NERVOUS SYSTEM

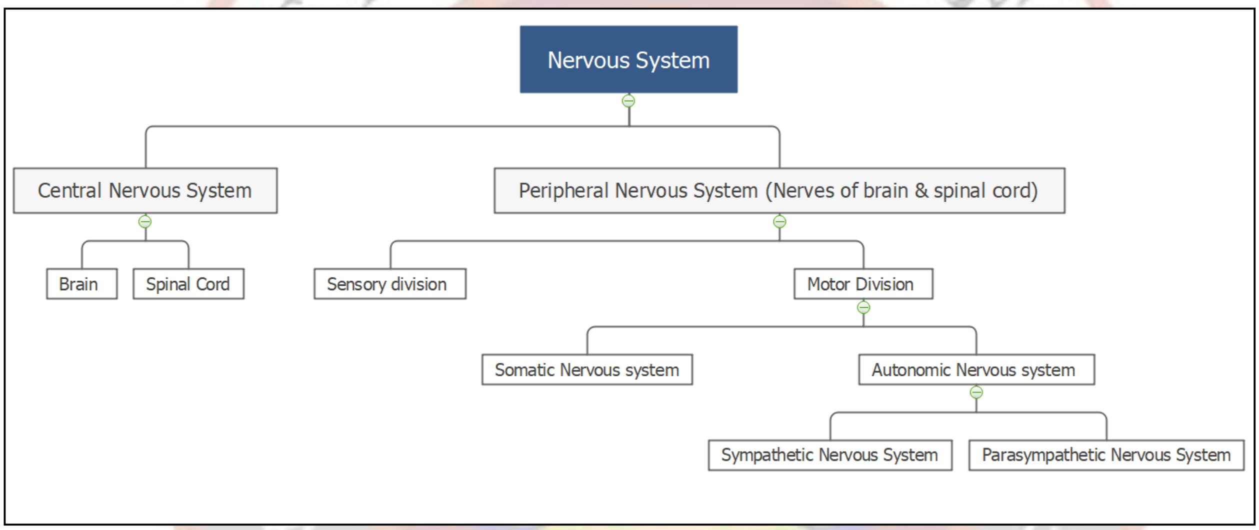
Nervous system

- **Detects and responds to changes inside and outside the body**
- One of the smallest, most complex of the 11 body systems
- Together with the endocrine system, it coordinates and controls vital aspects of body function and maintains homeostasis

Neurology – branch of medicine that deals with normal functioning & disorders of the nervous system

Organization of Nervous System

Nervous system is organized into central and peripheral nervous systems (CNS & PNS).



Central Nervous System

- **Consists of brain & spinal cord**
- Receives sensory information about its internal & external environment from afferent nerves
- Integrates & processes the input and responds by sending nerve impulses through motor nerves to effector organs i.e. muscles & Glands

Peripheral Nervous System

- **Consists of paired cranial & spinal nerves**
- Has two divisions – sensory & motor; Sensory division transmits impulses to CNS whereas motor division transmits from CNS to effectors
- Somatic nervous system of the motor division controls voluntary movement of skeletal muscles
- Autonomic nervous system of the motor division controls involuntary process & glandular activity

Enteric Nervous system – neurons confined to the wall of the GIT

- Helps to regulate the activity of the smooth muscle & glands of GIT

Functions of the Nervous System

1. **Sensory (input) function** – sensory information is carried to brain & spinal cord through cranial and spinal nerves
2. **Integrative function** – Nervous system processes sensory information by analyzing it & making decisions for appropriate responses
3. **Motor function** – once sensory information is integrated, nervous system may elicit an appropriate motor response by activating effectors through cranial & spinal nerves

Cells & Tissues of the Nervous System

- Two types of tissue/ cells are found in the nervous system

1. Excitable cells – **neurons/ nerve cells** (generate & transmit nerve impulses)
2. Non-excitable cells – **glial cells/ neuroglia**; connective tissue that supports the neurons

Neurons

- Has ability to respond to the stimulus & convert to electrical impulses called action potential
- Cannot divide; for survival need continuous supply of oxygen & glucose, can synthesize chemical energy (ATP) only from glucose
- Some neurons initiate action potentials while others act as relay stations
- Action potentials are initiated in response to stimuli from

1. Outside the body – **ex:** touch
2. Inside the body – **ex:** changes in the concentration of CO_2 in blood

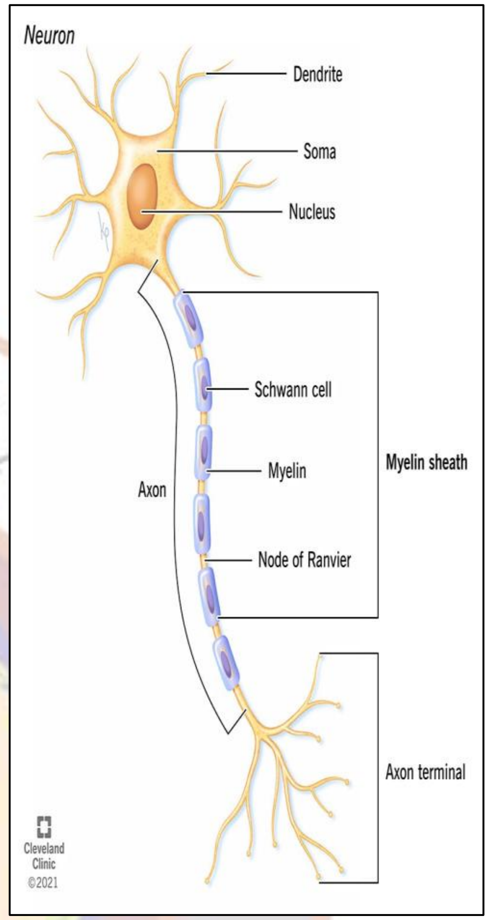
Stimulus – any change in environment that is strong enough to initiate an action potential

Action potential (nerve impulse) – an electrical signal that propagates (travels) along the surface of membrane of a neuron

Parts of a neuron

Each neuron has –

1. Cell body
2. Cell processes – One axon & Many dendrites



Cell Body

- Also called **perikaryon or soma**; consists of nucleus & cell organelles
- Typical cell organelles are present
- Clusters of ribosomes, RER – called Nissil bodies
- Forms grey matter of the nervous system and found at

1. Periphery of brain
2. Center of spinal cord

- Group of cell bodies are called

1. **Nuclei in CNS**
2. **Ganglia in PNS**

(Basal Ganglia in cerebrum is an exception)

Cell processes

- 2 kinds of cell processes – multiple dendrites and a single axon
- Both the processes form the white matter of nervous system and found at
    1. Periphery of spinal cord
    2. Center of brain
- Bundle of axons called nerves in PNS and tracts in CNS

Dendrites

- Receiving or input portions of neurons – receive and carry incoming action potentials towards cell bodies
- Short, tapering, highly branched
- Plasma membrane has numerous sites for binding chemical messengers from other cells
- In motor neurons, form part of synapses; sensory neurons – form sensory receptors that respond to specific stimuli

Axon/ Nerve fiber

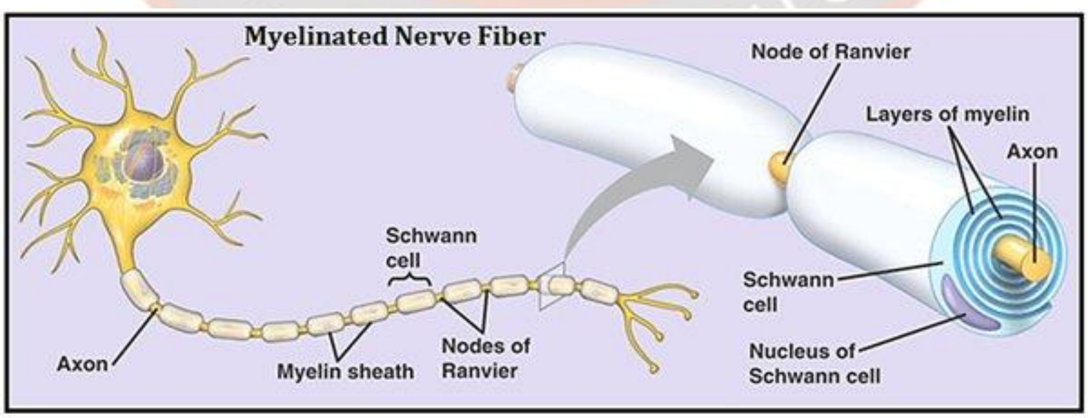
- Each neuron has only 1 axon

- Longer than dendrites; thin, cylindrical projection that begins at tapered end of cell body called axon hillock
- Carry impulses away from cell body; propagates towards another neuron, a muscle fiber or a gland cell
- Part of the axon close to axon hillock – initial segment
- In most neurons, nerve impulses arise at the junction of axon hillock and initial segment – trigger zone
- Membrane of axon is called axolemma & cytoplasm is called axoplasm
- Along the length, side branches called axon collaterals may branch off – end by dividing into many fine processes called axon terminals
- Tips of some axon terminals swell into bulb shaped structures called synaptic end bulbs – contain membrane-enclosed sacs, synaptic vesicles – store chemical neurotransmitters

Neurotransmitter – a molecule released from synaptic vesicles that excites or inhibits another neuron, muscle fiber or gland cell

