Brain and Spinal Cord

Objectives

After going through this lesson, the learners will be able to understand the following:

- Get a clear conception regarding origin and development of the central nervous system.
- Understand the structural organisation of brain and spinal cord
- Analyse the functioning of reflex action.
- Develop knowledge about the functioning of the central nervous system.

Content Outline

- Introduction
- Central Nervous System
  - Origin and Development of Central Nervous System
  - Organisation of CNS
  - Parts of Brain
  - Anatomy of Spinal Cord
  - Functions of Brain and Spinal Cord
- Summary

Introduction

Structurally and functionally the central nervous system constituting the brain and spinal cord is the most complicated and amazing system of the human body. Central nervous system along with its nerves maintain neural coordination between external and internal environments.Understanding a question and giving reply, dreaming, feeling emotional after watching a movie:- the neural processes for conducting these activities take place in different parts of the brain.

Brain can be compared with a super computer which receives stimulus, processes it with the help of previous experience stored as memory and expresses in the form of response.

Brain is made up of 100 billion neurons and 10-50 trillion neuroglia. Brain in average has a mass of 1300-1600 gms; male brain possesses more mass than the female brain.

During the animal evolution, ‘cephalisation’ a unique process of brain formation occurred.

Central Nervous System

Central Nervous System is rightly named as location wise it occupies central axial position and functionally it is the main part of the neural system.

Origin and Development of Central Nervous System

Brain development starts in a three week old embryo. The developmental sequences are as follows:

- At the dorsal side of the embryo the ectoderm layer thickens along the mid dorsal axis of the embryo to form a **neural plate** .
- Neural plate invaginates to raised lateral structures called **neural folds,** flanked by neural plates to form a neural **groove.**
- The neural groove gradually deepens and the upper edges of neural folds fuse to form a **neural tube** which later detaches from the surface ectoderm and sinks to deeper layers.
- Neural tube which has been formed during the fourth week of pregnancy develops into CNS. The brain is formed from the anterior region and spinal cord is formed from the caudal region.
- Small groups of cells detach from neural folds and go down and occupy position in between surface ectoderm and neural tube and form a **neural crest.** Some neurons which are located inside ganglia arise from neural crests.

As soon as the structure of the neural tube has been established, its anterior end begins to expand and gets marked by constrictions to form three **primary brain vesicles.** From anterior to posterior, these are **Prosencephalon** or fore brain, **Mesencephalon** or Midbrain and **Rhombencephalon** or Hindbrain; the rest of the neural tube becomes the spinal cord.

In the fifth week of pregnancy, primary brain vesicles get modified to **Secondary brain vesicles.** The Prosencephalon or Fore brain divides into **Telencephalon** and **Diencephalon** and **Rhombencephalon** constricts into **Metencephalon** and **Mylencephalon.**

