic nervous systems

	Parasympathetic	*Sympathetic*
Preganglionic neuron	Located in midbrain, pons and medulla oblongata and pass through III, VII, IX, X cranial nerves and also along S2–S4 segments of spinal cord	Located in lateral horn of spinal cord from Th 1–12 and L 1–2 segments
Preganglionic fibres	Longer (Fig. 13.3b)	Shorter (Fig. 13.3a)
Relay of impulses	Occurs in neurons close to viscera	Occurs in neurons little away from the viscera they supply
Postganglionic fibres	Short	Long
Neurotransmitter	Both at preganglionic endings and postganglionic endings, acetylcholine is released	At preganglionic endings, acetylcholine is released. At postganglionic endings, adrenaline is released, except in cases of sweat glands where acetylcholine is released.
Number of synapses	Preganglionic neuron makes synapses with much smaller number of neurons. Impulses are localised	Preganglionic neuron makes connection with large number of postganglionic nerve cells and impulses are widespread.
Postganglionic supply	Only the viscera are supplied by postganglionic fibres. These do not supply blood vessels of skelelal muscles	All the viscera are supplied by post-ganglionic fibres. The only exception is suprarenal gland which is supplied by the preganglionic fibres.
Functions	These activities are discrete as well as isolated and conserve the body energies	These activities are mass reactions, widely diffuse in their action. These reactions are catabolic in nature and are used in fright, flight or fight.
Action of skin	Nil	Sudomotor, pilomotor and vasomotor
Effect on blood vessels	Blood vessels to the glands of gastrointestinal tract are dilated	Blood vessels to skeletal muscles (cholinergic), heart and brain are dilated.
Effect of gastrointestinal system	Secretory to the glands, motor to the smooth muscles and inhibitory to the sphincters of gut	Decreases the secretory activity of glands, including the peristalsis of gut. It is motor to the sphincters.
Effect on pupil	Pupil is constricted, lens curvature is increased as in reading	Dilates the pupil.
Heart	Slows the pulse, maintains normal blood pressure	Tachycardia, rise in blood pressure. Dilates the coronaries
Lungs	Increase the secretions of glands of lungs and is bronchoconstrictor	Decreases the secretions, is bronchodilator. Adrenaline-like drugs are given in asthma.
Urinary bladder	Both filling and emptying of urinary bladder are controlled by parasympathetic	Supplies only blood vessels of bladder, sphincter vesicae is contracted by sympathetic action during ejaculation



Figs 13.3a and b: (a) Sympathetic nervous system, and (b) parasympathetic system

Female Reproductive Organs

The ovary and uterine tube receive their nerve supply from plexus around the ovarian vessels. This plexus is derived from renal, aortic plexuses and also from superior and inferior hypogastric plexuses. Sympathetic fibres derived from T10–T11 segments of spinal cord are vasomotor in nature whereas parasympathetic fibres are probably vasodilator in function.

Uterus

It is supplied by uterovaginal plexus, formed from the inferior hypogastric plexus. The sympathetic fibres are derived from T12 to L1 segments of spinal cord. Parasympathetic fibres arise from S2–S4 segments of spinal cord. Sympathetic system causes uterine contraction and vasoconstriction, while parasympathetic nerves produce vasodilatation and uterine inhibition. Vagina is supplied by nerves arising from inferior hypogastric plexus to uterovaginal plexus. These supply wall of vagina including vestibular glands and clitoris. Parasympathetic fibres cause vasodilator effect on the erectile tissue.

AFFERENT AUTONOMIC FIBRES

Autonomic afferents are peripheral processes of pseudounipolar cells in some cranial and spinal nerve ganglia. The terminals of autonomic nerves may be loops, rings, tendril-like endings, a few encapsulated ones in the walls of viscera. Viscera are sensitive to stretch, ischaemia and distension. These sensations cause pain and reach up to the level of consciousness.

General visceral afferent fibres are in III, VII, IX, X cranial nerves, sacral 2, 3, 4 nerves and in T1–L2 spinal nerves.

Vagus nerves has a large general visceral afferent component. The superior ganglion is somatic and inferior is visceral in nature. Their central processes end in dorsal nucleus of vagus or tractus solitarius. Afferents are reached from pharynx and oesophagus via IX, X cranial nerves which are concerned with swallowing reflexes. In the thorax, afferent fibres arise from walls of great vessels, aortic and carotid bodies and bronchial musculature (for cough reflex). General visceral afferent fibres from stomach and intestine also terminate in the dorsal nucleus of vagus which may be responsible for nausea and hunger.

