Neural Control and Coordination

21

INTRODUCTION

The process through which two or more organs interact and complement the funcitons of one another is called **co-orsdination**. In human beings nervous and endoerine system jointly coordinate and intergrate all the activities of different other organs in synchronised fashion.

Nervous system is responsible for rapid transmission of stimuli and its response by electro chemical signals which are short lived and very specific while endocrine system is responsible for slow transmission by specific chemicals i.e. hormones those travel through blood stream and act on target organs. The response of these hormones is long lasting and wide spread.

In all the multicellular animals above the level of sponges, the system meant to perceive stimuli detected by the receptors, to transmit these to various body parts and to effect responses through effectors, is called *nervous system*. In vertebrates, it is highly specialized and plays at least three vital roles which are following -

(1) **Sensory function :** It senses certain changes (stimuli) both with in body (internal environment) and out side body (external environment).

(2) **Integrative functions :** It analyses the sensory information, store some aspects, and makes decisions regarding appropriate behaviors.

(3) **Motor functions :** It may respond to stimuli by initiating muscular contractions or glandular secretions.

NERVOUS SYSTEMS IN VARIOUS ANIMALS

- The neural system of all animals is composed of highly specialised cells called **neurons** which can detect, receive and transmit different kinds of stimuli.
- The neural organisation is very simple in lower invertebrates. For example, in Hydra it is composed of a network of neurons.
- The neural system is better organised in insects, where a brain is present along with a number of ganglia and neural tissues.
- The vertebrates have a more developed neural system.

NERVE

1. Neurons

A neuron is a nerve cell with all its branches. Neuron is formed from neuroblast. It is the structural and functional unit of nervous system. It is the longest cell of the body.

(i) Cyton : It is also called perikaryon or soma or cell body. Its granular cytoplasm is called neuroplasm which has following structures :

- A large, spherical, centrally placed nucleus with a single nucleolus.
- Numerous fine threads called neurofibrils for the conduction of nerve impulses.
- A number of small, basophilic granules called **Nissl's granules** formed of rough endoplasmic reticulum with ribosomes and are sites of protein synthesis.
- Neuroplasm has large number of mitochondria to provide high energy for impulse conduction.
- A mature neuron has no centriole, so it cannot divide.
- Certain neurons having flask-shaped cytons and called **purkinje cells,** occur in the cerebellum of the brain.

(ii) Neuron processes : The processes of neurons, called **neurites,** extend varying distances from the cyton and are of two types – dendrites or dendrons and an axon or axis cylinder (neuraxon).

(a) Dendron : These are several short, tapering much branched processes. The dendrites contain neurofibrils, neurotubules, Nissl's granules and mitochondria. They conduct nerve impulse towards the cell body.

(b) Axon : This is a single very long, cylindrical process of uniform diameter. It arises from a conical projection, the **axon hillock**, of the cyton. The axon contains neurofibrils and neurotubules but lacks Nissl's granules. Axon is usually branched only terminally into slender branches called telodendria. The latter have knobbed ends called **endbulbs or axon terminals or buttons or synaptic knobs or end plates.** The synaptic knobs contain mitochondria and secretory vesicles.

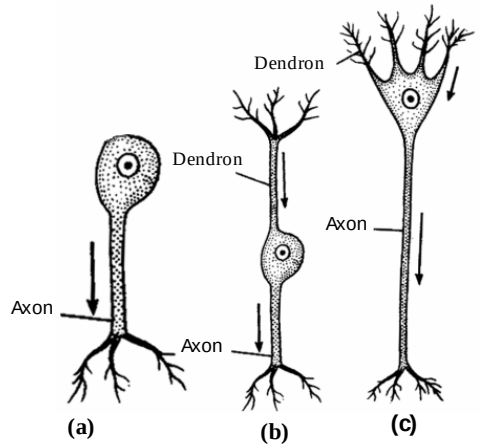
2. Types of neurons : Neurons are divided into different categories on different basis.

(i) On the basis of functions : Neurons are divided into three categories :

- **Sensory (afferent) neurons :** These are found in sense organs. Their dendrons receive the nerve impulse from the nerve process of the receptor cell while their axon forms the synapse with dendron of the next neuron. These may be naked or encapsulated e.g. olfactoreceptors and gustatoreceptors.
- **Internuncial neurons :** These are located in the dorsal horn of the spinal cord. These are called association neurons (when their axon synapses with the dendron of motor neuron of same side) or commissural neuron (when their axon synapses with the dendron of motor neuron of opposite side).
- **Motor (efferent) neurons :** These are always present in the ventral horn of the spinal cord. Their axon ends into the muscle fibres or glands cells. These conduct the nerve impulses to the effector organs which respond to the stimuli.

(ii) On the basis of number of nerve processes : Neurons are of three types –

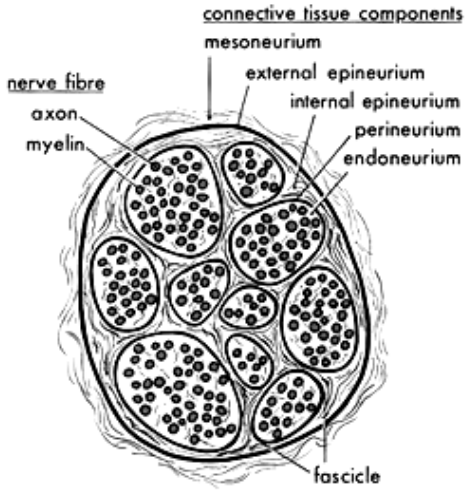
- **Unipolar neurons :** In these neurons, only one nerve process arises from the cyton which acts as axon but there is no dendron. **These are found only in early embryos.** The unipolar neuron of the adult gives rise to a single nerve process, which immediately divides into a dendron and an axon. Such unipolar neurons are called **pseudo-unipolar neurons.**
- **Bipolar neurons :** In these neurons, the cyton gives rise to two nerve processes out of which one acts as an axon while other acts as a dendron. These are found in the olfactory epithelium of nasal chamber and retina of eye.
- **Multipolar neurons :** In these neurons, the cyton gives rise to several nerve processes out of which one acts as an axon while remaining nerve processes act as dendrons. These are found in the central nervous system and the ganglia of autonomic nervous system of adult.



Types of Neurons (a) Unipolar ; (b) Bipolar ; (c) Multipolar

(iii) Types of Neurons or the basis of mylein sheath two types :

- **Medullated of myleinated fibre :** These are the fibres covered by mylein sheath. This fibres devlop from schwann cell Which forms mylein sheath mylein sheath is not continous but is absent at intervels. This areas devoid of mylein sheath is called as Nodes of Ranvier. While the area with mylein sheath is called internodes. They are more efficient in impulse conduction.
- **Non medullated or non-myleinated nerve fibres :** These are the fibres which is not covered by mylein sheath. They are enclosed by a schwann cells which do not form mylein sheath around axon. They appear greyish. It is mainly found in autonomic & somatic neural system.



Normal Nerve

BIOCHEMICAL ASPECT OF NERVOUS PHYSIOLOGY

All parts of a neuron transmit excitations (= impulses), but the transmission is always unidirectional. The dendrites and cytons usually constitute the impulse receiving parts which receive impulses directly from receptors, or from other adjacent neurons. The axons are specialized as fibres conducting impulses away from the receiving parts. Thus, the reaction or response impulses are always carried to the effectors by axons. That is why, the term '**nerve fibres**' is usually applied to the axons. The latter are 0.1 *mm* to one or more (upto 10) *metres* long and about 0.025 *m* thick on an average.

1. Main properties of nervous tissue : The nervous tissue has two outstanding properties excitability and conductivity.

(i) Excitability : It is the ability of the nerve cells and fibres to enter into an active state called the **state of excitation** in response to a stimulus. Excitation arises at the receptors on account of various stimuli such as light, temperature, chemical, electrical or pressure which constantly act on the organisms.

(ii) Conductivity : The excitation does not remain at the site of its origin. It is transmitted along nerve fibres. The transmission of excitation in a particular direction is called conductivity.

2. Definition of nerve impulse : A wave of reversed polarity or depolarization (action potential) moving down an axon is called a nerve impulse.

3. Mechanism of conduction of nerve impulse

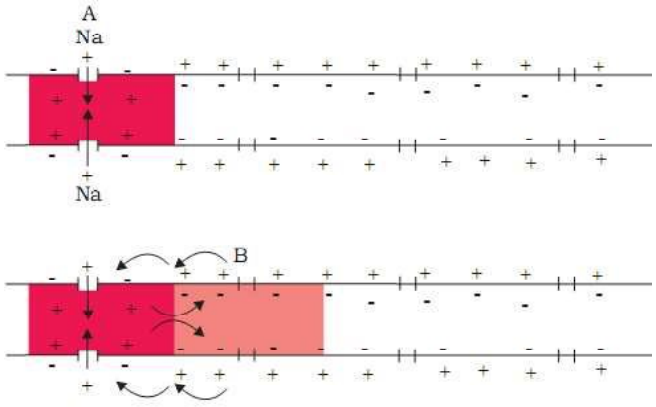
Most accepted mechanism of nerve impulse conduction is ionic theory proposed by **Hodgkin and Huxley.** This theory states that nerve impulse is an electro-chemical even governed by differential permeability of neurilemma to Na^+ and K^+ which in turn is regulated by the electric field.

(a) Transmission of nerve impulse along the nerve fibre

Polarization

(Resting membrane potential-RMP) :

- In a resting nerve fibre (a nerve fibre that is not conducting an impulse), sodium ions Na^+ and Cl^- predominate in the extracellular fluid, whereas potassium ions (K^+) predominate in the intracellular fluid (within the fibre).
- Intracellular fluid also contains large number of negatively charged (anions) protein molecules.
- Na^+ are 10 times more outside the neuron and K^+ ions are 25 times more inside the cell.
- Thus it makes a considerable difference between the ion concentration outside and inside the plasma membrane.
- It also causes a difference in electrical charges on either side of the membrane. The plasma membrane is electrically positive outside and negative inside.



Diagrammatic representation of impulse conduction through an axon (at points A and B)

- This difference is called potential difference. The potential difference across the plasma membrane is known as resting potential.
- This potential averages – 70 *mv* (– 40 to – 90 *mv*) in inner side of membrane in respect to outer side.
- A higher concentration of cations outside the membrane compared to the concentration of cations inside it. This state of the resting membrane is called **polarised state** and makes its inner side electronegative to its outside.

