Lateral ventricles (Paracoels): Each cerebral hemisphere has a cavity inside it, known as **lateral ventricle**. There are two lateral ventricles numbered as first and second ventricles. The two lateral ventricles are connected with each other by an **interventricular foramen** known as the **foramen of Monro**.

Third ventricle (Mesocoel): It is the ventricle of the diencephalon. The lateral ventricles communicate with third ventricle through the foramen of Monro.

Fourth ventricle (Metacoel): It is the ventricle of pons, medulla and cerebellum. It is present dorsal to the pons and medulla and ventral to the cerebellum. The ventricular communication between the third ventricle and fourth ventricle is known as **cerebral aqueduct** or **aqueduct of Sylvius** or **iter**.

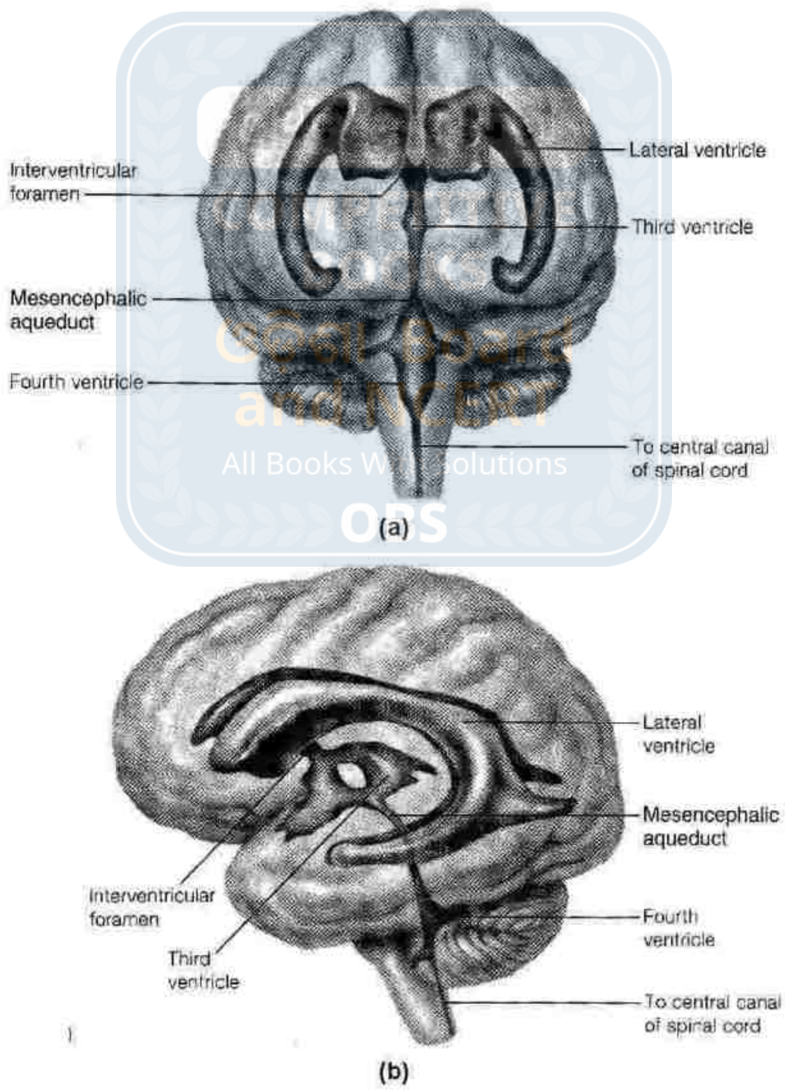


Fig. 20.10 : (a) Longitudinal frontal section of the brain and (b) Longitudinal sagittal section showing ventricles

TABLE - 20.1
FUNCTIONS OF THE BRAIN

I. Cerebral Hemispheres (Cerebrum) :

1. Frontal Lobes
   - (i) Voluntary motor control of skeletal muscle.
   - (ii) Higher intellectual processes, such as thinking, planning and decision-making and verbal communication.
2. Parietal Lobes
   - (i) Somatesthetic (cutaneous and muscular) sensations.
   - (ii) Word formation for the expression of thoughts and emotions.
3. Temporal Lobes
   - (i) Interpretation of auditory sensations.
   - (ii) Storage of auditory and visual experiences.
4. Occipital Lobes
   - (i) Coordination of eye movements.
   - (ii) Correlation of visual images with previous visual experiences and other stimuli.
5. Insula
   - (i) Memory encoding.
   - (ii) Integration of sensory information (e.g., pain) with visceral responses.

II. Diencephalon :

1. Thalamus
   - (i) Relay centre for sensory pathways to the cerebral cortex except smell.
   - (ii) Skeletal muscle coordination.
2. Hypothalamus
   - (i) Regulates anterior pituitary gland.
   - (ii) Regulates eating and drinking behaviour.
   - (iii) Regulates reproductive behaviour, such as sexual arousal and performance.
   - (iv) Regulates sleep and wakefulness.
   - (v) Generation and regulation of circadian rythm.
   - (vi) Regulates body temperature.
   - (vii) Participates in the generation of emotional behaviour, like anger, fear, pain and pleasure.

III. Brain Stem :

1. Midbrain
   - (i) Involved in visual reflexes.
   - (ii) Act as relay centre for auditory information.
2. Pons
   - (i) Acts as relay centre for the somatic and motor fiber tracts between the brain and the spina cord.
   - (ii) Regulates respiratory functions in coordination with medulla oblongata.
3. Medulla oblongata
   - (i) Acts as a relay centre for somatic and motor fiber tracts between the brain and spinal cord.
   - (ii) Regulates breathing and cardio-vascular functions.

IV. Limbic System :

- (i) Participates in the generation of emotional behaviour.
- (ii) Plays an important role in different kinds of learning.

TABLE - 20.2

THE CRANIAL NERVES

Name		Fibers	Comments
I.	Olfactory nerve	Afferent	Tract of brain; not true nerve. Carries input from receptors in olfactory (smell) epithelium.
II.	Optic nerve	Afferent	Tract of brain; not true nerve. Carries input from receptors in eye.
III.	Oculomotor nerve	Efferent	Innervates skeletal muscles that move eyeball up, dlown, and medially and raise upper eyelid; innervates smooth muscles that constrict pupil and alter lens shape for near and far vision.
		Afferent	Transmits information from receptors in muscles.
IV.	Trochlear nerve	Efferent	Innervates skeletal muscles that move eyeball downward and laterally.
		Afferent	Transmits information from receptors in muscle.
V.	Trigeminal nerve	Efferent	Innervates skeletal chewing muscles.
		Afferent	Transmits information from receptors in skin; skeletal muscles of face, nose, and mouth; and teeth sockets.
VI.	Abducens nerve	Efferent	Innervates skeletal muscles that move eyeball laterally.
		Afferent	Transmits information from receptors in muscle.
VII.	Facial nerve	Efferent	Innervates skeletal muscles of facial expression and swallowing; innervates nose, palate, and lacrimal and salivary glands.
		Afferent	Transmits information from taste buds in front of tongue and mouth.
VIII.	Vestibulocochlear nerve	Afferent	Transmits information from receptors in ear.
IX.	Glossopharyngeal nerve	Efferent	Innervates skeletal muscles involved in swallowing and parotid salivary gland.
		Afferent	Transmits information from taste buds at back of tongue and receptors in auditory-tube skin.
X.	Vagus nerve	Efferent	Innervates skeletal muscles of pharynx and larynx and smooth muscle and glands of thorax and abdomen.
		Afferent	Transmits information from receptors in thorax and abdomen.
XI.	Accessory nerve	Efferent	Innervates neck skeletal muscles.
XII.	Hypoglossal nerve	Efferent	Innervates tongue skeletal muscles.

20.2.1.3. Spinal Cord : The brain lodged in the cranial cavity continues as the spinal cord behind. The last division of the brain, the medulla leaves the cranial cavity through **foramen magnum** of the occipital bone of the skull as the spinal cord. The spinal cord is secured in the neural canal of the vertebral column. Like that of the brain, the spinal cord is surrounded by three protective layers, namely dura mater, arachnoid mater and pia mater from outer to inner. The space between the arachnoid mater and pia mater (sub-arachnoid space) is filled with CSF. The cord extends from the foramen magnum to the disk between the first lumbar and second lumbar vertebra. There are two continuous longitudinal depressions, one each along the middorsal and midventral sides of the cord. These are known as **dorsal** and **ventral fissures**, respectively. The cone shaped terminal part of the cord is known as **conus medullaris**. A fine connective tissue filament, known as **filum terminale** is attached to the conus medullaris. There is a bunch of spinal nerves at the posterior end of the spinal cord. This bunch is known as **cauda equina**, that looks like a horse tail.

Unlike the brain, in which the grey matter forms a cortex over white matter, grey matter in the spinal cord is central, surrounded by white matter. The grey matter is in the shape of the English alphabet "H" with two **dorsal** and two **ventral horns (Fig. 20.11)**. The white matter contains ascending (sensory) and descending (motor) myelinated fiber tracts. These tracts are

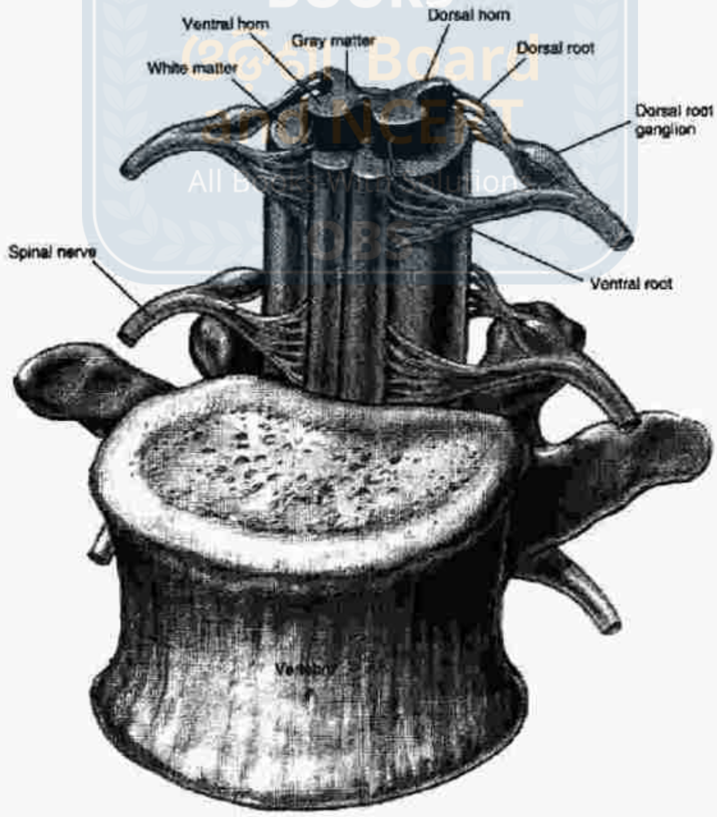


Fig. 20.11 : Structural organization of the spinal cord

arranged into six columns, known as **funiculi**. The names of the ascending tracts begin with the prefix spino- and end with the region of the brain, where it ends. Conversely, the names of descending tracts begin with the prefix denoting the brain region, where it begins and end with the suffix -spinal.

Groups of sensory (afferent) fibers from the peripheral nerves enter the spinal cord on the dorsal side via the dorsal roots. A swelling on each dorsal root, the **dorsal root ganglion** contains the cell bodies of the sensory or afferent neurons. The motor (efferent) fibers leave the spinal cord on the ventral side via the ventral roots. Some distance from the spinal cord, the two roots join to form a **spinal nerve** on each side.

20.2.2. Peripherial Nervous System (PNS) :

The PNS consists of the nerves arising from the brain **(cranial nerves)** and the nerves arising from the spinal cord **(spinal nerves)**. There are **12 pairs of cranial nerves** and **31 pairs of spinal nerves** in human. The summary of the cranial nerves and the type of signals transmitted by each is presented in the following table. The nerve fibers of all these nerves transmit signals between the CNS and all other parts of the body. It is to be noted that all the nerve fibers of the PNS are myelinated. A complete communication cycle involves an input from a peripheral parts by sensory (afferent) pathway followed by and appropriate output to the peripheral part in question by a motor (efferent) pathway. Therefore, the PNS is conveniently studied under two divisions: the **sensory (afferent) division** and the **motor (efferent) division (Fig. 20.12).**

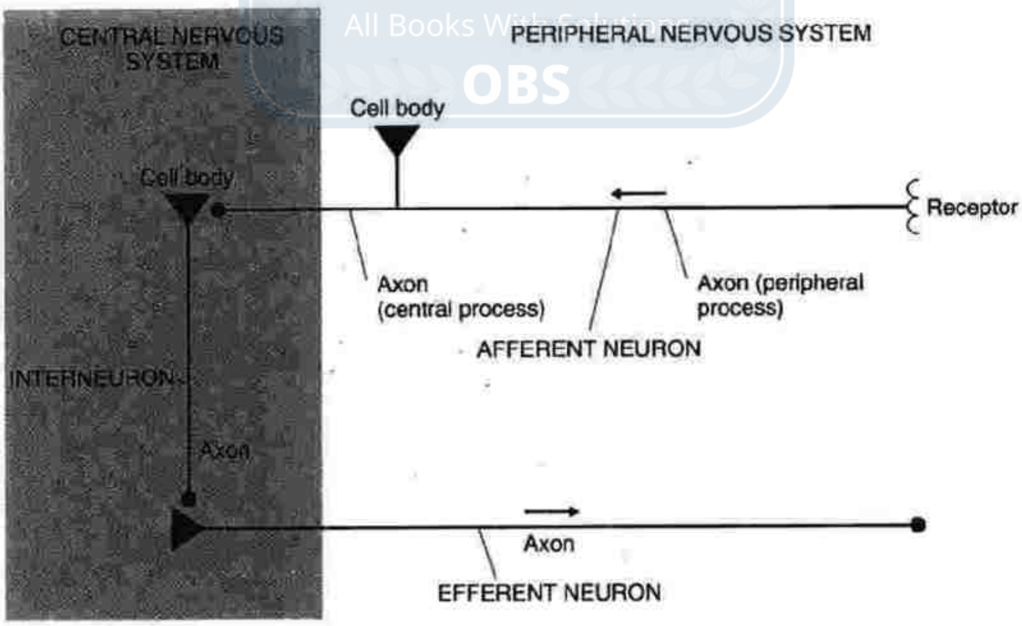


Fig. 20.12 : Sensory or afferent division of the PNS with a sensory neuron connecting the receptor with the CNS uninterrupted.

20.2.2.1. Sensory (Afferent) Division: As noted earlier, the sensory nerves convey information from the peripheral parts to the CNS. Such nerves consist of nerve fibers, which are classed as pseudounipolar neurons and whose cell bodies lie in the dorsal root ganglia outside the CNS. In fact, such a neuron has a very long axon divided into two parts: a peripheral part and a central part. The peripheral part makes its beginning at the receptor, travels a long distance uninterrupted and then terminates in a synapse with the dendrites in the CNS as a central part.

20.2.2.2. Motor (Efferent) Division: The motor (efferent) division of the PNS is more complicated than the sensory. It is divided into **somatic** and **autonomic nervous systems (Fig. 20.13)**. The neurons of the somatic system innervate the skeletal muscle, while the autonomic neurons innervate the smooth muscle, cardiac muscle, glands and neurons in the gastrointestinal tract.

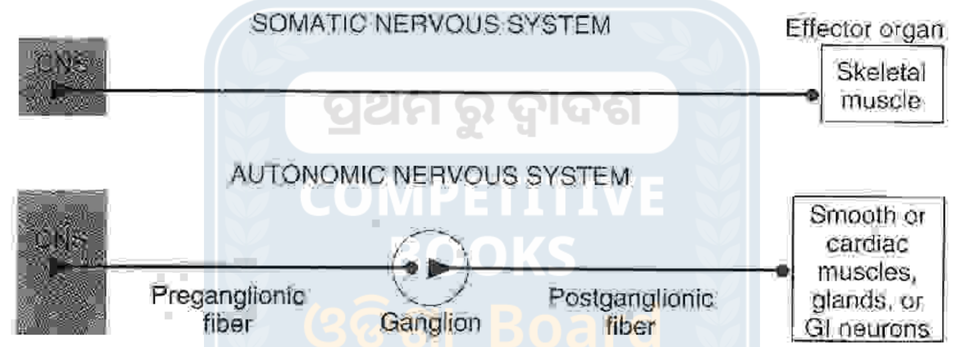


Fig. 20.13 : Motor division of the PNS. (a) Somatic nervous system, (b) Autonomic nervous system.

(a) Somatic Nervous System: It consists of all nerve fibers of the CNS innervating skeletal muscle. The cell bodies of these neurons are located in the brain stem or spinal cord. The myelinated nerve fibers leave the CNS and innervate skeletal muscle uninterrupted i.e. without a synapse. The neurotransmitters released by such neurons is acetylcholine.

Autonomic Nervous System: In this system, the innervation of the effector tissues and organs occur by two neurons and one synapse. The first neuron has its cell body in the CNS. The synapse is in an autonomic ganglion outside the CNS.The fiber preceding the synapse is known as **pre-ganglionic**, while the one succedes the synapse is known as **post-ganglionic**. Autonomic nervous system is subdivided into **sympathetic** and **parasympathetic** divisions.

The sympathetic division consists of sympathetic fibers that leave the CNS from the thoracic and lumbar regions of the spinal cord and therefore, this division is also termed as **thoraco-lumbar division**. Most of the sympathetic ganglia lie close to the spinal cord and form two **chains of ganglia**, known as **sympathetic trunks (Figs. 20.14 and 20.15)**. Other sympathetic ganglia called **collateral ganglia**, such as **celiac**, **superior mesenteric** and **inferior mesenteric ganglia** lie closer to the innervated organs. There are **22 sympathetic ganglia in**

each trunk. The parasympathetic fibers leave the CNS from the sacral region of the spinal cord and hence known as **cranio-sacral division**. In contrast to the sympathetic ganglia, the parasympathetic ganglia lie within the innervarted organs by the post-ganglionic neurons. Acetylcholine is secreted as the neurotransmitter between pre- and post-ganglionic fibers in both the sympathetic and parasympathetic divisions. In the parasympathetic division, the major neurotransmitter between the post-ganglionic fiber and the effector organ or tissue is also acetylcholine. However, in the sympathetic division, the major neurotransmitter between the post-ganglionic fiber and the effector is nor-epinephrine.

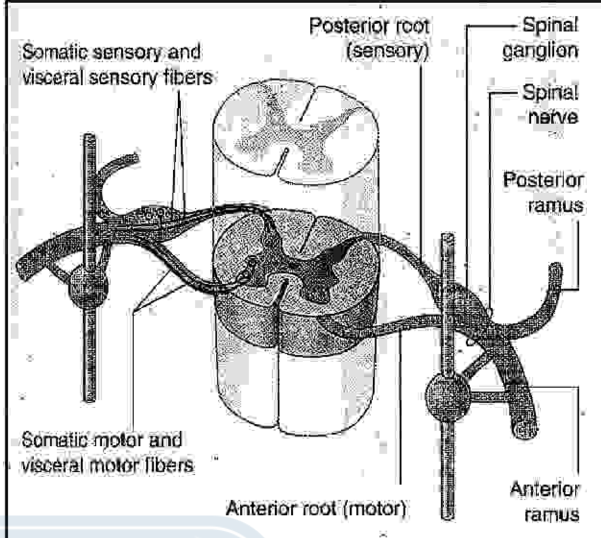


Fig. 20.14 : A sympathetic or spinal ganglion of the sympathetic trunk and its relationship with the spinal cord.

Autonomic responses occur without conscious control or awareness and therefore, this part of the nervous sytem has also been termed as **involuntary nervous system**.

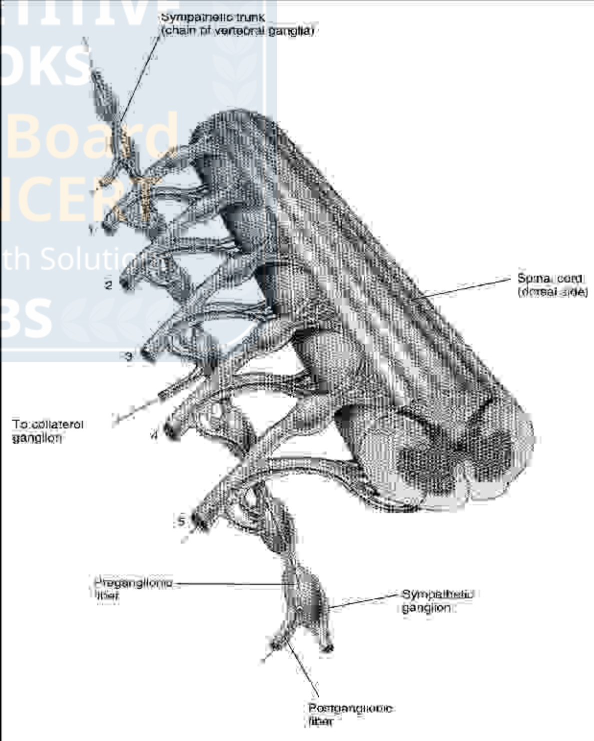


Fig. 20.15 : A part of the sympathetic trunk (chain of sympathetic ganglia) of the side and its relationship with the spinal cord.

20.3. REFLEX ACTION :

The functions of the sensory and motor divisions of the PNS is explained by considering **reflex action**. It is an unconscious motor response to a sensory stimulus. When a sensory receptor is stimulated by an appropriate stimulus, action potential is generated in the membrane of the sensory nerve fiber (neuron), which propagates to the spinal cord as an impulse. The axon or fiber of this neuron passes through the **dorsal root** of the spinal nerve. The cell body of this neuron is situated in a swollen part of the dorsal root known as the **dorsal root ganglion**. The neuron then synapses with the dendrites of another neuron called **interneuron** or **association neuron** or **integrator neuron** in the grey mater. The axon of the interneuron synapses with the dendrites of another neuron called **motor neuron** also in the grey matter of the spinal cord. The motor neuron sends a fiber through the **ventral root**, which innervates an effector (skeletal muscle or other effector tissues or organs). The brain is not directly involved in this response. Thus the impulse travels from the receptor to the effector describing a complete path and this path is known as a **reflex arc**. There are two fundamental types of relex action: **somatic motor** reflex and **autonomic (visceral) motor reflex (Fig. 20.16).**

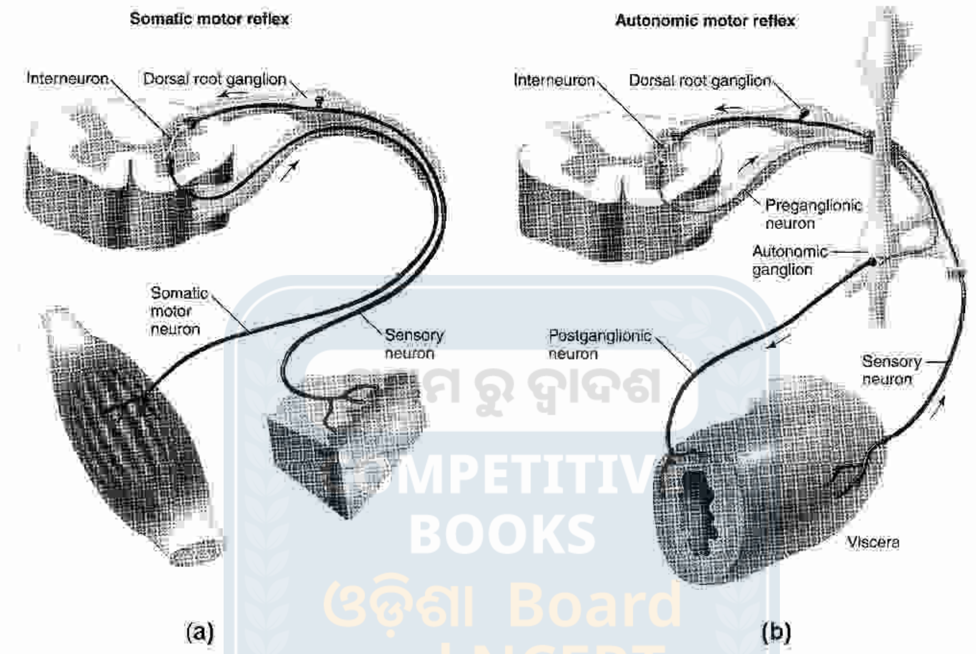


Fig. 20.16 : Two types of reflex action (explained in the text).
(a) Somatic motor reflex and (b) Autonomic (visceral) motor reflex.