CLINICAL ANATOMY

1 Removal of stellate ganglion improves the blood supply to the upper limb. But its removal causes Horner's syndrome which is comprised of:
   - Anhidrosis of the same side of face
   - Partial drooping of upper eyelid, i.e. ptosis
   - Enophthalmos
   - Constriction of the pupil
   - Loss of ciliospinal reflex
   - Flushing of face

2 Arteries of the upper limb are innervated by sympathetic fibres. Preganglionic fibres originate from the cell bodies of T2–T5 spinal segments. Fibres ascend in the sympathetic trunk and synapse with middle and inferior cervical ganglia. Postganglionic fibres join the nerves which constitute the brachial plexus, get distributed to the arteries of the upper limb in each region. These fibres may be cut to relieve the symptoms of Raynaud's disease.

3 Thoracic 2–5 ganglia and stellate ganglia may be removed in cases of intractable angina pectoris.

4 Arteries of lower limb are supplied by lower three thoracic and upper two lumbar segments of the spinal cord. Femoral artery is supplied by sympathetic fibres from femoral and obturator nerves. Posterior tibial artery receives the postganglionic fibres from common peroneal and tibial nerves.
   Buerger's disease may be treated by lumbar sympathectomy.

5 *Megacolon:* There is absence of ganglion cells and failure of innervation of the smooth muscle layers of pelvic colon.

6 *Referred pain:* If the somatic nerves from skin and afferent fibres from viscera enter the same segment of the spinal cord, the phenomenon of referred pain occurs. Visceral pain in the appendix is produced due to either spasm of its muscle, or distension of its lumen. The afferent impulses ascend through

the superior mesenteric plexus, lesser splanchnic nerve to reach the spinal cord at T10 level. Impulses from the skin around umbilicus are also carried by T10 segment.

Brain is more conscious of impulses from skin. So in early case of appendicitis, though there is stimulation of sympathetic fibres of appendix, person thinks the impulses are arising from skin of umbilicus. So pain of early appendicitis is referred to the umbilicus. Later on when parietal peritoneum is inflamed, pain is localised in the right iliac fossa.

7 Pain fibres from the body of the uterus pass with sympathetic nerves through the hypogastric plexus and the lumbar splanchnic nerves to cells on the dorsal roots of the lower thoracic and upper lumbar nerves. Afferents from cervix pass in dorsal roots of upper sacral nerves. Cauterization of cervix does not cause pain whereas stretch (dilatation) of cervix is painful.

Development

Sympathetic Portion

Sympathetic pathways consist of two neurons, i.e. preganglionic and postganglionic. The preganglionic neurons develop in the mantle layer of thoracolumbar segments of spinal cord, T1–L2 segments. These neurons are located in the general visceral efferent column or intermediate zone and form the lateral horn of the spinal cord. The axons arising from these neurons are myelinated and pass into ventral nerve roots to enter spinal nerves. After a short course, they leave the spinal nerve and pass towards postganglionic neurons.

Postganglionic neurons develop in the 5th week of intrauterine life; cells originating in the neural crest of the thoracic region migrate on each side of spinal cord towards the region immediately behind the dorsal aorta. Here they form a bilateral chain of segmentally arranged sympathetic ganglia interconnected by longitudinal nerve fibres. Together they form the sympathetic chains located on each side of vertebral column. From positions in the thorax, neuroblasts migrate towards cervical and lumbosacral region, thus extending sympathetic chain to their full length. The arrangement is obscured in the cervical region by fusion of the ganglia (Fig. 13.1).

Some neuroblasts migrate in front of aorta to form preaortic ganglia like coeliac, mesenteric ganglia.

The nerve fibres originating in the visceroefferent column (lateral horn) of thoracolumbar segments of spinal cord synapse with neurons of sympathetic ganglion at the same level in sympathetic chain or pass through the chain to preaortic or collateral ganglion. The preganglionic fibres have myelin sheath and stimulate sympathetic ganglion cells. Passing from spinal nerves to sympathetic ganglion, they form the white ramus communicans. Since the visceroefferent column extends from T1–L2 segments of spinal cord, white rami communicantes are found only at T1–L2 levels (Fig. 13.3a).

Axons of sympathetic ganglion cells are called postganglionic fibres and have no myelin sheath. They pass either to other levels of sympathetic chain or extend to heart, lungs and intestinal tract.

