

this. Joints are points of contact between bones, or between bones and cartilages. Force generated by the muscles is used to carry out movement through joints, where the joint acts as a fulcrum. The movability at these joints vary depending on different factors. Joints have been classified into three major structural forms, namely, fibrous, cartilaginous and synovial.

Fibrous joints do not allow any movement. This type of joint is shown by the flat skull bones which fuse end-to-end with the help of dense fibrous connective tissues in the form of sutures, to form the cranium.

In **cartilaginous joints**, the bones involved are joined together with the help of cartilages. The joint between the adjacent vertebrae in the vertebral column is of this pattern and it permits limited movements.

Synovial joints are characterised by the presence of a fluid filled synovial cavity between the articulating surfaces of the two bones. Such an arrangement allows considerable movement. These joints help in locomotion and many other movements. Ball and socket joint (between humerus and pectoral girdle), hinge joint (knee joint), pivot joint (between atlas and axis), gliding joint (between the carpals) and saddle joint (between carpal and metacarpal of thumb) are some examples.

20.5 DISORDERS OF MUSCULAR AND SKELETAL SYSTEM

Myasthenia gravis: Auto immune disorder affecting neuromuscular junction leading to fatigue, weakening and paralysis of skeletal muscle.

Muscular dystrophy: Progressive degeneration of skeletal muscle mostly due to genetic disorder.

Tetany: Rapid spasms (wild contractions) in muscle due to low Ca^{++} in body fluid.

Arthritis: Inflammation of joints.

Osteoporosis: Age-related disorder characterised by decreased bone mass and increased chances of fractures. Decreased levels of estrogen is a common cause.

Gout: Inflammation of joints due to accumulation of uric acid crystals.

SUMMARY

Movement is an essential feature of all living beings. Protoplasmic streaming, ciliary movements, movements of fins, limbs, wings, etc., are some forms exhibited by animals. A voluntary movement which causes the animal to change its place, is

called locomotion. Animals move generally in search of food, shelter, mate, breeding ground, better climate or to protect themselves.

The cells of the human body exhibit amoeboid, ciliary and muscular movements. Locomotion and many other movements require coordinated muscular activities. Three types of muscles are present in our body. Skeletal muscles are attached to skeletal elements. They appear striated and are voluntary in nature. Visceral muscles, present in the inner walls of visceral organs are nonstriated and involuntary. Cardiac muscles are the muscles of the heart. They are striated, branched and involuntary. Muscles possess excitability, contractility, extensibility and elasticity.

Muscle fibre is the anatomical unit of muscle. Each muscle fibre has many parallelly arranged myofibrils. Each myofibril contains many serially arranged units called sarcomere which are the functional units. Each sarcomere has a central 'A' band made of thick myosin filaments, and two half 'I' bands made of thin actin filaments on either side of it marked by 'Z' lines. Actin and myosin are polymerised proteins with contractility. The active sites for myosin on resting actin filament are masked by a protein-troponin. Myosin head contains ATPase and has ATP binding sites and active sites for actin. A motor neuron carries signal to the muscle fibre which generates an action potential in it. This causes the release of Ca^{++} from sarcoplasmic reticulum. Ca^{++} activates actin which binds to the myosin head to form a cross bridge. These cross bridges pull the actin filaments causing them to slide over the myosin filaments and thereby causing contraction. Ca^{++} are then returned to sarcoplasmic reticulum which inactivate the actin. Cross bridges are broken and the muscles relax.

Repeated stimulation of muscles leads to fatigue. Muscles are classified as Red and White fibres based primarily on the amount of red coloured myoglobin pigment in them.

Bones and cartilages constitute our skeletal system. The skeletal system is divisible into axial and appendicular. Skull, vertebral column, ribs and sternum constitute the axial skeleton. Limb bones and girdles form the appendicular skeleton. Three types of joints are formed between bones or between bone and cartilage – fibrous, cartilaginous and synovial. Synovial joints allow considerable movements and therefore, play a significant role in locomotion.