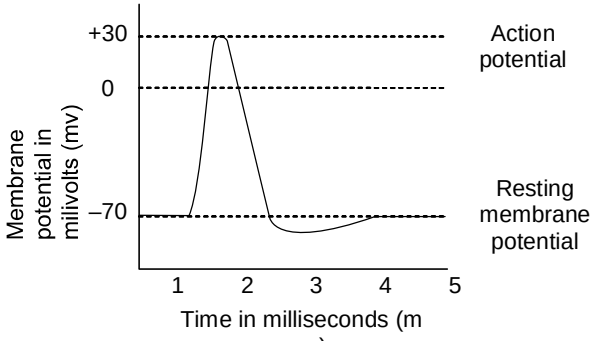
(b) Depolarization

(Action membrane potential or AMP) :

- When the nerve fibre is stimulated mechanically, electrically, thermally or chemically a disturbance is felt at the point of stimulation which gives rise to a local excitatory state.
- The membrane becomes permeable to sodium ions. The membrane is negatively charged on the outside and positively charged on the inside.
- The membrane with reversed polarity is said to be depolarized. This wave of depolarization travelling down a nerve fibre is called **action potential**. Infact, the action potential "moves" in the manner of a spark moving along a fuse.
- This "moving" action potential constitutes the **nerve impulse**. The action potential (impulse) is the basic means of communication within the nervous system.
- The action potential of + 45 *mv* on inner side of axolemma in respect to its outer side is also called **spike potential.**

(c) Repolarization :

- With the increase of sodium ions inside the nerve cell, the mebrane becomes less permeable to sodium ions whereas the permeability membrane to potassium ions increases.
- The sodium ions are pumped out of the cell and potassium ions are pumped into the cell until the original resting state of ionic concentration is achieved.
- Thus this makes the membrane negative on inside and positive on outside. This process is called repolarization.



Record of potential changes

- The last movement of ions is thought to take place by an **active transport** mechanism called sodium potassium pump (also called sodium potassium exchange pump or sodium pump).
- The sodium-potassium pump is a process of expelling out sodium ions and drawing in potassium ions against concentration and electrochemical gradient.
- The entire process of repolarization equires some time during which the nerve cannot be stimulated again.
- This period is called **refractory period**. During repolarization, as the cell returns to its resting potential, the neuron is ready to receive another stimulus.

THE SYNAPSE

The synapse is an area of functional contact between one neuron and another for the purpose of transferring information.

- Synapses are usually found between the fine terminal branches of the axon of one neuron and the dendrites or cell body of another.
- This type of neuron is called axo-dendrite synapse. **Sir Charles Sherrington** (1861-1954) was the first person who used the term 'synapse' to the junctional points between two neurons.

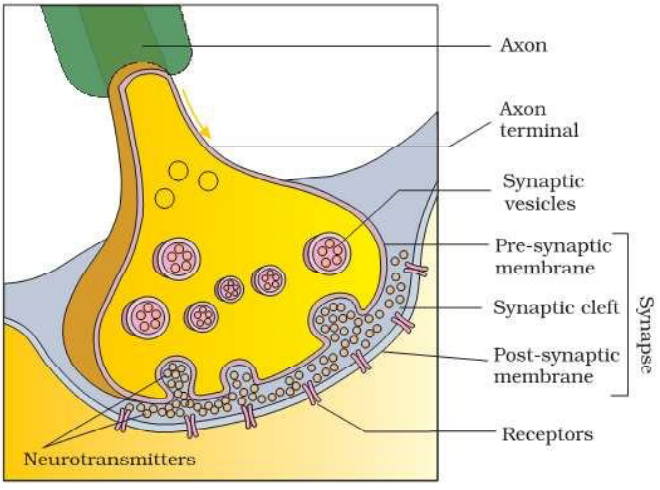


Diagram showing axon terminal and synapse

1. Structure of synapse :

- A typical (generalized) synapse consists of a bulbous expansion of a nerve terminal called a pre-synaptic knob lying close to the membrane of a dendrite.
- The cytoplasm of the synaptic knob contains mitochondria, smooth endoplasmic reticulum, microfilaments and numerous synaptic vesciles.
- Each vescile contains neurotransmitter (chemical substance) responsible for the transmission of the nerve impulse across the synapse.
- The membrane of the synaptic knob nearest the synapse is thickened and forms the presynaptic membrane.
- The membrane of the dendrite is also thickened and is called the post synaptic membrane.
- These membranes are separated by a gap, the **synaptic cleft.** It is about 200 *Å* across The post synaptic membrane contains large protein molecules which act as receptor sites for neurotransmitter and numerous channels and pores.
- The two main neurotransmitters in vertebrate nervous system are **acetylcholine (ACh) and noradrenaline** although other neurotransmitters also exist.

2. Mechanism of transmission of nerve impulse at a synapse :

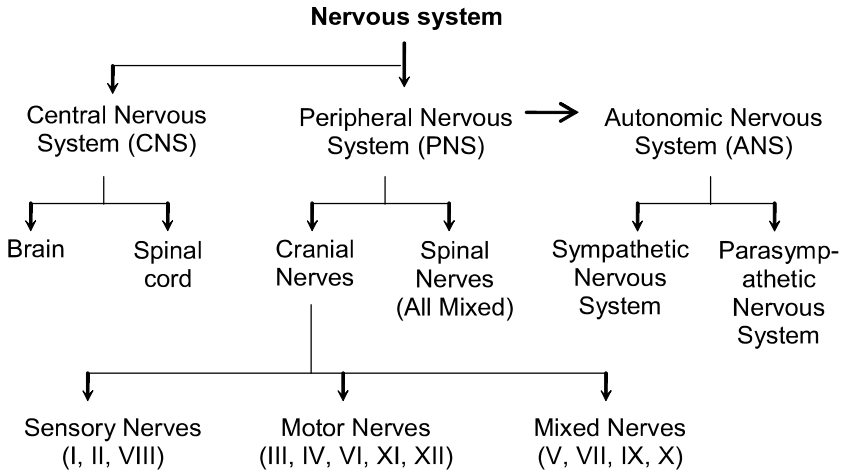
The process of chemical transmission across synapses was discovered by **Henry Dale** (1936). The physiological importance of synapse for the transmission of nerve impulses was established by **McLennan** in 1963. A brief description of the mechanism of synaptic transmission is given below

- When an impulse arrives at a presynaptic knob, **calcium ions** from the synaptic cleft enter the cytoplasm of the presynaptic knob.

- The calcium ions cause the movement of the synaptic vesicles to the surface of the knob. The synaptic vesicles are fused with the presynaptic membrane and get ruptured (exocytosis) to discharge their contents (neurotransmitter) into the synaptic cleft.
- The synaptic vesicles then return to the cytoplasm of the synaptic knob where they are refilled with neurotransmitter.
- The neurotransmitter of the synaptic cleft binds with protein receptor molecules on the post synaptic membrane. This binding action changes the membrane potential of the postsynaptic membrane, opening channels in the membrane and allowing sodium ions to enter the cell. This causes the depolarization and generation of action potential in the post-synaptic membrane. Thus the impulse is transferred to the next neuron.
- Having produced a change in the permeability of the postsynaptic membrane the neurotransmitter is immediately lost from the synaptic cleft. In the case of cholinergic synapses, acetylcholine (ACh) is hydrolysed by an enzyme **acetylcholinesterase (AChE)** which is present in high concentration at the synapse.
- The products of the hydrolysis are acetate and choline which are reabsorbed into the synaptic knob where they are resynthesized into acetylcholine, using energy from ATP.

PARTS OF NERVOUS SYSTEM

Nervous system is divided into three parts –



1. Central nervous system (CNS) :

In all the vertebrates including man, CNS is dorsal, hollow and non-ganglionated while in invertebrates when present, it is ventral, solid, double and ganglionated. CNS is formed of two parts :

(i) **Brain –** Upper and broader part lying in the head.

(ii) **Spinal cord –** Lower, long and narrow part running from beginning of neck to trunk. CNS is covered by 3 meninges and its wall has two type of matter.

2. Types of matter :

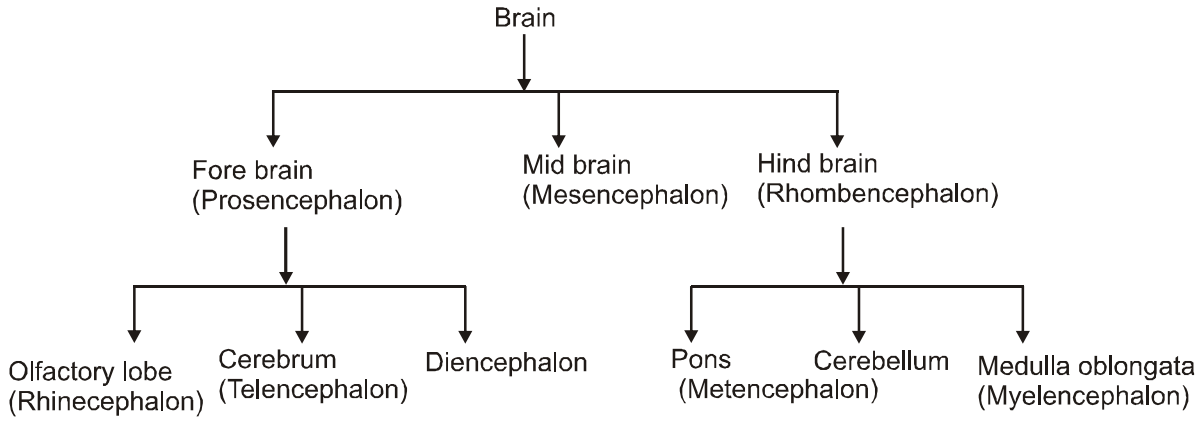
CNS of vertebrates is formed of two types of matter –

(i) **Grey matter :** It is formed of cell-bodies, non-medullated nerve fibres, neuroglea, dendrites of association neurons and motor neurons.

(ii) **White matter :** It is formed of medullated nerve fibres or **myelinated axon of motor and sensory neurons,** which appear white due to presence of medullary sheath.

STRUCTURE OF HUMAN BRAIN (ENCEPHALON)

It is soft, whitish, large sized and slightly flattened structure present inside cranial cavity of cranium of the skull. In man, it is about 1200-1400 *gm* in weight and has about 10,000 million neurons. Brain is made up of 3 parts :



1. Fore brain or Prosencephalon : It forms anterior two-third of brain and is formed of three parts.

(a) Olfactory lobes : These are one pair, small sized, club-shaped, solid, completely covered by cerebral hemisphere dorsally. Each is differentiated into two parts –

(i) Olfactory bulb : Anterior, swollen part, and

(ii) Olfactory tract : Posterior and narrow part which ends in olfactory area of temporal lobe of cerebral hemisphere.