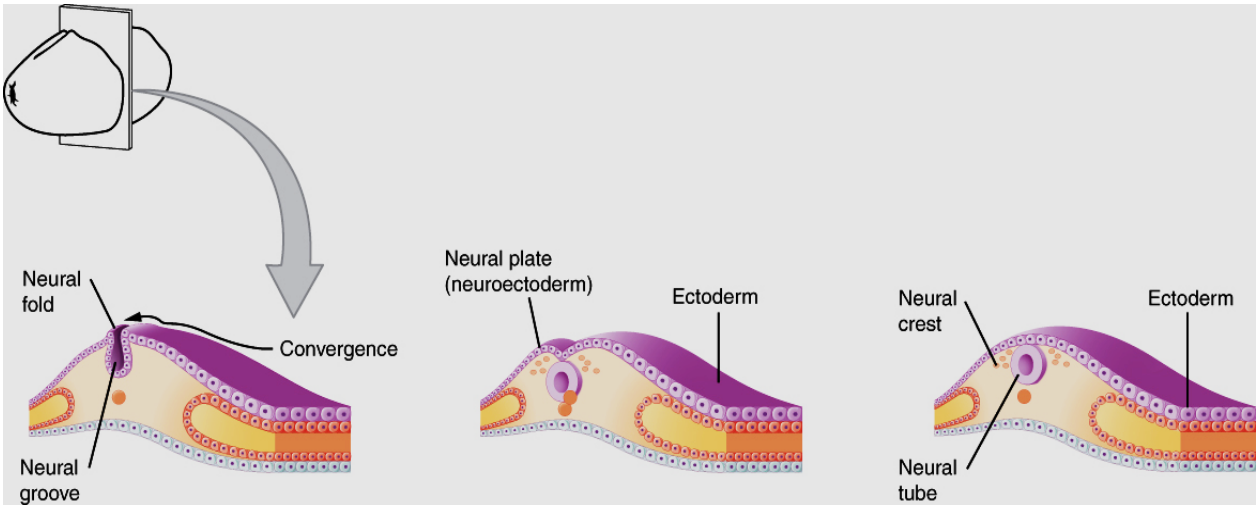


Fig. 1A Diagram showing the brain and major nerves of a 6 week old human fetus.

i. Olfactory
ii. Optic
iii. Oculomotor
iv. Trochlear
v. Trigeminal sensory
vi. Trigeminal motor
vii. Abducens
viii. Facial
ix. Vestibulocochlear
x. Glossopharyngeal
xi. Vagus
xii. Cranial accessory
xiii. Spinal accessory
xiv. Hypoglossal
xv. Cervical I, II, III and IV

The five vesicles, telencephalon, diencephalon, metencephalon, myelencephalon and rhombencephalon expand and modify into the adult brain.

Telencephalon develops two lateral outgrowths which expand and form **Cerebral hemispheres.** Two cerebral hemispheres are collectively called Cerebrum. The diencephalon undergoes specialisation and forms **hypothalamus** and **epithalamus**.

Mesencephalon, metencephalon and myelencephalon do not undergo much changes and form **midbrain**, **pons** and **cerebellum** and **medulla oblongata** respectively. All these parts except cerebellum form the brain **stem**.

The space at the centre of the neural tube remains continuous and enlarges at four specific regions to form **ventricles**.As the space within the cranium is much less compared to the vast enlargement taking place in the brain, so the brain experiences posterior and lateral pressure due to which the fore brain bends towards the brain stem. Forebrain is forced to take a horse shoe shape and grows posteriorly and laterally. During the growth, the forebrain completely grows over **diencephalon** and **midbrain**.

By 26th week, the continued growth of cerebral hemispheres causes the surfaces to form creases forming **gyri** and **sulci**. These creases cause accommodation of larger numbers of neurons.

Central nervous system occupies the central and axial position in the body. Functionally it also occupies the central and main part in neural coordination. It consists of two major parts; **Brain** and **Spinal cord**. Central nervous system remains protected by protective coverings.