Other fibres known as grey rami communicantes pass from sympathetic chain to spinal nerves and from there to peripheral blood vessels, arrector pilorum muscles and sweat glands. Grey rami communicantes are found at all levels of spinal cord.

Parasympathetic Portion

Preganglionic neurons are formed in the brain stem and sacral region of spinal cord.

These neurons in the brain stem are located in general visceral efferent column. These give rise to Edinger-Westphal nucleus, lacrimatory, superior salivatory and inferior salivatory nuclei and dorsal nucleus of vagus. Their axons constitute the cranial parasympathetic outflow (Fig. 13.3b).

The sacral preganglionic neurons are derived from the mantle layer of sacral part of the spinal cord, their axons constitute the sacral parasympathetic outflow.

Postganglionic neurons of cranial region are derived from neural crest cells. These neurons form ciliary, otic, sphenopalatine and submandibular ganglia and also the ganglia associated with various viscera supplied by vagus nerve. Postganglionic axons arise from these neurons in the ganglia and supply constrictor papillae, lacrimal, salivary glands and various viscera.

According to some investigators, postganglionic neurons of the brain arise from same region as the preganglionic neurons and migrate along the path followed by postganglionic fibres.

In the sacral region, the postganglionic neurons migrating from the sacral part of the spinal cord supply pelvic viscera and distal one-third of transverse colon, descending colon, pelvic colon, and rectum.

Appendix

Real leaders are ordinary people with extraordinary determination
Pain of the mind is worse than pain of the body

SUMMARY OF THE VENTRICLES OF THE BRAIN

LATERAL VENTRICLE

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

Body or Central Part

Roof: Trunk of corpus callosum.

Floor: Superior surface of thalamus, thalamostriate vein, stria terminalis, body of caudate nucleus.

Medial: Septum pellucidum, body of fornix (*see* Fig. 9.5a).

Anterior Horn

Roof: Anterior part of trunk of corpus callosum.

Anterior: Genu and rostrum of corpus callosum.

Floor: Head of caudate nucleus (*see* Fig. 9.7a).

Medial wall: Septum pellucidum and column of fornix.

Posterior Horn

Roof and lateral wall: Tapetum of corpus callosum.

Medial wall: Bulb of posterior horn above and calcar avis below (*see* Fig. 9.8).

Inferior Horn

Roof and lateral wall: Tapetum, tail of caudate nucleus, stria terminalis and amygdaloid nucleus.

Floor: Pes hippocampus, hippocampus, alveus, fimbria, dentate gyrus and collateral eminence (*see* Fig. 9.9).

THIRD VENTRICLE

The third ventricle lies between the two thalami. The components of its boundaries and recesses are enumerated:

Anterior wall: Lamina terminalis, anterior commissure, anterior column of fornix (*see* Fig. 9.1).

Posterior wall: Pineal body and cerebral aqueduct.

Floor: Optic chiasma, tubercinerium, infundibulum, mammillary body, posterior perforated substance and tegmentum of midbrain.

Roof: Ependyma, tela choroidea.

Lateral wall: Medial surface of thalamus, medial aspect of hypothalamus, epithalamus and interventricular foramen.

Recesses: Infundibular recess, optic recess, pineal recess, suprapineal recess (*see* Fig. 9.1).

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 (*see* Fig. 7.1).

Floor

Upper part: Facial colliculus on the dorsal surface of pons (*see* Fig. 7.2).

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 (*see* Fig. 7.2).

Recesses in roof: One median dorsal, two lateral dorsal and two lateral.

Apertures: One median — foramen of Magendie, two lateral — foramina of Lushka (left and right).

Continuity: Above with cerebral aqueduct
Below with central canal of spinal cord.
Table A.1 shows arteries of brain.

NUCLEAR COMPONENTS OF CRANIAL NERVES

CN I: OLFACTORY

Part of forebrain

CN II: OPTIC

Part of forebrain

CN III: OCULOMOTOR

1. General somatic efferent column for 5 extraocular muscles at level of superior colliculus.
2. General visceral efferent column for 2 sets of intraocular muscles (*see* Flowchart A.4, Volume 3).
3. General somatic afferent-mesencephalic nucleus of CN V. It receives proprioceptive impulses from extraocular muscles (*see* Figs 4.4a and b).

CN IV: TROCHLEAR

1. General somatic efferent column for supply of only superior oblique muscle at level of inferior colliculus.
2. General somatic afferent-mesencephalic nucleus of CN V. It receives proprioceptive impulses from the superior oblique muscle.