Function : These control the smell.

(b) Cerebrum :

- Cerebrum is divided into 4 lobes (a) frontal (b) parietal, (c) occipital, (d) temporal and (e) Insula.
- The **median fissure** divides the cerebrum into a right and a left cerebral hemisphere.
- **Function of Cerebrum –** It is a centre for Intelligence, Emotion, Will power, Memory, Consciousness, Imagination, Experience, Knowledge, Reasoning, Voluntary controls, Weeping and laughing, Micturition, Defecation.

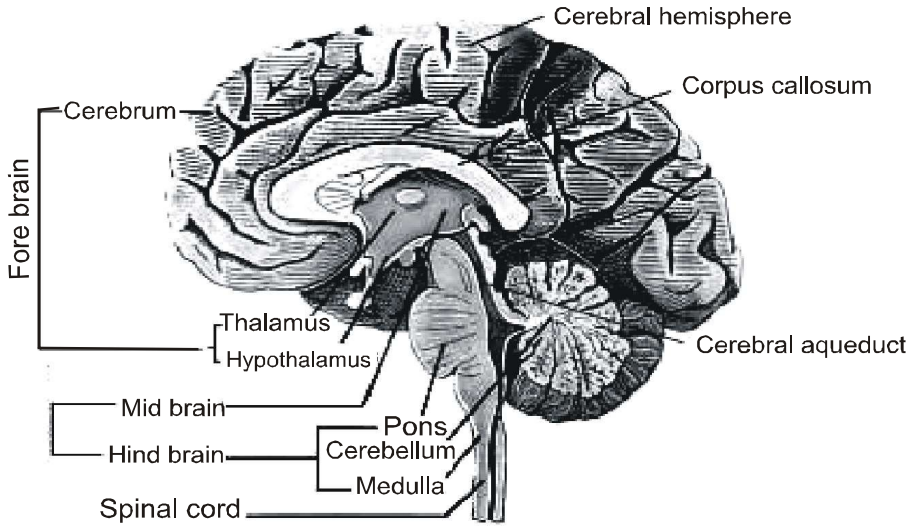


Diagram showing sagital section of the human brain

Note :

(i) Each cerebral hemisphere is with a fluid-filled cavity called **lateral ventricle or paracoel.**

(ii) Two cerebral hemispheres are interconnected by thick band of transverse nerve fibres of white matter called **corpus callosum.**

(iii) The peripheral portion of each cerebral hemisphere is formed of grey matter and is called cerebral cortex, while deeper part is formed of white matter and is called cerebral medulla.

Key Concepts:

(1) **Corpus callosum :** It is the unique feature of mammalian brain. It is the band of white neurons present between both cerebral hemisphere and connect them on medial surface.

(2) **Limbic system :** Limbic system present on inner border of cerebrum and floor of diencephalon, It is also called emotional brain or animal brain. Limbic system controlling emotion, animal behaviour like chewing, licking, sniffing, docility, tameness, affection (animals) rage, pain, pleasure, anger, sexual feelings, feer, sorrow grooming.

(c) Diencephalon :

Diencephaton cavity is called, **III ventricle or diocoel** the thin roof of this cavity is known as the epithalamus, the thick right and left sides as the thalami, and floor as the hypothalamus.

(i) Epithalamus :

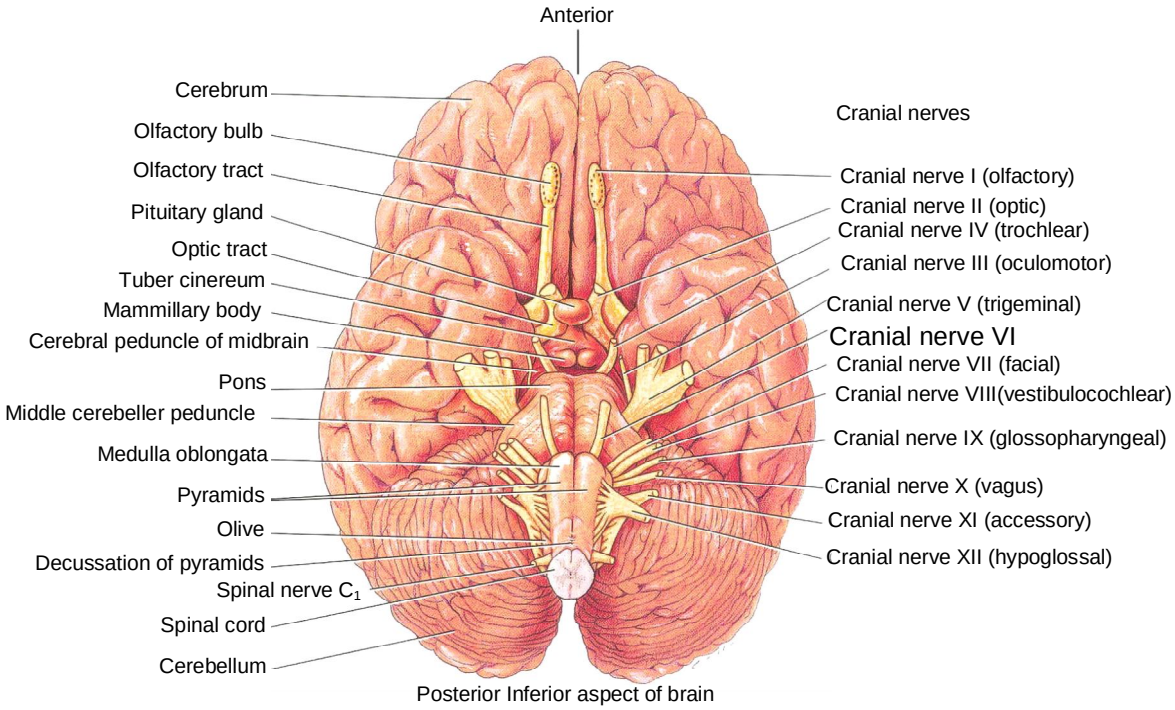
- It forms roof of third ventricle.
- The epithalamus is not formed of nervous tissue. It consists of piamater only. Hence, it is of relatively little significance as a nerve centre. Its anterior part is vascular and folded. It is called anterior choroid plexus.

(ii) Thalamus :

- A pair of mass of grey matter forms the superior part of lateral walls of the third ventricle.
- The thalamus is **principal relay station** for sensory impulses that reach the cerebral cortex from spinal cord, brain stem, cerebellum.

(iii) Hypothalamus :

- The hypothalamus is visible in the ventral view of the brain and forms the floor of diencephalon.
- Hypothalamus also gives a nervous process called infundibulum (forms pars nervosa) which meets a rounded non-nervous pharyngeal outgrowth called hypophysis.
- Both collectively form master gland called pituitary body.



Ventral view of brain

Note :

(i) Hypothalamus is a centre for Hunger, Thirst, Sweating, Sleep, Fatigue, Temperature, Anger, Pleasure, love and hate, Satisfaction.

(ii) It is also centre to release factors for endocrine glands.

- **Functions of Diencephalon –** It is a centre for

(a) *Carbohydrate metabolism*

(b) *Fat metabolism*

(c) It relays impulses from posterior region of brain and also to posterior region of brain.

Key Concepts

Cerebrum : Cerebral cortex is made up of grey matter and differentiated. **Sensory** and **associated area** confirm, recognise and evaluate for shape, colour, sound, taste and smell for sensory cells in relation with object.

2. Midbrain

- The midbrain is located between the thalamus/ hypothalamus of the forebrain and pons of the hindbrain.

It is formed of two parts –

(i) **Optic lobes :** These are one pair, large sized lobes present on dorsal side. Each is divided transversely into upper and larger superior coliculus and lower and smaller inferior coliculus. So there are four optic lobes, so called **optic/ corpora quadrigemina.**

(ii) **Cerebral peduncle** (crura cerebri) **:** They are the pair of thick bands of longitudinal nerve fiber present on the floor or ventral side of mid brain. This connects upper & lower region of brain.

- **Functions of Mid brain**

(i) Pair of anterior optic lobes (which are also known as superior colliculi) is related with vision.

(ii) Pair of posterior optic lobe (known as inferior colliculi) related with auditory.

(iii) These act as coordination centres between hind and fore brain.

Note : Midbrain and hindbrain form the **brain stem.**

3. Hindbrain

- The hindbrain comprises pons, cerebellum and medulla (also called the medulla oblongata).

(a) Cerebellum (Sandwitched brain) : Cerebellum is second largest portion of brain lies posterior to medulla and pons and inferior to posterior portion of cerebrum. It is butterfly shape structure. The superficial layer of cerebellum, called cerebellar cortex, consist of gray matter. Deep to gray matter are white matter tree called **'Arbor vitae' or tree of life.** Cerebellum has very convoluted surface in order to provide the additional space for many more neurons.

- **Functions of Cerebellum** –

(i) It is centre for co-ordination of muscular movement.

(ii) It is primary centre for balancing, equilibrium, orientation.

(b) Medulla oblongata : Medulla oblongata is the hindest and posterior most part of brain. Cavity is known as **IVth ventricle (metacoel)** which is continuous with central canal of spinal cord through Formen Magnum.

- **Funcitons of Medulla oblongata – It contains centre for** –

(i) Heart beats

(ii) Respiration

(iii) Digestion

(iv) Blood pressure

(v) Gut peristalsis

(vi) Swallowing of food

(vii) Secretion of gland

(viii) Involuntory function – e.g. vomiting, coughing vasoconstrictor, vasodilater, sneezing, hiccouping.

(ix) It control urination, defecation.