In somatic motor reflex, a somatic motor neuron conducts the impulse along a single axon from the spinal cord to the neuromuscular junction of a skeletal muscle (effector) [Fig. 20.16 (a)]. On the contrary, the autonomic motor control is executerd by two neurons, of which The first neuron, known as the pre-ganglionic which has its cell body in the grey matter of the brain or spinal cord. The axon synapses with another neuron, the post-ganglionic in a ganglion called **sympathetic (autonomic) ganglion**. The post-ganglionic neuron synapses with the target effector tissue or organ (cardiac muscle, smooth muscle and glands) [Fig. 20.16 (b)].

20.4. CONDUCTION OF NERVE IMPULSE :

It has been indicated in the preceding discussion that the conduction of nerve impulse is **partly electrical** and **partly chemical**. When it is along an axon, it is carried by an electrical phenomenon, but when it is carried from one neuron to the next across a functional junction (synapse), it is by a chemical phenomenon. Before we take up with the origin of an electrical signal in the axon membrane, let's understand about the distribution of ions (electrical charges) in both the intra- and extra-cellular aqueous environments of the neuron.

Positively charged and negative charged ions are distributed unequally between these two aqueous environments of almost all cells including the neurons. The plasma membrane stands as a selectively permeable barrier between the two environments. Ions can't crossover from one side to the other freely. However, a class of ions is only allowed to crossover at an appropriate time. This unequal distribution of ions between two sides of the plasma membrane creates a potential difference across the membrane, which is termed as **membrane potential** (electric ptential of the membrance). The unit of electric potential is volt (V) and since this potential in living system is very small, it is expressed in millivolt (mV).

20.4.1. Resting membrane potential :

All cells, at rest, maintain a potential difference across the plasma membrane, in which the inner side is negatively charged in comparison to the outer side. This potential is the resting membrane potential. Neurons maintain this potential at –70mV. Na^+ is more highly concentrated in the extracellular fluid than in the inner side, whereas K^+ is more highly concentrated on the inner side. The inner side of the membrane is negatively charged relative to the outer side.

Although all cells maintain a membrane potential, only a few have the property of altering the resting membrane potential at a small section of the membrane in response to a stimulus. Such alterations occur by changing the membrane permeability to specific ions such as Na^+ and K^+. These ions crossover down their gradient (downhill) through ion channels of the membrane. (However, during their crossingover against the gradient (uphill), ion specific enzymes and ATP are required.) The altered potential propagates along the axon of the neuron. This property has been termed as **excitability**. It is a unique property of neurons and muscle cells. The altered membrane potential has been termed as **action potential (AP)**. The propagation of the nerve impulse or in a better sense the action potential is unidirectional and occurs along the axon away from the cell body i.e. towards a synapse. The origin and propagation of action potential takes place in three steps: (1) **depolarization**; (2) **repolarization**; and (3) **reorientation**.

20.4.2. Depolarization [Fig. 20.17 (a)] :

As mentioned earlier that in a resting neuron membrane the Na^+ concentration is more on the outer side than on the inner side with the inner side having more negative charges. The membrane potential is measured at –70 mV. When the membrane is stimulated, the sodium ion channels open allowing Na^+ to crossover down its gradient. No metabolic energy of ATP is spent. Na^+ concentration on the inner side builds up and the negative charges decrease. Conversely, the Na^+ concentration on the outer side decreases and the positive charges decrease. This influx of Na^+ continues till the membrane potential is increased to +30. The electrical charges across the membrane at the site of stimulation is reversed transiently resulting in the formation of an action potential. This reversal of the membrane potential by the influx of Na^+ is known as **depolarization**.

20.4.3. Repolarization [Fig. 20.17 (b)] :

Following depolarization, there is an efflux of K^+ (outward movement) through potassium ion channels down its gradient and hence metabolic energy of ATP is not spent. The K^+ concentration builds up on the outer side of the neuron membrane decreasing the negative charges. Conversely, there is a decrease in the K^+ concentration in the intracellular environment resulting in a build up of negative charges. This process continues till the membrane potential again becomes –70 mV. This restoration of the membrane potential to a resting potential state by the efflux of K^+ is known as **repolarization**.

20.4.4. Reorientation [Fig. 20.17 (c)]:

Following repolarization, the membrane potential is restored at resting potential state i.e, at –70 mV. The ionic distribution is reversed relative to that in the resting membrane i.e. there is more Na^+ and K^+ in the intra and extracellular environments, respectively. The normal orientation is achieved by a process known as reorientation. The Na and K^+ exchange their places. However, this time, the flow of ions is against their concentration gradients. For this work, metabolic energy is spent. A membrane bound $Na^+ – K^+$ ATPase pump does the work at the expense of metabolic energy. At the end of the reorientation process, the normal polarity in respect of ionic distribution is reached with the membrane potential at – 70 mV.

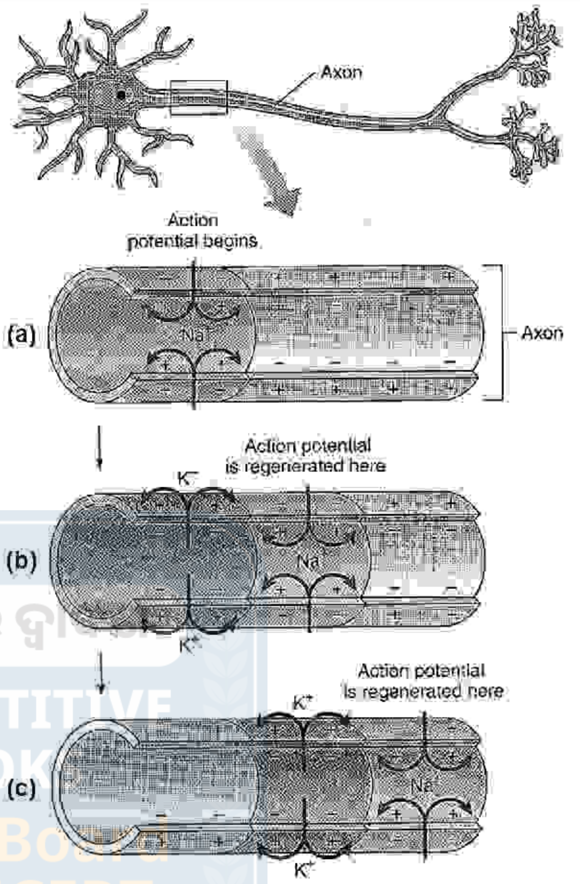


Fig. 20.17 : Three steps in the conduction of nerve impulse along a unmyelinated nerve fiber. (a) Depolarization, (b) Repolarization and (c) Reorientation

20.4.5. Types of Conduction :

We have learnt that there are two types of nerve fibers, namely myelinated and unmyelinated, based on the presence or absence of myelin sheaths. In accordance with this, two types of conductions have been explained.

20.4.5.1. Conduction along unmyelinated fiber: In unmyelinated nerve fibers, the axons are unsheathed or naked without myelin sheaths. An action potential is generated in the membrane at the site of stimulation. The membrane undergoes depolarization by a rapid influx of Na^+. This is followed by repolarization by an efflux of K^+. Concomitant with the repolarization of this part of the membrane, the adjoining forward part of the membrane is depolarized. Like this there is a wave of depolarization and repolarization in a forward direction in an electrifying speed. This is explained as the propagation of action potential and hence nerve impulse (Fig. 20.17).

20.4.5.2. Conduction along myelinated fiber: In myelinated nerve fiber, the axons are discontinuously sheathed by myelin sheaths at regular intervals. This leaves unsheathed nodes called **nodes of Ranvier**. Depolarization and repolarization of the axon membrane takes place only at these nodes. When the membrane at a node is depolarized and then repolarized, the adjoining node id depolarized. Thus the action potential moves from node to node. This type of conduction is known as **jumping** or **saltatory conduction (Fig. 20.18)**.

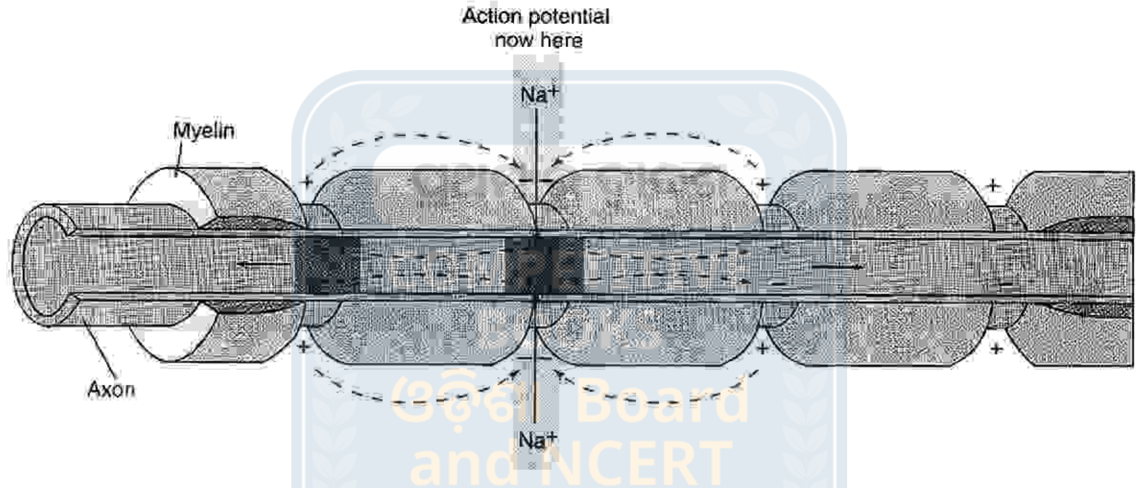


Fig. 20.18 : Saltatory conduction of nerve impulse along a myelinated nerve fiber.

20.4.6. Synaptic Transmission :

The nerve impulse in one fiber travels in one direction i.e. from the cell body along the axon to the axon terminal. The axon terminal forms a junction or synapse with the denrite of the next neuron. On reaching the axon terminal, the impulse is transmitted to the next neuron through the synapse. This transmission is known as **synaptic transmission.**

We have mentioned about two types of synapses such as electrical and chemical in the preceding section and we have also discussed that at the chemical synapse, the electrical potential (action potential) of the presynaptic neuron changes into a chemical signal. The chemical signal is known as a neurotransmitter, which is synthesized and stored in the synaptic vesicles of the presynaptic axon terminal. On getting a depolarization stimulus, the vesicles release the neurotransmitter into the synaptic cleft. Following its release, the following events take place in the membrane of the postsynaptic neuron.

1. An excitatory neurotransmitter, following its release, binds to the receptors on the postsynaptic membrane. This binding brings about a depolarization of the membrane.

2. The depolarization causes the opening of voltage regulated ion channels of the membrane.
3. Opening of ion channels facilitates the influx and outflux of ions. This produces an action potential in the postsynaptic membrane.
4. The depolarization stimulus of one region serves as a stimulus for the next region and the consequence is the propagation of the action potential in a forward direction. The propagation of the action potential is what we know as conduction of nerve impulse.

Classes of Neurotransmitters:

1. Acetylcholine
2. Biogenic amines: [Epinephrine, Norepinephrine, Dopamine, Serotonin and Histamin]
3. Aminoacids: [Aspartate, Glutamate, Glycine and Gamma aminobutyric acid (GABA)]
4. Neuropeptides: [Endorphins, Dynorphins and Enkephalins]
5. Gases: Nitric oxide (NO) and Carbon monoxide (CO)

20.5. SENSE ORGANS AND PERCEPTION :

The perception of the world through touch, taste, smell, hearing and vision is made through sensory receptors contained in sense organs. These organs change different forms of energy into nerve impulses, which are conducted to the CNS by sensory neurons. The brain then interprets these impulses into perceptions. The perceptions enable the individual to understand the environment around and allow interacting with the environment in an effective manner. There are five receptors, we need to discuss about. These are:

1. **Sense of touch (Cutaneous Sensation)**
2. **Sense of taste (Gustation)**
3. **Sense of smell (Olfaction)**
4. **Sense of equilibrium and balancing and hearing**
5. **Sense of vision**

20.5.1. Sense of touch (Cutaneous Sensation) (Fig. 20.19) :

The skin serves as the receptor of touch, pressure, temperature (heat and cold) and pain. Sensations to these stimuli are mediated by dendritic nerve endings of several neurons. The receptors for heat, cold and pain are the naked endings of sensory neurons. Sensations of touch are mediated by naked dendritic endings surrounding hair follicles and expanded dendritic endings called **Ruffini endings** and **Merkel's discs**. The sensations of touch and pressure are mediated by encapsulated dendrites forming **Meissner's corpuscles** and **pacinian corpuscles**. The receptors for cold are located in the upper part of dermis, while warm receptors are located in the deeper part of the dermis. **Nociceptors (receptors of pain)** are free sensory nerve endings of myelinated or unmyelinated fibers.

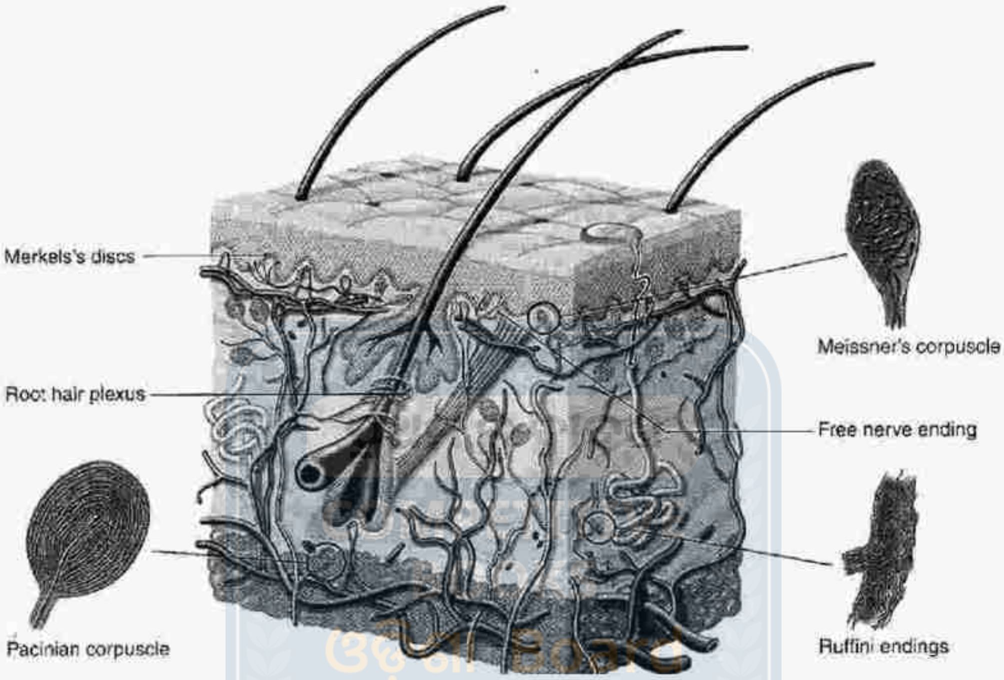


Fig 20.19 : Three dimensional longitudinal section of skin showing the receptors mediating the sense of touch.

20.5.2. Sense of Taste (Gustation) :

The sense of taste or gustation is perceived by barrel shaped **taste buds (Fig. 20.20)**, present on the dorsal side of the tongue. A taste bud consists of 50 to 100 specialized epithelial cells with long microvilli that extend through the pore to the external environment. The microvilli are in contact with saliva. Although these cells are not neurons, they behave as neurons when they are stimulated. They undergo depolarization and release neurotransmitter, which stimulates sensory neurons associated with the bud. The specialized epithelial

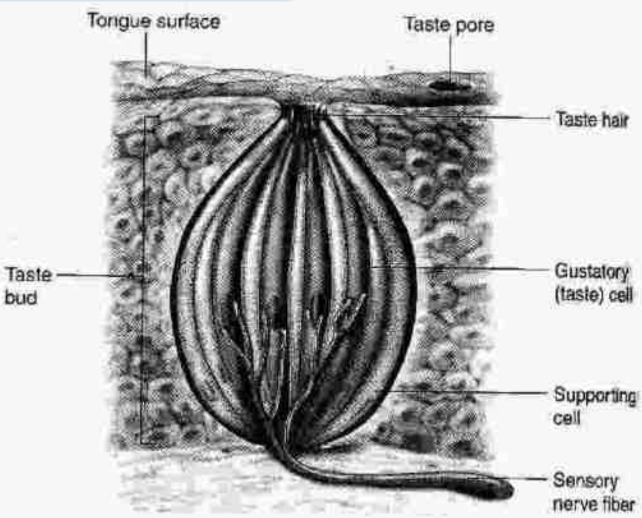


Fig. 20.20 : A taste bud with taste cells and sensory nerve fiber.

cells of the bud are known as **taste cells**. It was long believed that different regions of the tongue were specialized for different tastes, namely salty, sour, sweet and bitter. However, it is now established that each taste bud contains **taste cells** responding to each of the different tastes.

20.5.3. Sense of Smell (Olfaction) :

The receptors for the sense of smell are located in the olfactory epithelium, the internal lining of the olfactory apparatus (nasal canal). The olfactory apparatus consists of **receptor cells (bipolar neuron), supporting (sustentacular) cells and basal (stem) cells (Fig. 20.21)**. The basal cells regenerate new receptor cells to replenish the lost cells. The supporting cells are epithelial cells rich in enzymes that oxidize the hydrophobic (lipid soluble) odorants and make these molecules less lipid soluble thereby preventing their entry into the brain.

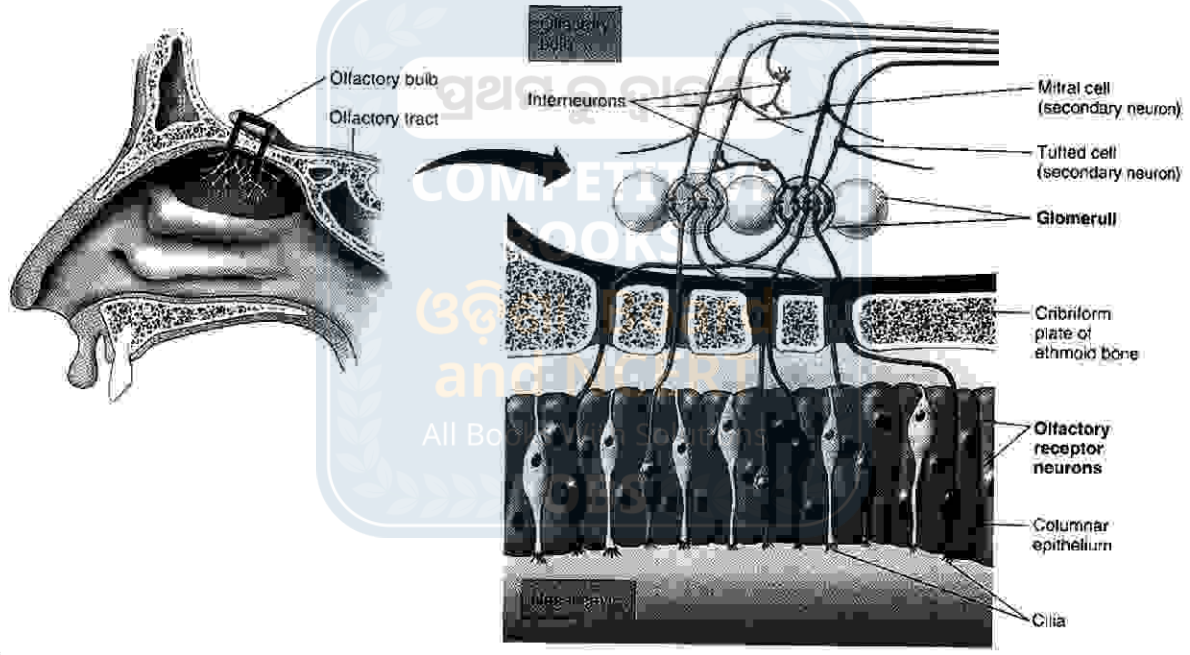


Fig 20.21: Receptors for the sense of smell (olfaction)

A receptor cell is a bipolar neuron, which has one dendrite, that projects into the nasal cavity. It terminates as a knob bearing cilia. The sensory cilia project into the nasal cavity. There is a single unmyelinated axon, which projects into the olfactory bulb through pores in the **cribriform plate of the ethmoid bone**. The axon of the receptor cell synapses with dendrites of neurons of the olfactory bulb, known as second-order neurons. The neurons of the olfactory bulb are arranged spherically forming characteristic structures known as **glomeruli**. The axons of these neurons move as a tract into the cerebral cortex, associated with hippocampus and amygdala. Unlike other sensory information, which are relayed to the cerebrum via the thalamus, olfactory information are relayed directly to the cerebrum.

20.5.4. Vestibular Apparatus and Equilibrium :

Equilibrium or orientation with respect to gravity is controlled by the **vestibular apparatus**. The apparatus consists of two parts: **an otolith constituted by utricle and saccule and three semicircular canals (Fig. 20.22)**. The sensory structure of the vestibular apparatus and cochlea (concerned with hearing) are situated within a **membranous labyrinth**, filled with a fluid, the **endolymph**. The membranous labyrinth is situated in a bony cavity of the skull, known as the **bony labyrinth**. There is a fluid called **perilymph** between the membranous labyrinth and bony labyrinth. Perilymph is similar in composition to the cerebrospinal fluid. Utricle, saccule and the crista ampullarus of the semicircular canals, contain recepter cell.