EXERCISES

1. Draw the diagram of a sarcomere of skeletal muscle showing different regions.
2. Define sliding filament theory of muscle contraction.
3. Describe the important steps in muscle contraction.

4. Write true or false. If false change the statement so that it is true.
- (a) Actin is present in thin filament
 - (b) H-zone of striated muscle fibre represents both thick and thin filaments.
 - (c) Human skeleton has 206 bones.
 - (d) There are 11 pairs of ribs in man.
 - (e) Sternum is present on the ventral side of the body.

5. Write the difference between :

- (a) Actin and Myosin
- (b) Red and White muscles
- (c) Pectoral and Pelvic girdle

6. Match Column I with Column II :

Column I

- (a) Smooth muscle
- (b) Tropomyosin
- (c) Red muscle
- (d) Skull

Column II

- (i) Myoglobin
- (ii) Thin filament
- (iii) Sutures
- (iv) Involuntary

7. What are the different types of movements exhibited by the cells of human body?
8. How do you distinguish between a skeletal muscle and a cardiac muscle?
9. Name the type of joint between the following:-
- (a) atlas/axis
 - (b) carpal/metacarpal of thumb
 - (c) between phalanges
 - (d) femur/acetabulum
 - (e) between cranial bones
 - (f) between pubic bones in the pelvic girdle

10. Fill in the blank spaces:

- (a) All mammals (except a few) have _____ cervical vertebra.
- (b) The number of phalanges in each limb of human is _____
- (c) Thin filament of myofibril contains 2 'F' actins and two other proteins namely _____ and _____.
- (d) In a muscle fibre Ca^{++} is stored in _____
- (e) _____ and _____ pairs of ribs are called floating ribs.
- (f) The human cranium is made of _____ bones.

CHAPTER 21

NEURAL CONTROL AND COORDINATION

- 21.1 *Neural System*
- 21.2 *Human Neural System*
- 21.3 *Neuron as Structural and Functional Unit of Neural System*
- 21.4 *Central Neural System*
- 21.5 *Reflex Action and Reflex Arc*
- 21.6 *Sensory Reception and Processing*

As you know, the functions of the organs/organ systems in our body must be coordinated to maintain homeostasis. **Coordination** is the process through which two or more organs interact and complement the functions of one another. For example, when we do physical exercises, the energy demand is increased for maintaining an increased muscular activity. The supply of oxygen is also increased. The increased supply of oxygen necessitates an increase in the rate of respiration, heart beat and increased blood flow via blood vessels. When physical exercise is stopped, the activities of nerves, lungs, heart and kidney gradually return to their normal conditions. Thus, the functions of muscles, lungs, heart, blood vessels, kidney and other organs are coordinated while performing physical exercises. In our body the neural system and the endocrine system jointly coordinate and integrate all the activities of the organs so that they function in a synchronised fashion.

The neural system provides an organised network of point-to-point connections for a quick coordination. The endocrine system provides chemical integration through hormones. In this chapter, you will learn about the neural system of human, mechanisms of neural coordination like transmission of nerve impulse, impulse conduction across a synapse and the physiology of reflex action.

21.1 NEURAL SYSTEM

The neural system of all animals is composed of highly specialised cells called **neurons** which can detect, receive and transmit different kinds of stimuli.

The neural organisation is very simple in lower invertebrates. For example, in *Hydra* it is composed of a network of neurons. The neural system is better organised in insects, where a brain is present along with a number of ganglia and neural tissues. The vertebrates have a more developed neural system.

21.2 HUMAN NEURAL SYSTEM

The human neural system is divided into two parts :

- (i) the **central neural system** (CNS)
- (ii) the **peripheral neural system** (PNS)

The CNS includes the **brain** and the **spinal cord** and is the site of information processing and control. The PNS comprises of all the nerves of the body associated with the CNS (brain and spinal cord). The nerve fibres of the PNS are of two types :

- (a) **afferent fibres**
- (b) **efferent fibres**

The afferent nerve fibres transmit impulses from tissues/organs to the CNS and the efferent fibres transmit regulatory impulses from the CNS to the concerned peripheral tissues/organs.