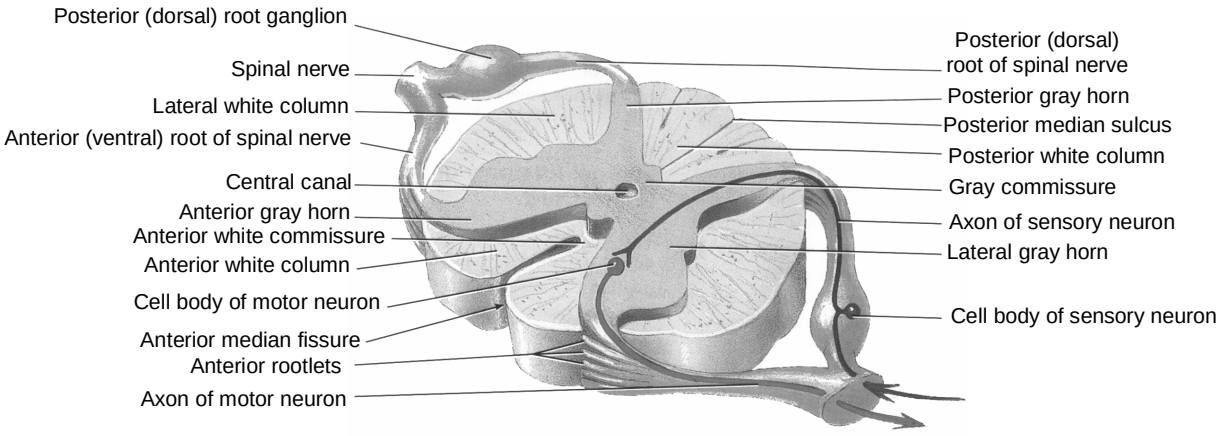
(x) The cardiovascular center – regulate rate, force of heart beats.

(xi) Medullary rhythmicity area – adjust basic rhythm of respiration.

(c) **Pons Varolii :** An oval mass, of white mater called the pons varolii, lies above the medulla oblongata. It consists mainly of nerve fibres which interconnect as bridge connecting spinal cord with brain and parts of brain with each other. Pons also with pneumotaxic area. Together with medullary rhythmicity area, they help control respiration.

SPINAL CORD

- **Structure of spinal cord :** Spinal cord is also covered by duramater, arachnoid & piamater. The outer-part of spinal cord is of white matter while inner-part contain gray matter. On the dorsa-lateral & ventro-lateral surface of spinal cord, the gray matter (butter fly like) projects outside & forms the one pair dorsal & ventral horn.



T.S. of the thoracic spinal cord of mammal

Key Concepts

(1) **Meninges :**

The meninges are connective tissue membranes which surround the brain and spinal cord of CNS. In mammals, CNS is covered by three meninges or membranes or cranial meninges. Brain meninges are continuous with spinal meninges

- The three layers of cranial meninges in order from superficial to deeper duramater, arachnoid and piamater. Duramater is nonvascular, tough made up of fibrous connective tissue.
- Arachnoid mater made up of reticular connective tissue with collagen and elastin fiber, while innermost vascular piamater (nutritive) made up of loose aerolar connective tissue.
- Between dura and arachnoid mater presence of sub dural space (no CSF in mammals here), between Arachnoid and piamater presence of sub-arachnoid space (with CSF in mammals, CSF also found in ventricles and central canal).

(2) **Cavities or ventricles of the brain :**

The ventricles consist of four hollow fluid filled space inside the brain and same duct for connection between these ventricle.

(i) Cerebrum – I and II ventricle or lateral ventricle or paracoel.

(iii) Diencephalon **:** Third ventricle or Diocoel.

(iv) Medulla oblongata : 4th ventricle or metacoel.

(3) **Cerebrospinal fluid :**

- All the ventricles of the brain, central canal of spinal cord are continuous and lined by a columnar, ciliated epithelium, the ependyma.
- They contain lymph-like extracellular fluid called the cerebrospinal fluid (C.S.F.).
- This fluid is secreted by the choroid plexuses by filtration of blood.

- The cerebro-spinal fluid (CSF) provides –

(i) Protection to brain from mechanical shocks, physical injury.

(ii) Optimum physiological fluid environment for neural functions *e.g.* conduction of nerve impulses, transport of aminoacids, sugars, O_2 etc.

(iii) The blood CSF barrier for selective transport process between blood and CSF.

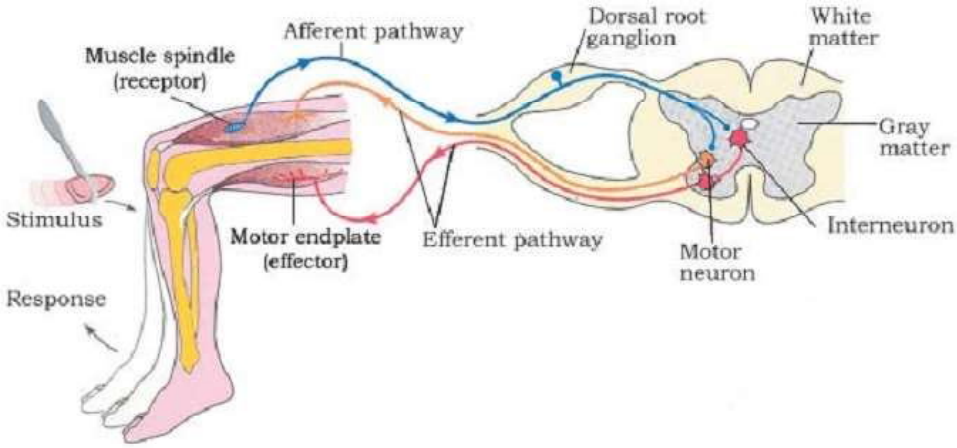
(iv) Nourishment to CNS.

(4) Oxygen and glucose requirements of brain : To control various functions of our body organs brain needs a large and constant oxygen (20% of the body's consumption) and blood glucose (15% of its consumption) supply. Brain deprived of oxygen creats mental confusion and leads to permanent damage with in 5 minutes.

REFLEX ACTION

Reflexes are fast predictable, automatic responses to change the environment. First of all Marshal Hall (1833) studied the reflex action. *Best* and *Taylor* defined reflex action "simplest form of irritability associated with the nervous system is reflex actions or a reflex reaction is an immediate involuntary response to a stimulus." The reflex actions are involuntary actions because these are not under the conscious control of the brain. Central nervous system is responsible for the control of reflex action.

Reflex arc is formed by the neurons forming the pathway taken by the nerve impulses in reflex action. The simplest reflexes are found in animals involving a single neuron and the following pathway -



Diagrammatic Presentation of reflex action (showing knee jerk reflex)

1. Component of reflex action :

The whole of the reflex are includes five parts –

(i) **Receptor organs :** Receptors are windows of the body or guards of the body. These are situated on all, important organs, for example – eyes, nose, ear, tongue, integument etc. These perceive the stimuli from out side the body.

(ii) **Sensory neurons :** These are also termed afferent neurons. These carry the stimuli from receptors to spinal cord. These neurons are situated in the ganglion on the dorsal side of spinal cord gray matter or brain stem.

(iii) **Association neurons or Integrating center :** These are also called intermediate neurons or interstitial neurons. These are found in spinal cord. They transfer the impulses from sensory neurons to motor neurons. Association neurons forms monosynaptic and polysynaptic reflex arc.

(iv) **Motor neurons :** These are situated in the ventral horn of spinal cord. These carry the impulses to effector organs.

(v) **Effector organs :** These are the organs, which react and behave in response to various stimuli, for example – muscles and glands.

2. Mechanism of reflex action :

- The time taken by a reflex action is too short, for example – in frog it is 0.3 meter per second and in man 5-120 meter per second.
- Whenever, a part of the body is stimulated by any stimulus, for example – pin pricking, then the stimulus is converted into impulse.
- This impulse is perceived by the dendrites of sensory neurons. From here, the stimulus reaches the spinal cord through axonic fibres.
- In the spinal cord, this stimulus passes through synaptic junctions and reaches the intermediate neurons, from where this stimulus reaches the effector organs through motor nerve fibres.
- As soon as the stimulus reaches the effector organs, it is stimulated and that part of the body is immediately withdrawn.
- The whole reflex action takes place so rapidly and quickly that we know it when it is completed.

PERIPHERAL NERVOUS SYSTEM

- It is formed of a number of long, thin, whitish threads called nerves extending between central nervous system and body tissues. Each nerve is formed of bundles of nerve fibres, fasciculi, held together by connective tissue and surrounded by a white fibrous connective tissue sheath called epineurium.
- The nerve fibres are classified into two categories on the basis of presence or absence of myelin (white fatty) sheath.

(1) Medullated or Myelinated nerve fibres.

(2) Non-medullated nerve fibres.

On the basis of function, the nerves are of three types

(1) **Sensory nerve**

(i) It contains only sensory nerve fibres.

(ii) It conducts nerve impulses from sense organs to CNS to produce sensation. *e.g.* Optic nerve, auditory nerve.

(2) **Motor nerve**

(i) It contains only motor nerve fibres.

(ii) It conducts nerve impulses from CNS to some muscles or glands to control their activities. *e.g.* Occulomotor nerve, hypoglossal nerve.

(3) **Mixed nerve**

(i) It contains both sensory and motor nerve fibres.

(ii) It conducts both sensory and motor impulses. *e.g.* All spinal nerves, trigeminal nerve.

On the basis of their origin, nerves are of two types

(1) Cranial or cerebral nerves which either arise from or end into brain.

(2) Spinal nerves which arise from spinal cord.

AUTONOMIC NERVOUS SYSTEM

(1) The autonomic nervous system is that part of the peripheral nervous system which controls activities inside the body that are normally involuntary, such as heart beat, peristalsis, sweating etc.

(2) It consists of motor neuron passing to the smooth muscle of internal organs. Smooth muscles are involuntary muscles. Most of the activities of the autonomic nervous system is controlled within the spinal cord or brain by reflexes known as visceral reflexes and does not involve the conscious control of higher centres of the brain.

- Overall control of the autonomic nervous system is maintained, however, by centres in the medulla (a part of the hind brain) and hypothalamus.
- These receive and integrate sensory information and coordinate this with information from other parts of the nervous system to produce the appropriate response.
- ANS plays an important role in maintaining the constant internal environment (homeostasis).
- Autonomic nervous system (ANS) automatically regulates the activities of smooth muscles, cardiac muscles and glands.
- This co-ordination is involuntary. Autonomic nervous system usually operates without conscious control.
- Autonomic nervous system is regulated by centres in brain like cerebral cortex, hypothalamus and medulla oblongata.

SENSORY RECEPTION AND PROCESSING

Animals possess some specialised structures to perceive the different type of changes (=stimuli) occurring in their external environment. These structrures are known as **sense organs.** After receiving these stimuli, sensory organs transmit these to the central nervous system through the sensory nerve fibres.