CN V: TRIGEMINAL

1. Special visceral efferent column for 4 muscles of mastication and 4 other muscles at upper level of pons.
2. General somatic afferent column:
    a. Spinal nucleus of CN V for pain and temperature from face.
    b. Superior sensory nucleus of CN V for touch and pressure from face.
    c. Mesencephalic nucleus of CN V for proprioceptive impulses from extraocular muscles, muscles of tongue and mastication.

CN VI: ABDUCENT

1. General somatic efferent column for lateral rectus at lower level of pons.
2. General somatic afferent—mesencephalic nucleus of CN V. It receives proprioceptive impulses from the lateral rectus muscle.

CN VII: FACIAL

1. Special visceral efferent column for muscles of facial expression at lower level of pons.
2. General visceral efferent for lacrimal, nasal, palatal and submandibular, sublingual glands (*see* Flowcharts A.1 and A.2, Volume 3).
3. Special visceral afferent and general visceral afferent (nucleus of tractus solitarius) for carrying taste from most of anterior two-thirds of tongue and afferents from glands supplied by it.
4. General somatic afferent from part of skin of auricle.

CN VIII: VESTIBULOCOCHLEAR

Special somatic afferent column:

Two parts: Vestibular nuclei: Medial, superior, spinal, lateral.

Cochlear nuclei: Dorsal and ventral.

All at pontomedullary junction.

CN IX: GLOSSOPHARYNGEAL

1. Special visceral efferent for one muscle of pharynx—the stylopharyngeus in medulla oblongata.
2. General visceral efferent for parotid gland (*see* Flowchart A.3, Volume 3).
3. Special and general visceral afferent (nucleus of tractus solitarius) for sensations of taste from posterior one-third tongue and circumvallate papillae, also carries general sensations from posterior one-third tongue, tonsil carotid body and carotid sinus.
4. General somatic afferent for proprioceptive fibres from the muscle.

CN X + CN XI: VAGUS AND CRANIAL PART OF CN XI

1. Special visceral efferent for muscles of larynx, pharynx, soft palate in medulla oblongata.
2. Special and general visceral afferents carry (nucleus of tractus solitarius) taste from posteriormost part of tongue, epiglottis and afferents from foregut and midgut derivatives.
3. General visceral efferent for glands of respiratory system and gastrointestinal tract till right two-thirds of transverse colon.
4. General somatic afferent from skin of external auditory meatus.

CN XI: SPINAL PART OF ACCESSORY NERVE

1. Special visceral efferent column in C1–C4 ventral horn cells of spinal cord for sternocleidomastoid and trapezius.
2. General somatic afferent—dorsal horns of C2–C4 segments of spinal cord. These receive proprioceptive impulses from the above two muscles.

CN XII: HYPOGLOSSAL

1. General somatic efferent column for all 4 intrinsic muscles of tongue and three extrinsic muscles: Styloglossus, genioglossus and hyoglossus in medulla oblongata.
2. General somatic afferent—mesencephalic nucleus of CN V. It receives proprioceptive impulses from the muscles of tongue.

Table A.1: Arteries of brain

1. **Vertebral artery, a branch of 1st part of subclavian artery, is divided into four parts**
   a. ***First part:*** Lies deep in the neck in the vertebral triangle; gives no branches.
   b. ***Second part:*** Passes in the foramen transversaria of C6–C1 vertebrae; gives spinal branches for supply of meninges and spinal cord (*see* Fig. 11.3).
   c. ***Third part:*** Lies in the suboccipital triangle, on the posterior arch of atlas vertebra and gives branches to muscles of suboccipital triangle.
   d. ***Fourth part:*** Enters the cranial cavity through foramen magnum. Joins with the same artery of opposite side to form basilar artery at the lower border of pons. The fourth part gives:
      i. Meningeal branches
      ii. Posterior spinal artery
      iii. Anterior spinal artery
      iv. Posterior inferior cerebellar artery
      v. Medullary branches.
2. **Right and left vertebral arteries unite at the lower border of the pons to form a median basilar artery, which gives following branches:**
   a. Anterior inferior cerebellar (*see* Fig. 11.4)
   b. Pontine branches
   c. Labyrinthine branches
   d. Superior cerebellar
   e. Posterior cerebral
3. **Internal carotid artery**
   a. Cervical part gives no branches.
   b. Petrous part gives (i) caroticotympanic for the middle ear, and (ii) pterygoid branch.
   c. Cavernous part gives branches to (i) trigeminal ganglion, and (ii) superior and inferior hypophyseal branches.
   d. Cerebral part gives following branches:
      i. Ophthalmic artery which supplies outer layers of eyeball and retina through central artery of retina which is an end artery
      ii. Anterior cerebral (*see* Fig. 11.13)
      iii. Middle cerebral
      iv. Posterior communicating
      v. Anterior choroidal
4. **Circle of Willis**

   Circle of Willis is formed by union of (i) anterior cerebral, (ii) terminal part of internal carotid, (iii) posterior communicating branch of internal carotid, (iv) joining the posterior cerebral branch of vertebral artery on each side (*see* Fig. 11.13). The two anterior cerebral arteries are joined by anterior communicating artery.