The PNS is divided into two divisions called **somatic neural system** and **autonomic neural system**. The somatic neural system relays impulses from the CNS to skeletal muscles while the autonomic neural system transmits impulses from the CNS to the involuntary organs and smooth muscles of the body. The autonomic neural system is further classified into **sympathetic neural system** and **parasympathetic neural system**.

21.3 NEURON AS STRUCTURAL AND FUNCTIONAL UNIT OF NEURAL SYSTEM

A neuron is a microscopic structure composed of three major parts, namely, **cell body**, **dendrites** and **axon** (Figure 21.1). The cell body contains cytoplasm with typical cell organelles and certain granular bodies called **Nissl's granules**. Short fibres which branch repeatedly and project out of the cell body also contain Nissl's granules and are called dendrites. These fibres transmit impulses towards the cell body. The axon is a long

fibre, the distal end of which is branched. Each branch terminates as a bulb-like structure called **synaptic knob** which possess synaptic vesicles containing chemicals called **neurotransmitters**. The axons transmit nerve impulses away from the cell body to a synapse or to a neuro-muscular junction. Based on the number of axon and dendrites, the neurons are divided into three types, i.e., **multipolar** (with one axon and two or more dendrites; found in the cerebral cortex), **bipolar** (with one axon and one dendrite, found in the retina of eye) and **unipolar** (cell body with one axon only; found usually in the embryonic stage). There are two types of axons, namely, **myelinated** and **non-myelinated**. The myelinated nerve fibres are enveloped with **Schwann cells**, which form a myelin sheath around the axon. The gaps between two adjacent myelin sheaths are called **nodes of Ranvier**. Myelinated nerve fibres are found in spinal and cranial nerves. Unmyelinated nerve fibre is enclosed by a Schwann cell that does not form a myelin sheath around the axon, and is commonly found in autonomous and the somatic neural systems.

21.3.1 Generation and Conduction of Nerve Impulse

Neurons are excitable cells because their membranes are in a polarised state. *Do you know why the membrane of a neuron is polarised?* Different types of ion channels are present on the neural membrane. These ion channels are selectively permeable to different ions. When a neuron is not conducting any impulse, i.e., resting, the axonal membrane is comparatively more permeable to potassium ions (K^+) and nearly impermeable to sodium ions (Na^+). Similarly, the membrane is impermeable to negatively charged proteins present in the axoplasm. Consequently, the axoplasm inside the axon contains high concentration of K^+ and negatively charged proteins and low concentration of Na^+ . In contrast, the fluid outside the axon contains a low concentration of K^+ , a high concentration of Na^+ and thus form a concentration gradient. These ionic gradients across the resting membrane are maintained by the active transport of ions by the sodium-potassium pump which transports 3 Na^+ outwards for 2 K^+ into the cell. As a result, the outer surface of the axonal membrane possesses a positive charge while its inner surface