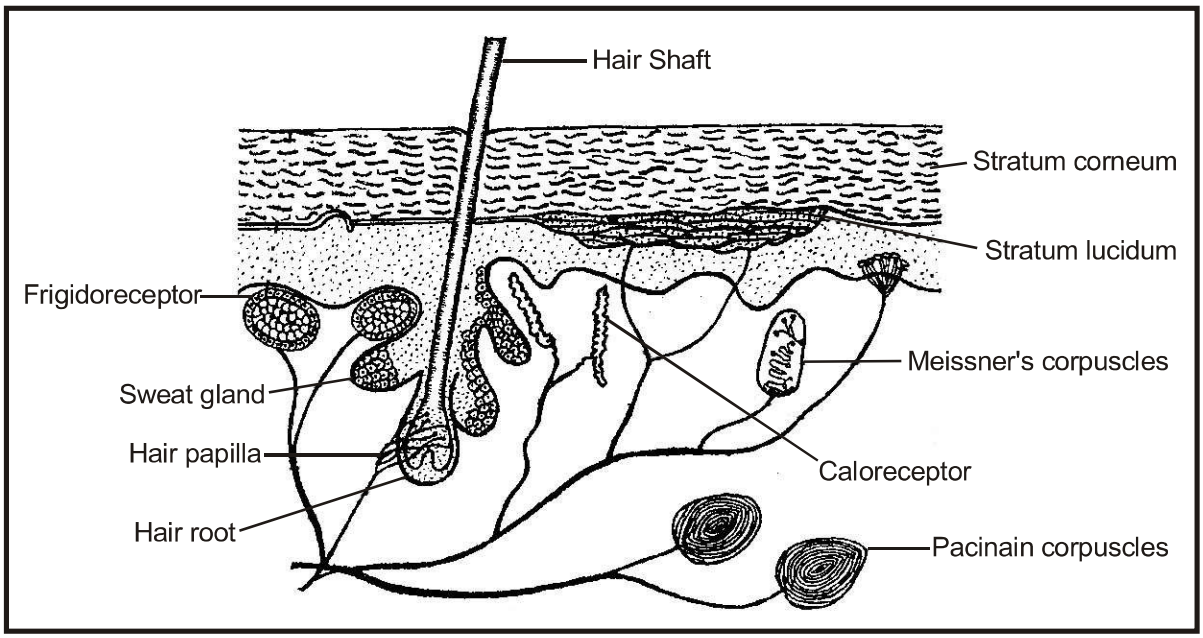
A sensory organ is only sensitive to a specific kind of stimulus to which it is specialized like temperature, chemicals, touch, light etc. Based on their location in the body sensory organs are of three. types :

1. **Exteroceptors :** These sense organs receive stimuli from external environment because they remain in contact with the external environment. Example- nose, eyes, tongue, ears and skin.
2. **Interoceptors :** These sensory organs are associated with internal environment of body and receive the changes taking place in the internal environment. Examples- changes in the composition of blood, concentration of carbon-dioxide, hunger, thirst, asphyxia etc.
3. **Proprioceptors :** These sensory organs are present in joints, tendons, muscles and connective tissues which perceive the tension and pressure exerted during the activities of equilibrium maintenance and orientainons of body.

In human body, five types of exteroceptors are found which are known as sense organs. The main sense organs include skin, eye, nose, ear and tongue.

CUTANEOUS RECEPTORS

Skin envelopes the entire body, and it is considered as tangoreceptor (fig.) Numerous sensory papillae are found in the dermis of skin to receive the stimuli of touch, pressure, cold, heat, temperature and pain. All these are of simple type of receptors. These sensory structures of skin receive impulses from the nerve endings in skin. These are of following types-



1. **Tactile Receptors :** These receptors are present as naked endings of sensory nerve fibres on the hair follicles in the dermis of skin. These are excited when the hairs come in contact with some object.

   Extensivly branched (arborized) endings are of sensory nerves are found in the papillae of dermis. These endings are very small sized encapsulated structures called sensory corpuscles. Those which are cylindrical and sensitive to touch are called **Meissner's corpuscles.** Their number is much more in nipples, lips, glans penis, palm, sole and in fingers. The number of these corpuscles decreases as a person grows older. The corpuscles sensitive to the strong and sustained contacts (pressure) are situated deep in the dermis and called as **Pacinian** corpuscles.

2. **Pain Receptors (Algesireceptors) :** Numerous branched sensory nerve fibres are scattered among the epidermis as well as dermal cells of skin. These possess naked nerve endings. These nerve endings are sensitive to chemical, electrical, and mechanical stimuli, which cause the sensations of pain in body.

3. **Thermo Cause Receptors :** A network of sensory nerve fibres is situated closely to the hair follicles in dermis of skin. These nerve fibres are sensitive to the stimuli related to temperature, These thermoreceptors make a person aware to stimuli of cold, heat etc. Because of this sense perception our hairs get erected during excessive cold. The sensory organs excited by cold and heat are known as ***frigidoreceptors*** and caloreceptors respectively.

EYE

* Eye and ear are also called **"teleoreceptors"**, because these receive impulse from far places.

(A) Eye (Photoreceptor) :-

* These are photosensitive organs.
* Each eye is an hollow ball like round structure, it is called eye ball. Each eye - ball is situated in the notch of bone in the skull. It is called "Eye - orbit". Human eyes are situated in eye orbit lateral to nose.
* Only $1/5^{th}$ part of whole eye is seen from out side in between the eye lashes.

  Remaining $4/5^{th}$ part is in the eye orbit.

(1) Eye lids or palpebrae :-

There are two muscular eyelids for the protection which having lashes at one side. Both the eyelids are named according to their situation i.e. upper & lower eyelids.

* Eyelids are immovable in snakes. Eyelids of fishes are absent.
* There is present one more transparent membrane in the eye. It is called nictitating membrane or third eye lid. it is actively working in rabbit. It is found constricted at one corner of eye ball , but at the time of need, it may be expanded over entire eye ball.
* Nictitating membrane is vestigeal in human. It is also called **"Plicasemilunaris".**
* Eye lashes are found at both the eyelids.

(2) Glands :- For the cleaning and for lubrication/ moisturising the exposure part of eye.

Following glands are founds in each eye.

(a) Meibomian glands :- These are present at Inner surface of eyelids. They secrete an oily substance, which is scattered at the edges of eye lids.

It prevent friction between two eye lid.

(b) **Lacrimal glands** :- At outer angle of each eye ball and associated with accessory lacrimal gland, which secrete water like substance, which moistures the cornea, eyelids and conjunctiva and cleans it. this water like substance is called "Tear". (Slightly alkaline contains bacteriolytic enzyme Lysozyme)

* Tear glands activate after four months of birth in human child.

(c) **Gland of zeis :** It is situated in margin of eye lid.

Harderian glands :- These are found inside the lower eye lids. These moisten the nictitating membrane.

* Harderian glands are absent in rabbit & **human**.

* In place of harderian glands, in mammals, meibomian glands are present. But in some mammals e.g. rats, shrews, whales etc., these harderian glands are found.

* These glands are also found in frog and birds.

(d) **Gland of moll :-** These are modified sweat gland found in the eye lashes.

(3) **Muscles of eye balls** :-

There are present 6 skeletal muscles in the eyeball which help in rotation of eye ball into eyeorbit. Out of these 4 are rectus muscles and 2 are oblique muscles. They are also called as extra occular muscles.

* Lateral or External rectus muscle rotates the eyeball towards outside i.e. from nose to ear. Medial or Internal rectus muscle rotates the eyeball toward inside i.e. from **ear** to nose.

* Superior rectus muscle and inferior oblique muscle collectively help the eyeball to rotate upwards.

* Inferior rectus muscle and superior oblique muscle collectively help the eyeball to rotate downwards.

* Rectus and oblique muscles collectively rotate the eye ball to all the sides around its axis.

* Any defect in one of the these eyeball muscles (e.g. muscle may remain small or extra large than required) causes **strabismus** or **squint eyes** . In this defect, eye ball remains inclined to any of the one side. Eye muscles are innervated by occulomotor (III). Pathetic (IV) and Abducens (VI) Nerve.

INTERNAL STRUCTURE OF EYE BALL :-

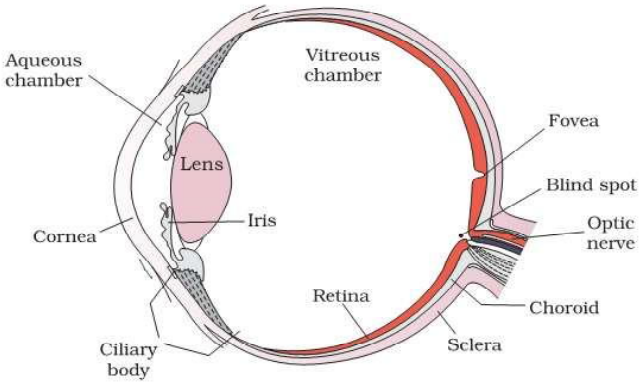


Diagram showing parts of an eye

The wall of remaining eye ball has three layers.

(1) **Fibrous tunic** :-

It is the outermost covering of eye ball. It is made up of hard and thick connective tissue.

The layer is divided into 2 parts.

(a) **Cornea** :-

It is the outer visible part of fibrous tunic. Covered by st. nonkeratinized squamous epithelium.

* The joint between cornea and sclerotic layer is called "**Limbus**" or "Sclero - corneal junction".

Cornea transplantation is successful because it lacks blood vessels.

(b) **Sclerotic layer/Sclera** :-

It is made up of white, hard, opaque thick fibrous connective tissue in rabbit but in frog, it is made up of cartilage. It is the inner portion of eye ball. It is non-vascularised. This layer is of white colour, so it is also called "White of eye".

* This part of eye is **mesodermal** in origin.

Inner layer of eyelids remain streched over anterior part of sclera (limbus) in the form of translucent membrane. It is called **conjunctiva**. It is made up of epidermis of skin. The thinnest epidermis is extend up to margin of cornea i.e. conjunctiva is the thinnest epidermis in animal body.

(2) Vascular tunic :-

It is the middle layer of eyeball. It is coloured part of eyeball. It is richly supplied with blood capillaries. Due to the presence of network of blood capillaries it is highly vascularized.

Melanin pigment is found in this layer. Due to the presence of melanin pigment eye looks like green, blue, brown, black in colour. Eyes of rabbit are red due to red melanin pigments, and in man eyes may be brown, black, blue, green according to the melanin present in it.

This layer has three parts :-

(a) Choroid layer :-

Choroid layer is the part of vascular tunic which lie below the sclerotic layer.

It contains abundant pigment cells & blood vessels.

It is dark brown. It darkens the cavity of eyeball to prevent internal reflection of light.

It nourishes the retina.

(b) Ciliary body :-

It is the lower swollen portion below limbus.

It has ciliary processes which project into eyeball.

It has ciliary muscles (i) circular (ii) meridional.

Inner end of meridional is attached to choroid & outer end at the junction of sclera and cornea.