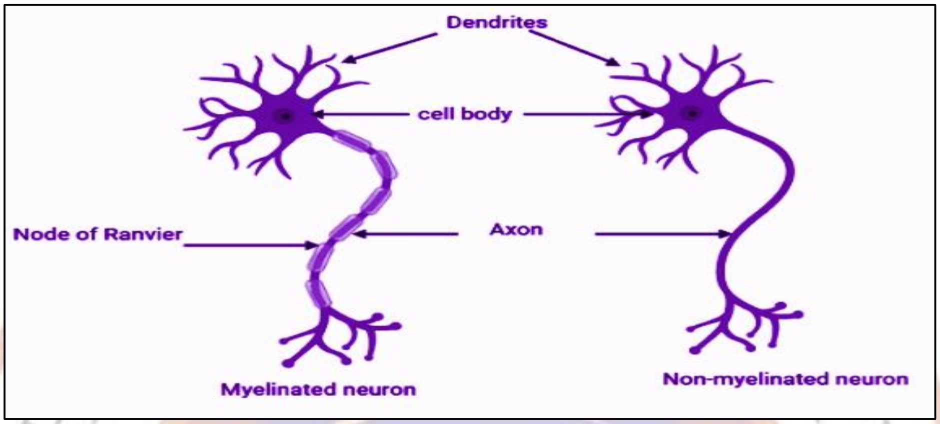
Myelinated axons/ nerve fibers

- Large axons & those of peripheral nerves are surrounded by myelin sheath
- It consists of a series of schwann cells arranged along the length of the axon & wrapped around it by number of concentric layers of plasma membrane
- Between the layers, small amount of fatty substance called myelin is present
- Outermost layer of schwann cell plasma membrane is called neurilemma
- Tiny areas of exposed axolemma between adjacent schwann cells are called Nodes of Ranvier – assist rapid transmission of action potentials in myelinated neurons



Unmyelinated axons/ nerve fibers

- **Ex:** Postganglionic fibers, small fibers in CNS
- Several axons embedded in one schwann cell
- No exposed axolemma – adjacent schwann cells are in close association
- Conduction of action potentials is significantly slower



Classification of Neurons

1. Structural classification – based on number of processes extending from the cell body

Multipolar neurons

- Several dendrites, 1 axon
- **Ex:** most neurons in brain & spinal cord, all motor neurons

Bipolar neurons

- 1 main dendrite, 1 axon
- **Ex:** Retina of eye, inner ear, olfactory area of brain

Unipolar neurons

- Dendrites & axon fuse together to form continuous process – pseudounipolar
- **Ex:** Sensory receptors – detect sensory stimulus like touch, pressure, pain or thermal stimuli

2. Functional classification – based on the direction in which nerve impulses are conveyed with respect to CNS

Sensory neurons/ afferent neurons

- Either contain sensory receptors at the ends or located just after sensory receptors
- Upon stimulation, sensory receptors are activated and action potential is generated in sensory neuron, which is conveyed to CNS through cranial or spinal nerves
- Unipolar in nature

Motor neurons/ efferent neurons

- Convey action potentials away from CNS to effectors in periphery through cranial or spinal nerves
- Multipolar in nature

Interneurons/ association neurons

- Located within CNS between sensory & motor neurons
- Integrate/ process incoming sensory information from sensory neurons and elicit a motor response by activation of appropriate motor neurons
- Multipolar in nature

Neuroglia

- Non-excitable cells that support the neurons and continue to replicate throughout the life
- Consists of 6 types of cells – 4 in CNS & 2 in PNS

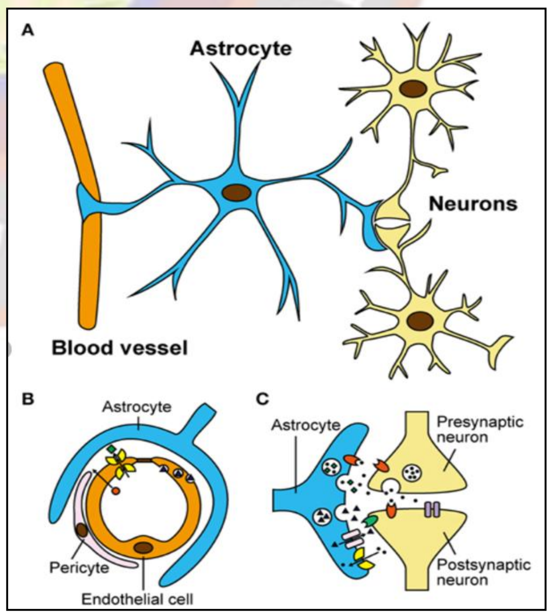
Neuroglia/ glial cells of CNS

Astrocytes

- Star shaped cells with many processes
- Largest & most numerous of neuroglia
- Small swellings present at the free ends of some processes – foot processes
- Found in large number adjacent to blood vessels – foot processes form sleeve around them
- Blood is separated from neurons by Blood Brain Barrier – formed by capillary wall, layer of astrocyte foot process

Blood Brain Barrier

- Selective barrier that protects brain from potent toxic substances & chemical variations in blood
- O_2, CO_2, glucose, lipid soluble substances likes alcohol quickly pass through
- Large molecule, many drugs, inorganic ions, amino acids – pass more slowly or do not pass at all



Oligodendrocytes

- Smaller than astrocytes, has few processes
- Found in clusters round nerve cell bodies in grey matter
- Located adjacent to and along the length of myelinated nerve fibers

- Form & maintain myelin sheath around axons in CNS (like schwann cells in PNS)

Ependymal cells

- Form epithelial lining of ventricles of brain & central canal of spinal cord
- Produce, possibly monitor & assist in circulation of CSF
- Also form blood-CSF barrier

Microglia

- Smallest & least numerous
- Function as phagocytes – remove microbes & damaged tissue in areas of inflammation & cell destruction

Neuroglia of PNS

Completely surround axons & cell bodies

Schwann cells

- Encircle PNS axons, form myelin sheath

Satellite cells

- Flat cells that surround the cell bodies of PNS ganglia
- Provide structural support, regulate exchange of materials between neuronal cell bodies & interstitial fluid

NERVES

Numerous neurons/ nerve fibers collected into bundles are called nerves. **Ex:** sciatic nerve – tens of thousands of axons. Each bundle is surrounded by several coverings of protective connective tissue

- **Epineurium** – fibrous connective tissue that surrounds and encloses number of bundles of nerve fibers
- **Perineurium** – smooth connective tissue that surrounds each bundle of nerve fibers
- **Endoneurium** – connective tissue sheath that surrounds single axon

Nerves are of 3 types –

1. **Sensory/ afferent nerves**
2. **Motor/efferent nerves**
3. **Mixed nerves**

Sensory/ afferent nerves

- Carry information from body to spinal cord, then to brain or to connector neurons of reflex arcs in spinal cord

Motor/ efferent nerves

- Originate in brain, spinal cord & autonomic ganglia
- Transmit impulses to effector organs
- 2 types
  - **Somatic nerves** – involved in voluntary & skeletal muscle contraction
  - **Autonomic nerves** – involved in cardiac & smooth muscle contraction and glandular secretion i.e all involuntary functions
  - Pathway involves preganglionic & postganglionic nerves

Mixed nerves

- In spinal cord, sensory & motor nerves arranged in separate groups called tracts
- Outside the spinal cord, both are enclosed in same sheath of connective tissue – called mixed nerves

Classification & properties of nerve fibers

Nerve fibers are classified into 3 major groups on the basis of following properties –

1. Amount of Myelination
2. Their diameter
3. Propagation speed

A-Fibers

- Largest diameter axons (5-20µm) & myelinated
- Have a brief absolute refractory period & conduct nerve impulses at a speed of 12-130 m/sec
- **Ex:** axons of sensory neurons that propagate impulses associated with touch, pressure, position of joints; axons of motor neurons to skeletal muscles

B-fibers

- Diameter is 2-3 µm, myelinated
- Exhibit conduction at a speed up to 15 m/sec
- Longer absolute refractory period than A-fibers
- **Ex:** axons of neurons that conduct sensory nerve impulses from viscera to brain & spinal cord; all axons of autonomic motor neurons extending from brain & spinal cord to autonomic ganglia

C-fibers

- Smallest diameter axons (0.5 – 1.5 µm), unmyelinated
- Propagation speed is 0.5 – 2 m/sec
- Exhibit longest absolute refractory period
- **Ex:**

1. Axons of neurons that conduct sensory impulses for pain, touch, pressure, heat & cold from skin & pain impulses from viscera
2. Autonomic motor fibers that extend from autonomic ganglia to stimulate heart, smooth muscle & glands

Electrophysiology

Electrophysiology deals with the electrical properties of biological cells and tissues & involves measurement of voltage changes or electric current.

Neurons being excitable cells, communicate with one another using 2 types of electrical signals –

1. **Graded potentials** – used for short-distance communication only
2. **Action potentials** – allow communication over long distances within the body

Action potential is due to movement of ions, specifically Na^+ & K^+ ions into and out of the cells. Action potential in muscle fiber is called muscle action potential. Action potential in neuron is called nerve action potential or nerve impulse.

Production of graded & action potentials depend on

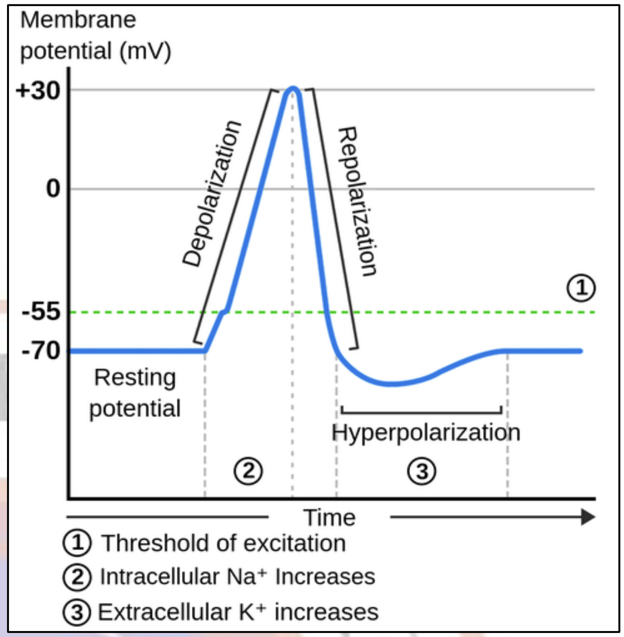
1. Existence of Resting Membrane Potential (RMP i.e. electrical potential difference/ voltage across membrane)
2. Presence of specific type of ion channels

Graded & action potentials occur because the membranes of neurons contain many different kinds of ion channels that open or close in response to specific stimuli. When ion channels open, they allow specific ions to move across plasma membrane down the electrochemical gradient. As ions move, they create a flow of electrical current that can change membrane potential.