   It gives:

   a. ***Central branches:*** These are long thin, numerus end arteries with supply deeper structures like internal capsule and basal ganglia.
   b. ***Choroidal branches*** of internal carotid and posterior cerebral arteries supply choroid plexuses of the ventricles.
   c. ***Cortical branches:*** These are:
      i. *Anterior cerebral:* Chief artery on the medial surface of cerebral hemisphere till parieto-occipital sulcus. It also supplies 1 cm wide area on the superolateral surface, along the superomedial border. The area includes motor and sensory areas of lower limb and perineum.
      ii. *Middle cerebral:* Main artery of the superolateral surface supplying major parts of motor and sensory areas. It also supplies motor speech area, auditory and vestibular areas.
      iii. *Posterior cerebral:* Chief artery of the tentorial surface and occipital lobe. This is the artery of visual cortex.

EFFERENT PATHWAYS OF CRANIAL PART OF PARASYMPATHETIC NERVOUS SYSTEM

Preganglionic parasympathetic fibres are present in 4 cranial nerves, e.g. cranial nerves III, VII, IX, X and along spinal nerves S2, S3, S4. Four ganglia namely ciliary, pterygopalatine, submandibular and otic are concerned with efferent parasympathetic fibres. Their connections are shown in Flowcharts A.1 to A.4 (*see* Volume 3).

CLINICAL TERMS

Brown-Séquard syndrome: The signs and symptoms are due to injury to one-half of the spinal cord. Following are at the level of injury:

a. Ipsilateral upper motor neuron paralysis.
b. Ipsilateral loss of conscious proprioception.
c. Contralateral loss of pain and temperature.

Following are due to injury to various tracts below the level of injury:

a. Ipsilateral lower motor neuron paralysis.
b. Ipsilateral loss of sensation over the cranial dermatome.

These (a), (b) are due to injury to nerve root at the level of injury (*see* Fig. 3.18).

Cauda equina syndrome: It occurs due to compression of cauda equina in the vertebral canal. L2–S5 nerve roots are affected. Its features are:

a. Loss of knee and ankle jerks.
b. Sensory loss in nerve root distribution.
c. Asymmetric areflexic lower motor neuron type of paralysis.
d. Later involvement of bowel and bladder.

Syringomyelia: There are cavities around the central canal. There is bilateral loss of spinothalamic fibres. Lateral spinothalamic tracts cross at once while anterior spinothalamic first ascend and then cross. There is loss of pain and temperature at one level and loss of touch and pressure at another level. So it is called "dissociated sensory loss" (*see* Fig. 3.19).

Conus medullaris syndrome: It is produced due to pressure on conus medullaris of spinal cord from where S2, S3 and S4 nerves arise. The symptoms and signs are:

a. Saddle-shaped anaesthesia on the bottom.
b. Loss of anal sphincteric reflex.
c. Urinary bladder and bowel get affected early.

There is no motor weakness and patient has normal knee and ankle reflexes.

Medial medullary syndrome: This syndrome occurs due to thrombosis of anterior spinal artery. There is paralysis of muscles of tongue on same side, associated with hemiplegia and loss of position sense in limbs on the opposite side (*see* Fig. 5.8).

Tabes dorsalis: Tabes dorsalis affects the posterior white column of spinal cord. It leads to bilateral loss of proprioceptive sensations and tactile discrimination below the side of lesion. The finger nose test is past pointing with eyes closed (*see* Fig. 3.6).

Lateral medullary syndrome or Wallenberg's syndrome: The lateral medullary syndrome leads to symptoms as:

a. *On the side of lesion:* Vertigo, vomiting, nystagmus (vestibular nuclei affected) and ataxia of limbs (inferior cerebellar peduncle). Horner's syndrome (sympathetic fibres) and dysphagia, hoarseness (nucleus ambiguus).
b. *On the opposite side of lesion:* Loss of pain and temperature from limbs and trunk (*see* Fig. 5.8).