(c) IRIS :-

Choroid layer or vascular tunic separates from sclerotic layer (Just after the cornea) inclines towards inner side and forms a coloured screen, it is called **iris. Muscles of iris are ectodermal in origin** where as the muscles of body are **mesodermal** in origin. There is present an aperture in the Centre of iris, it is called **Pupil**. Light rays enter in the eyeball through pupil.

2 types of muscles are related with iris.

(a) Radial dilatory muscles :-

These are outer unstriated muscles, these are expanded in the iris breadth wise. Iris becomes constricted if these muscles contract and diameter of pupil is increased at that time. It happens in dim light, it is called **Mydriasis**.

(b) Circular sphincter muscles :-

These are scattered in inner part of iris. Due to the contraction (In bright day light or high flashes of light) of these muscles in high light, Iris expands breadth wise and diameter of pupil is decreased. It is called **miosis**.

Iris controls the intensity of light by increasing or decreasing the diameter of pupil i.e. Iris acts as diaphragm of a camera. Except muscle of iris & ciliary body all vascular tunic of eye ball is **mesodermal** in origin. The parasympathetic fibres constrict & sympathetic fibre dilate the pupil. Colour of eye like blue, gray, brown is layer of pigmented cells.

(3) Neurosensory tunic :-

It is the inner most layer of eye ball and has 3 parts :-

(1) Pars ciliaris :- This part is attached with ciliary bodies. There are present spine like projections at the surface of ciliary body, these are called "**Orra serrata**:

(2) Pars iridica :- This part lies just after the iris. It has a layer of pigmented cells.

Pars iridica and pars ciliaris are made up of simple cuboidal epithelium.

(3) Pars optica :- It is also called Retina It is the part just below the choroid layer.

Structure of retina is complicated. It has following layers -

(a) Pigmented layer :- It is the outer most layer. In the cells of this layer, pigment is found called melanin (receptor cells).

(b) Sensory layer :- This layer is made up of specialized sensory cells. Rods and cones are found in this layer. Receptor cells are also known as photoreceptors/visual cells.

* Rods are long, thin, cylindrical structures/cells. These are numerous in number.(1110-1125 Lacs)
* Rods differentiates between light and dark. These are more sensitive than cones.
* A purple coloured pigment is found in rods called **Rhodopsin**/Visual purple.
* Cones are thick and small cells which differentiate among different colours in full light.(65 Lacs)

  Iodopsin/Visual violet is present in cones.
* Only rods are found in the retina of owl, because it is nocturnal animal, unlike hen which has only cones in its retina.
* A horizontal neurons layer is present just below the rods and cones, it is called **outer plexiform** layer. This layer connects rods and cones together.
* Then comes the layer of bipolar neurons. Each bipolar neuron has a dendron and one axon. Presence of bipolar neurons is a speciality of retina. Rest parts of body have multipolar neurons. Their dendrites form synapses between rods & cones.
* Axons are jointed together by specific nerve cells, called **Amacrine cells**. Such neurons do not have nerve fibres.
* The layer of amacrine cells is called "**Inner plexiform layer**".
* In between bipolar neurons, supporting cells are found and called **Muller's cells**.

(c) **Ganglionic layer :-** This layer is made up of nerve ganglia. These nerve ganglia form synapses with axons of bipolar neurons.

Axons of all nerve cells combine to form optic nerve. This optic nerve penetrates the retina and goes to brain.

At the point, at which retina is pierced by optic nerve, cones and rods are absent. So no image will be formed at that place. This point is known to be "**Blind spot**"**/Optic disc**.

Just above the blind spot at the optical axis of eye ball, there is a place, where only cones are present. Yellow pigments are found (xanthophyl) in these cones. So this place is known as **yellow spot** or **macula lutea** or **Area centralis**.

A groove or notch is found in area centralis, called **fovea centralis**.

* Fovea centralis is most sensitive part of eye. Cones are some what obliquely placed at this place. An enlarged image of object is formed here.
* Neurosensory tunic or retina of eye ball is ectodermal in origin.
* **Lens :-** A transparent, ectodermal, biconvex lens is present just after iris. In frog, lens is spherical in eyeball Lens is connected by ciliary body with the help of **"Suspensory ligaments"** called **zonula of zinn"** or **zonules.** These ligaments are flexible and this can slide the lens and can change it's focal length. Lens divides the cavity of eyeball into two chambers.

(a) **Aqueous chamber :-**

The part of eye ball which lies between cornea and lens is filled with an alkaline fluid, it is called aqueous humor. It is a type of transparent tissue fluid.

Iris divides this aqueous chamber into two parts:-

(i) **Anterior chamber** :-

This chamber lies between cornea and iris, it is called Venous chamber. Veins carry CO_2, metabolic wastes outside from here.

(ii) **Posterior Chamber :-**

This chamber lies between iris and lens, it is called arterial chamber. Arteries supply O_2 and nutrients here.

(b) **Vitreous chamber** :- Cavity of eye ball which lies between lens and retina is called vitreous chamber. A jelly like fluid (transparent and thick like albumin) is filled in this chamber, This is called vitreous humor.

* In this fluid 99% water, some salts, a mucoprotein called vitrin and a mucopolysaccharide-Hyaluronic acid are present. Gelatinous nature of vitreous humor is depend upon fibrillar protein & hyaluronic acid. It is form during embryonic stage. In this chamber Hyalocytes cells are found.
* Aqueous humor and vitreous humor both the fluids are secreted by the glands of ciliary body. Aqueous humor leak out by **canal of schlemm** into blood capillaries and again reach upto their veins.
* Both these fluid maintain proper pressure inside the cavity of eye ball. These check the eye ball from collapsing.
* If this canal of schlemm is blocked by any reason and fluids do not return back to veins fluid is increased in the chambers of eye.
* When amount of this humor is increased in the eye chambers then pressure is increased inside the eye ball. Thus retina pressure is increased. This is known as **glaucoma**.
* A thin **Hyaloid canal or Cloquet's canal** is also found in vitreous humor from blind spot to central point of lens. It provide nourishment to the developing lens which gradually atrophied.

WORKING OF EYES

* Light rays emitted by any object enter the eye. A small, real and inverted image of object is formed at retina. Sensory cells of retina are sensitized, and optic nerve carries this impulse to brain. At this time animal is able to see the object.
* Cornea, aqueous humor and biconvex lens completely refract the light rays coming from object. As a result of this an inverted image is formed at retina. Just like diaphragm of a camera iris of eye, decreases or increases the diameter of pupil according to light. Iris expands to decrease the pupil in high intensity of light so a small amount of light touches the retina.

  When light is dim, iris itself constricts to increase the diameter of pupil.

ACCOMMODATION OR FOCUSSING –

The ability to change the focal length of lens by changing the curvature of lens, is called **accommodation** power.

Only mammals and birds have this accommodation power in their eyes.

* This ability is very less in frog and it depends on the sliding of lens forward and backward to some extent.
* In normal condition muscle fibres of ciliary body remain relaxed and lens is stretched by its suspensory ligaments, and due to this lens is flat. A flat lens has more focal length. As a result of this eye can see long distant objects easily.
* To see near by objects, sphincter muscles of ciliary body contract and ciliary body becomes broad, suspensory ligaments becomes loose and relaxed. As a result of this relaxation of ligament lens becomes biconvex, and now its focal length is reduced. Now animal is able to see near by object easily.

TYPES OF VISION :-

(a) **Monocular vision or panoramic vision:-** Most of the vertebrates have their eyes situated on the lateral sides of head and due to this animal is capable to see large area of both the sides. It is called monocular vision.

e.g. rabbit, frog, horse (Most of the herbivorous animals have this type of vision)

(b) **Binocular vision:-** Most of the carnivorous mammals have eyes in front of their heads and side by side, so as to focus on one object by both the eyes. It is called binocular vision. e.g. Man, monkeys and apes.

(c) **Stereoscopic vision:-** It is three dimensional vision found in human.

(d) **Telescopic vision:-** This is found in birds.

* Largest eyeballs are found in horse.
* Sharpest vision is found in eagle.
* Shortest sight is found in monkey.

Chemical explanation of vision –

Cones and rods of eye are stimulated by light rays. It is a chemical event.

* A shiny visual purple pigment is found in rods of retina called Rhodopsin. It is formed by a protein **opsin** and a coloured pigment **Retinal**, just like haemoglobin of blood.
* **Opsin** is also called **scotopsin**.
* In bright light, rhodopsin is decomposed into opsin protein and retinal pigments. This chemical change is sight impulse. This sight impulse is carried by optic nerve to the brain, and animal is able to see.
* In dark, rods synthesize rhodopsin again with the help of opsin, retinal and enzyme.
* This is the reason that we can not see any thing, when we move to dark place from a enlighted place (for some time only) In the same way we are unable to see in light if we are coming from dark place because it will take time to synthesize or decompose the rhodopsin

It is called adaptation

* For resynthesis of rhodopsin, animal blinks its eyelids.
* Retinin is formed by vitamin A so deficiency of vit A causes night blindness.
* Cones able us to differentiate among colours and bright light. Cones have a pigment called Iodopsin in place of rhodopsin of rods. It is decomposed into **photopsin** and **retinal.**

There are three types of cones in retina:-

(a) Erythrolab - Red cones

(b) Chlorolab - Green cones

(c) Cynolab - Blue cones.

* We are able to acknowledge different colours due to these three types of cones and their combination.
* **Red, green** and **blue are the primary colours**.

Dimlight vision - Scotopic vision

Bright light vision - Photopic vision

* The eyes of some animals shine at night, because in the eyes of these animals, there is a pigment just outside the retina in the choroid layer of eyeball, which reflects the light rays coming from retina. This layer is called **Tapetum**. Due to this layer, these animals are capable to see in dark also.
* Kangaroo, hoofed mammals, elephants, whales etc. are having a silver shining layer of fibrous connective tissue called **Tapetum fibrosum**.
* In Elasmobranch fishes a reflecting colour pigment called **Guanine** is present in tapetum layer so it is called **tapetum lucidum**.
* Hunters and carnivorrus mammals like dogs, cats, tiger etc. have a layer in their retina called **tapetum cellulosum**.
* In the eyes of birds pecten is found.
* **Emmetropia:-** Normal vision of eyes is called emmetropia.

Some important defects of eye :-

1. Hypermatropia (far sightedness):-

* In this defect of eye, person is able to see objects placed at far distance but is unable to see objects close to him or her.
* This defect is due to small size of eyeball or flatness of lens. In this defect image is formed **behind the retina.** To cure this defect person should wear **convex** lenses in spectacles.
* Sometimes in old age this defect may occur due to reduction in the flexibility of lens or ciliary body, then it is known as **presbyopia**.