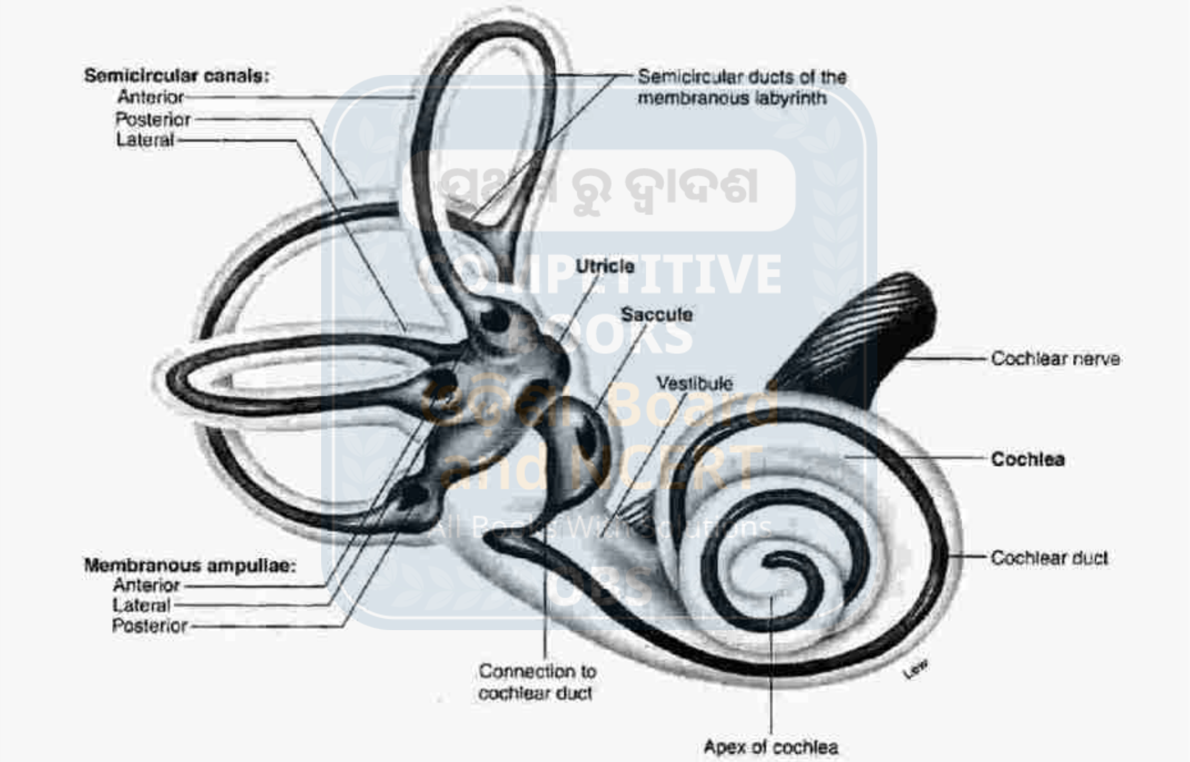


Fig 20.22 : Structure of the membranous labyrinth.

The receptors for equilibrium are modified epithelial cells, known as **hair cells** because of the presence of 20 – 50 hair like processes in each. All but one of these processes are **stereocilia** i.e. each has a protein filament surrounded by plasma membrane. The larger process is a true cilium, known as the **kinocilium [Fig. 20.23 (a)]**. When stereocilia are bent in the direction of the kinocilium, the plasma membrane is depressed and becomes depolarized **[Fig. 20.23 (b)]**. This causes the release of a neurotransmitter by the hair cells. The neurotransmitter stimulates the dendrites of sensory neurons that form a part of the vestibulo-cochlear nerve (VIII). When the stereocilia are bent in an opposite direction, the membrane is hyperpolarized and such cells release another neurotransmitter **[Fig. 20.23 (c)]**. This substance stimulates the sensory neurons of the same nerve in a different manner. Thus the hair cells are stimulated and transmit the body balance information to the CNS via the **vestibulo-cochlear nerve**.

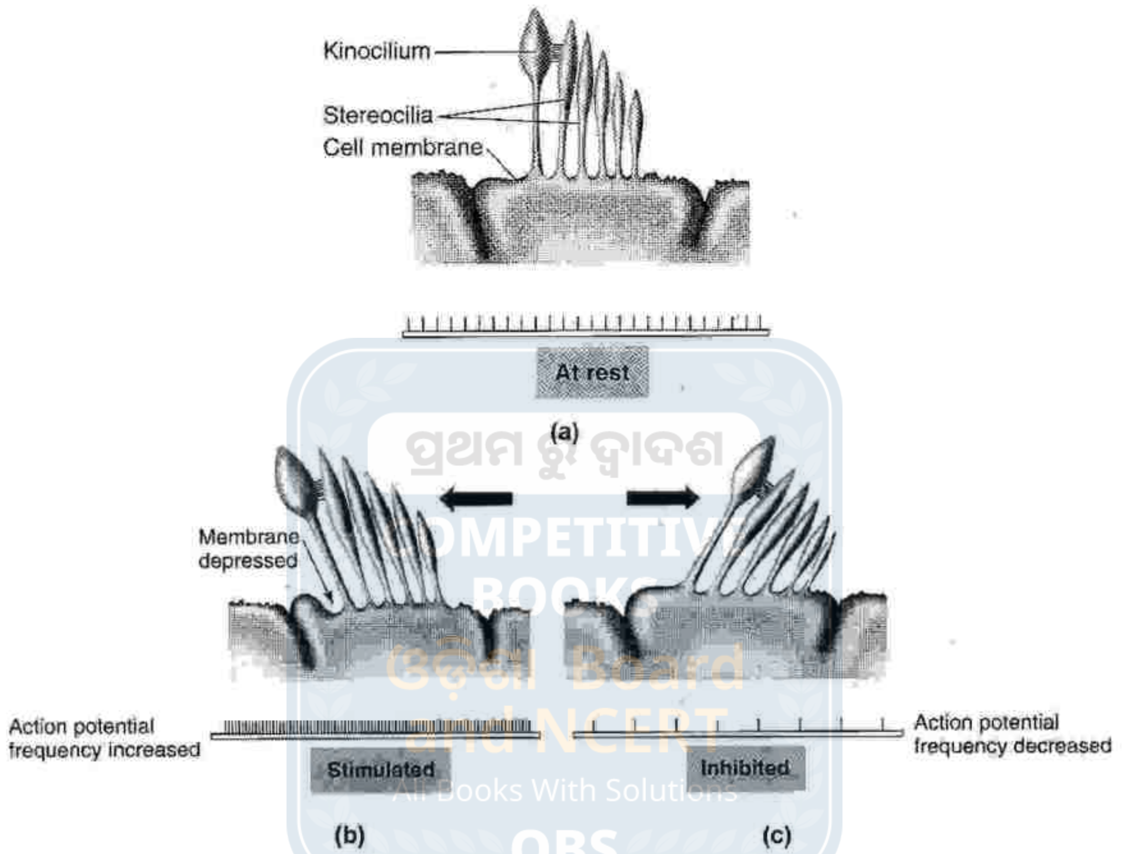


Fig. 20.23 : Hair (receptor) cells of the vestibular apparatus and their modes of action. (a) stereocilia and kinocilium at rest; (b) the receptor cell is stimulated and the innervating nerve is depolarized, (c) the receptor cell is inhibited and the nerve is hyperpolarized.

20.5.4.1. Utricle and Saccule: The utricle and saccule, each have a stretch of specialized epithelium, known as **macula**. The macula consists of **hair cells** and **supporting cells**. The hair cells project into the endolymph with the hairs embedded in a gelatinous membrane, known as **otolithic membrane**. The membrane contains micro-crystals of calcium carbonate. **The utricle regulates horizontal acceleration, while the saccule, vertical acceleration because of the differential orientations of the hairy processes into the otolithic membrane.** During forward acceleration, the otolithic membrane is drawn behind, pushing the hairs behind. Similarly, when there is a sudden brake on the acceleration, the hairs move forward. Likewise, when an aircraft takes off the ground, the hairs are pressed against the otolithic membrane and when a person descends in an elevator, the opposite effects take place. In every situation, there is a changed pattern in the action potential in the sensory nerve so as to maintain an equilibrium with respect to gravity. Thus utricle and saccule regulate linear accelerations i.e. changes in velocity in both horizontal and vertical planes (Fig. 20.24).

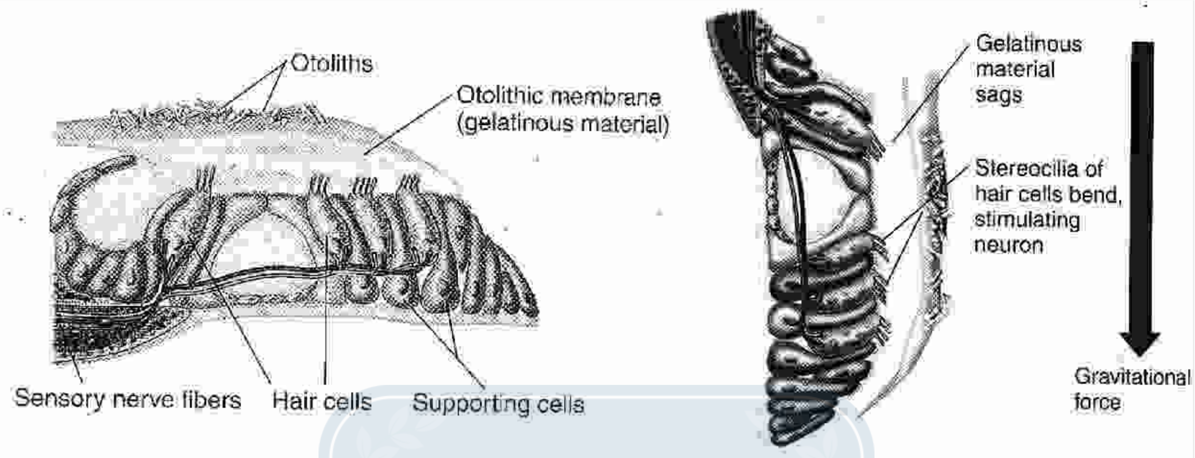


Fig. 20.24 : The structure and actions of the otolith organ
(a) the head is in an upright position, (b) the head is tilted forward.

20.5.4.2. Semicircular Canals: There are three semicircular canals projecting in three different planes at nearly right angle to each other. Each canal has a narrow projected part called the semicircular duct. At the base of each duct, there is a swelling called an **ampulla**. The sensory hair cells are situated in an elevated part of the ampulla called **crista ampullaris**. The hair processes of these cells are embeded in a gelatinous membrane known as the **cupula**. Cupula is denser than the endolymph. It works like the sail of a boat, which can be pushed in one direction or the other by the streaming endolymph. The endolymph functions analogous to that of the otolithic membrane. As the head rotates to the right, the endolymph makes the cupula to bend towards left, thereby stimulating the hair cells (Fig. 20.25). Somersaulting stimulates the hair cells of the anterior semicircular canal, while performing a cartwheel stimulates those of the posterior semicircular canal. The hair cells of the lateral semicircular canal are stimulated when one spins around a long axis of the body.

- **Nystagmus and Vertigo:**

  When someone is spinning, the eye muscles move opposite to the direction of the spin so as to fix the eye on one point. These involuntary oscillations of the eyes is known as vestibular nystagmus. When the spin is abruptly stopped, the muscles of the eyes still keep moving in an opposite direction. The person feels that every other thing around is spinning. This loss of equilibrium is known as vertigo.

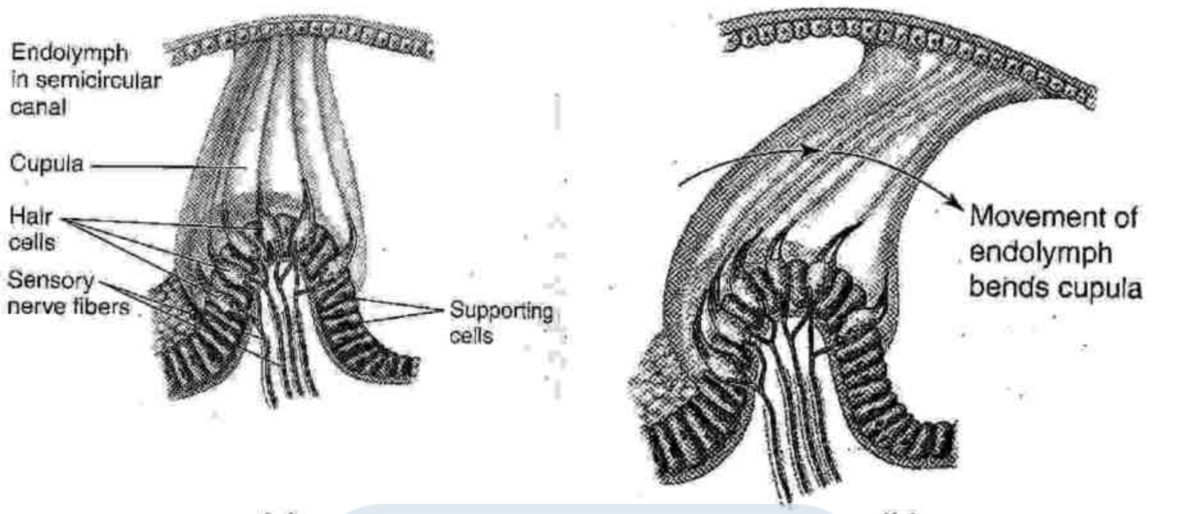


Fig. 20.23 : The structure and actions of cupula, (a) the head is in a forward direction, (b) the head is turned laterally.

20.5.5. Sense of hearing :

There is a pair of ears as the organs of hearing. Each ear is divided into three divisions, namely; 1. External ear, 2. Middle ear and 3. Internal ear (Fig. 20.26).

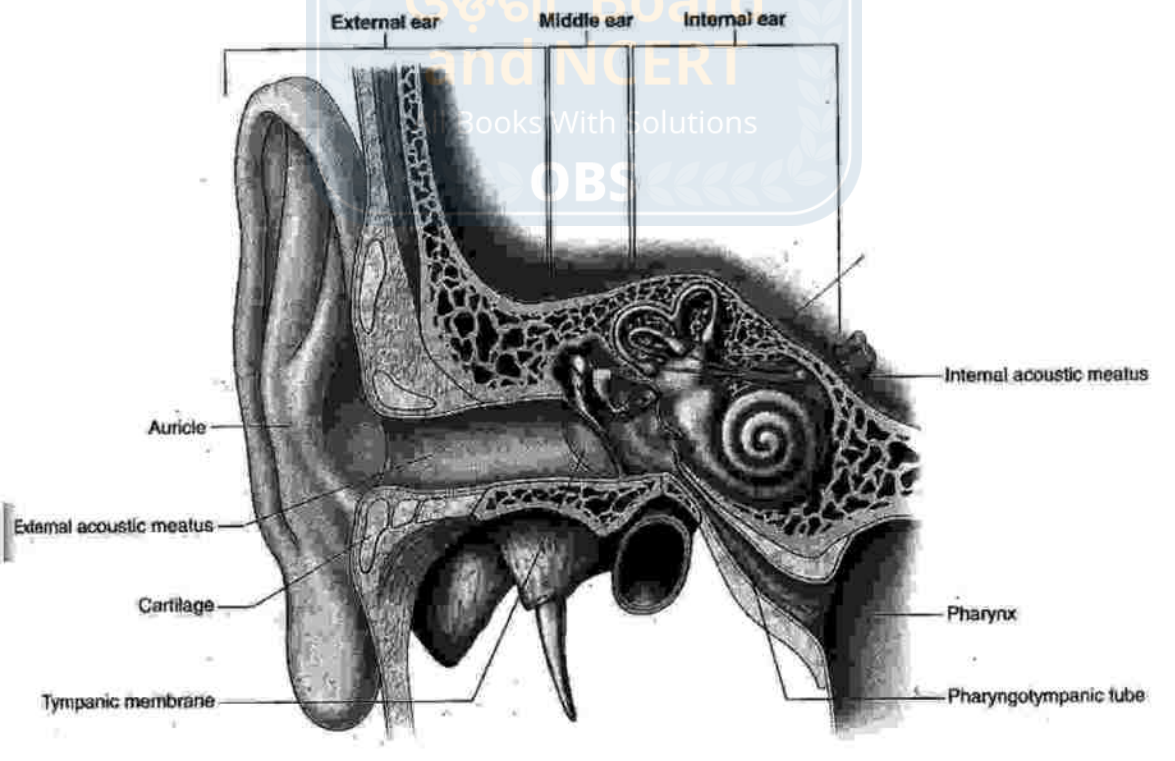


Fig. 20.26 : Gross structure of human ear.

20.5.5.1. External ear : The external ear consists of two parts: the **pinna** or **auricle** and the **external auditory canal** or **external auditory meatus (Fig. 20.26)**. The pinna is a funnel like external extension from the base of the ear cavity, supported by muscle and elastic cartilages. The pinna stands as a funnel, which traps the sound waves and transmits these into the middle ear through the external auditory meatus.

Fig. 20.27 : Middle ear and its relationships with the external and internal ears.

20.5.5.2. Middle ear : The middle ear is that part of the ear, which is between the **tympanic membrane (ear drum)** on the outer side and the **cochlea** on the inner side. The tympanic membrane separates the external auditory meatus from the middle ear cavity, an air filled cavity in the temporal bone of the skull. There are three bony **ear ossicles**, namely **malleus (hammer), incus (anvil)** and **stapes (stirrup)** in this cavity (Fig. 20.27). The malleus is attached to the tympanic membrane so that vibrations of this membrane are perceived by the malleus, which then transmits these to the stapes via the incus. The stapes, in turn is attached to a membrane of the cochlea, the **oval window**. The vibrations of the tympanic membrane are transmitted to the oval window through these three bones instead of just one explains about the protection of the nerve from damage in the event of high intensity sound. If the sound is too intense, the ossicles may buckle. The protection is increased by the **stapedius muscle**, which attaches to the neck of the stapes. High intensity sound stimulates this muscle to contract so that the stapes moves and detaches from the oval window. The middle ear communicates with the nasopharynx through a tubular duct, known as the **eustachian tube** or **auditory tube**. The tube helps maintain an equilibrium in the air pressure between the middle ear and nasopharynx.

20.5.5.3. Internal ear : The internal ear is constituted by the vestibular apparatus and cochlea. Both the structures lie in a dense bony capsule of the temporal bone of the skull, known as bony labyrinth. The vestibular apparatus is concerned with the act of equilibrium and balancing of the body, while the cochlea with hearing (Fig. 20.22). The part of the internal ear (membranous labyrinth) is already described in the maintenance of body balance and equilibrium.

20.5.5.4. Cochlea (Fig. 20.28) : The cochlea is about the size of a pea and is shaped like the spiral of a snail having three turns: apical, middle and basal. The cochlea is almost divided lengthwise into three fluid filled compartments by a fluid filled membranous tube, the **cochleatr duct**. Other two compartments are: **scala vestibuli** and **scala tympani**, the cochlear

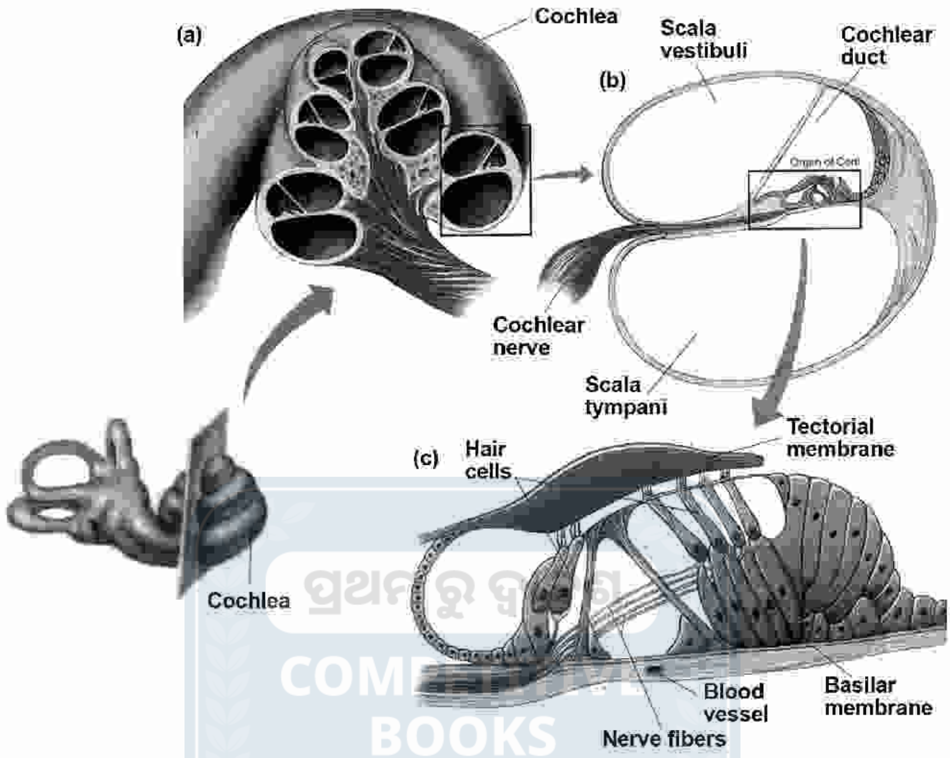


Fig. 20.28 : Cross section of the cochlea showing the sensory structure, the organ of Corti.

duct being one. Scala vestibuli is on the side of the cochlear duct and ends at the oval window, while scala tympani is below the cochlear duct and ends in a membrane covered **round window**. Both these compartments meet at the **helicotrema**. The cochlear duct is a continuation of the membranous labyrinth and hence contains endolymph, while scala vestibuli and scala tympani are filled with perilymph.

One side of the cochlear duct is formed by the **basilar membrane** to which is attached an **organ of Corti** or **spiral organ**. The organ of Corti is made up of single row of receptor cells, called the inner hair cells on the basilar membrane. In addition, there are multiple rows of outer hair cells. These cells have stereocilia projecting into the endolymph. The stereocilia of the outer hair cells are embedded in a gelatinous **tectorial membrane**.

20.5.5.5. Mechanism of hearing (Fig. 20.29): Sound waves of different intensities strike the tympanic membrane and create a vibration in it. Such vibrations are transmitted to the ear ossicles, present in the middle ear. Stapes, the third among the three is in contact with a membrane called the oval window. The vibrations are transferred to the perilymph of scala vestibuli. The pressure is then passed on to the perilymph of scala tympani through the helicotrema. The pressure in the perilymph causes the basilar membrane to vibrate. The consequence is the stimulation of the sensory hair cells, which rest on the basilar membrane. On stimulation, the hair cells release a transmitter substance, which brings about the depolarization of the nerve fiber membrane constituting the vestbulo-cochlear nerve (cranial

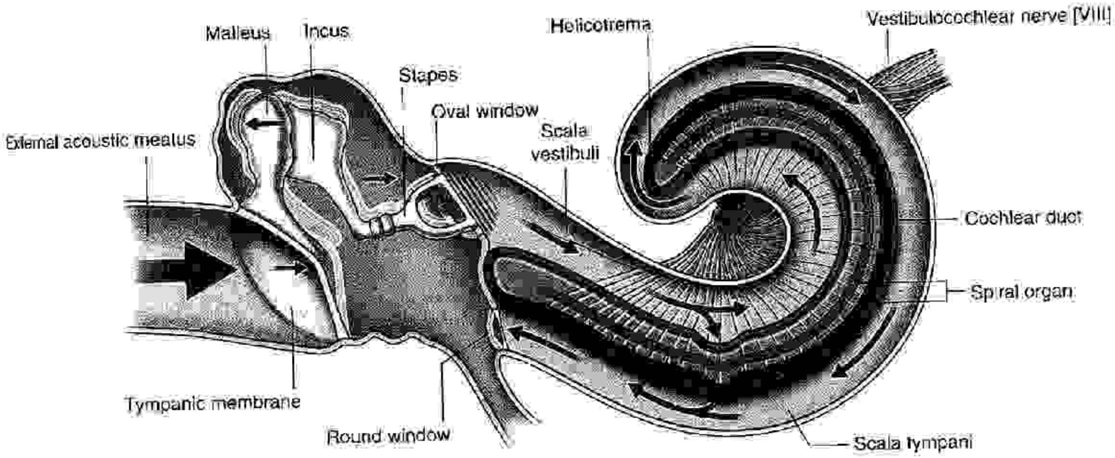


Fig. 20.29 : Mechanism of sound wave perception.

nerve VIII). The hair cells thus transform the pressure waves into receptor potentials.

20.5.6. Sense of Vision :

There is a pair of eyes in human as the organs of vision. The eyes trnasduce electromagnetic waves of light into nerve impulses, which is perceived and interpreted by the brain as an image of an object. Each eye is spherically shaped and is situated in a groove of the frontal region of the skull, known as **orbit**. The eye is held in position by flexible **eye ball muscles**.