Cerebellopontine angle syndrome: The anatomical structures located in cerebellopontine angle are choroid plexus of 4th ventricle, 7th and 8th nerves. A tumour here gives symptoms: Facial nerve paralysis and 8th nerve paralysis leading to deafness and vertigo. Flocculus of cerebellum involved leads to ataxia on the affected side.

Millard-Gubler syndrome: Millard-Gubler syndrome occurs due to lesion in the lower pons affecting pyramidal tract and fibres of 6th and 7th cranial nerves. The symptoms are:

a. Ipsilateral medial squint.
b. Ipsilateral paralysis of muscles of facial expression.
c. Contralateral hemiplegia.

Benedikt's syndrome: Benedikt's syndrome results due to lesion of tegmentum of midbrain involving superior brachium, fibres of 3rd nerve, red nucleus and medial lemniscus (*see* Fig. 5.17).

Weber's syndrome: Weber's syndrome involves corticospinal tract and 3rd nerve nucleus. There is lateral squint on same side and hemiplegia on the opposite side of body (*see* Fig. 5.17).

Parinaud's syndrome: This syndrome occurs due to compression of superior colliculi when these get pressed by tumour of pineal gland. There is paralysis of upper gaze only. Other eye movements are unaffected (*see* Fig. 5.17).

Thalamic syndrome: Thalamic syndrome is due to a vascular lesion. It is characterised by disturbances of sensations, hemiparesis or hemiplegia with hyperaesthesia and severe spontaneous pain. Pleasant as well as unpleasant sensations are exaggerated.

Subarachnoid haemorrhage: Subarachnoid haemorrhage is the collection of blood in the subarachnoid space at the base of brain. These are also called the cisterns. The circle of Willis lies in the interpeduncular cistern. Any small branch usually due to persistent hypertension may rupture to give rise to subarachnoid haemorrhage.

Cerebral stroke: The neurological signs and symptoms due to lack of blood supply constitute the cerebral stroke. It is mostly due to rupture of any of the arteries especially central branch of middle cerebral artery supplying the internal capsule.

Charcot's artery of cerebral haemorrhage: The largest branch of anterolateral central branches of middle cerebral artery is called Charcot's artery of cerebral haemorrhage. It supplies internal capsule which has motor fibres for one side of body. Damage to artery causes opposite side hemiplegia.

Sparing of macula in thrombosis of posterior cerebral artery: Macula is represented at the occipital pole. It is supplied by branches of middle cerebral artery or by anastomosis between middle and posterior cerebral arteries. So thrombosis of posterior cerebral artery does not harm the macula (*see* Fig. 4.13).

Hydrocephalus: Hydrocephalus is an abnormal increase in the volume of CSF within the skull. It may be due to increased production, blockage in circulation or decreased absorption of CSF.

Hydrocephalus may be "internal" within ventricular system causing increased intracranial pressure and brain damage. If CSF accumulates in the subarachnoid space, the condition is called external hydrocephalus (*see* Fig. 2.7).

Parkinsonism: Lesion of corpus striatum leads to parkinsonism. It gives rise to:

a. Lead pipe rigidity or hypertonicity.
b. Movements are slow (*see* Fig. 8.23).
c. Loss of automatic associated movements and also loss of facial expression.
d. Involuntary movement like tremors, pin rolling movements of hand.
e. Bends forwards during walking.

Babinski's sign: In case of lesion of corticospinal tract there is dorsiflexion of big toe and fanning of other toes in response to scratching the skin on the lateral side of sole. This sign is positive in case of upper motor neuron lesion.

When corticospinal tract is damaged, the influence of other tracts becomes obvious which cause dorsiflexion of 1st toe and fanning of other toes. In infants and children up to two years Babinski's sign is normally present as the tracts are not fully myelinated (*see* Fig. 1.8).

Poliomyelitis: It is a viral disease which involves anterior horn cells leading to flaccid paralysis of the affected segments. It is lower motor neuron paralysis (*see* Fig. 3.6).

Following is the comparison between upper motor neuron and lower motor neuron paralysis:

LMN paralysis	*UMN paralysis*
Muscle tone abolished	Muscle tone increased
Leads to flaccid paralysis	Leads to spastic paralysis
Muscles atrophy later	No atrophy of muscles
Reaction of degeneration seen	Reaction of degeneration not seen
Tendon reflexes absent	Tendon reflexes exaggerated
Limited damage	Extensive damage

Cerebral vascular disease: It is quite common in old age and manifest in different ways.

a. Haemorrhage—cortical or subcortical
b. Thrombosis
c. Embolism.