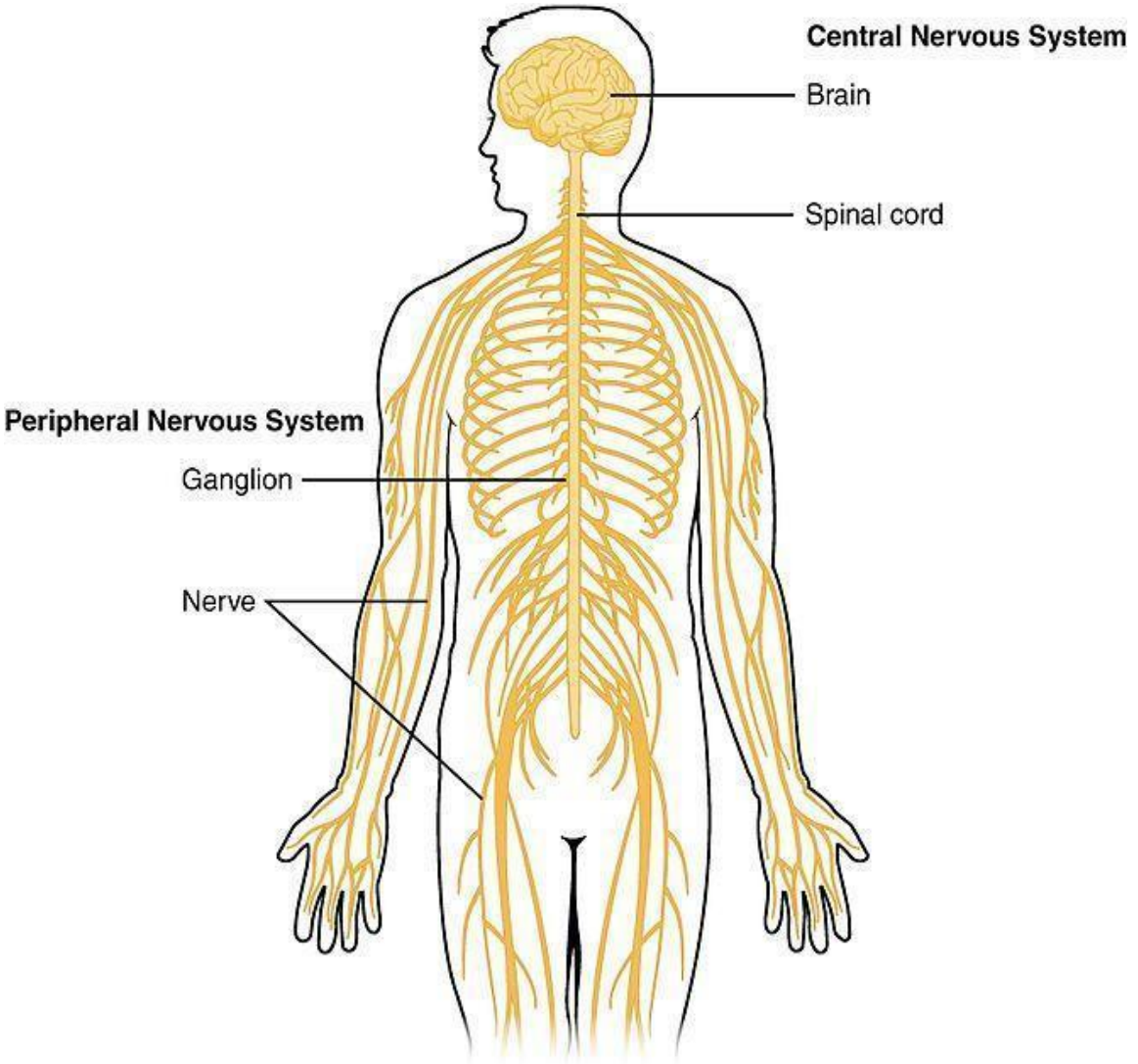


Fig. 2. Central nervous system and Peripheral nervous system

Protective Covering of Brain

Central nervous system is protected by (i) **Bony Covering** (ii) **Meninges** (iii) A **Protective Fluid.** Apart from that, the brain is also protected from harmful substances of blood from the blood **brain barrier**.

(i) **Bony covering**

Brain is protected by bony **cranium**, commonly called the **brain box.** The vertebral foramina of all the vertebrae are placed one above the other to form a tubular vertebral canal, surrounded by vertebrae. Spinal cord runs through this vertebral column and remains protected by vertebrae.

The skull consists of 22 bones, which are broadly divided into facial bones (14) and cranial bones (08). The cranial bones are joined together by immovable joints to form cranial cavity, which encloses and protects the brain.

(ii) **Meninges** Meninges are connective tissue covering which is the second level protection for CNS. Cranial meninges cover the brain and spinal meninges cover the spinal cord.

The three parts of meninges are similar in both cranial and spinal meninges. The three meninges are the (a) outer **dura mater** (b) middle **arachnoid mater** and (c) innermost **pia mater**. These three connective membranes lie outside the CNS organs and inside the cranium and vertebral column.

(a) Dura Mater It is the outermost and toughest layer, made up of fibrous connective tissue. It is two layered where it surrounds the brain and single layered in the spinal cord. At several places, the duramater extends inwards to form partitions in the cranial cavity. These flat partitions are known as dural septa which limit excessive movements of the brain within the cranial cavity.