20.5.6.1. Structure (Fig. 20.30): The eye ball is covered by an outer layer of fibrous tunic, known as **sclera**. Sclera is avascular (without blood supply) connective tissue, which gives a spherical shape to the eye ball. At the anterior face, the sclera is transparent through which rays of light enter into the eye. This transparent part of the sclera is known as **cornea**. The middle layer is a highly vascular pigmented connective tissue, known as **choroid**. It supplies blood to the eye ball. The choroid separates off from the sclera at the anterior face, where it bears the name of **iris**. The iris has a circular aperture at its centre, known as **pupil**. The iris contains both longitudinal and radial muscles. Both muscles have opposing actions. The contraction of the longitudinal muscles dilates the pupil, while the contraction of the radial muscles constricts the pupil. This act is executed in response to the intensities of light entering into the eye. The posterior part of the iris is pigmented that gives the eye its characteristic colour.

- **Glaucoma :**

  The aqueous humor is secreted by a vascular tissue of the body. It is drained into the venous system via the canal of Schlem. However, in some instances, the aqueous humor is formed faster than it is removed. If this situation prevails, the intra-ocular pressure exerted by the fluid increases creating a condition what is known as glaucoma. This may damage the nerve fibers of the eye and and may result in complete loss of vision.

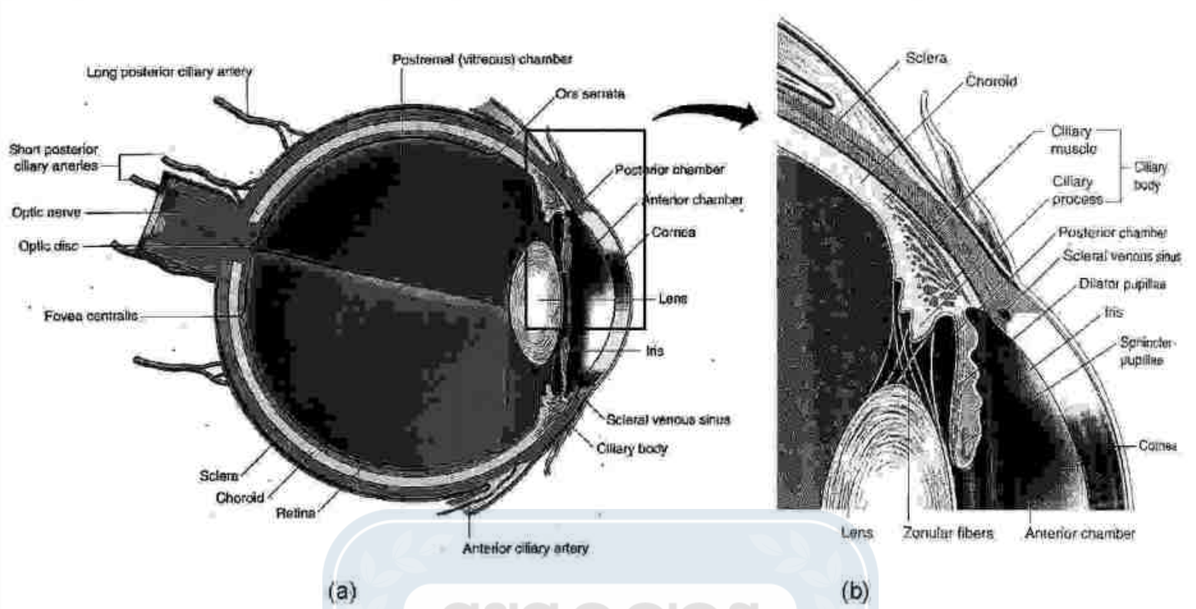


Fig. 20.30 : Structure of human eye. (a) entire eye in two dimension and (b) a part of it (enclosed in the box) is magnified.

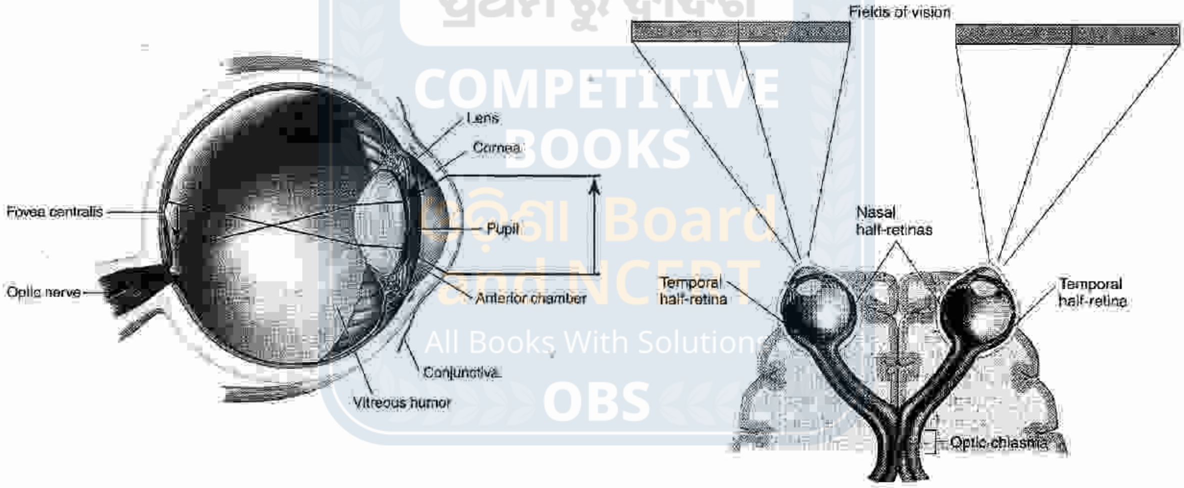
A biconvex lens is suspended from a muscular process called **ciliary body**, which connects the choroid and encircles the entire lens. **Zonular fibers** suspend the lens from the ciliary body. The zonular fibers together constitute the **suspensory ligament**. The space between the cornea and the iris is known as the **anterior chamber**, while the space between the iris and the ciliary body is the **posterior chamber**. Both the chambers are filled with a fluid known as **aqueous humor**. This fluid is secreted by a vascular tissue of the ciliary body and passes through the pupil into the anterior chamber. It nourishes the avascular lens and cornea. Aqueous humor is drained into a venous sinus known as **canal of Schlemm**, from where it returns to the venous blood. The chamber behind the lens is known as the **vitreous chamber** filled with a thick and viscous fluid, known as **vitreous humor**.

The vitreous chamber is lined by a sensory layer, known as **retina**. The retina contains two types of photoreceptor cells or neurons, the **rods** and **cones** in a single layer. Rods, which distinguish between intensities of light, contain a purple pigment called **rhodopsin**. Cones perceive and distinguish different colours. Human is **trichromatic** i.e there are three types of cone cells in the human retina, which perceive red, blue and green colours. Outer to this layer, there are two other layers of neurons, an inner layer of **bipolar neurons** and an outer layer of **ganglion cells**. The adjacent layers are connected by synapses. The fibers of the ganglion cells gather together at a point called the **optic disc**, where they exit the retina as the **optic nerve**. This region lacks the photoreceptors and hence is known as the **blind spot**. The optic disc is also the site of entry and exit of blood vessels. Another area of the retina is known as **fovea centralis** or **yellow spot**, where cones are most concentrated. The image is formed on fovea centralis, which gives clarity to vision.

- **Cataract:**

  The eye lens changes its colour with age. The opacity increases and the vision is gradually impaired. This condition is known as cataract. The opaque lens is removed surgically and an artificial lens is implanted. Effective vision is restored although the power of accommodation is lost.

20.5.6.2. Image Formation (Fig. 20.31) : An image of an object is formed on the retina by obeying the fundamental principles of light refraction. The curvatures of the cornea and the lens are such that an inverted image of an object is formed on the retina. Secondly, the visual field i.e. the object that is projected on the retina is reversed in each eye. The cornea and lens focus the right part of the visual field on the left half of the retina of each eye and conversely, the left haft of the visual field is focused on the right half of the retina of each eye. This is because of the crossing over of the optic nerves and formation of an **optic chiasma**, an X shaped structure.



(a) (b)

Fig. 20.31 : Image formation in the eye. (a) inverted image formation and (b) right to left image switching on the retina.

- **Accommodation and Loss of Accommodation (Presbyopia):**

  The ability of the eyes to focus the image on the retina with the variation of the distance of the object from the cornea is known as accommodation. Accommodation is accompanied by the contraction and relaxation of two types of ciliary muscles. Accommodation ability is measured by a near point of vision test. The near point of vision is the minimum distance from the eyes from which the image of an object can be focused on the retina. This distance increases with age. Almost everyone over the age of 45 yrs is significantly affected. The loss of accommodation ability with age has been defined as presbyopia.

- **Impairments in normal vision:**

  As long as the eyes are able to accommodate with the distance from the object, there is normal vision. Normal vision is termed as *emmetropia*. However, this property of accommodation is decreased with age and the eye ball changes its shape permanently due to some reason or other, the image can't be focused on the retina. Instead, the focus point is either in front or behind the eye ball. In such cases, the vision becomes impaired or abnormal. Two types of abnormal visions are classed: *hyperopia* (farsightedness) and *myopia* (nearsightedness). Secondly, if the curvatures of the cornea and the lens are uneven, an impairment known as *astigmatism* results.

- **Red Green Colourblindness:**

  It is a recessive sexlinked disorder, in which either L (red) or M (green) cones are absent in the retina. These people are dichromates, since their retina has two types of functional cones. The absence of functional M cones, a condition called deuteranopia is the most common form of colourblindness. The absence of L cones (protanopia) is less common and the absence S (blue) cones (tritanopia) is least common. Photopsins, cone pigments are encoded by genes present on the X chromosome. Since men have one X cheomosome, red-green colourblindness is far more common in males (incidence of 8%) than in womwn (incidence of 0.5%).

SAMPLE QUESTIONS

GROUP - A

(Objective-type Questions)

1. Choose the correct answer:

(i) The myelin sheath around a nerve fiber in the peripheral nervous system is form by:

(a) Oligodendrocytes (b) Microglial cells

(c) Schwann cells (d) Astrocytes

(ii) The somatic sensory neuron conducts nerve impulse:

(a) From a somatic receptor to the central nervous system.

(b) From central nervous system to the skeletal muscle.

(c) From the central nervous system to the smooth muscle and or glands.

(d) From a visceral receptor to the central nervous system.

(iii) The cerebrospinal fluid is present:

(a) In the subdural space only

(b) In the subarachnoid space only

(c) In the ventricles and central canal only.

(d) Both (b) and (c)

(e) Both (a) and (b)

(iv) The brain stem consists of :

(a) Diencephalon, midbrain and pons

(b) Diencephalon, midbrain and medulla oblongata

(c) Midbrain, cerebellum and medulla oblongata

(d) Midbrain, pons and medulla oblongata.

(v) Emotional states are regulated by:

(a) Corpora quadrigemina (b) Limbic system

(c) Basal nuclei (d) Corpus callosum

(vi) Hypothalamus is a part of:

(a) Telencephalon (b) Metencephalon

(c) Diencephalon (d) Mesencephalon

(vii) Memory is regulated by:

(a) Hypothalamus (b) Hippocampus only

(c) Amygdala only (d) Both (b) and (c)

(viii) The superior colliculi of corpora quadrigemina are involved in:

(a) Auditory reflexes (b) Visual reflexes

(c) Releasing pituitary hormones (d) Relaying of cutaneous information

(ix) In most people, the right side of the hemisphere controls the movements of:

(a) The right side of the body primarily

(b) The left side of the body primarily

(c) Both the right and left sides of the body equally
(d) Head and neck only

(x) In control of emotion and motivation, the limbic system works together with:
(a) Pons (b) Thalamus
(c) Hypothalamus (d) Cerebellum

(xi) Lateral geniculate nuclei relay:
(a) Auditory information (b) Olfactory information
(c) Visual information (d) Gustatory information

(xii) Temperature regulation of the body is done by:
(a) Thalamus (b) Cerebellum
(c) Hypothalamus (d) Medulla oblongata

(xiii) Respiratory and cardiovascular functions are controlled by:
(a) Medulla oblongata (b) Cerebellum
(c) Diencephalon (d) Telencephalon

(xiv) Autonomic nervous system consists of nerves with:
(a) One neuron with one synapse
(b) Two neurons with two synapses
(c) One neuron with two synapses
(d) Two neurons with one synapse

(xv) Parasympathetic ganglia are located
(a) in a chain parallel to the spinal cord
(b) In the dorsal roots of the spinal nerves
(c) Next to or within the organs innervated
(d) In the brain

(xvi) The neurotransmitter of preganglionic sympathetic fiber is
(a) Norepinephrine (b) Epinephrine
(c) Acetylcholine (d) Dopamine

(xvii) Depolarization is characterized by:
(a) Influx of sodium ions. (b) Efflux of potassium ions
(c) Influx of potassium ions (d) Efflux of sodium ions

(xviii) Gustation is related to
(a) Sense of smell (b) Sense of taste
(c) Sense of vision (d) Sense of hearing

(xix) Balance and equilibrium of the body is maintained by
(a) Semicircular canals only (b) Saccule only
(c) Utricle only (d) All the above

(xx) The retina consists of
(a) Unipolar neurons (b) Bipolar neurons
(c) Multipolsr neurons (d) Pseudounipolar neurons

2. **Express the following statements in one word:**

(i) The singular long process of a multipolar neuron.

(ii) The functional junction between two neurons.

(iii) The nervous system constituted by cranial and spinal nerves.

(iv) The cell that forms myelin sheaths around nerve fibers of the peripheral nervous system.

(v) The neuron possessing one each of an axon and a dendron.

(vi) The nerve fiber that carries neural information from the central nervous system to the receptors.

(vii) A collective name for the connective tissue coverings of the brain and spinal cord.

(viii) The fluid that is present in the subarachnoid space, ventricles and central canal.

(ix) Metencephalon and myelencephalon together constitute a part of the brain.

(x) Midbrain, pons and medulla oblongata together constitute a part of the brain.

(xi) The fiber tract connecting the two cerebral hemispheres.

(xii) Corpus striatum is a predominant part of the subcortical nuclei. Name the nuclei.

(xiii) The system and hypothalamus that regulate the emotional states of a person. Name the system.

(xiv) The vascular tissue that secretes the cerebrospinal fluid.

(xv) The thalamic nuclei that relay visual information to the occipital lobe.

(xvi) The inferior colliculi are the relay centres of a neural information. Name the neural information.

(xvii) The regulatory centres of the respiratory system and cardiovascular system lie in a part of the brain. Name it.

(xviii) Coordination of movements is executed by a part of the brain. Name it.

(xix) The communication between the third and fourth ventricles of the brain.

(xx) A fine connective tissue filament attached to the conus medullaris of the spinal cord.

(xxi) The chemical substance that is secreted into the synaptic cleft by the presynaptic neuron.

(xxii) The unconscious motor response to a sensory stimulus.

(xxiii) The influx of sodium ions changes the polarity of distribution of electrical charges across the membrane of a nerve fiber. Name the process.

(xxiv) The conduction of nerve impulse along a myelinated nerve fiber.

(xxv) Equilibrium or orientation with respect to gravity is controlled by an apparatus.

(xxvi) The part of the membranous labyrinth connected with hearing.

(xxvii) The tubular connection between the middle ear and pharynx.

(xxviii) The part of the retinal that doesn't contain any photoreceptor cell.

(xxix) The part of the retina, where an image is formed with highest resolution.

(xxx) Phtoreceptor cells of the retina that perceive colour.

(xxxi) The fluid present in the membranous labyrinth.

(xxxii) The fluid present in the bony labyrinth.

3. Correct the sentences, if incorrect, without changing the words underlined:

(i) Somatic motor neurons conduct nerve impulse from the sensory receptors to the central nervous system.

(ii) The central nervous system is constituted by the cranial and spinal nerves.

(iii) The autonomic motor neurons with their control centres constitute the somatic division of the peripheral nervous system.

(iv) The functional junction between a neuron and an effector cell is known as a synapse.

(v) In human, all synapses are electrical.

(vi) The sequence of the meninges from outer to inner is piamater, arachnoid mater and duramater.

(vii) Cerebrospinal fluid is secreted by the meninges.

(viii) The functional junction between the two cerebral himispheres is known as corpus striatum.

(ix) Pineal gland arises from a part of the diencephalon, known as hypothalamus.

(x) The mass of cell bodies and axons running through the brain stem is known as corpus callosum.

(xi) Superior colliculi relay auditory information to the occipital lobe of the cerebrum.

(xii) Medulla oblongata coordinates movement and equilibrium.

(xiii) Foramen of Monro connects the third ventricle with the fourth ventricle.

(xiv) In the spinal cord, the outer part is made by white matter, while the inner by gray matter.

(xv) The gray matter consists of medullated nerve fibers.

(xvi) The somatic nervous system is constituted by nerves with two types of neurons and a synapse in a ganglion.

(xvii) Acetylcholine is secreted as the neurotransmitter between pre and postganglionic fibers in both the sympathetic and parasympathetic divisions.

(xviii) In somatic motor reflex, the motor transmission is executed by one each of preganglionic and postganglionic neurons with a synapse in a sympathetic ganglion.

(xix) Efflux of sodium ions and influx of potassium ions during nerve impulse conduction have been characterized as repolarization.

(xx) The correct order of the ear ossicles from outer to inner is incus, malleus and stapes.

(xxi) Stapes is in contact with a round window.

4. Fill in the blanks with appropriate words:

(i) The central nervous system is constituted by ____ and ____.

(ii) The structural and functional unit of the nervous system is known as ____.

(iii) The basophilic granular material present in the neuron cytoplasm is known as _____.

(iv) The axons of some neurons are encapsulated by an insulating lipid material, known as _____.

(v) The myelin sheaths around the nerve fibers in the central nervous system are formed by _____ cells.

(vi) The efferent motor neurons that conduct impulse from the central nervous system to the visceral effectors are known as _____.

(vii) The functional junction between two neurons is known as _____.

(viii) The junction between a neuron and an effector is known as _____.

(ix) The impulse transmission across a synapse is carried out by a chemical substance, known as a _____.

(x) The middle meninx of the brain is known as _____.

(xi) The brain is covered by a delicate connective tissue layer called _____.

(xii) The dense fibrous connective tissue layer that forms a lining of the cranium is known as _____.

(xiii) The subarachnoid space is filled with a fluid called _____.

(xiv) The cerebrospinal fluid is secreted by _____.

(xv) The brain stem is constituted by midbrain, _____ and medulla oblongata.

(xvi) Two cerebral hemispheres are connected by a fibrous tract, known as _____.

(xvii) The cerebrum surface is marked by the presence of elevations and depressions, known as _____ and _____, respectively.

(xviii) The mass of cell bodies and axons that run through the brain stem constitutes _____.

(xix) Corpora striata are integral parts of the predominant subcortical nuclei called _____ nuclei or ganglia.

(xx) Lateral geniculate nucleus relays _____ information to _____ lobe of the cerebrum.

(xxi) Medial geniculate nucleus relays _____ information to _____ lobe of the cerebrum.

(xxii) Superior colliculi and inferior colliculi are concerned with _____ and _____ functions, respectively.

(xxiii) The degeneration in the caudate nucleus causes a dominant genetic disorder, known as _____.

(xxiv) The respiratory centres are situated in _____ and _____ of the brain.

(xxv) Coordination in speech and movement are controlled by _____ of the brain.

(xxvi) Two lateral ventricles communicate with each other and with the third ventricle through _____.

(xxvii) The ventricular communication between the third and fourth ventricles is known as _____.

(xxviii) There are _____ pairs of cranial and _____ pairs of spinal nerves in human.

(xxix) The bunch of spinal nerves at the posterior end of the spinal cord, resembling a horse tail is known as _____.

(xxx) An autonomic nerve consists of _____ number of neurons and _____ number of synapses.

(xxxi) The nerve fibers of the afferent (sensory) division convey information from the receptors to the central nervous system. Such fibers are classed as _____ neurons in respect of the number of processes.

(xxxii) Two neurons of an autonomic nerve fiber are termed as _____ and _____.

(xxxiii) The autonomic nervous system consists of two divisions, namely _____ and _____.

(xxxiv) The conduction of a nerve impulse along a myelinated nerve fiber is known as _____ conduction.

(xxxv) The vestibular apparatus is constituted by the utricle, the saccule and _____.

(xxxvi) Changes in linear acceleration i.e. in velocity are regulated by ______ and _____, while changes in angular velocity are regulated by _____.

(xxxvii) The spirally coiled structure attached to the membranous labyrinth, which serves as the organ of hearing is known as _____.

(xxxviii) The sensory part of the cochlea is known as _____.

(xxxix) The innermost layer of the eye ball that contains the sensory cells is known as _____.

(xl) The visual sensory cells are of two types, namely _____ and _____.

GROUP - B
(Short Answer-type Questions)

1. Answer the following within three sentences each:

(i) What is the function of myelin sheath?

(ii) Why are gray matter and white matter named so?

(iii) Is there any difference between an efferent neuron and motor neuron?

(iv) What is the role of limbic system?

(v) Which parts of the brain regulate memory?

(vi) What is a chemical synapse?

(vii) Cerebrospinal fluid is being secreted continuously by the choroid plexus. How is this volume kept constant?

(viii) What do you understand by cerebral lateralization?

(ix) How is the day night cycle regulated by melatonin?

(x) What is a spinal nerve? Where does it originate from?

(xi) Describe a pseudounipolar neuron.

(xii) What are preganglionin and postganglionic nerve fibers? These are characteristic features of which section of the nervous system?

(xiii) What is a sympathetic trunk? Describe about what it is made up of .

(xiv) What is a reflex arch?

(xv) What is an action potential? How does it help in the conduction of the nerve impulse?

(xvi) What is synaptic transmission?

(xvii) Are there different regions in the tongue for different tastes? Yes or No. Justify.

(xviii) What is a vestibular apparatus? How does it help maintain balance and equilibrium with respect to gravity?

(xix) How does the cochlea perceive the auditory stimulus?

(xx) What is the role of fovea centralis in the image formation by the eye.

2. Differentiate between two words in each of the pairs of words:

(i) Axon and Dendron

(ii) Schwann cell and Oligodendrocyte

(iii) Somatic nervous system and Visceral nervous system

(iv) Bipolar and Multipolar neurons

(v) Afferent neurons and Efferent neurons

(vi) Chemical synapse and Electrical synapse

(vii) Corpus callosum and Corpus striatum

(viii) Medullated and Nonmedullated nerve fibers

(ix) Sympathetic system and Parasympathetic system

(x) Somatic motor reflex and Autonomic motor reflex

(xi) Depolarization and Repolarization

(xii) Aqueous humor and Vitreous humor

(xiii) Endolymph and Perilymph

(xiv) Rod cells and Cone cells

GROUP - C
(Long Answer-type Questions)

1. Describe the structure of human brain and enumerate important functions of each part of it.

2. Give an account of the mechanism of generation and propagation of a nerve impulse.

OR

Describe the mechanism of conduction of nerve impulse.

❑ ❑ ❑

CHEMICAL COORDINATION AND REGULATION

CHAPTER 21

The body's control and coordination are maintained by two systems. One, being the nervous system, the other is the endocrine system. These two systems act as body's communication systems. The systems integrate among various systems and enable the body to work as a unified whole. Alternately speaking, the body functions in a state of internal homeostasis and adapts itself to the ever changing external physical environment as and when necessary. Proper functioning of these two systems guarantees the continued existence of the individual in the ever changing environment. If things go wrong in these systems, the body breaks apart. In the preceding chapter we have described about the structure and the working mechanism of the nervous system. In the present chapter we shall acquaint you with the endocrine glands, the hormones they secrete and their physiological functions.