2. Myopia or Nearsightedness or short sightedness:-

* In this defect of eye, person is able to see objects near/ close to him or her but is unable to see objects placed at far distance.
* This is due to enlargement of eyeball or increased convexity of lens.
* In this defect image is formed before the retina because light rays coming from distant objects converge before retina.
* To overcome this defect person should wear concave lenses in spectacles.

3. **Astigmatism:-** In this defect curvature of cornea is changed as a result of that light rays do not focus on macula lutea but somewhere else, causing incomplete and blurred vision. This defect may be cured by cylindrical lenses.

4. **Night blindness:-** This is due to deficiency of vit A. In this disorder synthesis of Rhodopsin is reduced, as a result of this person is unable to see in dim light or night.

5. **Xerophthalmia:-** It is due to keratinisation of cunjunctiva and cornea, and conjuctiva becomes solid. It is also due to deficiency of vit A.

6. **Trach**oma:- In this defect of eye, a watery liquid oozes out from eyes in excess amount so eyes become red due to irritation. It is caused by a microbe Chlamydia trachomatis.

7. Strabismus:- It is due to loosening or contraction of the any of 6 skeletal muscles which give the proper position to the eye ball in its orbit. Thus eye ball inclines towards one side of orbit. It is strabismus or squint eyes.

   Particular muscle may be cured by operation and this defect is cured.

8. Cataract:- In this defect, lens becomes more solid, brown or more flat. It occurs in old age mostly. The lens becomes opaque, and reduces its power of accommodation. At this stage person can not see. A new lens is administered in place of defective lens by operation.

9. Glaucoma:- If the canal of schlemm is blocked in eyeball, aqueous humour can not return to veins again as a result pressure is increased in eye chambers and retina is damaged, and person becomes totally blind.

10. Photophobia:- In this defect proper image is not formed in bright light.

11. Colour blindness:- It is genetic disorder of X-chromosome. It is due to recessive gene. Colourblind persons can not differentiat in red and green colour.

EAR

SENSE ORGAN - EAR :

(B) Statoacoustic organ ear :- These are also called phonoreceptors.

* All the vertebrates have one pair of ears back to the eyes,

There are two main functions of ears :-

(1) To receive sound waves (hearing)

(2) To maintain body balance. Main function of ear is to maintain the balance of body.

Structurally ear may be divided into three parts:-

(a) External ear (b) Middle ear
(c) Internal ear

(a) External ear :-

It is the outer part of ear. It is well developed in mammals only. External ear may be divided again into 2 parts

(i) Ear pinna, (ii) Ear canal

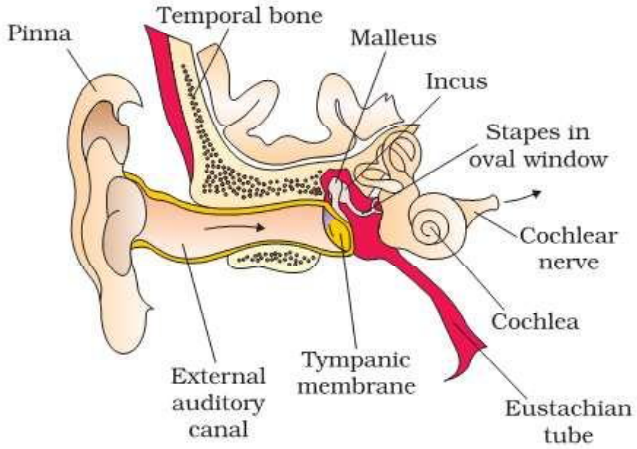
(i) Ear pinna :- These may be small or large, **fan like** structure, important feature of mammals, but absent in **whale, seal, *Ornithorhynchus*** etc. The skin of ear pinna is hairy. These are having yellow elastic cartilage. A rabbit can move its pinna according to its will, just like dog, cat, cow etc. but a man can not move his pinnae. Muscles of man's ear pinna are vestigeal. Pinna covers some of the ear canal, this part is called **choncha**.

(ii) Ear canal or External auditory meatus :- It is a 24 mm long canal which is expanded from base of pinna to inner side.

* Along with mammals, **birds** and **reptiles** also have ill or less developed ear canal.

* At the end of ear canal a stretched, thin, obliquely placed membrane is present, it is called **ear drum** or **tympanic membrane**. It separates the ear canal to middle ear.

* In the wall of external auditory meatus or ear canal there are found modified sweat glands called **ceruminous** glands. These secrete **cerumen** or ear wax, which moisten the ear drum and protects it.
* Ear drum remains always in stretched position because malleus ear ossicle/bone pulls it towards tympanic cavity by tensor tympani muscle.
* Ear drum is a part of middle ear.



Diagrammatic view of ear

(b) **Middle ear :-** Middle ear is also called tympanic cavity. It is filled with air. This cavity is covered by a flask like bone called tympanic bulla. This bone is a part of temporal bone of skull.

* Middle ear cavity is connected by pharyngeal cavity through a canal. It is called **Eustachian duct**.

  Due to this tube, pressure at both the side of tympanic membrane remains always equal. This duct maintain sound equilibrium. It expels high volume sounds through mouth, to avoid the damage of ear drum.
* Tympanic cavity is connected by internal ear cavity by two apertures

  (i) Oval aperture fenestra ovalis (oval window) and

  (ii) Spherical aperture fenestra rotundus (round window). A thin and firm membrane covers each aperture.
* Three ear ossicles are present and arranged in a chain with movable joints connected together in tympanic cavity. These ear ossicles are :-

(a) **Malleus :-** It is situated towards outer ear. It is the largest of three and of hammer shaped malleus is formed by the modification of articular bone of jaw.

* Inner broad part of malleus is connected by incus. Malleus and incus are Joint together by synovial hinge joint.

(b) **Incus :-** The ossicle is anvil shaped. It is formed by the modification of quadrate bone of jaw. Its outer broad part is connected by malleus and inner thin part is connected by **stapes.** Incus is joined by stapes by **ball and socket joint**.

(c) **Stapes :-** It looks like stirrup of horse. It is formed by the modification of hyomandibular **bone of jaw**.

* It is the smallest bone of body
* Stapes is connected to incus at one side and on the other side it is connected to membrane stretched over fenestra ovalis.
* [In the tympanic cavity of frog only one ear ossicle is found it is called **columella auris**. Malleus and incus are absent here.]

  All the three ear ossicles are arranged in ear cavity by ligaments. These carry sound wave from ear drum to internal ear through fenestra ovalis.

Internal ear :-

It consist of (1) Bony Labyrinth (2) Membranous Labyrinth.

* Internal ear is enclosed in the petrous part temporal bone which form a bony capsule out side the internal ear it is called bony labyrinth. It is the cavity of hearing apparatus.
* Internal ear is a complex structure made up of semi transparent membrane. It is called membranous labyrinth.
* Bony labyrinth and membranous labyrinth are connected by a cavity called perilymph cavity. Perilymph liquid is filled in it.

* Endolymph is filled in membranous labyrinth.
* There are two main bag like chambers in membranous labyrinth, **utriculus and sacculus.**

  Both these chambers are connected together by a thin canal called **sacculo - utricular duct**.
* A thin endolymphatic duct opens into sacculo - utricular duct. This endolymphatic duct opens into **endolymphatic sac** situated at back side of skull on the other side.

  Utriculus is comparatively large. Three semicircular canals arise from utriculus at 90^0 angle to each other and open into utriculus again. These are called

  (i) Anterior or superior semicircular canal

  (ii) Posterior semicircular canal

  (iii) External or lateral or horizontal semicircular canal.
* Anterior and posterior canals arise in the form of a single canal called "**Crus commune**"
* The distal end of each semicircular canal is some what swollen, called **Ampulla**.
* Sacculus is smaller than utriculus. Its back side is coiled like spring. It is called **cochlear canal**. It is also known as **lagena**.
* The length of cochlear canal of human, rabbit and whale are 2¾ , 2½ and 1½ coils respectively.
* Cochlear canal is connected by sacculus by a small duct called **ductus reuniens**.
* All the coils of cochlear canal are connected together by flexible ligaments.
* In the centre of coils of cochlea in human, there are present a pillar like structure called **modiolus**.

(D) Internal structure of inner ear:-

* The inner wall of membranous labyrinth is lined by cuboidal epithelium and outer wall is lined by connective tissue richly supplied with blood capillaries.
* Membranous labyrinth is empty inside. Its cavity is filled by endolymph which is a milky, mucilagenous fluid.
* Distal end of each semicircular canal becomes swollen called ampulla. In this ampulla, internal cuboidal epithelium forms a ridge like projection called **acoustic ridge** small immovable microvilli are found at the free edges of sensory cells of acoustic ridge. These microvilli are numerous in number. These are called stereocilia, along with these there are found single movable cilium called **kinocillium**. Otoconia are absent in crista of ampulla. All the microvilli of ridge are bind together like a bag and form **cupula**.
* One structure each is present in utriculus and one in sacculus, these are called **Maculae**. Numerous $CaCO_3$ particles are found in endolymph these are called **Otoconia.**
* These sensory cells situated in internal ear are in contact with small nerves. All these thin nerve combine to form **vestibular nerve (branch of auditory nerve)**.
* Sensory crista and maculae are related with equilibruim of body
* Cristae control and maintain body equilibruim at the time of movement and maculae regulate this at static position.

(E) Internal Structure of Cochlea & Cochlear canal Cochlear duct is connected by bony labyrinth in such a way that it divides the cavity of labyrinth into dorsal and ventral chambers. So in a transverse section of cochlea following three chambers are seen clearly.

(i) Scala vestibuli:- It is situated at dorsal side and is filled with perilymph.

(ii) Scala tympani:- It is situated at the ventral side below the cochlear duct. It is also filled by perilymph.

(iii) Scala media:- It is the triangular cavity of cochlear duct that is situated between scala vestibuli and scala tympani. It is filled with endolymph.

* Thin dorsal wall of cochlear duct is called vestibular membrane or Reissner's membrane.
* Ventral wall of scala media is thick called basilar membrane. Scala vestibuli and scala tympani are connected through a small aperture at the free edge of cochlea. This aperture is called **helicotrema**.
* Scala media is blind (closed) at its both the sides.