Resting Membrane Potential (RMP)

Difference in electrical charge on each side of membrane in the resting state due to difference in concentration of ions across plasma membrane is called **Resting membrane Potential (RMP)**. It arises due to

1. Unequal distribution of ions
2. Inability of anions to leave the cell



3. Electronegative nature of Na^+ - K^+ ATPase

- At rest, charge on outside is positive & inside is negative
- Main extracellular cation – Na^+
- Main intracellular cation – K^+
- In resting state, there is a continual tendency for these ions to diffuse down the concentration gradients – K^+ outwards, Na^+ inwards
- Impulse is initiated by stimulation of sensory nerve endings or by passage of impulse from another neuron
- Transmission of action potential occurs due to the movement of ions across the nerve cell membrane
- Upon stimulation, permeability of nerve cell membrane to these ions changes
- A typical Resting Membrane Potential is –70 mV – states that inside cell is negative relative to outside

Action Potential & Nerve Impulse

Action Potential or Impulse is a sequence of rapidly occurring events that decrease & reverse the membrane potential and then eventually restore it to the resting state due to the movement of ions. It has 2 main phases – **depolarization & repolarization**

- Depolarization phase – negative membrane potential becomes less negative, zero & then positive
- Repolarization – membrane potential is restored to resting state of –70 mV

After repolarization, there may be **hyperpolarization** phase where the membrane potential becomes more negative than resting level. An action potential occurs in membrane of axon when depolarization reaches certain level called threshold i.e. –55 mV (follows all or none principle).

Depolarization

- In response to stimulus, membrane of axon depolarizes to threshold
- Voltage gated Na^+ channels open readily – inflow of Na^+ - inside becomes –55 mV
- Action potential is triggered, causes membrane potential to change from –55 mV to +30 mV

- Depolarization is very rapid, enable conduction of nerve impulse along entire length of neuron in few millisec
- Passes in one dimension only

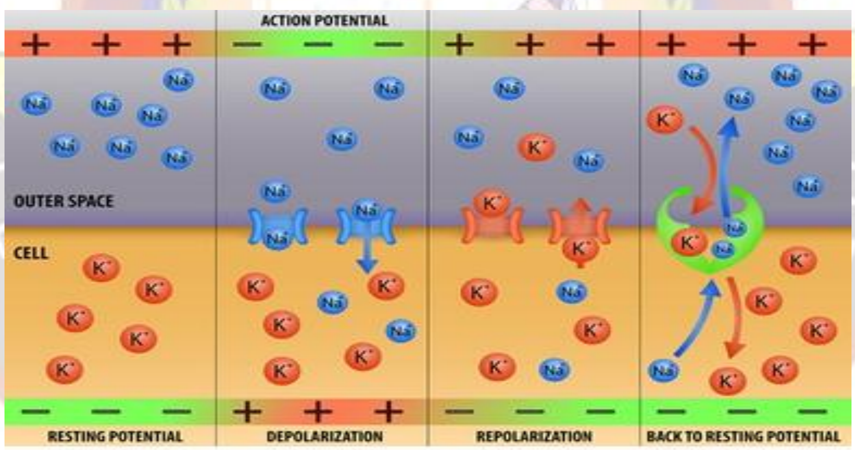
Repolarization

- Almost immediately following the entry of Na^+, voltage-gated K^+ channels open and K^+ floods out
- Closing of previously opened Na+ channels
- Na^+ inflow slows down, K^+ outflow accelerates
- Membrane potential becomes +30 mV to –70 mV – return to resting state
- Na^+ - K^+ pump restores original resting state and repolarises the neurons

Refractory period – the phase during which re-stimulation is not possible

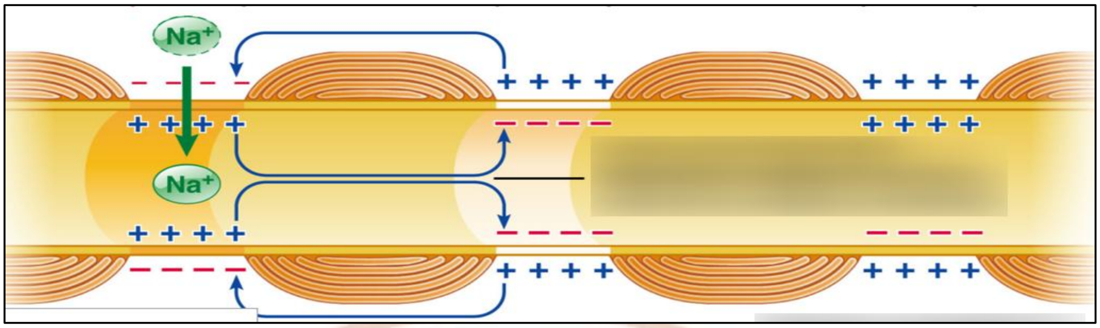
Hyperpolarization

- Voltage-gated K^+ channels remain open, causing outflow of K^+ ions in large amounts
- Membrane potential becomes more negative i.e. –90 mV

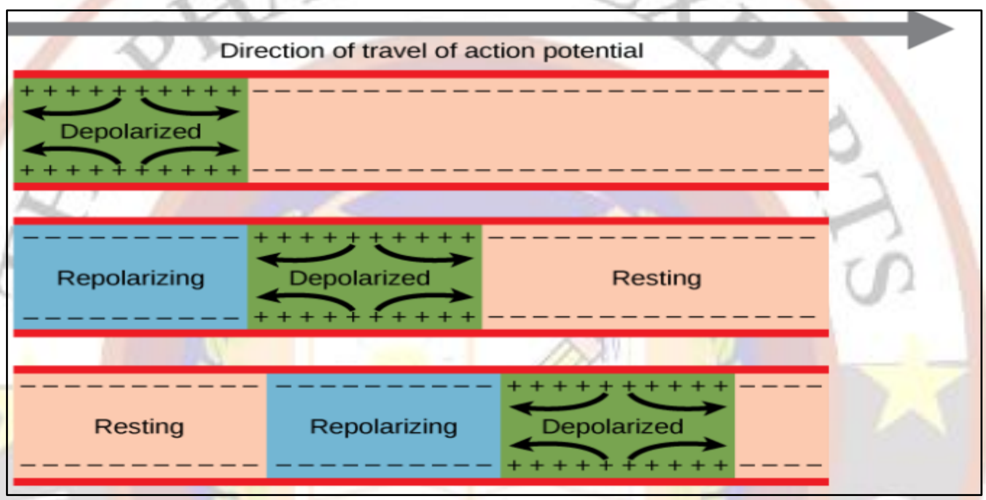


Propagation of action potential

In myelinated neurons, insulating property of myelin prevents movement of ions. Therefore, electrical changes across membrane occur only at nodes of ranvier. Impulse at one node causes depolarization, which passes along myelin sheath to next node & flow of current appears to leap. This type of propagation of action potential is called **saltatory conduction**.



Propagation of action potential by step by step depolarization & repolarization is called **continuous conduction.**



Speed of conduction depends on diameter of neuron – larger the diameter, faster the conduction. Myelin fiber conducts action potentials faster than unmyelinated fibers.

Synapses

Synapse is the region where communication occurs between 2 neurons or between a neuron & an effector cell (OR) Synapse is the point at which the action potential passes from presynaptic neuron to the postsynaptic neuron.

- Presynpatic neuron – a nerve cell that carries nerve impulse towards a synapse
- Postsynaptic cell – a cell that receives signal; it may be a post synaptic neuron or an effector cell

At free end, axon of presynaptic neuron breaks up into minute branches that terminate in small swellings called synaptic knobs, which store chemical neurotransmitters.

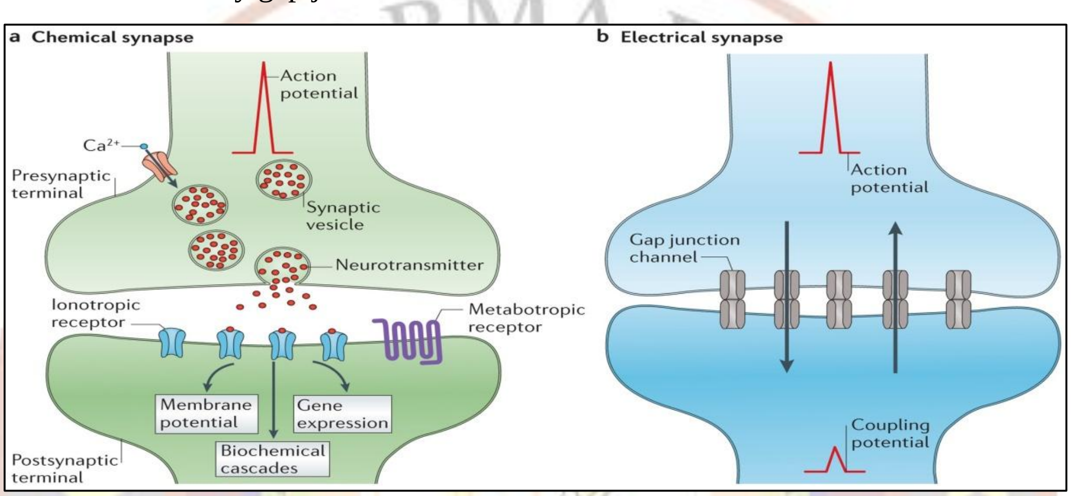
- Synapses are of 2 types – electrical & chemical

Electrical Synapses

At electrical synapse, action potential conducts directly between plasma membranes of adjacent neurons through gap junctions. They have connexons that act like tunnels connecting cytosol of two cells directly. This allows flow of ions & spread of action potential from cell to cell. **Ex:** Gap junctions in visceral smmoth muscle, cardiac muscle, developing embryo, also in brain.