The word endocrine is derived from two Greek roots; one being *endon*, meaning within and the other *krinein*, meaning to secrete. Simplifying the meaning we refer it to as internal secretion. We understand secretion. What is then internal? Any secretion that is directly discharged into the blood is an internal secretion. Explaining it in another way, internal secretions are secreted from ductless glands, which are discharged into the blood. These ductless glands have been termed as endocrine glands and their secretions as hormones. A hormone, following its secretion, acts on a target cell, tissue or organ and brings about an appropriate response. A hormone is a biologically active compound, which acts on its target in a specific manner even at its lowest concentration.

William Bayliss and Earnst Starling (1902) demonstrated that an active substance secreted from the mucosa of the small intestine stimulated the release of pancreatic juice from the pancreas. This active substance was named as secretin. Earnst Starling (1905) used the word hormone for secretin. Thereafter, research and investigation in this area have gone so far as establishing the study of endocrine glands, their secretions, and their physiological roles as a separate area of study, known as endocrinology.

There are two principal types of glands in the body: 1. Exocrine and 2. Endocrine. Exocrine glands are glands, which release their secretions into lumens through ducts (e.g., salivary glands, gastric glands, liver, exocrine pancreas, etc.). Endocrine glands, coversely are without ducts. These release their secretions directly into the blood. Refer to Table 21.1 for a complete list of endocrine glads of the body.

21.1. CLASSES OF HORMONES :

Hormones secreted from the endocrine glands vary widely in their chemical structures. Howver, all hormones are placed under four comprehensive classes: 1. amine hormones; 2. glycoprotein hormones; 3. polypeptide and protein hormones; and 4. steroid hormones.

1. **Amine Hormones:** These hormones are derived from amino acids tyrosine and tryptophan. These include the hormones secreted by the thyroid, adrenal medulla and pineal glands.

2. **Glycoprotein Hormones:** A glycoprotein hormone molecule consists of a long polypeptide with more than 100 amino acids. Carbohydrate residues are found to be attached to the polypeptide. These include thyroid stimulating hormone (TSH), follicle stimulating hormone (FSH) and lutenizing hormone (LH).

- **Pheromones:**

Pheromones are substances produced by one animal, that act at a distance on another animal to produce hormonal, behavioural and other physiological changes. These substances are prevalently secreted by invertebrates for effective communication among themselves. Two female roommates have a tendency to synchronize their menstrual cycles i.e. cycles tend to occur almost at the same time. This effect has been termed as dormitory effect. It has been established that an armpit odorant is responsible for this synchronization. This synchronization will not occur in another roommate, whose nasal apertures are plugged with cotton. This suggests that the chemical agent, that is known as a pheromone, acts through the olfactory sense. Pheromones are important regulatory molecules in the urine, vaginal fluid and other secretions in most mammals, which regulate the reproductive cycles and behaviour.

3. **Polypeptide and Protein Hormones:** Polypeptide hormones generally contain less than 100 amino acids. A majority of hormones are polypeptide hormones. In a protein hormone, however, two or more polypeptides interact by forming covalent bonds. Insulin by far is the best example from this class, which contains two polypeptides interacting with each other by two disulfide bonds.

4. **Steroid Hormones:** These hormones are derived from cholesterol, a class of lipids. Hormones secreted from adrenal cortex, testis and ovary are steroids. Some hormones of the placenta are also steroids.

- **Anabolic Steroids:**

Steroid hormones, as such are protein anabolic hormones i.e. they promote protein synthesis and hence promote growth of the body. These steroids are, therefore, termed as anabolic steroids. Keeping this in view, some synthetic steroid hormones, particularly androgens have been synthesized for therapeutic purpose. These are prescribed by a registered medical practitioner under exigency only. However, weight lifters, sprinters, body builders and other athletes misuse such steroids with a hope to make their body more competitive to others in athletic meets. These steroids in addition to protein synthesis promotion, induce a number of undesirable side effects. In addition, administration of such synthetic androgens negatively feeds back the gonadotropin secretion from the anterior pituitary. Looking at these mass misuse, international and national athletic organizations have imposed a ban on the use of such anabolic steroids and have screening procedures. A penal code has been prescribed for athletes, who have been found guilty of misusing anabolic steroids.

21.2. ENDOCRINE GLANDS :

Endocrine glands are distributed all throughout the body. There are many endocrine gland, namely, pituitary, thyroid, parathyroid, adrenal, which have exclusive endocrine functions. Other glands, in addition to the execution of their physiological roles, have endocrine functions. Among such glands are hypothalamus, pancreas, testis, ovary, gastro-intestinal tract, placenta, pineal, thymus, liver, kidney and many more. A comprehensive account of the endocrine glands in respect of their locations and physiological roles are presented in Fig. 21.1.

21.2.1. PITUITARY :

Pituitary, also known as **hypophysis** lies in a concavity, known as **sella turcica** of the **sphenoid bone** of the skull. It connects to the hypothalamus that constitutes the floor of the diencephalon by a stalk, known as **infundibulum**. Pituitary is made by the apposition of two parts: **1. posterior pituitary** or **neurohypophysis** and **2. anterior pituitary** or **adenohypophysis (Fig. 21.2)**. Although these two parts originate from ectoderm, their embryological origins are different. The neurohypophysis originates from the floor of the diencephalon i.e. it is neural in origin, while adenohypophysis originates from the pharyngeal ectoderm. Following their origin and formation, they associate forming a complete pituitary gland.

21.2.1.1. Anterior Pituitary(Adenohypophysis): The anterior pituitary of adult human further consists of two distinct parts: **(i) pars distalis**; and **(ii) pars tuberalis (Fig. 21.2)**. Pars distalis is the bulk part of adenohypophysis and secretes all tropic hormones. Pars tuberalis is a thin extension of tissue surrounding the infundibulum. A third lobe of adenohypophysis namely, pars intermedia is present between the two existing lobes in the human fetus. However, in due course of development, it merges with pars distalis i.e. it is absent in adult human pituitary.

- **Prohormones and Prehormones:**

  Hormone molecules that regulate metabolism are often synthesized as inactive molecules or precursors, which undergo modifications and turn into active hormones. These precursors are termed as pre- pro-hormones. In the first step, it undergoes a cleavage to form a pre-hormone, while in the second, the pre-hormone turns into an active hormone. For example, insulin is synthesized by the beta cells as a pre-pro-insulin, which by cleavage turns into pro-insulin. The pro-insulin, in turn undergoes a modification to turn into active insulin. The term pre-hormone is sometimes used to indicate the precursors of active hormones. Some such activations are indicated below:

Gland	Pre-hormone	Active Hormone
Skin	Vitamin D_3	1,25 Dihydroxyvitamin D_3
Testis	Testosterone	Dihydrotestosterone
Thyroid	Thyroxine (T_4)	Triiodothyronine (T_3)

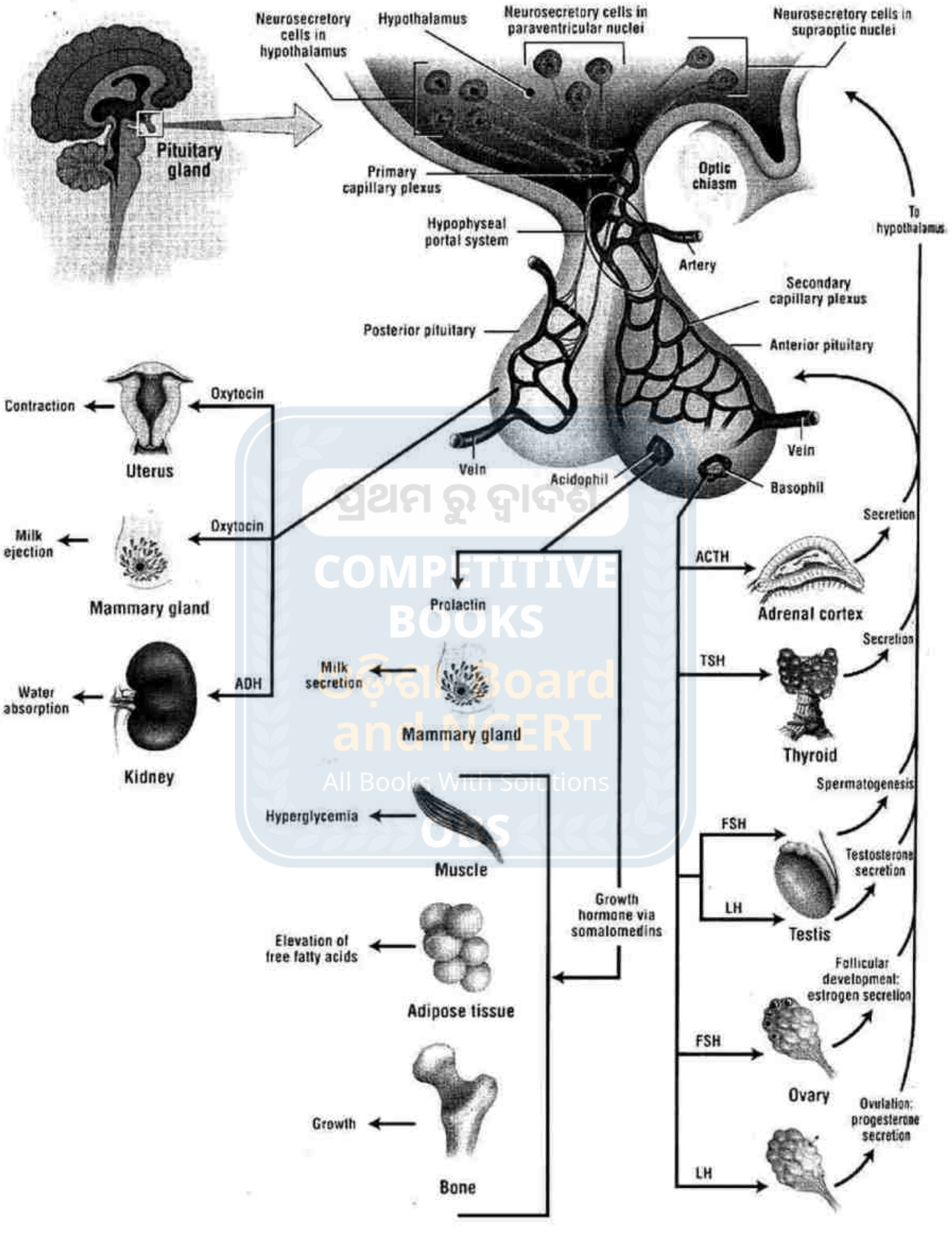


Fig. 21.1 : An overview of relationships between the hypothalamus and pituitary and pituitary and its target of glands.

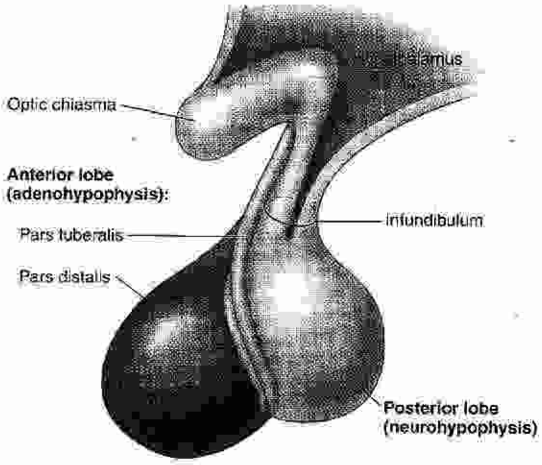


Fig. 21.2 : Gross structure of the pituitary gland

Histologically, pars distalis contains two primary types of cells based on their staining properties: **chromophobes** and **chromophils.** The chromophils are subdivided into **acidophils (alpha cells)** and **basophils (beta cells)**. Acidophils secrete growth hormone or somatotropic hormone (GH / STH) and prolactin (PRL), while basophils secrete follicle stimulating hormone (FSH), lutenizing hormone (LH), thyroid stimulating hormone (TSH) and **adrenocorticotropic hormone (ACTH)**.

21.2.1.2. Blood Supply to the Pituitary: While studying the structure and functions of the pituitary gland, a study about its blood supply is of paramount importance because it forms the basis of a very fine functional relationship among the three elements namely, the hypothalamus, the neurohypophysis and the adenohypophysis.

There is no neural connection between the anterior and posterior pituitary elements. Connection is established only through the bloodvascular system. **Superior hypophysial arteries** from the internal carotid artery supply blood to pars tuberalis, median eminence and infundibulum. These arteries break up into capillaries which form a plexus in the median eminence at the base of the hypothalamus, known as the **primary capillary plexus**. The blood from the primary plexus id drained by venules, which join together and form a **hypothalamo-hypophysial portal vein**, which enters into the anterior pituitary and breaks up into another capillary plexus, known as the **secondary capillary plexus (Fig. 21.4)**.

21.2.1.3. Hormones of Anterior Pituitary: The hormones of the anterior pituitary were identified as **trophic hormones** because they were believed to nourish the cells of the target organ. However, when this correlation was proved to be wrong, **trophic was shortened to tropic**, meaning attracted to. As many as seven hormones are known to be secreted from the anterior pituitary. A brief description about each one's physiological role is presented hereunder.

1. **Growth Hormone (GH) or Somatotropic Hormone (STH) or Somatotropin:**
   - Growth hormone is a **protein anabolic hormone** i.e. it stimulates amino acid movement into muscle cells and **promotes protein synthesis**. Synthesis and accumulation of proteins accounts for a general growth of the body.
   - It induces **hyperglycemia** i.e. it increases the blood sugar level by **glycogenolysis** (breakdown of glycogen) in liver cells. This effect is known as the **diabetogenic effect**.
   - It acts on adipose tissue and releases free fatty acids into the blood.
   - It acts on liver cells and induces the synthesis of a class of polypeptides known as **somatomedins**. One of these somatomedins, known as **insulin-like growth** factor I (IGF I) is known to promote growth of long bones by acting on the epiphysial cartilages.
2. **Prolactin (PRL) or Lactogenic Hormone, Luteotropic Harmone (LTH) :**
   - It promotes mammary gland development and induces **milk formation (lactation)** in females following the birth of a baby.
   - It promotes general growth like that of the growth hormone.
   - It induces **hyperglycemia**.
   - It increases fat deposition.
   - It also induces the growth of male sex accessory organs
3. **Thyroid Stimulating Hormone (TSH) or Thyrotropin:**
   - It acts on the thyroid gland as its target gland and promotes the secretion of **triiodothyronine (T3)** and **thyroxine (T4)**.
4. **Adrenocorticotropic Hormone (ACTH) or Corticotropin:**
   - Its target of action is adrenal cortex. It stimulates the zona fasciculata and perhaps zona reticularis of the cortex to secrete glucocorticoids (Corstisol).
5. **Follicle Stimulating Hormone (FSH) or Folliculotropin:**
   - In the male, it acts on the **seminiferous tubules** and promotes the **spermatogenesis** process.
   - It acts on the sertoli cells of the seminiferous tubules and induces the synthesis of **androgen binding proteins (ABP)**.
   - In the female, it acts on the **primary ovarian follicles** and promotes their growth.
6. **Lutenizing Hormone (LH) or Interstitial Cell Stimulating Hormone (ICSH):**
   - In the male, it stimulates the **interstitial cells** of the testis to secrete **androgens**.
   - In the female, it is responsible for the final maturation of the **ovarian follicles**.
   - It stimulates ovulation, formation of **corpus luteum** and secretion of **progesterone** from corpus luteum.

7. **β - lipotropin (β - LPH):**

- It is a polypeptide of the anterior pituitary, which is not directly secreted by it. Instead, a large polypeptide, known as **proopiomelanocortin (POMC)** is secreted by the cells, believed to secrete ACTH.
- It is then cleaved by a suitable enzyme producing ACTH and β - LPH. β - LPH is cleaved to form three polypeptides, namely **endorphin**, **enkephalin** and **MSH** (melanocyte stimulating hormone).
- β MSH doesn't have any apparent role in adult human nor is it secreted from the anterior pituitary.
- Endorphin and enkephalin are believed to act as body's **natural analgesics** i.e. **endogenous pain relieving molecules**.

21.2.1.4. Hormones of Posterior Pituitary: Posterior pituitary secretes two polypeptide hormones, namely **oxytocin** or **pitocin** and **vasopressin** or **antidiuretic hormone (ADH)**. These two hormones are considered as neurohormones, since these are synthesized by **neurosecretory cells** in the hypothalamus. As mentioned earlier that neurosecretory cells are specialized neurons of the hypothalamus, which have acquired the function of secretion. There are two such nuclei (clusters of neuron cell bodies), named as **supraoptic** and **paraventricular nuclei** in the hypothalamus (Fig. 21.3). The long axons of these neurosecretory cells descend down the infundibulum to the posterior pituitary and terminate in a capillary plexus. Note that there are two types of neurosecretory cells in the hypothalamus. One group, having relatively shorter axons terminate in the primary capillary plexus in the median eminence, discharging the releasing and release inhibiting hormones. The other group, having long axons, terminate in the capillary plexus in the posterior pituitary. These cells release oxytocin and vasopressin.

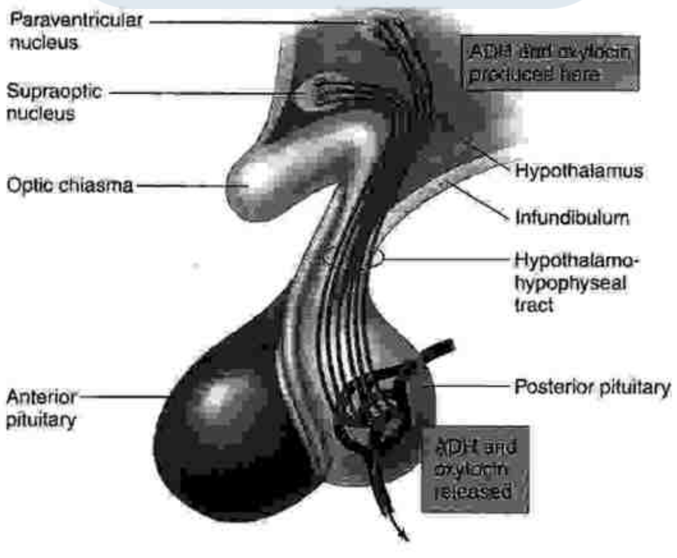


Fig. 21.3 : Neurosecretory cells and neurosecretion

1. **Oxytocin (Pitocin):**
   - In the female, oxytocin stimulates the contraction of the uterus to facilitate parturition (child birth).
   - It stimulates the contraction of the mammary gland alveoli and ducts, which results in milk ejection in the lactating mother. However, the oxytocin is released in response to the suckling of the nipple by the baby.
   - In the male, it is believed to facilitate the ejaculation of semen.
2. **Vasopressin [Antidiuretic Hormone (ADH)]:**
   - It acts on the proximal renal tubule and promotes the absorption of water from the glomerular filtrate.
   - Its deficiency causes a disease, known as **diabetes incipidus** i.e. there is a loss of water by frequent urination of dilute urine.

21.2.1.5. Hypothalamic Control of Anterior Pituitary Functions : Recall that there is no neural or any type of communication between the posterior pituitary and anterior pituitary other than vascular. The only communication is via the blood vascular system. Investigations have proved that the functioning of the anterior pituitary is under the regulation of the hypothalamus via the bloodvascular system. Some neurons in the hypothalamus work together in regulating the functions of the anterior pituitary. Their cell bodies are present in groups, constituting nuclei. These neurons have acquired secretory functions and hence are known as **neurosecretory cells**. These cells secrete a number of reasing and release-inhibiting hormones into the primary capillary plexus, known to stimulate or inhibit specific cells of the adenolypophysis to secrete or inhibit the release of tropic hormones. Releasing hormones stimulate and augment the secretion of the corresponding tropic hormone, while release-inhibiting hormone inhibits the release of the said tropic hormone. These hormones reach the anterior pituitary only via the **hapothalamohypophysial portal vein**. Thus, the pituitary gland is under the regulation of the hypothalamus. The age old held idea that pituitary gland is the master gland becomes obsolete.

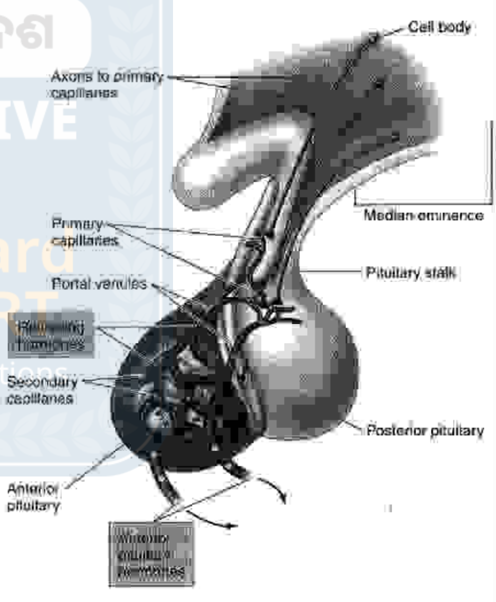


Fig. 21.4 : Hypothalamic control of pituitary functions.

Releasing and Release-Inhibiting Hormones: The hypothalamus exercises its control over the anterior pituitary through the mediation of some releasing and release-inhibiting hormones and other chemical agents. A summary of this is presented below.

Releasing and Release-inhibiting Hormones	Effects
1. Thyrotropin releasing hormonr (TRH)	Stimulates the secretion of TSH and PRL
2. Growth hormone releasing hormone (GHRH)	Stimulates secretion of GH
3. Growth hormone release-inhibiting hormone (GIH) [also known as somatostatin (SST)]	Inhibits the secretion of GH and TSH
4. Gonadotropin releasing hormone (GnRH)	Stimulates the secretion of FSH and LH.
5. Corticotropin releasing hormone (CRH)	Stimulates secretion of ACTH
6. Prolactin release-inhibiting hormone (PIH) (also known as dopamine)	Inhibits secretion of PRL

The entire story is summarized in the Fig. 21.5.

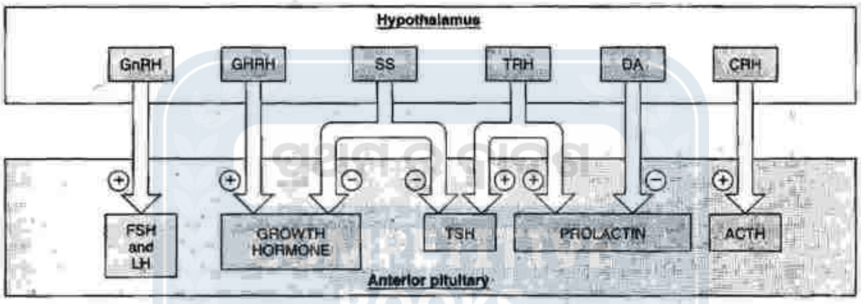
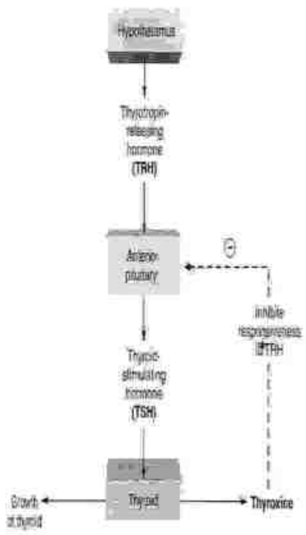


Fig. 21.5 : Summary of hypothalamic releasing and release-inhibiting hormones and their roles in the stimulation or inhibition of anterior pituitary (plus indicates stimulation and minus indicates inhibition).