(b) Arachnoid Cavity: The middle meninx, the arachnoid mater forms a loose covering. Below the arachnoid space is the present **subarachnoid space.**

(c) Piamater: It is composed of delicate connective tissue and is richly supplied with blood vessels. It clings tightly to the brain.

(iii) **Cerebrospinal Fluid:** CSF is found in and around the brain and spinal cord. It forms a liquid cushion and provides buoyancy to the brain. It reduces the weight of the brain by 97% and protects it from getting crushed. CSF protects the brain and spinal cord from jerks and bolts. It also provides nourishment to the brain.

Organisation of Central Nervous System

The neural system can be broadly divided into the central nervous system and **peripheral nervous system**. (Peripheral nervous system is already discussed in Module-1).

The central nervous system consists of the brain and **spinal cord**. The skull encloses the brain, which is made up of about 10^{11} neurons. Twelve pairs of cranial nerves arise from the base of the brain. Each nerve consists of hundreds to thousands of axons of neurons, bundled together along with connective tissues. Each nerve follows a definite path and performs a single and particular function.

The spinal cord is connected to the brain through **foramen magnum** (a large space present at the lower side of the skull). Spinal cord is encircled by the vertebral column. Thirty one pairs

of nerves arise from the left and right lateral side of the spinal cord. Each spinal nerve performs a specific function and serves a particular part.

Parts of Brain

Brain is a soft, pinkish brown structure located safely inside the cranium. Brain is made up of neurons and neuroglia.

Structurally the brain consists of many parts. Each part performs one or more than one function. Brain is divided into three parts : (a) **Fore Brain** (b) **Midbrain** (c) **HindBrain.** Hollow ventricular chambers are filled with cerebrospinal fluid. Ventricles are spaces in the brain which arise due to expansions of neural tube lumen at embryonic stage.

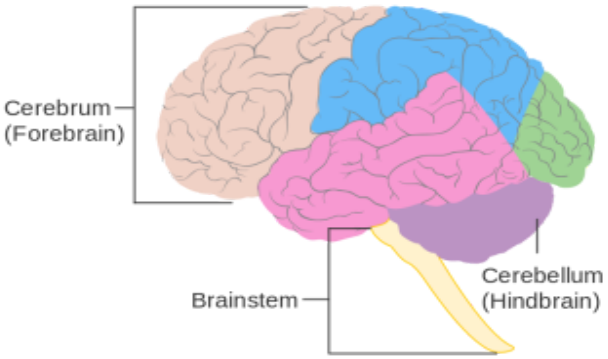
Forebrain consists of **cerebrum**, **thalamus** and **hypothalamus.** Cerebrum is the most conspicuous part of the brain and occupies about 83% of total mass of brain During development, the forebrain is forced to take a horse shoe shape and grows posteriorly and laterally and thus it completely grows over **diencephalon** and **midbrain**. Almost the entire surface of cerebral hemispheres is marked by elevations made up of tissues, called **gyri** (singular gyrus) and furrows, called sulci (singular sulcus). Deeper and prominent furrows are called '**fissures**'. Median longitudinal fissure divides cerebral hemispheres. Another transverse fissure separates cerebrum from cerebellum.

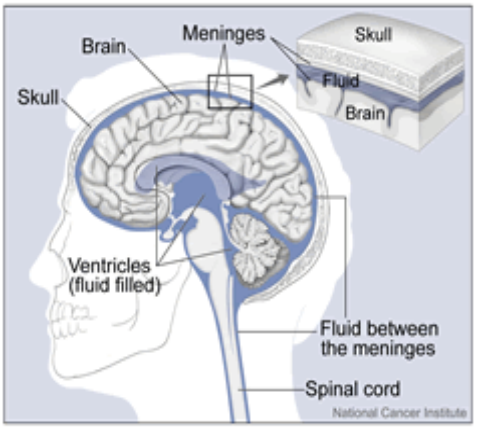
Cerebral hemisphere is divided into five lobes- frontal, parietal, temporal, occipital and insula. The **central sulcus** separates the frontal lobe from the parietal lobe. Occipital lobe which lies at the posterior part of the brain is separated from the parietal lobe by **parietal occipito sulcus**. The **lateral sulcus** separates the temporal lobe from the overlying parietal and frontal lobes. The fifth lobe insula lies deeply buried within the lateral sulcus and forms a part of it. The insula is surrounded by parts of temporal, parietal and frontal lobes and can not be seen on the surface view.