Advantages

- Faster communication
- Synchronization – a large number of neurons or muscle fibers can produce action potentials in unison if connected by gap junctions



Chemical Synapses

At chemical synapses, plasma membrane of presynaptic and post synaptic neurons are close, but do not touch and are separated by synaptic cleft. Nerve impulses cannot be conducted, therefore, indirect form of communication occurs.

- In response to nerve impulse, presynaptic neuron releases neurotransmitters that diffuse in synaptic cleft & bind to receptors in plasma membrane of post synaptic neuron
- Post synaptic neuron receives chemical signal – produce post synaptic potential
- Thus, presynaptic neuron converts electrical signal to chemical signal; post synaptic neuron receives chemical signal and generates electrical signal
- There is a synaptic delay of 0.5 millisec

Characteristics

- Signal conduction is more slow than electrical signal
- Only one way transfer of information

A neurotransmitter that causes depolarization of post synaptic membrane is said to be excitatory. Thus, a depolarizing post synaptic potential is called an **excitatory post synaptic potential (EPSP)**. A neurotransmitter that causes hyperpolarization of post synaptic membrane is said to be inhibitory. Thus, a hyperpolarizing post synaptic potential is called **inhibitory post synaptic potential (IPSP).**

Neurotransmitter Receptors

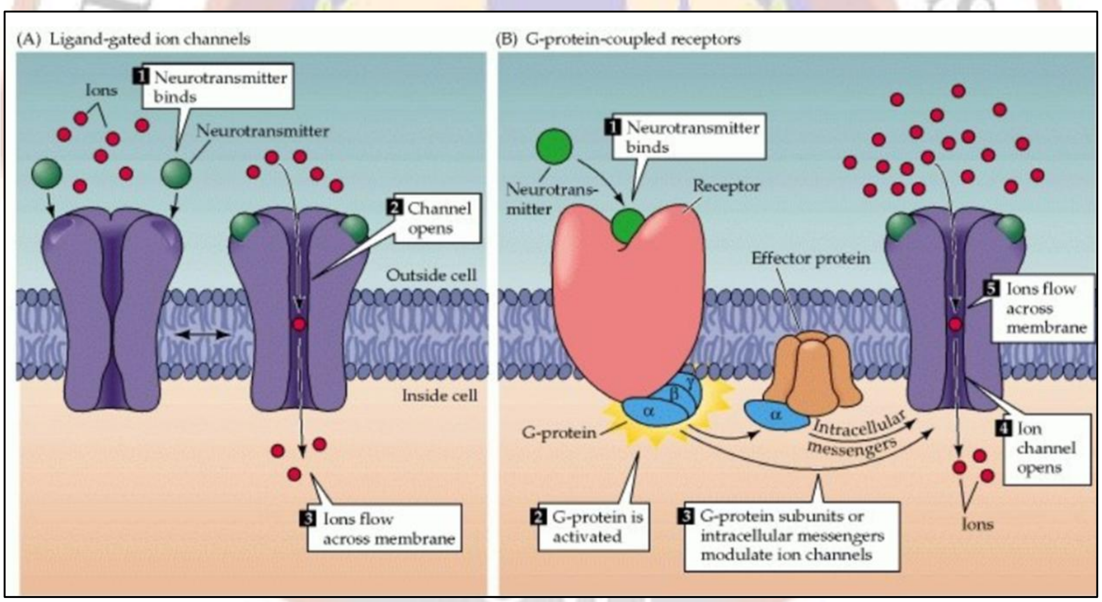
Receptors are of 2 types – ionotropic & metabotropic.

Each receptor has 1 or more neurotransmitter binding sites. When a Neurotransmitter binds to receptor, ion channel opens causing formation of post synaptic potential, which is either excitatory or inhibitory.

Ionotropic Receptor

It is a type of neurotransmitter receptor that contains a neurotransmitter binding site and an ion channel, which are components of same protein. **Ex:** ligand-gated channel

- In the absence of neurotransmitter, the ion channel component of the receptor is closed
- Binding of correct neurotransmitter to the receptor, ion channel opens and an EPSP or IPSP occurs in postsynaptic cell



- When Excitatory neurotransmitter binds to receptor, cation channels open forming EPSPs & allow passage of cations Na^+, K^+, Ca^{2+}
- When Inhibitory neurotransmitter binds to receptor containing chloride channels, opening of Cl^- channels cause formation of IPSPs & Cl^- ions diffuse inwards causing hyperpolarization

Metabotropic Receptor

It is a type of neurotransmitter receptor that contains a neurotransmitter binding site but lacks an ion channel as part of its structure. Receptor is coupled to separate ion channel by a type of membrane protein called G-Protein. **Ex:** G-Protein coupled receptors

- When Neurotransmitter binds to receptor – G-Protein either directly opens/ closes ion channel OR act indirectly by activating another moelcule, a second messenger into cytosol that opens/ closes the ion channel
- Thus, neurotransmitter binding site & ion channel are components of different proteins

Neurotransmitters

Neurotransmitters are the chemicals that are released into the synaptic cleft and may cause either excitation or inhibition of the post-synaptic cells. Many also act like hormones.

These are synthesized by nerve cell bodies, actively transported along axons & stored in synaptic vesicles. Released by exocytosis in response to action potentials & diffuse synaptic cleft and act on specific receptor sites on post-synaptic membrane. Immediately after action, either inactivated by enzymes or taken back into synaptic knobs.

Based on the size, these are of 2 types –

1. Small-molecule neurotransmitters
2. Neuropeptides

Small-molecule Neurotransmitters

Ex: Acetylcholine (Ach), Aminoacids, biogenic amines, ATP & other purines, Nitric Oxide (NO), Carbon monoxide(CO)

- Act by binding to ionotropic receptors

Acetylcholine (Ach)

- It is excitatory at neuromuscular junction (NMJ) and at other sites, inhibitory
- Inactivated by splitting into acetate & choline by the enzyme acetylcholinesterase

Aminoacids

- Glutamate & aspartate has excitatory effects
- GABA (Gamma Amino Butyric Acid) & Glycine has inhibitory effects

Biogenic amines

- **Ex:** Norepinephrine (NE), Epinephrine, Dopamine, Seratonin (5-HT)
- Cause Excitation or Inhibition
- Norepinephrine (NE), Dopamine & Epinephrine are called catecholamines
- Inactivated by enzymes catechol-o-methyl transferase (COMT) & monoamine oxidase (MAO)

ATP & other purines

- Adenosine, ATP, ADP, AMP – excitatory in nature

Nitric Oxide (NO)

- Excitatory neurotransmitter and formed when needed in our body

Carbon monoxide (CO)

- Also excitatory neurotransmitter

Neuropeptides

Neurotransmitters consisting of 3-40 aminoacids linked by peptide bonds are called neuropeptides. They are widespread & numerous in CNS & PNS.

Act by binding to metabotropic receptors and cause excitation or inhibition. They also serve as hormones. Examples include –

Substance P

- Enhance perception of pain i.e. transmit pain-related input

Enkephalins

- Inhibit pain impulses by suppressing release of substance P

Endorphins

- Same mechanism as enkephalins

Dynorphins

- Control pain & registering emotions

Hypothalamic releasing and inhibiting hormones

- Regulate release of hormones by anterior pituitary

Angiotensin II

- Stimulate thirst, regulate Blood Pressure in brain
- As a hormone, it causes vasoconstriction & release of aldosterone

Cholecystokinin (CCK)

- "stop eating signal"
- As hormone, regulates pancreatic enzyme secretions during digestion

Neuropeptide Y

- Stimulate food intake
- Has role in stress response

CENTRAL NERVOUS SYSTEM

The Central Nervous System (CNS) consists of Brain & Spinal Cord. Both Brain & Spinal cord are protected from damage & injury.

- Brain by skull
- Spinal cord by vertebrae that form spinal/ vertebral column

Further protection is offered to both, by membranous coverings called **MENINGES**.

MENINGES

Meninges are the protective connective tissue coverings that completely surround the brain & spinal cord. They lie between skull and brain & between vertebral foramen and spinal cord.

From superficial (outside) to deep (inward), they are as follows –

1. **Dura Mater**
2. **Arachnoid Mater**
3. **Pia Mater**

Subdural space – space between dura mater & arachnoid mater; filled with interstitial fluid

Subarachnoid space – space between arachnoid mater & pia mater; filled with cerebrospinal fluid (CSF)

Epidural space – space between dura mater & wall of vertebral canal

Dura mater

- **Superficial layer** – consists of 2 layers of dense irregular fibrous connective tissue
- Inner layer sweeps inwards, form membranous extensions that partially divide the cranial cavity. Membranous extensions include –

  Falx cerebri – separates two cerebral hemispheres

  Falx cerebelli – separates two cerebellar hemispheres

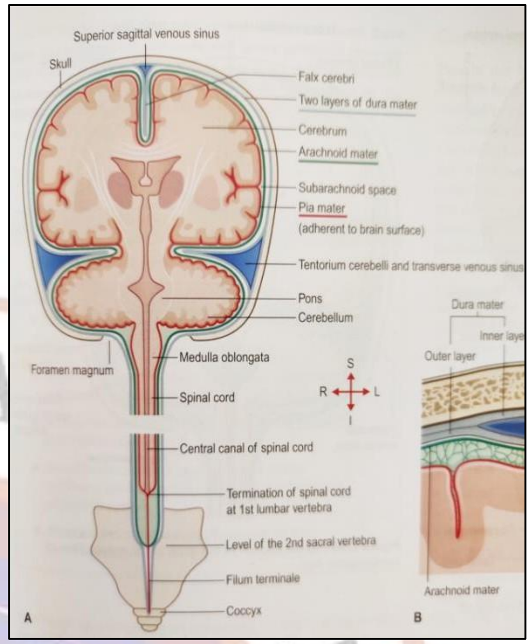
  Tentorium cerebelli – separates cerebrum & cerebellum
- Spinal dura mater forms loose sheath around the spinal cord – extends from foramen magnum to 2nd sacral vertebra, thereafter encloses filum terminale & fuses with periosteum of coccyx
- Nerves entering & leaving the spinal cord pass through the epidural space