Negative Feedback of Anterior Pituitary by Thyroid Hormones

● **Feedback Control:**

Many target glands are under the regulation of anterior pituitary tropic hormones and the anterior pituitary secretions in turn are under the regulation of the hypothalamus. There is a delicate hypothalamus-anterior pituitary-target gland regulation axis. Under ideal conditions, all these glands secrete precise quantity of hormones so that there is a physiological state of equilibrium in the body. However, under some abnormal situations, the target glands secrete more or less hormones than normal. This would destabilize the state of equilibrium. But, nevertheless, there is a feed back control mechanism by which any excess or deficient quantity of a particular target gland hormone exerts an appropriate influence on the anterior pituitary so as to secrete a precise quantity of a tropic hormone in order to bring the target gland hormone concentration back to normal. These control mechanisms are known as feedback control mechanisms. There are two types of feed back mechanisms: negative and positive.

Any excess of a target gland hormone negatively feeds back the anterior pituitary to secrete less tropic hormone so as to adjust the secretion of the target gland hormone. In positive feed back mechanism, the reverse series of actions take place.

Secretions of tropic hormones like ACTH, TSH, FSH and LH are controlled by negative feedback mechanisms. LH exhibits a positive feedback regulation mechanism.

21,2.2. THYROID GLAND :

There is a single thyroid gland, situated in the neck inferior to the larynx. It consists of **right and left lobes** connected by an **isthmus (Fig. 21.6)**. The thyroid tissue is made up of numerous spherical thyroid follicles embedded in a mass of extracellular material made up of reticular fibers and a rich network of blood capillaries. . These follicles are the structural and functional units of the thyroid gland. A follicle is lined by a single layer of cuboidal epithelium (Fig. 21.7). The follicle cells synthesize and release their product into the lumen of the follicle.

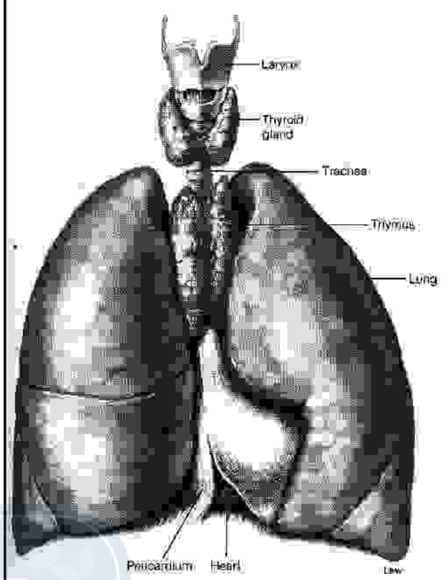


Fig. 21.6 : Location of the thyroid and thymus glands in human.

The lumen of the follicles is filled with a gelatinous substance called **colloid**. The colloid contains an **iodinated glycoprotein**, **thyroglobulin**. Thyroglobulin is the inactive storage form of the thyroid hormones [triiodothyronine (T_3) and thyroxine (T_4)]. Thyroxine (T_4) is not the active form of the hormone. It s converted to triiodothyronine (T_3) inside the target cells. Therefore, T_3 is the potent form of the thyroid hormone. In addition to the follicular cells, the thyroid tissue also contains pale staining **parafollicular cells**. These cells are arranged peripheral to the follicles. These cells are the source of **calcitonin**.

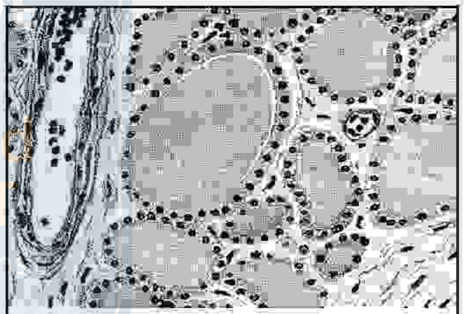


Fig. 21.7 : Cross section of thyroid showing the thyroid follicles and parafollicular cells.

21.2.2.1. Functions of Thyroid Hormones: Thyroid hormones are synthesized by the follicular cells from the amino acid tyrosine and iodide radical collected from the blood. On entering into the thyroid follicle cells, iodide radical is oxidized to iodine. Tyrosine is iodinated forming mono and diiodotyrosine, which couple in a reaction forming triiodothyronine (T_3). Two molecules of diiodotyrosines couple and consequently form thyroxine (T_4). T_3 and T_4 are biologically active forms of thyroid hormones. Among these two, T_3 is biologically more active than T_4. T_4 has negligible biological activity.

- Thyroid hormones, in cooperation with growth hormone promote many aspects of growth of the body.
- These are essential for **normal differentiation of central nervous system** in the fetus.
- Increase the **basal metabolic rate (BMR)** by enhancing cellular respiration in most tissues. Basal metabolic rate is calorie expenditure at rest.
- Enhance the rate of protein synthesis.

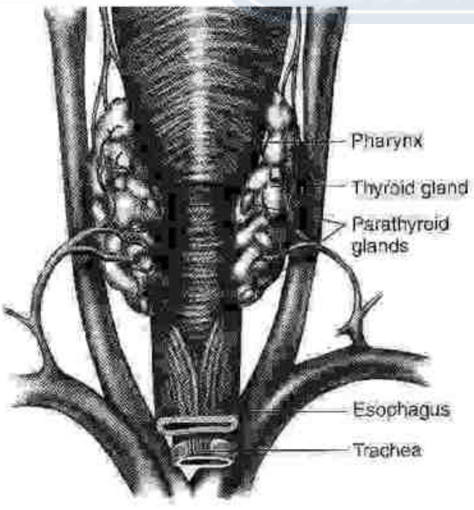
- Have a **hyperglycemic** effect i.e. increases blood glucose level.
- Have a **lipolytic effect** on the liver, thereby increasing the cholesterol level in the blood

Functions of Calcitonin: Calcitonin, secreted by the parafollicular cells of the thyroid gland regulates the blood calcium level at a constant by preventing bone dissolution and by promoting the excretion of calcium in the urine.

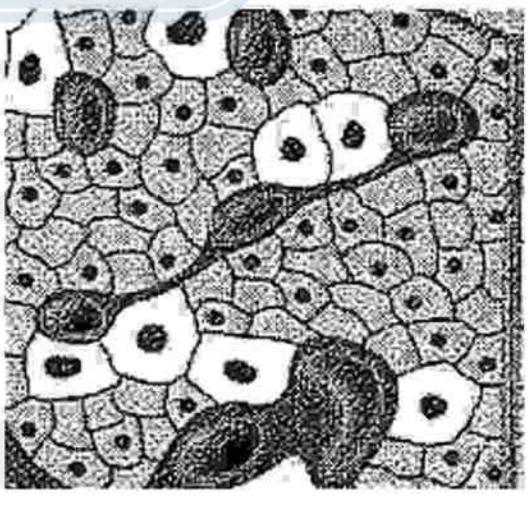
- **Synergistic, Permissive and Antagonistic Effects of Hormones:**
  - **When two hormones cooperate with each other to express an effect, both the hormones are known as synergists, the effect is known as synergistic and the phenomenon as synergism.**
  - **When a hormone enhances the activity of a second hormone, the effect is known as permissive effect.**
  - **When the action of one hormone is opposite to another, the effect is known as antagonistic effect.**

21.2.3. PARATHYROID GLAND :

There are two pairs of parathyroid glands, one pair being superior and other pair inferior, embedded in the posterior part of the of the thyroid gland [Fig. 21.8 (a)]. Each gland is embedded by a thin connective tissue capsule. The parathyroid cells are arranged into cords or clumps, surrounded by rich network of capillaries. The gland is made up of two types of cells: principal or chief cells and oxyphil cells [Fig. 21.8 (b)]. Oxyphil cells are larger, found either singularly or in small groups. These cells are less numerous than the chief cells.



(a)



(b)

Fig. 21.8 : Human parathyroid gland. (a) Location, (b) Cross section through parathyroid.

Parathyroid hormone (PTH) or **parathormone** is the only hormone secreted by the parathyroid glands.

21.2.3.1. Functions of Parathyroid Hormone: It promotes an increase in the blood calcium level by acting on the bones, kidneys and intestine. It encourages the osteoclasts (bone resorbing cells) to resorb bone and release calcium into blood. It stimulates the kidneys to reabsorb calcium from the glomerular filtrate.

21.2.4. PANCREAS:

Pancreas is a **composite organ** consisting of two elements: an **exocrine element** secreting pancreatic juice and an **endocrine element** secreting several hormones. The endocrine part is found scattered among the exocrine acini as richly vascularized spherical ball of cells, known as **islets of Langerhans**. Each islet is surrounded by fine fibers of reticular connective tissue. Special staining techniques distinguish four different types of cells such as **alpha, beta, delta** and **pancreatic polypeptide (PP) cells**. Alpha cells constitute about 20% of the entire population of cells and are located around the periphery of the islet. Beta cells are by far the most numerous constituting about 70% of the islet cells and are present primarily at the centre. The remaining cell types are minor and are found scattered throughout the islet.

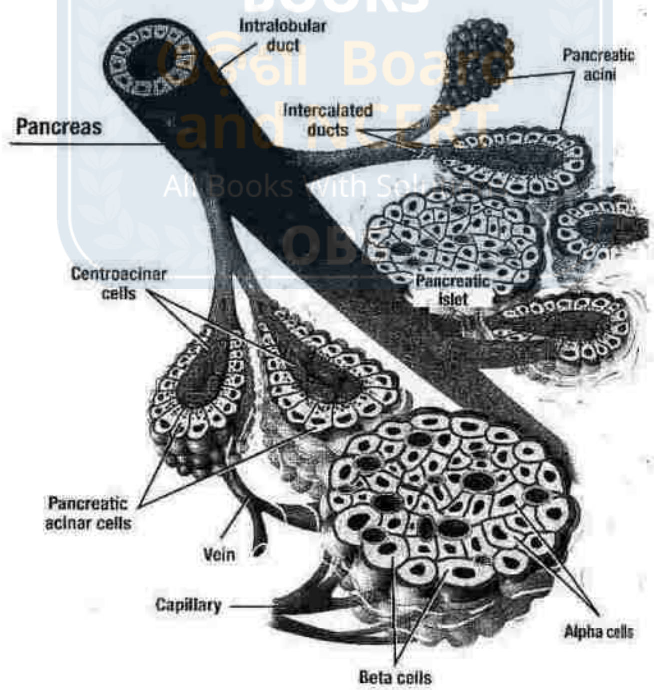


Fig. 21.9 : Histological structure of the pancreas in three dimension.

21.2.4.1. Hormones of Pancreas: Each cell type secretes a hormone, which has unique physiological functions. The alpha and beta cells secrete **glucagon** and **insulin**, respectively.

The delta cells secrete **somatostatin**, which has a role in inhibiting the growth hormone secretion. PP cells secrete a **pancreatic polypeptide**, whose functions have not been established as yet.

21.2.4.2. Functions of Insulin :

- Insulin is **hypoglycemic** i.e. it decreases blood glucose level by facilitating glucose entry into adipose tissue cells, muscle cells and liver cells.
- It promotes glycogen synthesis in muscle and liver cells from glucose that has entered into these cells.
- It promotes fatty acid synthesis and triglyceride deposition in adipose tissue.
- It promotes amino acid uptake by muscle and liver cells and increases protein synthesis in such cells.
- It increases lipid synthesis in liver cells.
- Its deficiency causes a disease, known as **diabetes mellitus**. In diabetes mellitus, glucose concentration in the blood is elevated.

21.2.4.3. Functions of Glucagon :

- Glucagon's action is antagonistic to that of insulin.
- Glucagon is **hyperglycemic** i.e. secretion of more glucagon elevates the blood glucose concentration above normal.
- It acts on the liver depot of glycogen, hydrolyzes it and releases free glucose into the blood, thereby elevating the blood glucose level. This breaking down process of glycogen into glucose is known as **glycogenolysis**.
- It promotes **gluconeogenesis** in the liver cells. Gluconeogenesis is a biochemical process, whereby glucose is formed from non carbohydrate source, here in particular from amino acids.

21.2.5. ADRENAL GLAND :

There is a pair of adrenal gland in human. Adrenal gland is also known as **suprarenal gland** because each is associated with the superior pole of the kidney like a cap. It is a composite gland consisting of two elements: an **outer cortex** and an **inner medulla (Fig. 21.10)**. Although these two elements are associated together forming a single structure, they have different embryological origins, structures and functions. The medulla is derived from neural ectoderm, while the cortex from mesoderm. Each adrenal gland is surrounded by a dense irregular connective tissue capsule and embedded in adipose tissue at the superior pole of the kidney. The cortex secretes steroid hormones, while the medulla secretes amine hormones.

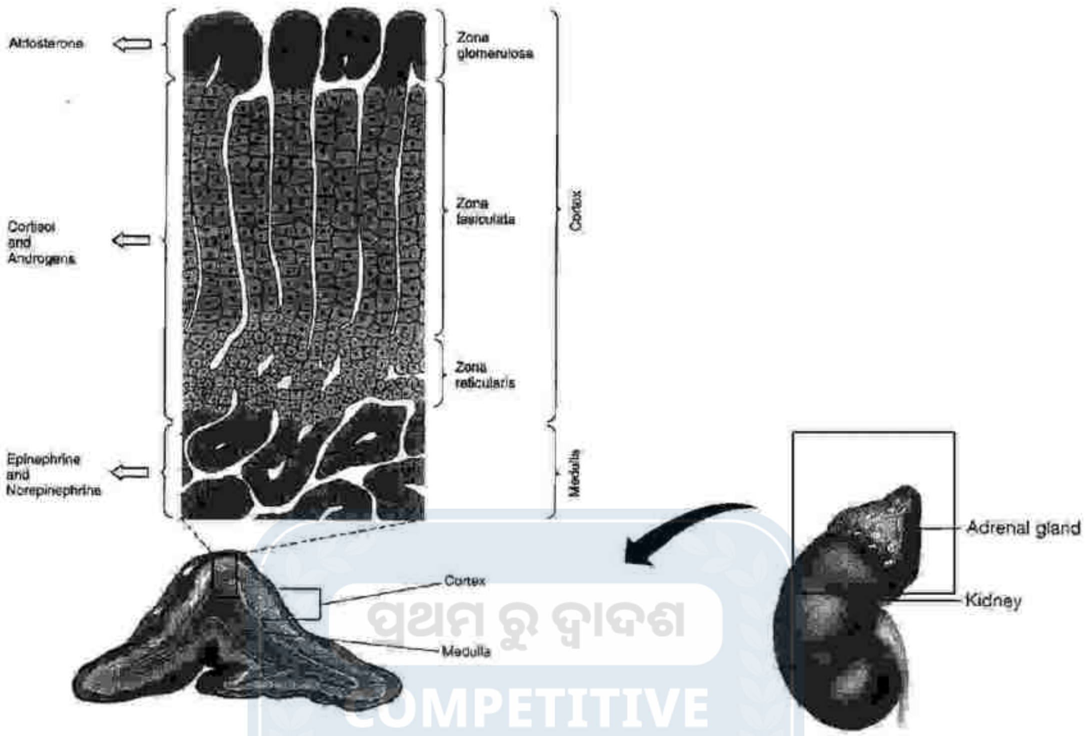


Fig. 21.10 : Gross and histological structures of human adrenal gland (both cortex and medulla).

21.2.5.1. Structure of Adrenal Cortex: The cortex has three concentric zones: **1. zona glomerulosa, 2. zona fasciculata** and **3. zona reticularis (Fig. 21.10)**. Although all these zones are of the same organ, they are functionally diverse i.e. secrete different hormones.

1. **Zona glomerulosa:** This is a thin zone below the capsule. It consists of cells arranged in small clumps. The cells of this zone secrete a hormone called **aldosterone**, a **mineralocorticoid**, concerned with **mineral metabolism**.

2. **Zona fasciculata:** This is the middle zone and thickest of all. The zone consists of longitudinal cords of cells.

3. **Zona reticularis:** This zone is innermost and lies adjacent to the medulla. The cells are arranged in cords and clumps.

Zona fasciculata and reticularis secrete two classes of steroid hormones, known as **glucocorticoids** and **androgens**. Among the glucocorticoids are **cortisol** and **corticosterone**. Cortisol is the predominant glucocorticoid in human. Cortical androgens include **dehydroepiandrosterone** and **androstenedione**. Glucocorticoids are concerned with carbohydrate metabolism. The androgens of the cortex are relatively weaker compared to the androgens secreted from the testis. These androgens practically have no effect on males, while in females, express male secondary sexual characters, when secreted in overdoses. All steroid hormones secreted from the adrenal cortex are classed as corticosteroids. Zona fasciculata and zona reticularis are stimulated by ACTH (corticotrpin), secreted from the anterior pituitary, while zona glomerulosa is stimulated by **rennin-angiotensin** system.

- **Cushing's Syndrome:**

  The disease was first described by Cushing in 1932. This is s hyper-functioning of the adrenal cortex. The syndrome is characterized by an oversecretion of cortisol from the cortex. There are several causes of oversecretion of cortisol. Primarily, it may be due to an adrenocortical tumor (adenoma or carcinoma). A secondary cause may be due a pituitary tumor in the cells secreting ACTH. More ACTH is secreted from the anterior pituitary. More ACTH will stimulate the cortex to secrete more cortisol, which leads to Cushing's syndrome. The syndrome is characterized by hyperglycemia, hypertension, and muscular weakness.

21.2.5.3. Functions of corticosteroids:

- The potent mineralocorticoid, secreted from the zona glomerulosa is aldosterone. It regulates **mineral metabolism**. It acts on the kidney tubule and promotes Na and water absorption and K^+ excretion in the urine.
- The predominant glucocorticoid in human is cortisol secreted by zona fasciculata and perhaps also by zona reticularis. It promotes **gluconeogenesis** (formation of glucose from amino acids) and inhibits glucose utilization. Thus, cortisol elevates blood glucose level i.e. it is **hyperglycemic**.
- Cortisol is lipolytic i.e. break down lipids and release fatty acids into the blood.

  All cprticosteroids are protein anabolic hormones. They promote protein synthesis.
- Stress stimulates the cortex to secrete more cortisol, which is known to suppress the immune respone. More cortisol, primarily enables a subject to cope up with stressful situations. In other words, if the cortisol level is elevated, the subject may die. However, if the stress is prolonged, the immune response continues to be suppressed. This may increase the susceptibility to infections and diseases in the subject.

- **Renin-Angiotensin-Aldosterone System:**

  When there is a reduced blood flow and pressure in the renal artery, cells of the juxtamedullary apparatus of the kidney secrete an enzyme, renin into the blood. The enzyme cleaves a ten amino acid polypeptide, angiotensin I from a plasma protein, angiotensinogen. Angiotensin I reaches the blood capillaries of the lung, where it is again cleaved to form a eight amino acid polypeptide, angiotensin II. Angiotensin II stimulates adrenal cortex to secrete more aldosterone, which promotes retention of more water and salt by the kidneys. The result is an increase in the blood volume, blood pressure and blood flow in the renal arteries.

- **Glucocorticoids as immune response suppressors:**

  Glucocorticoids are known to suppress the immune system and hence immune response. These are therefore, used as pills, creams, injections and sprays to suppress the immune response and inflammation. These drugs are useful in treating inflammatory diseases like asthma and rheumatoid arthritis. Some such glucocorticoids used to suppress inflammation are prednisolon and dexamethasone.

21.2.5.4. Structure of Adrenal Medulla: Medulla forms the core of the adrenal gland. It is made up of cells that are modified sympathetic post-ganglionic neurons, arranged in cords. The neurons have lost their axons and dendrites during development. These are secretory cells, which synthesize and secrete a class of hormones, known as **catecholamines**. The catecholamines include **epinephrine (adrenaline)** and **nor-epinephrine (nor-adrenaline)**. The cells of adrenal medulla stain with chromates and hence are termed as **chromaffin cells.**

21.2.5.5. Functions of catecholamines:

- The effects of catecholamines are similar to those caused by the stimulation by the sympathetic nervous system.
- The catecholamines increase the cardiac output and heart rate.
- Increase respiratory rate and hence metabolic rate.
- Promote **hyperglycemia** (increase in the blood glucose level) by **hepatic glycogenolysis** (glycogen breakdown in liver cells).
- Have lipolytic action i.e. stored lipids are broken down and free fatty acids are released into the blood.
- Epinephrine is known as an **emergency hormone** because it handles emergency situations like hypoglycemia arising due to stress. The response exhibited by the medulla under emergency situations has been termed as **fight or flight response.**

21.2.6. PINEAL GLAND:

There is a single pineal gland, situated on the roof of the third ventricle of diencephalon is encircled by the meninges of the brain. It starts to regress at the age of 7 years and appears in the adult as a fibrous tissue. It is innervated by sympathetic nerves from the superior cervical region, there being no direct connection with the brain.

It secretes a hormone called **melatonin**. The secretion of this hormone is stimulated by the **suprachiasmatic nucleus** of the hypothalamus. This nucleus is the centre of **circadian rhythm**, a rhythm of physiological activity that follows a 24 hour pattern. The activity of this nucleus is influenced by the length of the day (day light) so that it is synchronized to a day night cycle (Fig. 21.11).

21.2.6.1. Functions :

- Day light stimulus is perceived by the retina and is transmitted to the suprachiasmatic nucleus via the hypothalamus. The activity of the nucleus is suppressed, thereby decreasing the sympathetic stimulation of the pineal. The consequence is a decrease in melatonin secretion.
- The melatonin secretion increases with darkness during night and reaches a peak at midnight. The regulation of melatonin secretion by light is brought about by a retinal pigment, **melanopsin**.
- Melatonin inhibits the gonadotropin releasing hormone (GnRH) from the hypothalamus. Its secretion in children between 1 to 5 years of age is maximum. Followed by this, there is a stedy decline in its level reaching its lowest level at the onset of puberty. This fact suggests about the role of melatonin in the onset of puberty.

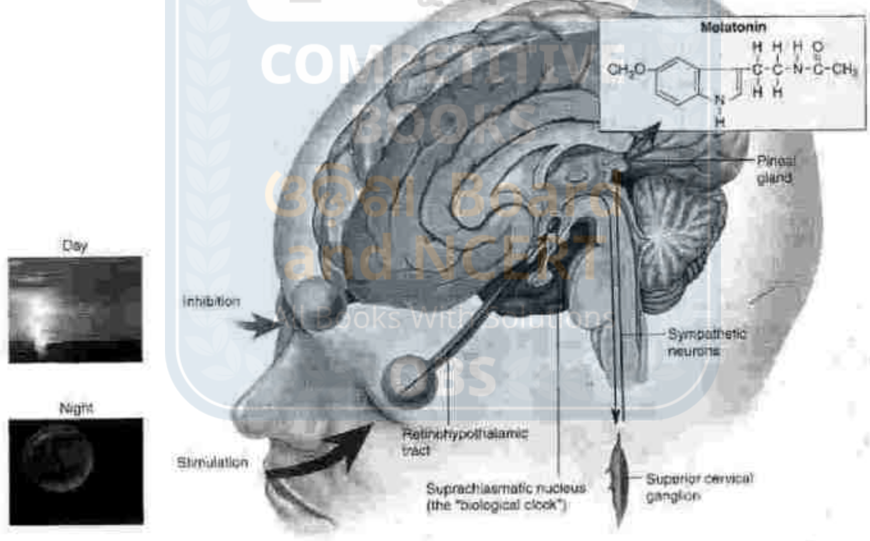


Fig. 21.11 : Regulation of melatonin secretion by the pineal gland.

- **Melatonin Pill:**

  Melatonin secretion changes, when a person works in night shifts or flies different time zones. The latter induces an effect, which is known as jet lag. In such cases, melatonin pills may be taken to restore normalcy. Melatonin reduces the time period required to fall asleep. It may be useful for elderly people, who suffer from insomnia (loss of sleep).