Two cerebral hemispheres are connected by **corpus callosum**, a band of white matter. It consists of several millions axons which maintains homotopic and heterotopic interhemispheric connections. Corpus callosum helps to transfer information between two hemispheres. Severe corpus callosum hampers sharing of information between the right and left hemispheres and results in cognitive development, learning and behavioural changes.

Encircling the corpus callosum and upper part of the brainstem is the present **limbic system.** The lower part of the limbic system is located on the floor of diencephalon. The Limbic system is called the "emotional brain" as it plays a vital role in the expression of many feelings like pleasure, anger, fear etc. **Amygdala** is a pair of almond shaped set of neurons located medially deep inside the temporal lobe that structurally belongs to basal ganglia but functionally a part of the limbic system. It plays a key role in processing of memory, emotional responses, decision making etc. amygdala has been found to be associated with emotional responses related to fear, anxiety and aggression. It also plays a prime role in emotional learning and retention of emotional memories. Damage of both the amygdala in persons results in loss of certain kinds of fear for example, fear of snakes, wild animals or held at gunpoint etc.

Hippocampus is another important constituent of the limbic system. There are two hippocampus on either side of the brain in vertebrates and humans. It is involved in the formation of new memories and is also associated with learning and emotions. The damage of one or both the hippocampus by diseases like Alzhemier's or due to some accidents causes loss of memory and inability to form long term memory.





Each part of cerebral hemisphere has three basic regions (i) Cerebral cortex lying superficially looks grey in fresh brain tissue, so called "**grey matter**".(ii) an internal "**white matter"** mainly constituting myelinated nerve fibres and (iii) **basal nuclei.**

Seated quite deeply in cerebral hemispheres are present three masses of grey matter which are called **nuclei.** These nuclei are collectively called **basal nuclei**. Main function of basal ganglia is to initiate and terminate movements of the body. Basal ganglia also influence many functions of the cerebrum like cognitive, sensory, linguistic etc.

Cerebral cortex This is the region where our conscious mind resides. This region enables us to think, remember, communicate, understand, and initiate voluntary movements. This part consists of neuron cell bodies, dendrites and unmyelinated nerve fibres.

In 1906, K. Brodmann mapped the cerebral cortex and numbered 52 areas, now known as **Brodmann area.**

Cerebral cortex possesses three functional areas (i) **Motor area** lies in the posterior part of the frontal lobes and it controls voluntary movements. (ii) **Sensory area** is concerned with conscious awareness of sensation. These areas lie in the parietal, temporal and occipital lobes. (iii) **Association area** communicates with the motor area and sensory area and analyse the sensory inputs with the help of previous experience and memory and help to act.

Each cerebral hemisphere is basically associated with intelligence, the ability to read, write, speak, composing music, making calculations, imagination, storing memories etc. It has been found that maximum metabolic activities and blood flow take place in the cerebral cortex.

Cerebral hemispheres are used for almost all human activities. Although structurally both the hemispheres look similar but functionally each of the hemispheres possesses a unique ability of its own. This is known as lateralization. In most people, the left hemisphere has greater control over language, mathematics and logic. The right hemisphere is more free spirited. It has more dominant control over spatial skills, artistic and musical skills, intuition etc. usually right dominant cerebral cortex people are usually left handed.

Diencephalon constitutes thalamus, hypothalamus and epithalamus which extend from cerebrum to brain stem. Diencephalon is the central core and remains surrounded by the cerebral hemispheres. It measures about 3 cm. in length.

Thalamus

The thalamus makes up 80% of diencephalon.it remains deeply seated, well hidden inside the brain. Thalamus is the main site for relay for most sensory impulses that reach the primary sensory areas of the cerebral cortex from the spinal cord and brainstem. Nerve impulses between different areas of the cerebrum are relayed by thalamus. This activity is of great importance as it maintains consciousness.