Arachnoid mater

- **Middle layer** that lies between outer dura mater and inner pia mater

- It is a thin layer of fibrous connective tissue consisting of collagen & elastic fibers

- Passes over convolutions of brain
- Accompanies the inner layer of dura mater in formation of falx cerebri, falx cerebelli & tentorium cerebelli
- Continues downwards & envelops spinal cord
- Ends by merging with dura mater at the level of 2^{nd} sacral vertebra



Pia mater

- **Innermost delicate layer of connective tissue containing many minute blood vessels**
- Adheres to surface of brain & spinal cord
- Completely covers the convolutions of the brain & dip into each fissure
- Continue downwards & surround the spinal cord
- Beyond the end of spinal cord, it **continues as filum terminale**, pierces arachnoid tube and goes on with dura mater to fuse with periosteum of coccyx

VENTRICLES

Ventricles are the irregular shaped cavities in the brain that contain cerebrospinal fluid (CSF). They include –

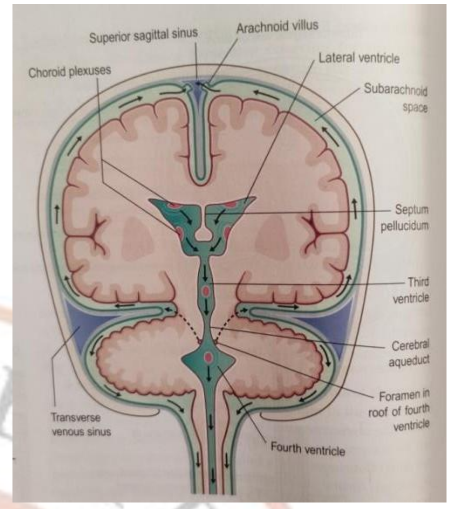
1. Left & right lateral ventricles
2. Third ventricle
3. Fourth ventricle

Lateral ventricles

- Lie within cerebral hemispheres, one on each side of the median plane just below corpus callosum
- Separated from each other by the membrane – septum pellucidum/ septum lucidum
- Lined with ciliated epithelium
- Communicate with third ventricle by interventricular foramina

Third ventricle

- It is a cavity situated below the lateral ventricles & between two parts of the thalamus



- Communicate with fourth ventricle by a canal called **cerebral aqueduct**

Fourth ventricle

- A diamond-shaped cavity situated below & behind the third ventricle, between the cerebellum and pons
- Continues below with central canal of spinal cord
- Communicate with subarachnoid space by foramina in its roof
- CSF enters the subarachnoid space through these openings

CEREBROSPINAL FLUID

CSF is a clear, colorless slightly alkaline fluid with a specific gravity of 1.005.

Composition

Mainly water

Oxygen, glucose, mineral salts

Plasma proteins – small amounts of albumin & globulin

Few leucocytes

Small amounts of creatinine & urea

Lactic acid

Cations – Na^+, K^+, Ca^{2+}, Mg^{2+}

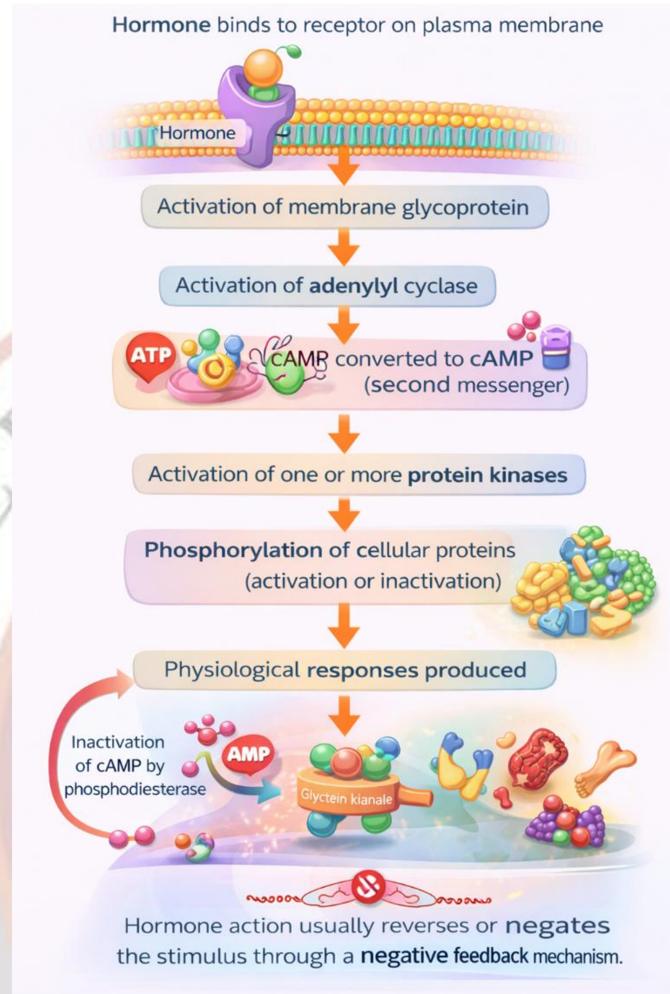
Anions – Cl^-, HCO^{3-}

Total volume of CSF is 80-150 ml in adults. It continuously circulates through ventricles in brain & spinal cord and around the brain & spinal cord in subarachnoid space.

Formation & circulation of CSF

CSF is secreted into each ventricle by **choroid plexus**, a network of blood capillaries in the walls of ventricles & surrounded by ependymal cells. It forms Blood-CSF barrier.

CSF is gradually reabsorbed into blood through tiny finger-like projections of arachnoid mater called **arachnoid villi**. Normally, CSF is reabsorbed as rapidly as it is formed by the choroid plexus, at a rate of about 20 mL/ hr. Therefore, pressure & volume of CSF is maintained constant.

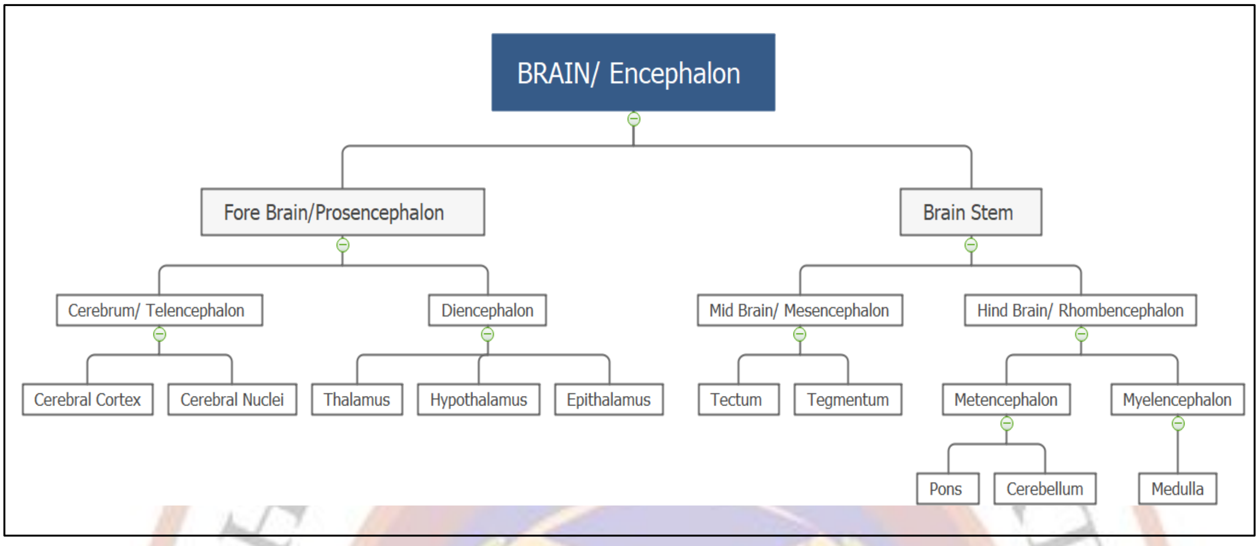


Functions of CSF

1. **Mechanical protection** – acts as a shock absorbing medium that protects delicate tissues of brian & spinal cord
2. **Chemical protection** – provides optimal chemical environment for accurate neuronal signaling, even a slight change in chemical composition disrupts production of action potentials
3. **Circulation** – medium for exchange of nutrients & waste products between the blood and adjacent nervous tissue
4. **Regulation of breathing** – bathes the surface of medulla that contains central respiratory chemoreceptors

BRAIN

Brain is the large organ weighing 1.4 kg & lies in cranial cavity. It has following parts –



Brain stem continues with spinal cord. Posterior part of it has cerebellum & superior part has diencephalon.

Supported on the diencephalon & brain stem is the largest part of the brain called Cerebrum.

- Cerebral/ carotid artery is the main artery that supplies oxygenated blood to the brain
- Venous blood from brain drains into dural venous sinuses & then downwards into internal jugular veins

FORE BRAIN/ PROSENCEPHALON

Cerebrum

It is the largest part of the brain & called 'seat of intelligence' because of its ability to read, write speak, make calculations, remember past, plan for future etc. It consists of cerebral cortex & cerebral nuclei.

Superficial layer is of grey mater (cell bodies) & deeper layer is of white mater (axons/ nerve fibers).