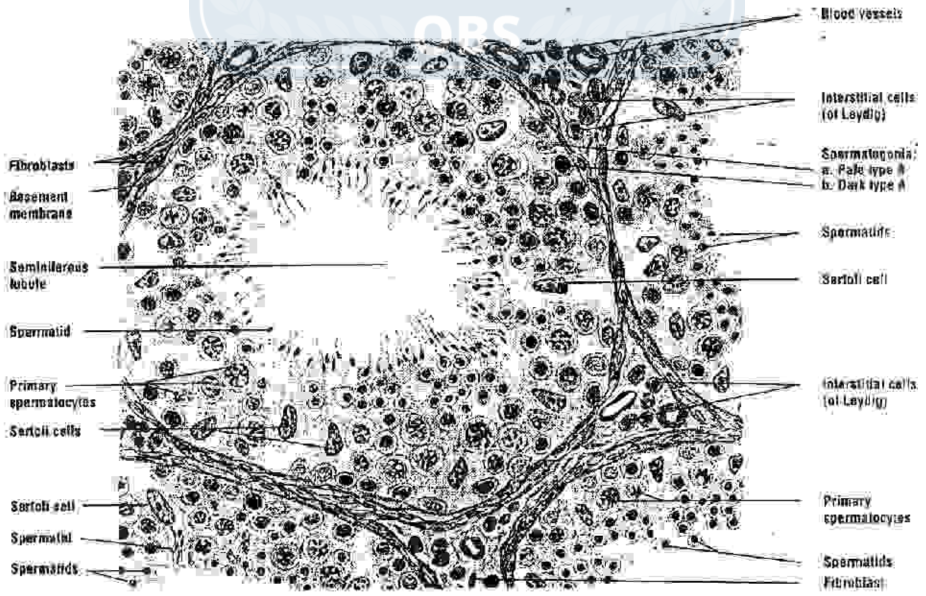
  The cited beneficial effects are not yet proved. Therefore, the opinion is against the uncontrolled use of melatonin pills without the prescription of a practitioner.

21.2.7.GONADS:

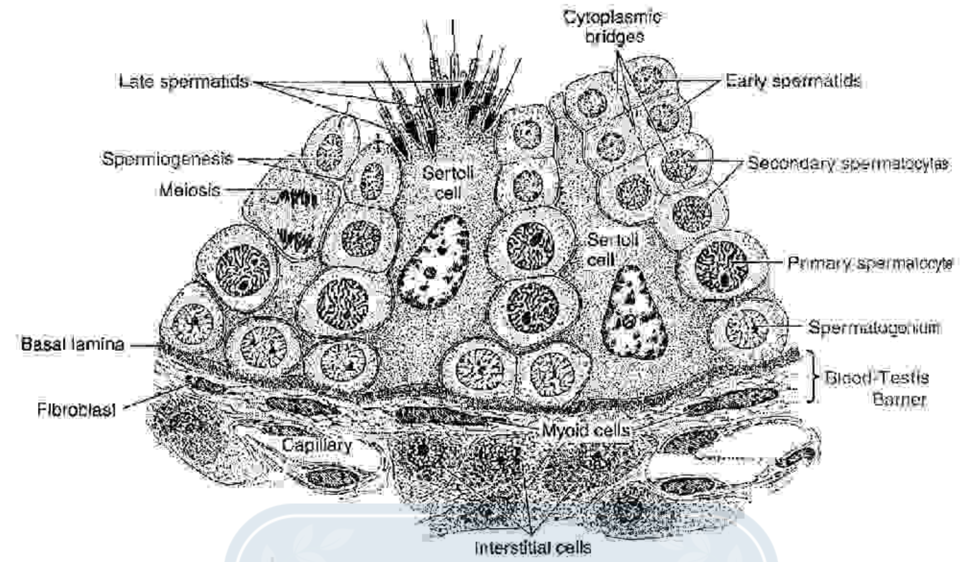
Gonads are the primary sex organs. There are two types of gonads: **testis in the male** and **ovary in the female**. Accessory sex structures are associated with gonads constituting reproductive systems, the male or the female. Testis and ovary function as endocrine glands in addition to their gamete formation and maturation functions. Most of their hormones are steroid hormones, which are collectively called **gonadal steroids**. However a few peptide hormones are secreted from the gonads.

21.2.7.1 TESTIS:

(a) Structure (Fig. 21.12) : Human male has **a pair of testis**, situated outside the abdominal cavity in a **scrotum**. The scrotum communicates with the abdominal cavity through **inguinal canals**. Each testis is surrounded by a thick connective tissue capsule called **tunica albuginea**. It thickens and extends inwardly into each testis as a **mediastinum testis**. A thin connective tissue septum extends from the mediastinum testis and subdivides it into about 250 compartments called **testicular lobules**, each containing 1-4 coiled **seminiferous tubules**. Each seminiferous tubule is lined by stratified cuboidal epithelium containing dividing spermatogenic cells and large nondividing somatic cells, known as **Sertoli** or **sustentacular cells.** The tight junctions between adjacent Sertoli cells, the basal lamina and the myoid (muscle like) cells constitute a **blood-testis barrier**. The seminiferous tubules lie in a mass of loose connective tissue, containing fibroblasts, muscle like cells, nerves, blood vessels, lymphatic vessels and epithelial cells called **interstitial cells of Leydig**. These interstitial cells of Leydig secrete a class of steroid harmones, known as **androgens**.



(a)



(b)

Fig.21.12 : Transverse section through human testis. (a) A single seminiferous tubule with cells of Leydig in the interstial tissue and (b) A magnified part of the seminiferous tubule showing the blood-testis barrier, Sertoli cells and its relationship with the differenting spermatogenic cells.

(b) Testicular Hormones: As mentioned in the preceding section, the interstial cells of Leydig secrete **male steroid hormones**, collectively called **androgens**. **Testosterone** is the major androgen secreted by the testis. Sertoli cells, cells of Leydig, maturing male germ cells secrete **estradiol**, a predominant female steroid hormone, primarily secretd by the ovary. Sertoli cells are the primary targets of FSH stimulation. Under its influence, **inhibin** and **antimullerian hormone (AMH)** or **mullerian inhibiting hormone (MIH)** are secreted from the Sertoli cells. Sertoli cells contain an enzyme, aromatase, which converts testosterone into estradiol. Inhibin negatively feeds back the secretion of FSH from the anterior pituitary. It is made from three polypeptides, namely, α, βA and βB. α joins with either βA or βB to form one or the other type of inhibin. βAβB combination forms another hormone, **activin**, which stimulates FSH secretion from the anterior pituitary rather than inhibit it.

(c) Functions of Testicular Hormones:

- Along with FSH, testosterone is required for the initiation and continuation of spermatogenesis.
- Testosterone is necessary for the development and maintenance of male genitalia (penis and scrotum).
- It maintains **male accessory sex organs** (prostate, seminal vesicles, epididymis and vas deferens).
- It is essential for the development and expression of **male secondary sexual characters**.

- Inhibin, secreted by the Sertoli cells negatively feeds back the secretion of FSH from the anterior pituitary.
- Antimullerian hormone (AMH), secreted also by the Sertoli cells inhibits the development and differentiation of mullerian ducts, which later differentiate as the oviducts in the female. The consequence is the differentiation of a wolffian duct, which later differentiates as the vas deference.
- Actiivin, as mentioned earlier, stmulates the secretion of FSH from the anterior pituitary.
- Testosterone has protein anabolic effects i.e. promote protein synthesis in muscle cells.

21.2.7.2. OVARY :

(a)Structure (Fig. 21.13): There is a pair of almond shaped ovaries in the pelvic cavity. Unlike the testes, the ovaries are intra-abdominal. A part of the ovary is attached to the broad ligament by a peritoneal fold known as **mesovarium**. Another part is attached to the wall of the uterus by an ovarian ligament.

Histologically, the ovary consists of single surface layer of squamous to cuboidal epithelial cells, constituting the germinal epithelium. Inner to this layer, there is a mass of dense irregular

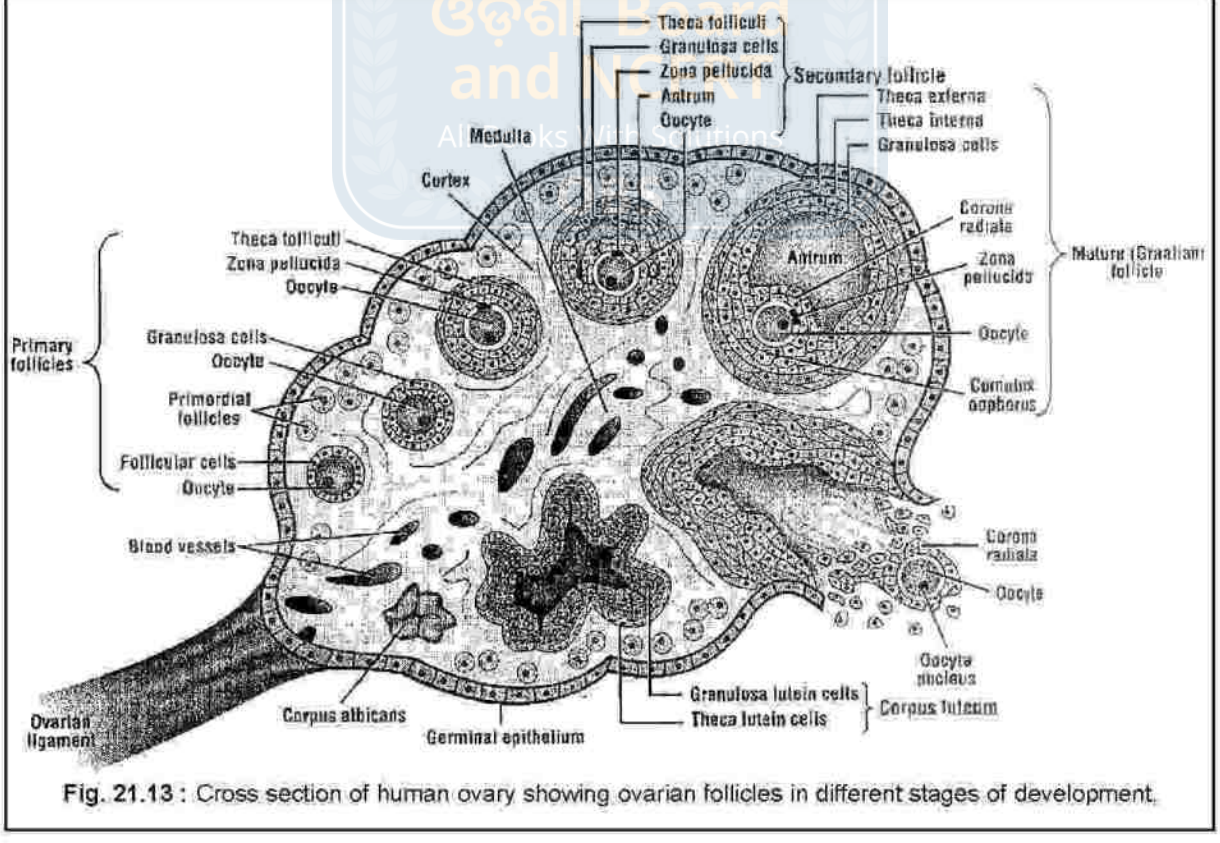


Fig. 21.13 : Cross section of human ovary showing ovarian follicles in different stages of development.

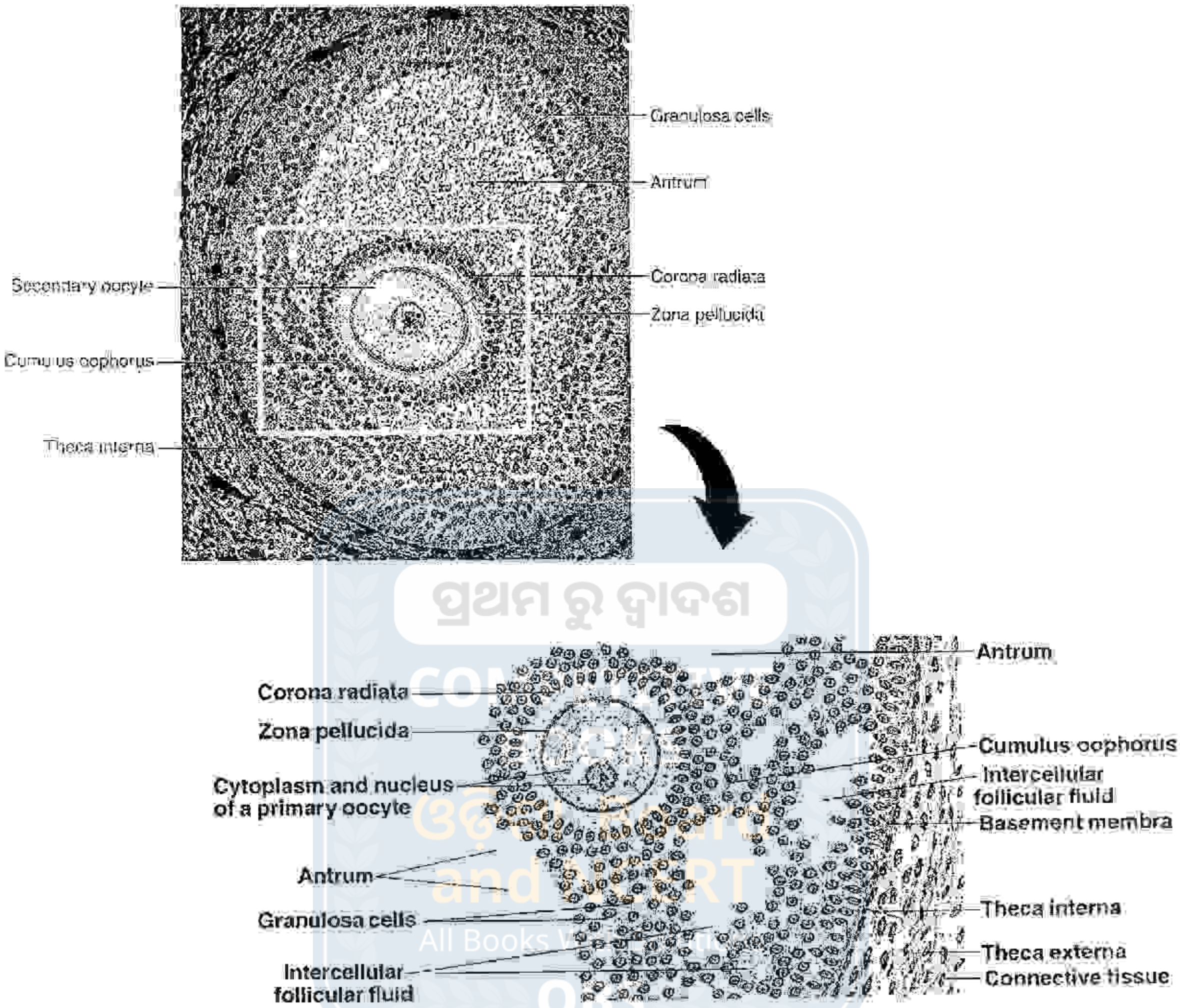


Fig.21.14 : A mature (graafian follicle)

connective tissue called **tunica albuginea**. Internal to the tunica albuginea is a cortex. Below the cortex, there is a highly vascularized mass of connective tissue called medulla or stroma. There is no distinct boundary between the cortex and medulla or stroma.

The germ cells differentiate as oogonia during the embryonic life. The oogonia divide by equational divisions and enter into the phase of maturation as primary oocytes. **The primary oocytes are arrested at the diplotene stage of the second maturation division and remain as such until the onset of puberty.** A primary oocyte is surrounded by a single layer of squamous follicle cells. This structure constitutes a **primordial follicle**. These follicles are situated in the cortex and at puberty, are stimulated by FSH and LH to differentiate into several later stage follicles, such as **primary**, **secondary** or **antral** and **mature** or **graafian follicles**. Concomitant with the changes in the oocyte, the surrounding follicle cells grow by mitosis and form layers of cuboidal cells, known as granulosa cells. The **granulosa cells** are surrounded by thecal cells from the stroma. A thin **basement membrane** separates the granulosa from the theca. As the follicle grows, a follicular fluid accumulates among the granulosa cells. As the fluid grows in volume, it accumulates in a cavity called **antrum.** The granulosa cells segregate into granulosa cells surrounding the developing oocyte and peripheral granulosa cells. The oocyte with its surrounding granulosa cells remain attached to the peripheral granulosa cells by a hillock of the same granulosa cells, known as **cumulus oophorus**. The ovarian follicle possessing the above mentioned features constitutes a **mature or graafian follicle (Fig. 21.14)**. It contains a secondary oocyte, ready for ovulation.

(b) Ovarian Hormones: The granulosa cells are the primary source of the **female steroid hormones**, collectively known as **estrogens**. The granulosa cells also secrete **inhibin**, which negatively feeds back FSH secretion from the anterior pituitary. The major estrogen secreted from the ovary is **estradiol**. The secondary oocyte is released from the graafian follicle, which then turns into a blood filled **corpus haemorrhagicum**. The blood is being absorbed *in situ* and the structure turns into a **corpus luteum**. Both the granulosa and thecal cells constitute the luteal cells, which start secreting **estradiol** and **progesterone**. Granulosa cells alone can't secrete estrogens. They require the help of thecal cells. The thecal cells secrete androgens under the stimulation of LH, which diffuse into granulosa cells and are converted into estrogens under the stimulation of FSH.

(c) Functions of Ovarian Hormones:

- Estradiol is responsible for the growth and development of the vagina, uterus, fallopian tube and oviduct at the onset of puberty.
- Along with prolactin (PRL), it is necessary for the growth of breasts at the onset of puberty.
- Though not remarkable like those in males, female secondary sexual characters develop and differentiate under the influence of estradiol.
- Estradiol with FSH and LH regulates the menstrual cycle.
- Inhibin negatively feeds back FSH secretion from the anterior pituitary.
- Progesterone is essential for preparing the uterus for implantation of the embryo following fertilization. In this case, the corpus luteum persists and continues to secrete progesterone. If fertilization doesn't occur, corpus luteum regresses.
- Progesterone is essential for the maintenance of pregnancy i.e. as long as pregnancy continues, corpus luteum persists and continues to secrete progesterone.

21.3. MECHANISM OF HORMONE ACTION :

Hormones are chemical messengers, which act on specific target cells and induce them to express an appropriate physiological response so as to make the cell function in a state of physiological homeostasis . In this process, a hormone molecule acts as the **first messenger**, which transmits a signal to the target cell in either of the two ways. It either transmits the signal to an intracellular molecule of the target cell or directly to the genes present in the nucleus of the target cell. Whatever may be the means, the hormone molecule acts as a signaling molecule and this signal is translated into an effect or response in the target cell. The expression of the response continues as long as the hormone molecule transmits the signal. When a state of equilibrium in respect of the particular response has reached, the hormone molecule stops transmitting the signal. The consequence is that the target cell stops expressing the response. The amplified intracellular physiological response induced by the signaling hormone is known as **signal transduction**.

All hormones act on their target cells by two fundamental mechanisms. A class of hormones, are water soluble or polar, which can't cross the plasma membrane lipid barrier, transmit their signals from outside on binding to their membrane integral protein receptors. These include hormones such as peptides and proteins, glycoproteins and catecholamines with the exception of thyroid hormones and glucocorticoids. All steroid hormones are lipid soluble. They can cross the lipid barrier and indeed, they do so and move to the nucleus via the cytoplasm and transmit the signal directly to the genes. Thus, the gene expression is either elevated or depressed.

21.3.1. Hormones that use second messenger mechanisms (Fig. 21.15) :

This mechanism is exhibited by **water soluble peptide and protein, glycoprotein and catecholamine hormones**. Each such hormone has a specific membrane integral receptor protein. Close to the receptor protein, on the inner side of the membrane, there is a **G protein (guanyl nucleotide protein)** in an inactive state. There is another membrane integral protein in close vicinity of the G protein, this time an enzyme, known as **adenylate or adenylyl cyclase**. It too is a membrane integral protein and is present in an inactive state. When activated, it catalyzes the conversion of ATP into 3′, 5′ cyclic AMP. This molecule acts as a **second**

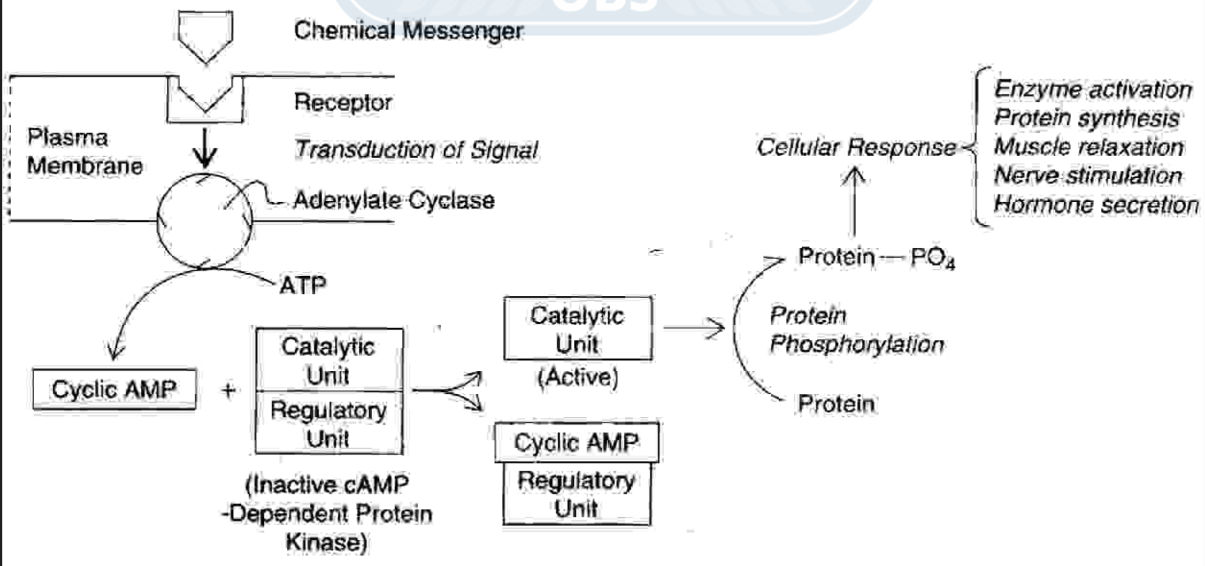


Fig. 21.15 : Mechanism of action of hormones that utilize second messenger.

messenger, the hormone molecule being the first messenger. **E.W.Sutherland (1972)** demonstrated the role of 3′,5′ cyclic AMP as the prime second messenger in the mechanism of the above mentioned class of hormones. The second messenger takes over from the hormone molecule the act of transmitting the signal in an intracellular environment. At the end the signal is translated into a response through one or a few biochemical reactions. At equilibrium, an intracellular enzyme, phosphodiesterase hydrolyses 3′, 5′ cyclic AMP into an inactive form. Under this situation, the signal transmission stops and the physiological response comes to a halt. Finally the hormone molecule dissociates from its receptor. In addition to cyclic AMP, **cyclic GMP (cyclic guanosine monophosphate), inositol triphosphate, diacyl glycerol** and **calcium ions** so act as second messengers.