Hypertensive encephalopathy: This is a manifestation of sustained elevation of diastolic blood pressure in the form of multiple diffuse small lesions distributed all over, result in a variegated picture of the circle of Willis (berry's aneurysm).

Nerve supply: The arteries of the brain are supplied with sympathetic nerves which run onto them from carotid and vertebral plexuses.

They are extremely sensitive to injury and readily react by passing into prolonged spasms. This by itself may be sufficient to cause damage to brain tissue since even the least sensitive neurons cannot withstand absolute loss of blood supply for a period more than 3–7 minutes.

MULTIPLE CHOICE QUESTIONS

1. Match the structures on the left with their related structures on the right.

Left	*Right*
a. General somatic afferent	i. Vestibulocochlear nerve
b. Special somatic afferent	ii. Trigeminal
c. Special visceral efferent	iii. Oculomotor
d. General somatic efferent	iv. Accessory

2. Special features of the parts of brain:

Left	*Right*
a. Olivary nucleus	i. Cerebellum
b. Dentate nucleus	ii. Midbrain
c. Facial colliculus	iii. Pons
d. Substantia nigra	iv. Medulla oblongata

ANSWERS

1. a. – ii, b. – i, c. – iv, d. – iii, **2.** a. – iv, b. – i, c. – iii, d. – ii.

FURTHER READING

1 Alexander GE, Dehong MR, Strick PL. Parallel organization of functionally segregated circuits linking basal ganglia and cortex. *Ann Rev Neurosci* 1986; 9:357–82.

2 Bjorklund A, Hokfelt T, Owman C (eds). The peripheral Nervous System. Handbook of Chemical Neuroanatomy. Vol 6 Amsterdam: Elsevier 1988.

3 Brodal P, Bjaalie JG. Organisation of the pontine nuclei Neurosci Res 1992; 13:83–118.

4 Browder J, Kaplan HA. Cerebral Dural Sinuses and their Tributaries Springfield, Illious: Thomas 1976.

5 Crossman AR, Neary D. Neuroanatomy. An Illustrated Colour Text 2nd edition. Edinburgh Churchill Livingstone 2000.

6 Duvernoy HM, Delon S, Vannson JL. Cortical blood vessels of the human Brain. Brain Res Bull 7:519–79 1981.

7 Garg, Kaul, Bahl. Textbook of Neuroanatomy, 4th edn., CBS Publishers & Distributors

8 Gebhart Al, Petersen SE, Thach WT. Role of the posterolateral cerebellum in langnage. *Ann NY Acad Sci* 2002; 978: 318–33.

9 Hubel DH. Eye, Brain and Vision Scientific American Library Series No. 22 1988.

10 Jones EG. The Thalamus New York ; Plenum Press 1985; 403–11.

11 Kaplan HA, Ford DH. The Brain Vascular System Amsterdam: Elsevier 1966.

12 Leigh RJ, Zee DS. The Neurology of eye movement, 3rd edition Oxford. Oxford University Press 1999.

13 Macchi G, Jones EG. Toward an agreement on terminology of nuclear and subnuclear division of the motor thalamus. *J Neurosurg* 1997; 86(4):670–85.

14 Nadol IB. Comparative anatomy of the cochlea and auditory nerve in mammals Hear Res 1988; 34:253–66.

15 Nieuwenhuys R, Voogd J, Huijzen C Van. The human central nervous system. A synopsis and atlas 3rd edition Berlin : Spring Verlag 1988.

16 Papez JW. A proposed mechanism of emotion Arch Neurol Psychiat 1937; 38:725–43.

17 Paulson OB. Blood brain barrir, brain metabolism and cerebral blood flow Eur Neuropsychopharmacol 2002; 12 (6): 495– 501.

18 Penfield W, Rasmussen T. The Cerebral Cortex of man. New York ; Macmillan 1950.

19 Penney JB Jr, Young AB. Striatal inhomogeneities and basal ganglia function. Mov Disord 1986; 1:3–15.

20 Schmahmann JD, Sherman JC. The cerebellar cognitive affective syndrome. Brain 1998; 121:561–79.

21 Schoenen J, Faull RLM. Spinal cord: Cytoarchitectural, dendro architectural and myeloarchitectural organisation. In : Paxinos G (ed) The Human Nervous system. San Diego, CA : Academic Press: 1990; 19–53.