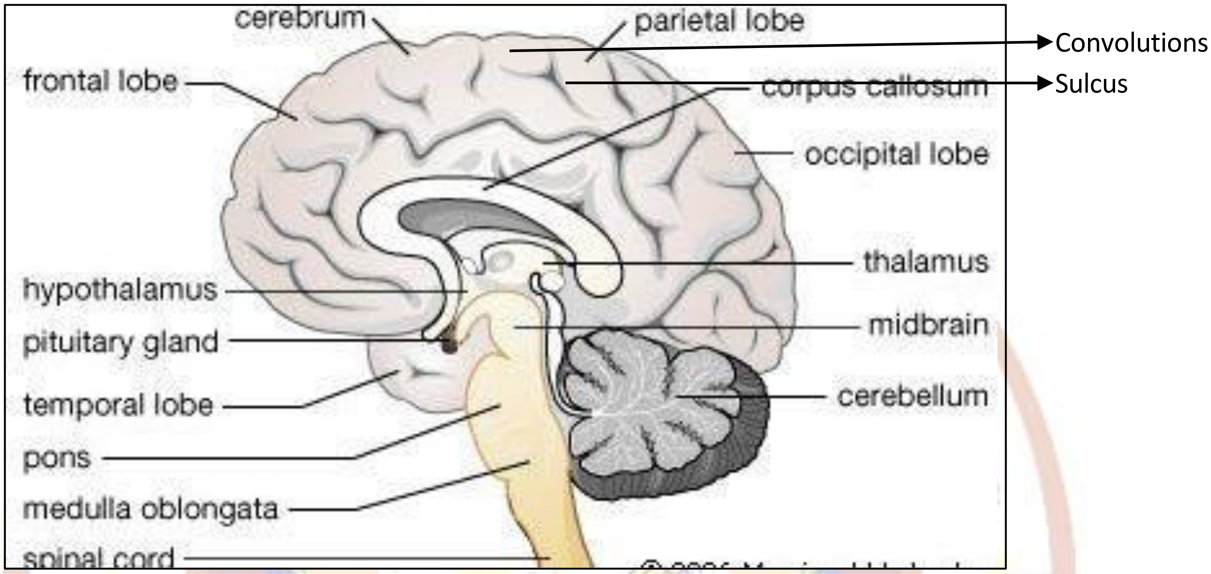
Cerebral Cortex

- It is the region of gray matter that forms outer rim of cerebrum & shows many infoldings or furrows
- Folds are called **Gyri/ convolutions** Deepest grooves –

Fissures Shallower grooves –

Sulci

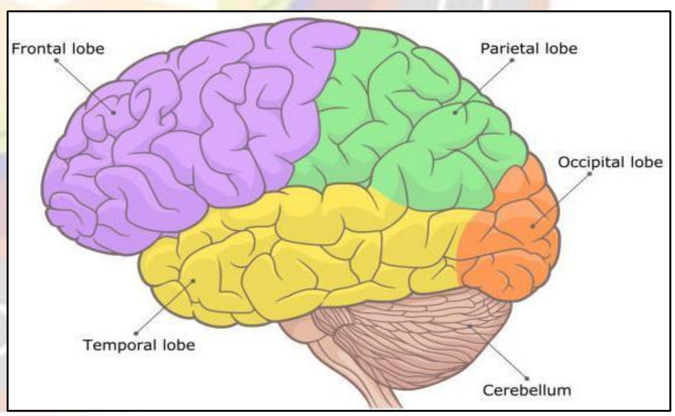
- Most prominent fissure – **longitudinal cerebral fissure**, separates cerebrum into right & left halves called cerebral hemispheres with falx cerebri
- Hemispheres are connected internally by **corpus callosum** – a band of white matter containing axons/ nerve fibers



Lobes of cerebrum

Each hemisphere has lobes that are named after the bones that cover them. They are as follows –

1. Frontal lobe
2. Parietal lobe
3. Occipital lobe
4. Temporal lobe



Central sulcus – separates frontal & parietal lobes

Lateral cerebral sulcus – separates frontal & temporal lobes

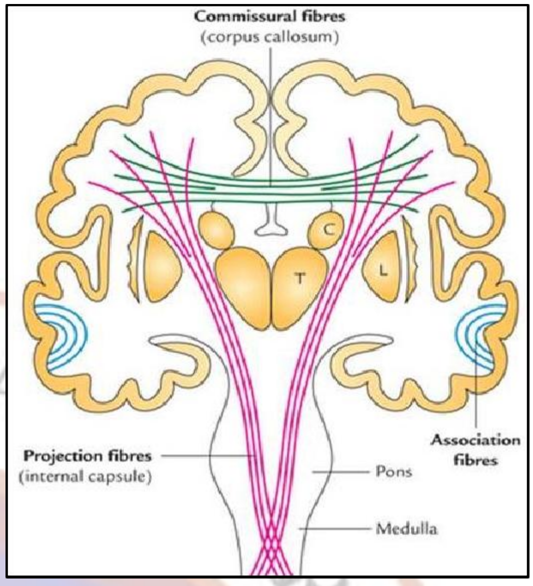
Parieto-occipital sulcus – separates parietal & occipital lobes

Cerebral white mater/ cerebral tracts

Within the cerebrum, the lobes are connected by masses of nerve fibers or tracts. They consist primarily of myelinated axons; include both afferent & efferent fibers that link different parts of the brain & spinal cord.

Different tracts are as follows –

1. **Association tracts** – contain axons that conduct nerve impulses between gyri in the same hemisphere
2. **Commissural tracts** – contain axons that conduct nerve impulses from gyri in one cerebral hemisphere to corresponding gyri in the other cerebral hemisphere. **Ex:** Corpus callosum
3. **Projection tracts** – contain axons that conduct nerve impulses from cerebrum to lower parts of CNS & with spinal cord



Cerebral Nuclei

Basal ganglia

- Collection of 3 nuclei present deep in each cerebral hemisphere is called basal ganglia
- Act as relay stations with connections to many parts of the brain
- Initiates and fine controls the complex movements & learned coordinated activities – posture & walking

Functions of cerebral cortex

1. Higher-order functions – language, thinking, reasoning, moral decision making & learning
2. Sensory perception – perception of pain, temperature, touch, sight, hearing, taste & smell
3. Initiation & control of skeletal muscle contraction and therefore voluntary movement

Functional areas of the cerebral cortex

Different types of functional areas include –

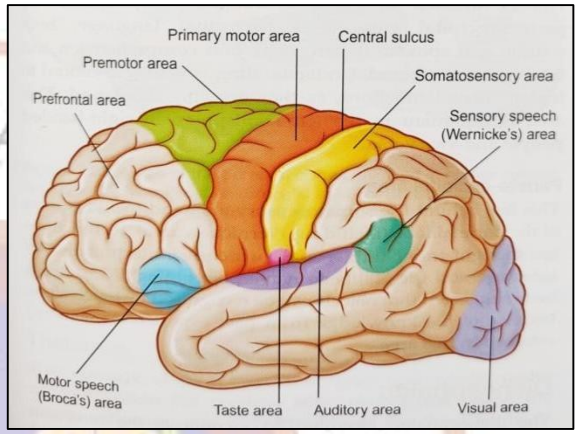
1. **Motor areas** – direct skeletal muscle movements
2. **Sensory areas** – receive & decode sensory impulses – enable sensory perception
3. **Association areas** – integration & processing of complex mental functions such as intelligence, memory, reasoning, judgement & emotions

In general, areas of the cortex lying anterior to the central sulcus associated with motor functions & those lying posterior with sensory functions.

Motor areas

Primary motor area

- Lies in frontal lobe, immediately anterior to central sulcus
- Control skeletal muscle activity
- Motor area of right hemisphere control voluntary muscle movement on left side of the body & vice versa
- Damage to either side – paralysis



Motor speech area (Broca's area)

- Situated in frontal lobe just above lateral sulcus
- Controls muscle movements needed for speech
- Dominant in left hemisphere in right handed people & vice versa

Sensory areas

Somatosensory area

- Area immediately behind central sulcus
- Perception of sensations of pain, temperature, pressure & touch, awareness of muscular movement & position of joints
- Area of right hemisphere, receives impulses from left side of the body & vice versa

Auditory (hearing) area

- Lies immediately below lateral sulcus within temporal lobe
- Receive & interpret impulses transmitted from inner ear by cochlear (auditory) part of vestibulocochlear nerves (8th cranial nerves)

Olfactory (smell) area

- Lies deep within temporal lobe
- Impulses from olfactory epithelium of nose transmitted via olfactory nerves (1st cranial nerves) – received & interpreted

Taste (Gustatory) area

- Lies just above lateral sulcus in deep layers of somatosensory area

- Impulses from sensory receptors in taste buds are received & perceived as taste

Visual area

- Lies behind parieto-occipital sulcus & includes greater part of occipital lobe
- Optic nerve (2nd cranial nerve) pass from the eye of this area, which receives & interprets the impulses as visual impressions

Association areas

These areas are connected to each other & other areas of cerebral cortex by association tracts. They receive, coordinate & interpret impulses from sensory & motor cortices, permit higher cognition abilities.

Premotor area

- Lies in frontal lobe, immediately anterior to motor area
- Coordinate movement initiated by primary motor cortex, ensuring learned patterns of movement can be repeated

Prefrontal area

- Extends anteriorly from the premotor area to include remainder of frontal lobe
- Perception & comprehension of passage of time, ability to anticipate consequences of events & normal management of emotions

Sensory speech (Wernicke's area)

- Situated in temporal lobe, adjacent to parieto-occipital area
- Language, both written & spoken is perceived; comprehension & intelligence are based
- Dominant in left hemisphere in right-handed people & vice versa

Parieto-occipital area

- Lies behind somatosensory area and includes most of the parietal lobe
- Spatial awareness, interpretation of language and ability to name objects

Diencephalon

It is present superior to mid brain & connects cerebrum & the brainstem. It contains numerous nuclei involved in a wide variety of sensory & motor processing between higher & lower brain centers.