Hypothalamus

It is located inner to the thalamus and is comparatively a smaller part of diencephalon. Irrespective of its size it controls a great number of functions. It is one of the major regulators of homeostasis. Some of the important functions are as follows:-

- Hypothalamus controls the activities of the pituitary gland by secreting releasing hormones and inhibitory hormones. These hormones respectively activate and inhibit the release of anterior pituitary hormones.
- Hypothalamus along with the limbic system controls the emotional and behavioural patterns. They regulate the expression of pleasure, anger, fear etc.
- Hypothalamus regulates circadian rhythm and maintains consciousness.
- Hypothalamus possesses a feeding and thirst centre. It controls the food intake by satiating the feeling.

Epithalamus

It is the smallest and most dorsal region of diencephalon. It lies posterior to thalamus. It consists of **Pineal gland.** Pineal gland secretes hormone melanin which induces sleep signals. Thus epithalamus along with hypothalamus regulates sleep wake signals.

Brain Stem

It is the part of the brain located between diencephalon and spinal cord. Being situated in between the cerebrum and spinal cord, the brain stem coordinates the functioning between the brain and the rest of the body by communicating information. It is responsible for controlling important body functions like blood pressure, heart rate, breathing, swallowing, consciousness etc.

Brain stem consists of **midbrain, pons** and **medulla oblongata**.

MidBrain

Midbrain, also called mesencephalon, is located between diencephalon and pons. It is quite small and is about 2.5 cm. long. A hollow duct (**cerebral aqueduct**) runs through midbrain and connects the third and fourth ventricle.

Function

It helps in performing important functions in motor activities like eye movement, auditory and visual processing; for example- spatial relationship of the objects in relation to the position of the viewer.

HindBrain

Hind brain also known as **rhombencephalon** consists of (i)Pons (ii) Medulla oblongata and (iii) Cerebellum.

(i) Pons

It lies between mid-brain and medulla oblongata. It is located above the medulla and anterior to the cerebellum. It is a swollen brain stem region and is about 2.5 cm. long.

Function

In association with medullary respiratory centres, pons help to maintain normal rhythm of breathing.

(ii) Medulla Oblongata

Medulla oblongata or simply medulla is the most inferior part of the brain stem. It merges below with the spinal cord. It is conical in shape. The cavity of the spinal cord extends upward and expands in the medulla to form the fourth ventricle.

Functions

Although medulla is very small in size but it controls many important vital functions some of these functions are as follows:-

- Cardiac centre located in medulla adjusts the rate of contraction of the heart to meet the body's needs.
- Respiratory centre controls rate of respiration on negative feedback. In association with pons, it regulates breathing rhythm.

- Medulla oblongata also regulates sneezing, hiccups, vomiting, coughing and swallowing.

(iii) Cerebellum

It is located at the top part of the brain stem. It is a cauliflower shaped part of the brain located dorsal to pons and medulla and protrudes under occipital lobes. It is bilaterally symmetrical, consisting of two cerebellar hemispheres connected by a narrow **vermis**.

Function

- It maintains posture and balance of the body.
- Cerebellum plays a role in cognition and problem solving.

Spinal Cord

Origin

Spinal cord develops from the caudal portion of the embryonic neural tube.

Spinal cord is about 42 cm. or 17 inches long, 1.8 cm. in width, glistening white, tubular structure occupying the axillary position in the body.

Protective covering

Spinal cord extends from the foramen magnum of the skull at the level of first and second lumbar vertebrae. It is located within the vertebral canal of the vertebral column. The vertebrae provide the main protection to spinal cord, vertebral ligaments, meninges and cerebrospinal fluid.

Meninges

Brain and spinal cord are protected by three connective tissue covering called meninges. Meninges covering the spinal cord are called **spinal meninges.** Like cranial meninges spinal meninges also consist of **dura mater**, **arachnoid mater** and **pia mater**. Between dura mater and arachnoid space and interstitial fluid filled **subdural space** is present.another cushion of fat and connective tissue located inside **epidural space** (a space between vertebral column and dura mater) provides additional protection to spinal cord.