22 Sperry RW. Consciousness, Personal Identify and the divided brain Neuropsychologia 1984; 17:153–66.

23 Strazielle N, Ghersi-Egea JF. Choroid plexus in the Central Nervous System: Biology and Physiopathology. *J Neuropathol Exp Neurol* 2000; 59(7):561–74.

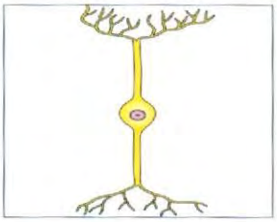
24 Turnbull IM, Brieg A, Hassler O. Blood supply of cervical spinal cord in man. A microangiographic cadaver study. J Neurosurg 1966;24:951–65.

25 Zeki S. A Vision of the Brain, Oxford: Blackwell Scientific, 1993.

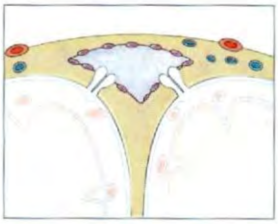
26 Zhang ET, Inman CBE, Weller RO. Interrelationships of the pia mater and the perivascular (Virchow-Robin) spaces in the Human Cerebrum. *J Anat* 1990;170:111–23.

SPOTS

1. a. Identify the structure.
   b. Where are such structures found?

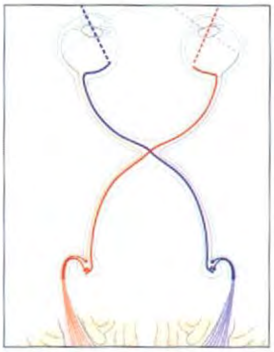


2. a. Name the structure.
   b. Enumerate its folds.

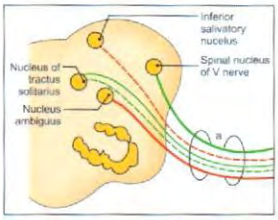


3. a. Identify the structure.
   b. Where does it terminate?

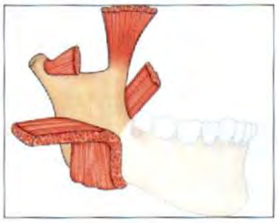
4. a. Identify the structure.
   b. What is the effect if its crossing fibres are damaged?



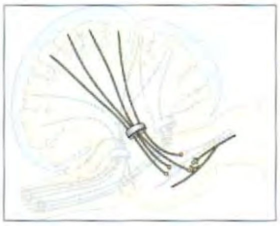
5. a. Identify the structure.
   b. Name its functional components.



6. a. Identify the structure.
   b. Name the muscles attached to it.
   c. What is the nerve supply?

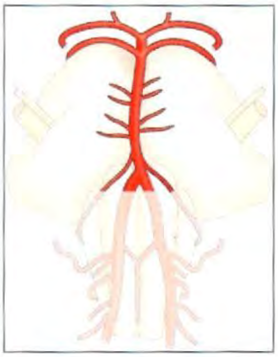


7. a. Name the structure.
   b. Name its fibres.



8. a. Identify the part.
   b. What is its blood supply?

9. a. Identify the structure.
   b. Name its branches.



10. a. Identify the structure.
    b. What are its parts?

ANSWERS OF SPOTS

1. a. Bipolar neuron
   b. Retina, nasal mucous membrane, taste buds, cochlear ganglion and vestibular ganglion (special senses)

2. a. Meningeal layer of dura mater
   b. Falx cerebri, falx cerebelli, tentorium cerebelli and diaphragma sellae

3. a. Lateral corticospinal tract
   b. Neurons of anterior horn of spinal cord

4. a. Optic chiasma.
   b. Bitemporal hemianopia

5. a. IX or glossopharyngeal nerve
   b. SpVE: Special visceral efferent
      GVE: General visceral efferent
      GVA: General visceral afferent
      SpVA: Special visceral afferent
      GSA: General somatic afferent

6. a. Ramus of mandible
   b. Temporalis, masseter, lateral pterygoid and medial pterygoid
   c. Mandibular branch of trigeminal nerve

7. a. Middle cerebellar peduncle
   b. Corticopontocerebellar fibres

8. a. Occipital lobe
   b. Posterior cerebral artery

9. a. Basilar artery
   b. Anterior inferior cerebellar, pontine, labyrinthine, superior cerebellar and posterior cerebral

10. a. Corpus callosum
    b. Rostrum, genu, body and splenium.

Index