It surrounds 3rd ventricle & includes following structures –

1. **Thalamus**

2. **Hypothalamus**

3. **Epithalamu**

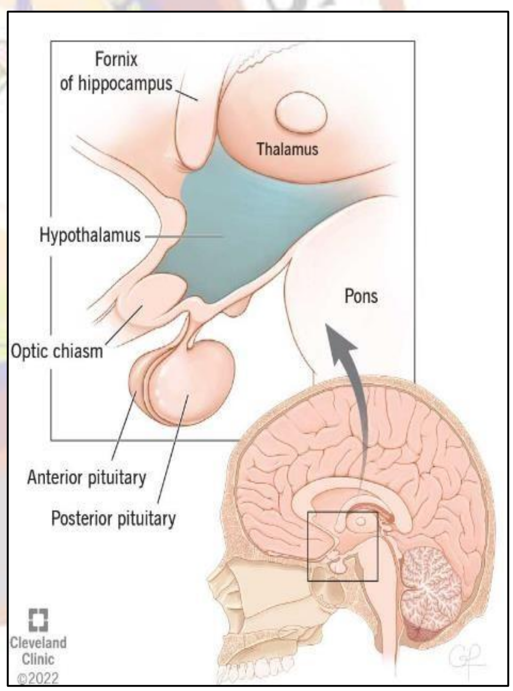
s **Thalamus**

- Makes up 80% of diencephalon & consists of paired oval masses of gray matter organized into nuclei with interspersed tracts of white mater
- Present within cerebral hemispheres just below corpus callosum, one on each side of 3rd ventricle

Functions

1. Major relay station for most sensory impulses that reach primary sensory areas of cerebral cortex from spinal cord to brainstem
2. Contributes to motor function by transmitting information from cerebellum & basal nuclei to primary motor area of cerebral cortex
3. Relays nerve impulses between different areas of cerebrum
4. Plays a role in maintenance of consciousness **i.e.** involved in arousal

Hypothalamus



- Small part of diencephalon located inferior to thalamus, immediately above pituitary gland
- Consists of number of nuclei
- Linked to posterior lobe of pituitary by nerve fibers & to anterior lobe by complex system of blood vessels
- One of the major regulators of homeostasis

Functions

1. Production of hormones – releasing & inhibiting hormones; control output of hormones from both anterior & posterior lobes of pituitary gland
2. Control of the ANS – regulate contraction of smooth muscle, cardiac muscle & secretion of many glands
3. Regulation of emotional & behavioral patterns – expression of rage, aggression, fear, pain, pleasure & sexual arousal
4. Regulation of eating & drinking

- Feeding center – promotes eating

- Satiety center – sensation of fullness & cessation of eating
- Thirst center – cause sensation of thirst; intake of water relieves the thirst

5. Control of body temperature

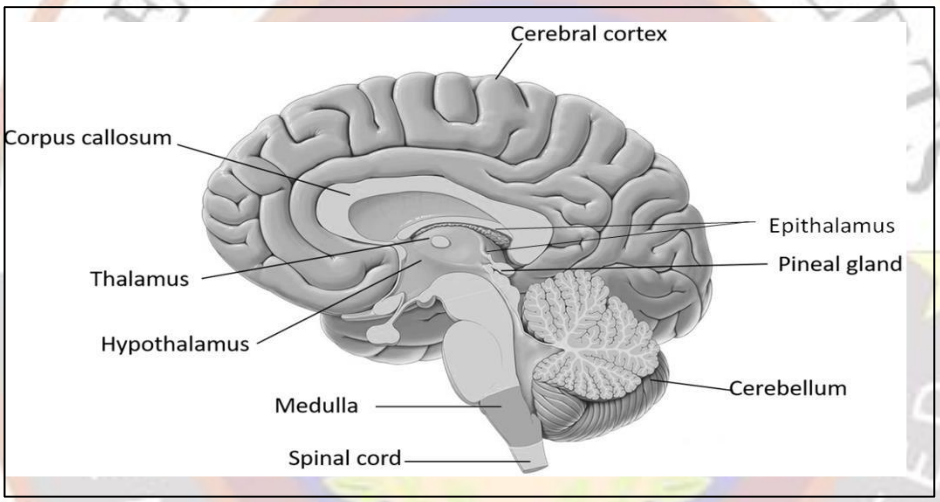
- Functions as body's thermostat

6. Regulation of circadian rhythms

- Induce sleeping & waking cycles

Epithalamus

It is a small region superior & posterior to thalamus and consists of pineal gland, which is of small pea size & protrudes from posterior midline of 3rd ventricle. It secretes hormone melatonin that regulates circadian rhythms.



BRAIN STEM

It is the part of the brain present between spinal cord & diencephalon. It consists of the following structures –

1. **Mid brain**
2. **Hind brain**

Mid Brain or Mesencephalon

- 2.5 cm long, situated around cerebral aqueduct between cerebrum above & pons below
- Consists of both nuclei & tracts – connect cerebrum with lower parts of brain & with the spinal cord
- Nuclei – act as relay stations for ascending & descending nerve fibers; role in auditory & visual reflexes

- Contains important nuclei called substantia nigra; neurons that release dopamine extend from substantia nigra to basal ganglia & help in the control of subconscious muscle activities

Hind Brain or Rhombencephalon

It consists of

1. **Metencephalon** – Pons & Cerebellum
2. **Myelencephalon** – Medulla oblongata/ Medulla

Pons

- Situated in front of cerebellum, below midbrain and above medulla
- Grey mater lie deep and white mater on surface
- Consists of both nuclei & tracts
- Has pneumotaxic area – operates in conjunction with respiratory center in medulla oblongata – control respiration
- Tracts form a bridge between two hemispheres; also part of ascending & descending motor tracts
- Nuclei associated with 4 pairs of cranial nerves
  1. **Trigeminal nerves (V)**
  2. **Abducens nerves (VI)**
  3. **Facial nerves (VII)**
  4. **Vestibulocochlear nerves**

(VIII) Medulla oblongata/ Medulla

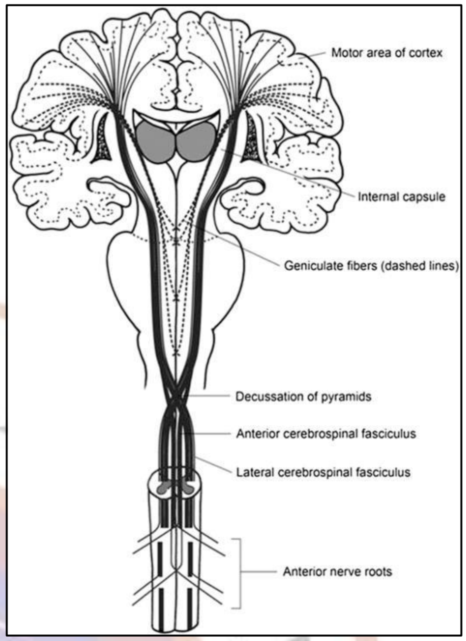
- Most inferior region of the brain stem
- Extends from pons above, continuous with spinal cord below
- 2.5 cm long, lies within cranium above foramen magnum
- Outer – white matter contains sensory & motor tracts extending between spinal cord & brain
- Inner – Gray matter

Decussation (crossing) of the pyramids

- Motor nerves descending from motor area in cerebrum to spinal cord cross from one side to the other (**i.e.** left hemisphere controls the right half)

- Sensory decussation is also present

Medulla contains several nuclei that control vital body functions associated with autonomic reflex activity. They are as follows –



Cardiovascular center

- Regulate force & rate of heart beat, diameter of blood vessels, blood pressure

Medullary Respiratory center

- Controls rate & depth of respiration i.e. basic rhythm of breathing
- Functions in close association with pneumotaxic area of pons

Reflex center of vomiting, swallowing, coughing, sneezing & hiccupping

- Vomiting center – causes vomiting
- Deglutition center – promotes deglutition (swallowing)
- Vomiting, coughing, sneezing – protective reflexes – expel irritants

Reticular Formation

- Broad region where white matter & gray matter exhibit a network like arrangement is known as Reticular Formation
- Extends from superior part of spinal cord, throughout brainstem and into inferior part of diencephalon
- Neurons have both sensory & motor functions

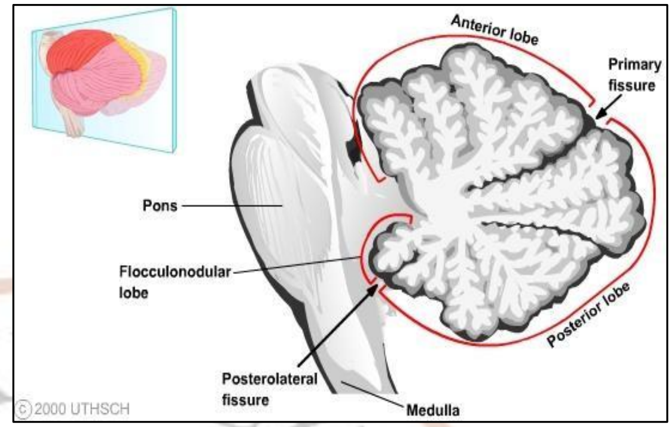
Reticular Activating System (RAS)

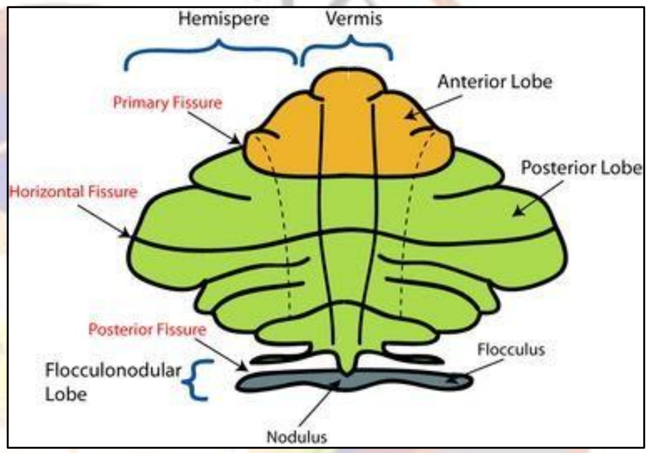
- Ascending portion (sensory) of reticular formation is called RAS
- Main function – consciousness

1. Alertness of individual, awareness & orientation
2. Also active during arousal
3. Maintain attention (concentration on single object) & alertness
4. Prevents sensory overload