(F) **Organ of Corti:-** A sensory ridge is present at the whole length of central line at epithelium lining of basilar membrane of scala media. It is called organ of corti. It has two types of cells (i) Sensory cell (ii) Supporting or suspensory cell. Three type of suspensory cell (i) Cells of Dieter's or basal cells (ii) Pillar cells or rod cells (iii) Hensen's cells or rectangular cells.

* In between the empty spaces of sensory and suspensory cells a lymph like fluid cortilymph is filled. This space is called tunnel of corti.
* Numerous microvilli called stereocilia (sensory hair) are present at the free surface of each sensory cell.
* At the ventral surface of sensory cells there are thin fibres of auditory nerve present that form cochlear branch.
* At the organ of corti a thin jelly like membrane is inclined called tectorial membrane. In this membrane, all the sensory hair's free edges are embeded.
* Main credit of hearing goes to " Organ of corti".

(G) **Mechanism of Ear :-**

* Ears are stato- acoustic organs of body. Thus these help the body to hear and balancing the body.

(a) **Equilibrium:-** The first and basic function of ears is to maintain balance of body.

* This act is done by utriculus, sacculus and three semicircular canals. Equilibrium impulse/sensation is of two types:-

(i) **Static balancing:-** Its relation is from the point of view of gravity and position of head in static conditions of body and its changes.

* The senses of these changes (of head) are produced and carried mainly by utriculus, sacculus and their sensory cristae i.e. maculae.
* Sensory hair of ridge are sensitized by **otoconia or otolith or ear dust**. These sensations or impulses are carried to brain by auditory nerve After it messeges of appropriate reactions are send through motor fibres to the skeletal muscles of body.

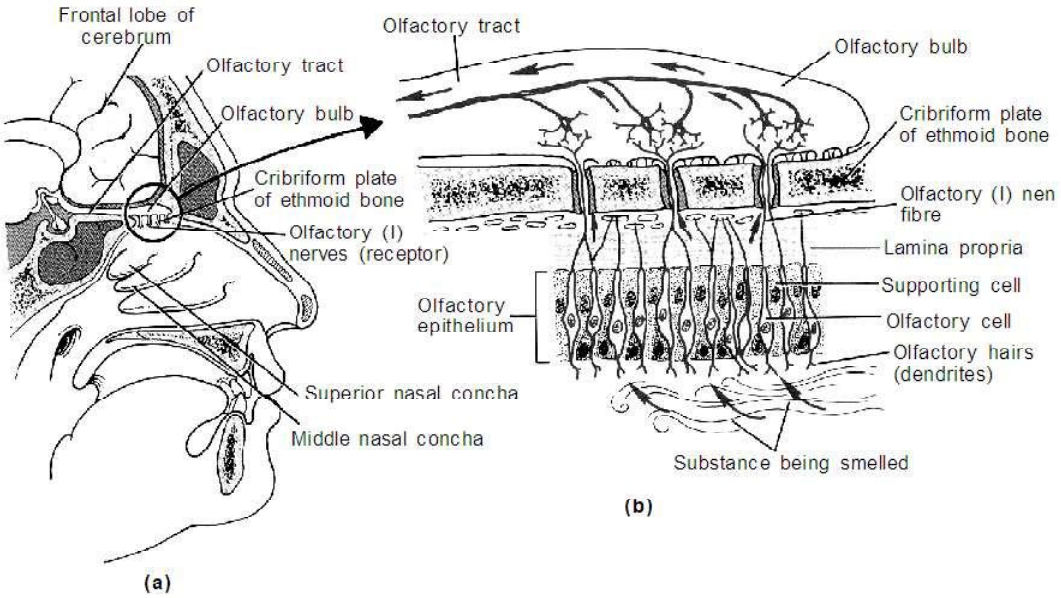
(ii) **Dynamic equilibrium:-**

* It is the action to maintain balance of body during movement.
* This act is done by sensory ridges of ampula of semicircular canals.
* At the time of movement the endolymph of ampula produces waves in it. Cupula of ampula are effected by these waves and sensory cells cupula are irritated. This sensation or stimulation is carried to brain by auditory nerve and proper messeges are send to muscle of legs in reply. Due to this body is balanced at the time of walking.

(b) **Hearing:-**

* This act is done by " Organ of Corti ".
* Sound waves are collected by ear pinnae. These sound waves travel through ear canal and hit the ear drum. As a result of it ear drum get vibrated.
* These vibrations reach up to stretched membrane of fenestra ovalis through ear ossicles. Ear ossicles work as lever.
* As a result of this travelling (from ear drum to fenestra ovalis) sound waves become more strong.
* When the membrane of fenestra ovalis starts vibrating, perilymph of scala vestibuli also starts vibrating, some vibrations reach up to scala tympani (fenestra rotundus) and its perilymph.
* Due to these vibrating waves, reissner membrane and basilar membrane of the walls of scala media also start vibrating. These vibrations travel through endolymph reach upto organ of corti. The organ of corti also starts vibrating.
* At this place, sensory hair of sensory cells (cells of organ of corti) hit by the tectoreal membrane. Now stimulation of hearing takes place.
* Cochlear nerve carries this impulse to brain through auditory nerve. Appropriate messeges are send to receptor organs by brain accordingly.
* Vibrations / waves produced by cochlea travel through perilymph, reach up to membrane stretched at fenestra Rotandus and are destroyed.
* Some sound waves are also destroyed, when coming from helicotrema.

NOSE



Olfactoreceptor :

– Olfactoreceptors are situated in the upper part of nasal chamber in olfactory epithelium.

– This membrane is called **as schnederian membrane.**

– Olfactoreceptors are related with olfactory bulb. It is the extension of limbic system.

– This bulb is situated below the frontal lobe of cerebral hemisphere and above the ethamoid bone of nasal chamber.

– Three types of cells are found in the olfactoreceptors. These are –

(i) Bipolar olfactory nerve cells

(ii) Columnar epithelial cells

(iii) Mucous glands

(1) **Bipolar olfactory nerve cells :** It is special types of nerve cells

– Sensory hair are found at the anterior end of olfactory cells. They contact with external environment in nasal chamber.

– Sensory hairs are related with dendrites of bipolar nerve cells.

– Middle part of olfactory cell is cyton.

– Posterior part of olfactory cell is axon which is nonmyleinated.

(2) **Columnar epithelial cells :** It is also called as supporting cells. They are present arounds the bipolar olfactory cells.

– They provides support to the olfactory cells.

– Some small conical cells are also found at the basal part of olfactoreceptor and provide base to the olfactoreceptor.

– A layer of connective tissue lies below the olfactoreceptor. It is also called as Lamina propria.

(3) **Mucous glands :** It is called as **Bowman's gland**. It is situated in the Lamina propria. It opens at the outer part of olfacto receptor through fine duct. Their secretory mucous substance dissolve the smell particle and carry to the sensory hair of olfactory cells. Nonmyleinated axons of all olfacto sensory cells makes the synapse with dendrites of multipolar neurone of olfactory bulb. The number of receptors stimulated indicates the strength of smell.

* In addition to smell receptor, a network of nerves is found in the nose, mouth and tongue.

The network formed by trigeminal nerve of V cranial nerve. It is also known as Dentist's nerve, reacts to messages of pain of teeth. It also convey the message of smell to brain. Such as ammonia, vinegar etc.

The trigeminal can protect by warning about harmful chemical in the air. Bowman's glands inside the nose release mucous fluid to get rid of the irritating susbtances. Loss of the sense of smell is known as **anosmia**. It occur due to congenital abnormalities of Olfactory bulbs or nerves.

TONGUE OR ORGAN OF TASTE

A thick, muscular and movable organ, the tongue is found in the mouth cavity. Tongue bears four types of small papillae which are located with taste buds. Taste buds are much numerous in the circumvallate and foliate papillae. Taste buds are formed by the transformation of epithelial cells of the tongue. A taste bud possesses two types of cells -

1. **Supporting Cells :** These cells are elongated in middle region. They do not bear sensory hairs at their free ends.
2. **Sensory cells :** These cells are elongated, buldge in middle part, they bear sensory hair at their free ends.

Each taste bud is flask or barrel shaped. It's upper part opens at the epithelial surface of the tongue through a fine pore. These sensory hairs, exposed to outside through the gustatory pore are stimulated by the food substances. The sensory cells are chemoreceptor in nature and taste the food while it is dissolved in saliva. Food substances get mixed with saliva to enter into the pores of taste buds (Fig.).

In human different regions of the tongue are sensitive to different taste. Anterior and free end of the tongue are sensitive to sweet and salty, lateral sides to soury taste, while the posterior part is particularly sensitive to bitter taste.

Types of receptors

- **General Senses** –

Touch	–	Tangoreceptors (Thigmoreceptor)
Temperature	–	Thermoreceptor
Heat	–	Caloreceptors
Cold	–	Frigidoreceptors
Pain	–	Algesireceptors
Current of water	–	Rheoreceptors
Electric current	–	Galvanoreceptors
Gravity	–	Georeceptors
Muscle position	–	Proprioreceptors
Equilibrium	–	Statoreceptors
Hunger, thirst etc.	–	Interoceptors
Blood pressure	–	Baroreceptors
Osmotic pressure	–	Osmoreceptors
Chemical changes	–	Chemoreceptors
Vibration	–	Vibroreceptors

- **Special Senses**

Vision	–	Photoreceptors
Hearing	–	Phonoreceptors
Smell	–	Olfactoreceptors
Taste	–	Gustatoreceptors

(1) Receptors of vision, hearing and smell receive stimuli from distance, hence called teloreceptors.

(2) Tangoreceptors or mechanoreceptors

(i) Merkel's disc (Corpuscles) : Epidermis of non hairy (glabrous) skin, hollow cup shaped disc.

(ii) Meissner's corpusle : Dermis of skin of the finger tip, lips and nipples. Sense of touch and gentle pressure.

(iii) Pacinian corpuscle : Present in subcutaneous tissue of palm, sole of finger etc. stimulated by strong pressure contact.

(iv) Corpuscle of golgi : Subcutaneous tissue of fingers.

(v) Corpuscle of mazzoni : Sub cutaneous tissue of fingers.

(vi) Grandy's corpuscles : Beak of birds.

(vii) Herbst corpuscles : Mouth part of birds.

(viii) Free never ending : Present in skin, perceive the sensation of touch.

(3) Thermoreceptors

(i) Ampullae of lorenzini : Scoliodon (Fishes)

(ii) Organ of ruffini : Caloreceptor - Heat

(iii) End bulb of krause : Fridoreceptor - cold

(4) Tactile receptors in mammals are maximum on face

(5) Current of water : Rheoreceptors lateral line sense organ in fishes and tadpole of amphibians detect the water current.