Piamater, the innermost meninx is a thin layer closely adhered to the spinal cord. It is richly supplied with blood capillaries, which supply nutrients and oxygen.

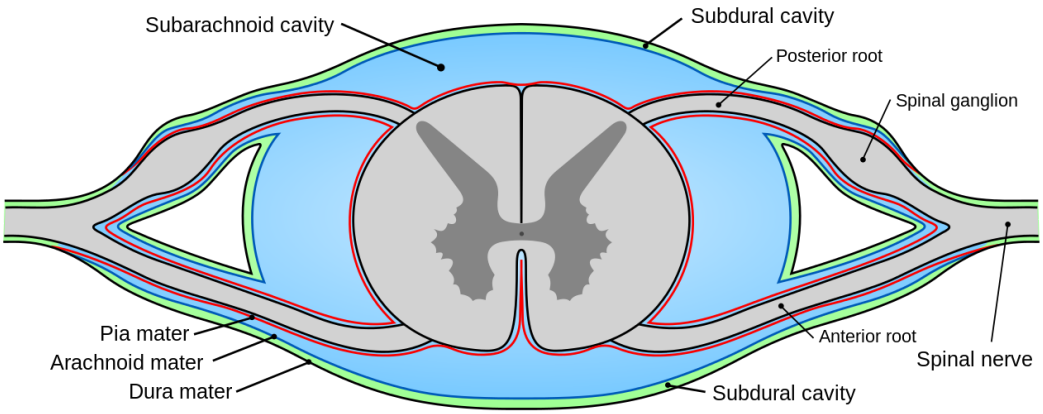


Fig. **Sectional view of Spinal cord**

Anatomy of Spinal Cord

External anatomy

Spinal cord is roughly cylindrical and slightly flattened anterior posteriorly. During early childhood, the vertebral column and spinal cord grow simultaneously. At the age of 4-5, the growth of the spinal cord stops but the growth of the vertebral column continues. As a result, in adults, the spinal cord does not reach the tip of the vertebral column.

Internal anatomy

Cross sectional view of spinal cord shows it to be flattened from front to back with two grooves marking its surface. One of these grooves is deeper and is called **anterior median fissure** and another less shallower is called **posterior median sulcus.** Cross section of spinal cord reveals white matter encircling grey matter occupying the innermost core in the form of 'H' or 'butterfly' shape. White matter basically consists of myelinated axons of neurons. Grey matter mainly consists of dendrites, cell bodies, unmyelinated axons and neuroglia. At the centre of grey matter is present a **central canal**.

The grey matter on each side of the spinal cord is subdivided into regions called 'horns'. The posterior (dorsal) grey horns consist of cell bodies and axons of interneurons and axons of incoming sensory neurons. The anterior(ventral) grey horns contain the cell bodies of somatic motor neurons and some interneurons. Poliomyelitis virus destroys anterior horn motor neurons. Early symptoms include fever, headache, muscle pain and weakness. Later paralysis occurs and patients may die due to paralysis in the respiratory tract.

Reflex Action and Reflex Arc

Spinal cord along with spinal nerves together controls some of the rapid human responses to sudden environmental changes. When unknowingly we pick up a hot object the muscles grasping the object may suddenly relax and the object is dropped. This sudden response is called **reflex action**.