- If inactive, causes sleep and damage leads to coma

Cerebellum





- Present posterior to medulla & pons; inferior to posterior portion of cerebrum
- Like cerebrum has highly folded surface
- Ovoid/ butterfly shaped containing 2 hemispheres that are separated by a narrow median strip called **Vermis**
- Outer – gray matter (cerebellar cortex)
- Deep – white matter (arbor vitae)
- Not under voluntary control

Internal structure

Within the cerebellum, three anatomical lobes are divided by two fissures

1. **Primary fissure**
2. **Posterolateral fissure**

Lobes include –

1. **Anterior lobe**
2. **Posterior lobe**
3. **Flocculonodular lobe**

Cerebellum can also be divided into three functional areas

1. **Cerebrocerebellum** – largest area, responsible for planning movements & motor learning, regulate coordination of muscle activation as well as eye movements
2. **Spinocerebellum** – functions in regulating body movements by allowing for error corrections
3. **Vestibulocerebellum** – involved in controlling balance and flexes of the eyes

Functions

Main role – to monitor and regulate motor behavior without any need for conscious awareness

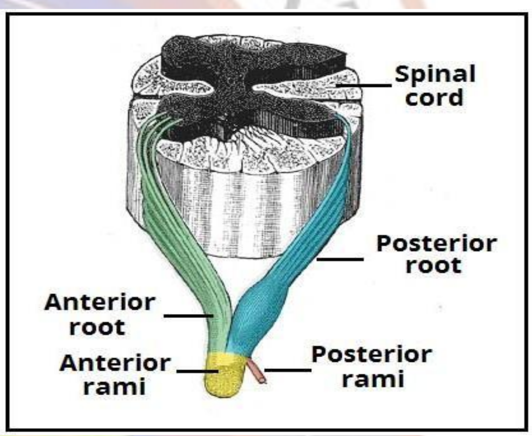
1. Controls coordination & movement of skeletal muscle

2. Controls balance, posture & maintains equilibrium
3. Process some types of memory

SPINAL CORD

- Spinal cord is an elongated, almost cylindrical part of the CNS, suspended in the vertebral canal of the vertebral column
- Protected by meninges & CSF
- Continuous above with medulla oblongata & extends from upper border of the atlas to lower border of 1st lumbar vertebra
- App. 45 cm long in adult males – thickness of the little finger
- Except for cranial nerves, SC is the nervous tissue link between brain & rest of the body

External Anatomy



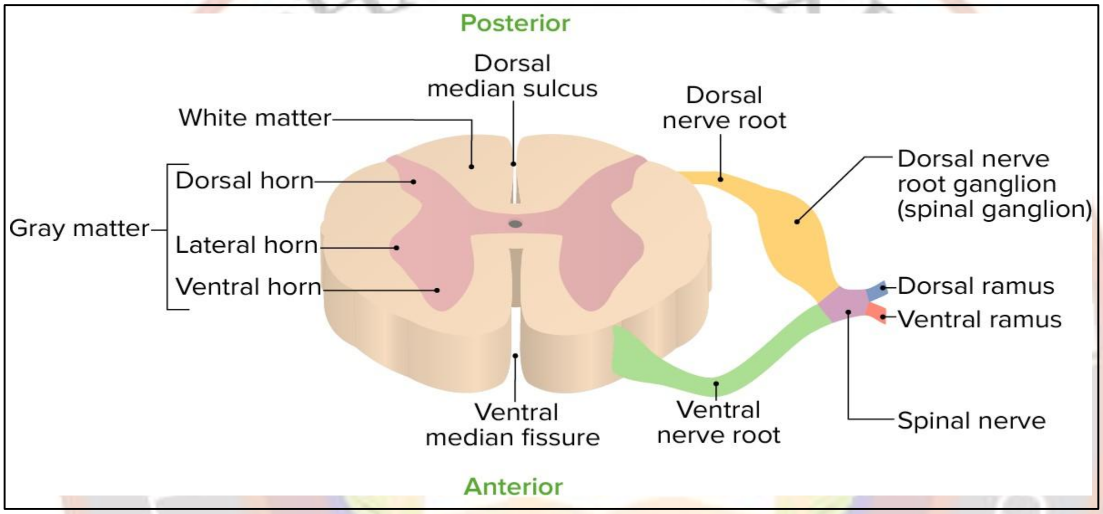
- Spinal nerves form the **paths of communication** between spinal cord/ brain & various organs and tissues of specific regions of the body
- SC appears to be segmented because, spinal nerves emerge at regular intervals from intervertebral foramina
- Sensory nerves from organs & tissues enter & pass upwards in spinal cord to brain (ascending pathway), whereas motor nerves from the brain pass downwards in spinal cord to effectors (descending pathway)
- Two bundles of axons called **roots**, connect each spinal nerve to segment of the spinal cord
  - i. **Posterior/ dorsal root** – contain axons of sensory neurons; conduct impulses from sensory receptors like skin, muscles & internal organs to CNS
  - ii. Each posterior root has a swelling – **posterior/ dorsal root ganglion** – contains cell bodies of sensory neurons
  - iii. **Anterior/ ventral root** – contain axons of motor neurons; conduct impulses from CNS to effectors
- Spinal cord is shorter than the vertebral column
- Roots of the nerves from lumbar, sacral & coccygeal regions form **cauda equina**

Internal Anatomy

- Transverse section shows white matter surrounds an inner core of gray matter

White Matter

- Two grooves penetrate white matter of the spinal cord and divide it into right & left sides
    1. **Anterior/ ventral median fissure**
    2. **Posterior/ dorsal medial sulcus**
- White matter is arranged in 3 columns or tracts – **Anterior, Posterior & Lateral** tracts
- Tracts are formed by sensory & motor nerve fibers and fibers of interneuron



Gray Matter

- Gray matter is shaped like letter H or butterfly
- On each side, it is subdivided into regions called **horns**
    1. Posterior (dorsal) gray horn
    2. Anterior (ventral) gray horn
    3. Lateral gray horn – present only in thoracic & upper lumbar segments
- Cross bar of H is called **gray commissure** & the center has small space called central canal
- Central canal extends entire length of the spinal cord & filled with CSF and its superior end is continuous with 4th ventricle

Nerve tracts in the spinal cord

1. Sensory tracts
2. Motor tracts

Sensory Tracts

- Contains neurons that transmit impulses towards the brain, called sensory/ afferent/ ascending neurons
- Two main sources of sensation from which impulses are transmitted to brain via the spinal cord are –
    1. Skin – stimulated by pain, heat, cold, touch, pressure
    2. Tendons, muscles and joints – stimulated by stretch
- Sensory input travels along the white tracts towards the brain & motor output travels from brain along these tracts towards skeletal muscles and other effector tissues
- Gray matter receives and integrates incoming sensory & outgoing motor information
- By 3 neuron system, the sensory impulses reach sensory area of opposite hemisphere of cerebrum
- By 2 neuron system, nerve impulses reach cerebellar hemispheres on same side

Motor tracts

- Contains neurons that transmit nerve impulses away from brain called motor/ efferent/ descending neurons
- Stimuli of motor neurons cause –
    1. Contraction of muscle
    2. Glandular secretion
- Motor output from brain to muscles are made up of two types of descending pathways
    1. Direct pathway/ pyramidal pathway – convey nerve impulses from cerebral cortex, cause voluntary movements of skeletal muscles
    2. Indirect motor pathway/ extrapyramidal pathway – convey nerve impulses from brainstem, cause involuntary muscle movement

Functions of spinal cord & spinal nerves

1. **White matter** – contain sensory & motor tracts; highway for conduction of sensory nerve impulse towards brain & motor impulses from brain towards effector tissues
2. **Gray matter** – site for integration (summing) of excitatory postsynaptic potentials & inhibitory postsynaptic potentials
3. **Spinal nerves** & nerves that branch from them connect CNS to sensory receptors,

muscles & glands in all parts of the body

Reflexes & reflex arcs

Reflex – a fast, involuntary, unplanned sequence of actions that occur in response to a particular stimulus.

- Reflexes are of 2 types
  1. **Inborn** – ex: pulling away hand form hot surface
  2. **Learned/ acquired** – ex: activities required to drive a car
- Depending on the site, reflexes are of following types –
  1. **Spinal reflex** – when integration takes place in the spinal cord gray matter; ex: patellar reflex/ knee jerk
  2. **Cranial reflex** – when integration takes place in the brainstem rather than spinal cord; ex: tracking movements of eyes reading the sentence
  3. **Somatic reflex** – involve contraction of skeletal muscles
  4. **Autonomic (visceral) reflex** – not consciously perceived; ex: responses of smooth muscle, cardiac muscle, glands – heart rate, digestion, urination etc.

Reflex Arc

Definition: Nerve impulses propagating into, through and out of the CNS follow specific pathways depending on the kind of information, its origin & its destination. The pathway followed by nerve impulses that produce a reflex is called a reflex arc (reflex circuit).

It includes the following five functional components –

1. Sensory receptor

- Distal end of sensory neuron or an associated sensory structure serves as a sensory receptor
- Responds to specific stimulus i.e. change in internal or external environment by producing graded potentials
- When Potential reaches threshold, one or more nerve impulses are triggered in sensory neuron

2. Sensory neuron

- Nerve impulses propagate from sensory receptor to sensory neuron, then to the axon terminals located in gray matter of spinal cord or brainstem

3. Integrating center

- One or more regions of gray matter within CNS acts as an integrating center

- Can be a single synapse between sensory neuron and a motor neuron
- More often consists of one or more interneurons, which may relay impulses to other interneurons as well as to motor neuron

4. Motor neuron

- Impulses triggered by the integrating center propagate out of the CNS along a motor neuron to part of the body that will respond

5. Effector

- It is the part of the body that responds to motor nerve impulse **i.e.** muscle or gland
- It's action is reflex
- If skeletal muscle is involved – somatic reflex
- If smooth/ cardiac muscle is involved – autonomic reflex