21.3.2. Hormones that bind to nuclear receptors (Fig. 21.16) : Unlike the hormones discussed in the above section, steroid hormones are nonpolar and hence can cross the hydrophobic lipid barrier of the plasma membrane of target cells. **Thyroid hormones** and **glucocorticoids also can cross the barrier into target cells**. These hormone molecules are bound to their specific **protein receptors**, while in circulation. They cross over the plasma membrane barrier to the cytoplasm and are translocated to the nuclear envelop with the help of **cytoplasmic receptor** proteins. The molecules cross over the nuclear envelop and bind to their specific **nuclear receptors**. The nuclear receptor-hormone molecule complex then binds to a specific part of the DNA, known as **response element** of that particular hormone. The response element of the DNA (gene) undergoes transcription followed by translation. A polypeptide is synthesized, which indeed is the cellular response to that hormone molecule. This class of hormones, therefore, acts by elevating or depressing the expression of specific genes.

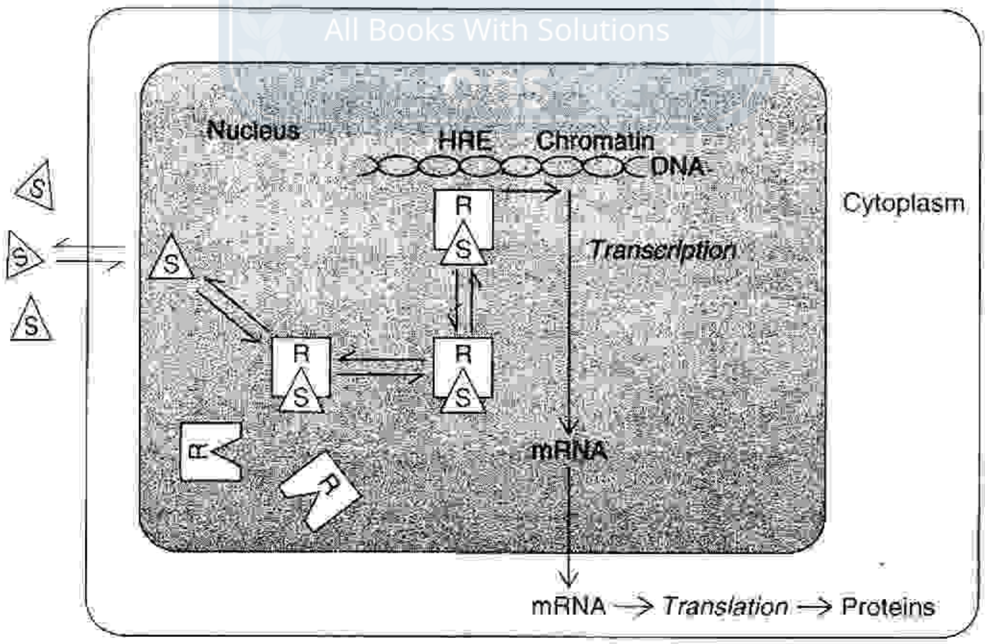


Fig. 21.16 : Mechanism of action of hormones that bind to nuclear receptors

21.4. HYPO AND HYPER ACTIVITY OF ENDOCRINE GLANDS :

Very precise quantities of hormones are required to exhibit a physiological response. Secondly, hormones act in their lowest possible concentrations. Therefore, hormone concentrations need to be delicately balanced. If there is a small fluctuation in the concentration of a hormone, there is a marked change in the physiological response. Mostly these changes are short lived and the function shifts back to normal by adjustments by several mechanisms. One of such mechanisms is the feedback mechanism. If the abnormal situation in the hormone concentration persists, we identify it as a malfunctioning of the endocrine gland. The glands do so due to infection, noxious chemical agents or loss of responsiveness to the target hormone. Hypo-activity of a gland refers to its sub-normal secretion of a hormone, while hyper-activity refers to above-normal secretion of a hormone. In the event of hypo- and hyper activity, some pathological conditions, sometimes very severe are expressed.

21.4.1. Hypo- and Hyper-secretion of Growth Hormone:

Growth hormone promotes skeletal growth by acting on **epiphysial cartilages of long bones** (epiphysis is the growing cartilaginous end of a long bone) of children and adolescents. This action is mediated by somatomedins. Recal that growth harmone doesn't directly act on its target cells, but rather through somatomednis. Somatomedins are synthesized by liver cells under the influence of growth harmone. Somatomedins act on chondrocytes (cartilage forming cells) and stimulate them to divide and secrete more and more cartilage substance. A part of this cartilage is changed into bone, thus enabling the bone to grow in length. The epiphyses become bony at the onset of puberty, but nevertheless, growth hormone continues to be secreted and continues to exercise its influence. Against this backdrop, let's consider three instances of abnormal growth hormone functioning.

- **Gigantism:**

  Hypersecretion of growth hormone in children produces gigantism. As mentioned earlier, growth hormone acts on epiphyses and promotes linear growth of long bones before the epiphyses have closed. Such children are known to grow to a height of upto eight feet.

21.4.1.1. Dwarfism: An inadequate secretion of growth hormone during the growing years results in **dwarfism**. Contrary to this concept on dwarfism, another condition of dwarfism has been identified as **Laron dwarfism**. In this case, there is an adequate growth hormone secretion. However, the target cells don't respond to the growth hormone molecules due to a lack of receptors. This is considered as a genetic defect.

21.4.1.2. Acromegaly: An excess secretion of growth hormone after the closure of the epiphyses can't lengthen the bones and hence can't increase the height. There is, however, disfigured growth of bones, wherever there is an opportunity of growth. The consequence is an elongation of jaw bones, deformities in the bones of the face, hands and feet. Accompanied by these changes, the soft tissues also grow and the skin becomes coarse.

21.4.2. Hypo- and Hyper functioning of Thyroid :

There is a very delicate hypothalamus-anterior pituitary-thyroid axis i.e. precise TRF secretion from the hypothalamus is required for the secretion of TSH from the anterior pituitary, which in turn stimulates the thyroid gland to release thyroid hormones into the blood. This axis needs to be at equilibrium and if it shifts, hypo- and hyper-functioning of the gland, manifested by severe to very severe pathological conditions arise. Hypo- and hyper-functioning of the thyroid are studied under hypo- and hyper-thyroidism heads, respectively.

21.4.2.1. Hypo-thyroidism: Subnormal secretion of thyroid hormones from the thyroid gland is known as hypo-thyroidism. There are four possible reasons for the subnormal secretion of thyroid hormones, namely, **defective thyroid, insufficient hypothalamic thyrotropin releasing hormone, inadequate TSH secretion from the anterior pituitary** and **intake of inadequate iodine** in the diet. It is manifested in three forms, such as, **endemic (iodine deficiency) goiter, myxedema** and **cretinism**.

(a) Endemic (Iodine deficiency) Goiter: This thyroid abnormality results from a deficiency of dietary iodine. In the absence of iodine, the thyroid is unable to produce sufficient T_3 and T_4 (thyroid hormones) and hence negative feedback mechanisms of the hypothalamus and anterior pituitary is lacking. The consequence is a high level of secretion of TSH from the anterior pituitary, which exerts its direct influence on the thyroid gland. The thyroid is stimulated to undergo hyperplacia (abnormal growth), visible from outside as a swelling in the neck region. Such people have a low basal metabolic rate and decreased resistance to cold stress. They gain body weight and become lethargic.

- **Myxedema:**

  Hypothyroidism in adults causes myxedema. It is caused by an accumulation of mucoprotein in the subcutaneous connective tissue. The symptoms include swelling of the hands, feet, face and tissue surrounding the eyes.

(b) Cretinism: This is another form of hypo-thyroidism. Greatest risk of developing this abnormality is between first trimester of prenatal life to six months after birth. Children require thyroxine for normal body growth, since thyroxine promotes protein synthesis. More importantly, during the prenatal life, thyroxine is essential for proper development of the central nervous system. If, during this period, thyroid hormones are absent, normal development of the brain is hampered and such children suffer from severe mental retardation. Treatment with thyroxine soon after birth restores the development of normal intelligence.

21.4.2.2. Hyper-thyroidism : Above normal secretion of thyroid hormones causes hyper-thyroidism. Recall from your study on mechanism of hormone action that glycoprotein hormones and a few more bind to membrane integral receptors of target cells. TSH, being a glycoprotein hormone from the anterior pituitary binds to receptors on thyroid gland cells and stimulates them to secrete thyroid hormones. However, in an abnormal situation, the protein receptors behave as though they are foreign molecules and incite the immune system to produce antibodies, which are called **autoantibodies**. These autoantibodies, in a competition to TSH, bind to the TSH receptors and stimulate more and more thyroid hormone production and release. Excess thyroid hormones can't negatively feed back the stimulation by autoantibodies. The consequence is a continuous stimulation of the thyroid, which then undergoes hyperplacia and develops a goiter. This condition has been termed as **Graves' disease** or **toxic goiter** or **thyrotoxicosis**. This condition is accompanied by bulging eyes or **exopthalmus** due to edema in orbits and hence this abnormality is also identified as **exopthalmic goiter**. There is an increase in the basal metabolic rate accompanied by weight loss, nervousness, irritability and intolerance to heat.

21.4.3. Diabetes mellitus :

Diabetes mellitus is the physiological consequence of an increase in blood glucose concentration above normal (hyperglycemia). It was known that the deficiency of insulin only contributes towards hyperglycemia. **Frederick Banting** and **Charles Best (1921)** demonstrated that insulin deficiency causes hyperglycemia and this physiological condition is known as diabetes mellitus. This condition has been classed as **type 1 diabetes mellitus** or **insulin dependent diabetes mellitus** (explained in the text later).

However, it is now known that there may be adequate insulin, but nevertheless there is hyperglycemia. This indicates that in some instances, insulin may be unable to stimulate the uptake of glucose by the cells. The role of insulin is to facilitate the uptake of glucose from the blood by cells. Diabetes mellitus is characterized by **polyurea (frequent urination), polydipsia (frequent feeling of thirst), polyphagia (increased apetite), glycosuria (excretion of sugar in the urine), hyperglycemia (elevated blood glucose level), ketosis (formation of ketone bodies), acidosis** and **coma**.

There are two major forms of diabetes mellitus: type **1. [insulin dependent diabetes mellitus (IDDM)]** and **type 2. [non insulin depencent diabetes mellitus (NIDDM)]**.

21.4.3.1. Type 1: Type 1 diabetes, once known as **juvenile onset diabetes**, since it appears in people below the age of 20, is insulin dependent. In type 1, the beta cells are progressively destroyed by autoimmune attack by killer T lymphocytes. The consequence is that there is an insulin deficiency. Exogenous insulin is required to sustain life. It accounts for only 10% of documented diabetes cases. It is non-genetic. Obesity has no correlation with the incidence of type 1 diabetes.

21.4.3.2. Type 2: Type 2 accounts for 90% of the documented cases. Since it afflicts people over the age of 40, it is also known as **maturity onset diabetes**. It occurs due to an inability of insulin to facilitate the uptake of plasma glucose by cells. It is hereditary. People with both type 2 parents are at a high risk of getting this diabetes.

21.4.4. Addison's Disease :

It is a disorder of the adrenal cortex. and was identified and characterized by **Addison (1855)**. It is caused by an inadequate secretion of both glucocorticoids and mineralocorticoids from the adrenal cortex. Inadequate glucocorticoids fail to negatively feed back the ACTH secretion from the anterior pituitary. Mineralocorticoid and glucocorticoid secreting cells may be exhausted leading to the complete destruction of the adrenal cortex. The symptoms are hypoglycemia, low blood pressure, increased melanin pigmentation of the skin, sodium and potassium imbalance, dehydration, rapid weight loss and general weakness. A person, if not administered with corticosteroids, dies sooner or later mainly due to an electrolyte imbalance. The one described is Addison's disease of primary origin. Secondary and tertiary origins of the same may be due to hypothalamus (a failure of CRH secretion) and anterior pituitary (absence of functional ACTH secreting cells), respectively.

SAMPLE QUESTIONS

GROUP - A

(Objective-type Questions)

1. Choose the correct answer:

(i) Banting and Best (1921) established that:

(a) Deficiency of thyroxine causes hypothyroidism
(b) Oversecretion of cortisol causes Cushing's syndrome
(c) Deficiency of insulin causes hyperglycemia
(d) Oversecretion of growth hormone causes gigantism

(ii) Which one of the facts about hormones is correct?

(a) Hormones are proteins
(b) Hormones are released into the blood
(c) Hormones have no specific targets
(d) Hormones are secreted by exocrine glands.

(iii) Which one of the following is not true?

(a) Steroid hormones act through second messengers
(b) Glycoprotein hormones include TSH, FSH and LH.
(c) Epinephrine and norepinephrine are catecholamines.
(d) Sertoli cells secrete androgen binding protein.

(iv) Which of the following statements about the hypothalamic releasing and release-inhibiting hormones is true?

(a) They are secreted into capillaries in the median eminence.
(b) They are transported by portal veins to the anterior pituitary.
(c) They stimulate the secretion of specific hormones from the anterior pituitary.
(d) All of the above are true.

(v) The hormone primarily responsible for increasing the basal metabolic rate and promoting the maturation of the brain is:

(a) Cortisol (b) ACTH
(c) TSH (d) Thyroxine

(vi) Which of the following statements about adrenal cortex is true?

(a) It is not innervated by nerve fibers.
(b) It secretes some androgens.
(c) The zona glomerulosa secretes aldosterone.
(d) The zona fasciculata is stimulated by ACTH.
(e) All of these are true.

(vii) Which of the following statements about insulin is true?

(a) It is secreted by alpha cells of islet of Langerhans.
(b) It is secreted in response to a rise in blood glucose concentration.

(c) It stimulates the synthesis of glycogen and fat.
(d) Both (a) and (b) are true.
(e) Both (b) and (c) are true.

(viii) Steroid hormones are secreted by
(a) Adrenal cortex only.
(b) Gonads only.
(c) Thyroid only.
(d) Both (a) and (b).
(e) Both (b) and (c).

(ix) The secretion of which of the following hormones will be augmented in a person with endemic goiter.
(a) TSH
(b) Thyroxine
(c) Triiodothyronine
(d) All of the above.

(x) Which of these hormones uses cAMP as a second messenger?
(a) Testosterone (b) Cortisol
(c) Insulin (d) Epinephrine

(xi) Which of these hormones may have a role in circadian rhythm.
(a) Estradiol (b) Insulin
(b) ACTH (d) Melatonin

(xii) Which one of the following about ACTH is true?
(a) It stimulates the entire adrenal cortex.
(b) It stimulates zona glomerulosa only.
(c) It stimulates both zona fasciculata and reticularis.
(d) It stimulates zona reticularis only.

(xiii) Which one of the following statements is false?
(a) Corpus luteum secretes progesterone.
(b) Progesterone maintains pregnancy.
(c) FSH stimulates interstitial cells of Leydig.
(d) Sertoli cells are somatic cells, secreting androgen binding protein.

(xiv) Granulosa cells secrete:
(a) Cortisol (b) Estadiol
(b) Testosteron (d) Progesterone

(xv) Which of the following is correct?
(a) T_4 changes into T_3 in the target cell.
(b) T_3 changes into T_4 in the taget cell.
(c) T_3 and T_4 act as such on target cell.
(d) T_3 changes into T_4 and vice versa in the target cells.

2. **Express the following statements in one word:**
   - (i) The study of glands secreting hormones and their functions.
   - (ii) The part of the brain that secretes the releasing and release-inhibiting hormones.
   - (iii) The stalk that attaches the pituitary with the hypothalamus.
   - (iv) The part of the hypothalamus, where the primary capillary plexus is present.
   - (v) The division of the anterior pituitary that secretes the tropic hormones.
   - (vi) The hormone, which acts on the renal tubule and promotes the absorption of water.
   - (vii) The hormone that regulates the height before adolescence.
   - (viii) The hormone that promotes early stages of gametogenesis.
   - (ix) The hormone that promotes the development of breasts.
   - (x) The hormone that acts on the smooth muscle of uterus and facilitates the birth of a baby.
   - (xi) The blood vessel that carries the releasing release-inhibiting hormones from the hypothalamus to the anterior pituitary.
   - (xii) The iodinated glycoprotein present in the colloid of the thyroid.
   - (xiii) Hypothyroidism in children with severe mental retardation.
   - (xiv) Hyperthyroidism, which is caused by auto-immune attack
   - (xv) The hormone that stimulates the interstitial cells of the gonads.
   - (xvi) A synonym for adrenal gland.
   - (xvii) The cortical steroid hormone that regulates mineral metabolism.
   - (xviii) The pathological condition in which inadequate glucocorticoids and mineralocorticoid fail to negatively feedback the secretion of ACTH from the anterior pituitary.
   - (xix) The hormone that fluctuates in its concentration, when one flies different time zones.
   - (xx) The formation of glucose from noncarbohydrates.
   - (xxi) Breakdown of glycogen into glucose.
   - (xxii) The interstitial cells that secrete androgens.
   - (xxiii) The graafian follicle turns into a progesterone secreting endocrine structure following ovulation.
   - (xxiv) The phenotypic characters, which identify the sex of the individual.
   - (xxv) A collective name for adrenal medullary hormones.

3. **Correct the sentences without changing the words underlined:**
   - (i) Thyroid stimulating hormone is an <u>amine hormone</u>.
   - (ii) Posterior pituitary (neurohypophysis) <u>originates from neural ectoderm</u>.
   - (iii) Pars tuberalis secretes <u>all the tropic homones of the anterior pituitary</u>.
   - (iv) <u>Pituitary is attached to the</u> epithalamus.
   - (v) Growth hormone induces <u>hyperglycemia</u>.

(vi) Growth hormone excess in an adult human causes gigantism.

(vii) Prolactin induces milk ejection.

(viii) Adrenocorticotropic hormone acts on adrenal gland.

(ix) Deficiency of antidiuretic hormone causes diabetes mellitus.

(x) Releasing inhibiting hormones are secreted from the posterior pituitary.

(xi) Calcitonin is secred from the parathyroid gland.

(xii) Alpha cells of islet of Langerhans secrete somatostatin.

(xiii) Adrenocorticotropic hormone acts on zona glomerulosa and promotes the secretion of aldosterone.

(xiv) Cortisol and epinephrine are hyperglycemic by promoting gluconeogenesis and glycogenolysis, respectively.

(xv) Cells of the adrenal cortex are called chromaffin cells.

(xvi) Day light induces the pineal gland to secrete less melatonin.

(xvii) Sertoli cells secrete androgens.

(xviii) Granulosa cells of the ovary secrete estrogens.

(xix) Steroid hormones use the second messenger mechanism in their action on target cells.

(xx) Dwarfism is a consequence of prolactin deficiency before adolescence.

(xxi) Deficiency of dietary iodine causes thyrotoxicosis.

4. Fill in the blanks with appropriate words:

(i) The active substance from the small intestine that stimulated the release of pancreatic juice was discovered by ______ and ______ in 1902.

(ii) The word hormone was used by ______ in 1905 for the active substance, secretin.

(iii) Glycoprotein hormones include ______, FSH and LH.

(iv) Epinephrine and norepinephrine together constitute a group of hormones, known as ______.

(v) All steroid hormones are derived from the parent compound, ______.

(vi) The role of 3,5 cAMP as a second messenger in the mechanism of hormone action was suggested by ______.

(vii) Some hormones act through cell membrane receptors that stimulate adenylate cyclase activity and formation of ______.

(viii) The pituitary gland is attached to the floor of a part of fore brain, known as ______.

(ix) The pituitary is constituted by adenohypophysis and ______.

(x) The anterior pituitary is regulated by ______, a part of the diencephalon.

(xi) Adrenal medulla is constituted by cells that stain with chromates and hence are known as ______ cells.

(xii) Posterior pituitary secretes two hormones, namely ______ and ______.

(xiii) The group of hormones that binds to nuclear receptors is derived from the parent compound, ______.

(xiv) Tropic hormones are secreted from _____ of the anterior pituitary.

(xv) The hormone, _____ promotes breast development in the female.

(xvi) Oversecretion of growth hormone in adults causes an abnormality, known as _____.

(xvii) ACTH is formed from a larger polypeptide, known as _____.

(xviii) FSH stimulates the Sertoli cells to synthesize androgen binding protein and two hormones, namely inhibin and _____.

(xix) During development, the regression of mullerian ducts occur in the male by a hormone called antimullerian hormone. This hormone is secreted from the _____ cells of the testis.

(xx) The hormone _____ is responsible for the ejection of milk from the breast of the lactating mother.

(xxi) The growth promoting effects of growth hormone are mediated by _____, polypeptides synthesized by the liver cells under its influence.

(xxii) Delta cells of the pancreas synthesize _____, which acts as growth hormone inhibiting hormone.

(xxiii) Parafollicular cells of the thyroid gland secrete a hormone, known as _____.

(xxiv) The iodinated glycoprotein present in the thyroid follicle is known as _____.

(xxv) Interstitial cells of the testis are the targets of action of _____.

(xxvi) Blood calcium level is monitored by hormones _____ and _____.

(xxvii) The releasing and inhibiting hormones of the hypothalamus act on the anterior pituitary via a blood vessel, known as _____.

(xxviii) Alpha cells of the pancreatic islets secrete a hormone, known as _____.

(xxix) Over secretion of thyroid hormones causes an abnormality of the thyroid, known as _____.

(xxx) The enzyme _____ catalyzes the conversion of ATP into 3,5 cyclic AMP.

(xxxi) Estrogens are secreted by _____ cells of the ovary.

(xxxii) Corpus luteum is an important source of a steroid hormone, _____.

(xxxiii) Day Night cycle is regulated by a hormone, _____, secreted from _____.

(xxxiv) _____ has been designated as emergency hormone.

(xxxv) Inadequate secretion of both glucocorticoids and mineralocorticoids from the adrenal cortex causes a disease, known as _____.

(xxxvi) During stress, the immune system is suppressed by the hormone _____.

(xxxvii) There is an insulin insufficiency in _____ diabetes mellitus.

(xxxviii) Severe retardation of the nervous system in children due to a lack of thyroid hormones has been identified as _____.

(xxxix) Excess release of _____ can lead to water retention and consequently high blood pressure.

GROUP - B

(Short Answer-type Questions)

1. Answer the following within three sentences each:

(i) What is the relationship between hypothalamus and anterior pituitary?
(ii) Pituitary is not a master gland. Is it correct?
(iii) How are insulin and glucagon related?
(iv) Name the hormone secreted by the delta cells of the pancreatic islet. What is its function?
(v) Pancreas is a mixocrine gland. Explain
(vi) Why are catecholamines termed as emergency hormones?
(vii) How does cortisol handle stress?
(viii) Explain diabetes incipidus.
(ix) What is the main cause of type 1 diabetes mellitus?
(x) What is corpus luteum? What is its role?
(xi) What are secondary sexual characters? Which hormone regulates these in males?
(xii) What is a glycoprotein hormone? How many of these you have studied?
(xiii) What is a steroid hormone? How does it act on its target cell?
(xiv) How many hormones are secreted from the posterior pituitary? Mention one important function of each.
(xv) What is a flight or flight response?

2. Differentiate between two words in the following pairs of words:

(a) Exocrine gland and Endocrine gland
(b) Enzyme and Hormone
(c) Peptide hormone and Steroid hormone
(d) Anterior pituitary and Posterior pituitary
(e) Insulin and Glucagon
(f) Adrenal cortex and Adrenal medulla
(g) Epinephrine and Norepinephrine
(h) First messenger and Second messenger
(i) Testosterone and Estradiol
(j) Follicle stimulating hormone and Lutenizing hormone
(k) Estrogen and Progesterone
(l) Hypothyroidism and Hyperthyroidism
(m) Endemic goiter and Exopthalmic goiter
(n) Type I diabetes mellitus and Type II diabetes mellitus
(o) Diabetes mellitus and Diabetes incipidus

GROUP - C

(Long Answer-type Questions)

1. Give an account of the structure of human pituitary gland and describe the functions of hormones secreted from it.

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