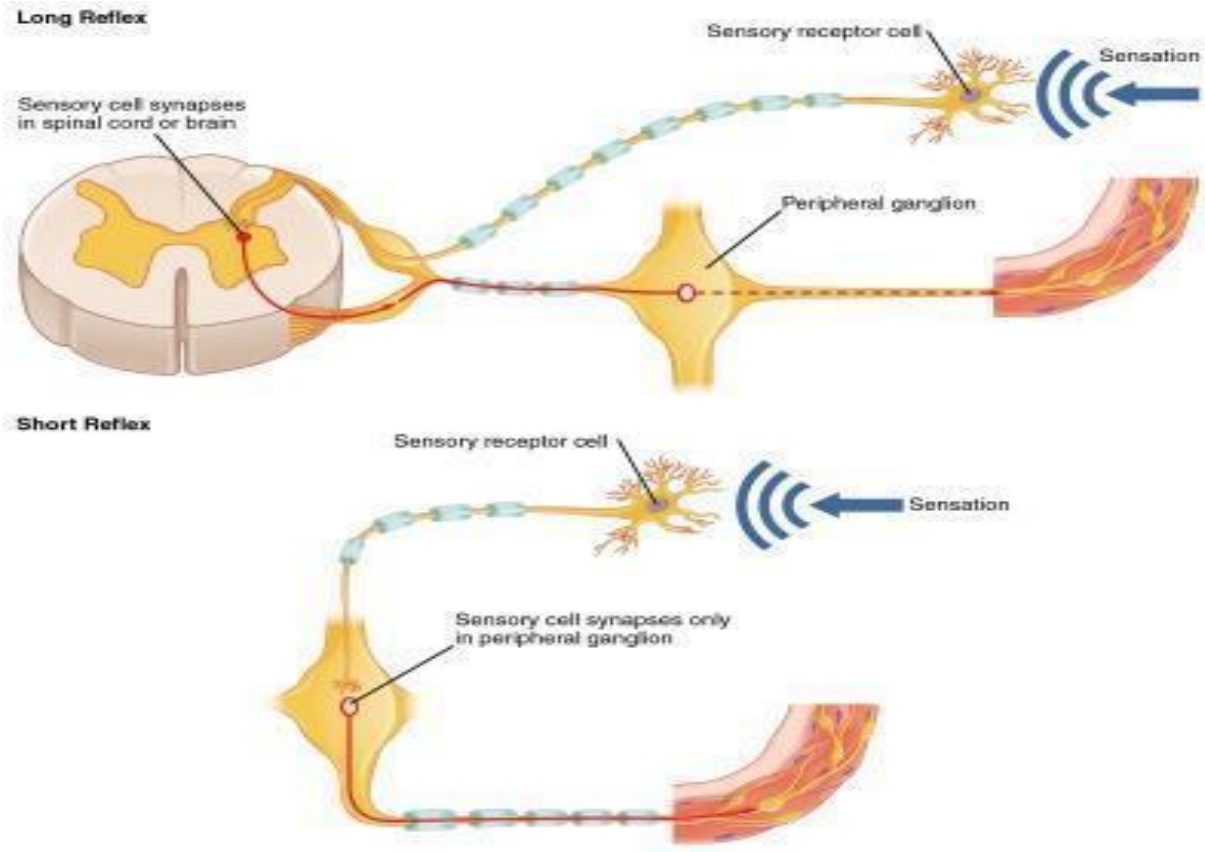


Fig. Reflex Arc

Reflex action is performed through a specific neural pathway called the **reflex arc**. Reflex arc possesses five components. These are

(i) **Receptors**- site of stimulus

(ii) **Sensory neurons** transfer afferent impulses to central nervous system

(iii) **Integration centre** consists of short interneurons which form synapses between sensory neurons and motor neurons.

(iv) **Motor neurons** conduct different impulses from the integration centre to an effector organ

(v) **Effectors** are muscle fibres or glands which respond to different impulses and undergo contraction or secretion respectively.

Functions of Brain and Spinal Cord

- Brain controls thought, emotions, behaviour and many basic life activities like maintaining breathing rhythm, blood pressure etc. it stores memory, enables learning, reading, writing, problem solving, analysing, interpretation by observing others activity. Cerebellum maintains posture and maintains equilibrium. It regulates secretion of hormones.
- Spinal cord collects a large amount of information coming to it through the peripheral nervous system and transmits to the brain. It also protects the body from sudden environmental changes by responding through reflex action.

Summary

- Central nervous system constitutes the brain and spinal cord.
- Brain and spinal cord are protected by several protective covering like bony case, connective tissue layer, cerebrospinal fluid etc.
- Brain is the seat of intelligence, analysis, thought, memory storage, emotions, creativity etc.
- CNS receives responses from sense organs and coordinates the functions of the body.