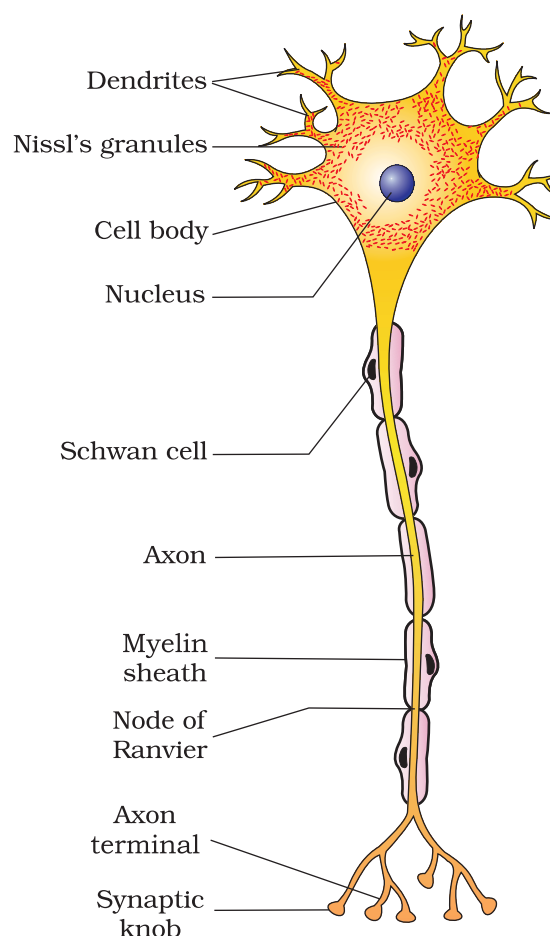


Figure 21.1 Structure of a neuron

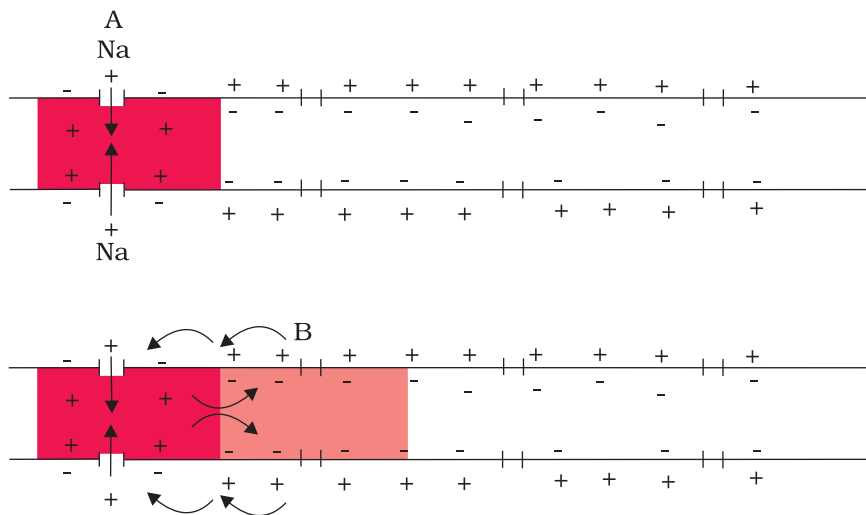


Figure 21.2 Diagrammatic representation of impulse conduction through an axon (at points A and B)

becomes negatively charged and therefore is polarised. The electrical potential difference across the resting plasma membrane is called as the **resting potential**.

You might be curious to know about the mechanisms of generation of nerve impulse and its conduction along an axon. When a stimulus is applied at a site (Figure 21.2 e.g., point A) on the polarised membrane, the membrane at the site A becomes freely permeable to Na⁺. This leads to a rapid influx of Na⁺ followed by the reversal of the polarity at that site, i.e., the outer surface of the membrane becomes negatively charged and the inner side becomes positively charged. The polarity of the membrane at the site A is thus reversed and hence depolarised. The electrical potential difference across the plasma membrane at the site A is called the **action potential**, which is in fact termed as a **nerve impulse**. At sites immediately ahead, the axon (e.g., site B) membrane has a positive charge on the outer surface and a negative charge on its inner surface. As a result, a current flows on the inner surface from site A to site B. On the outer surface current flows from site B to site A (Figure 21.2) to complete the circuit of current flow. Hence, the polarity at the site is reversed, and an action potential is generated at site B. Thus, the **impulse** (action potential) generated at site A arrives at site B. The sequence is repeated along the length of the axon and consequently the impulse is conducted. The rise in the stimulus-induced permeability to Na⁺ is extremely short-lived. It is quickly followed by a rise in permeability to K⁺. Within a fraction of a second, K⁺ diffuses outside the membrane and restores the resting potential of the membrane at the site of excitation and the fibre becomes once more responsive to further stimulation.

21.3.2 Transmission of Impulses

A nerve impulse is transmitted from one neuron to another through junctions called synapses. A **synapse** is formed by the membranes of a pre-synaptic neuron and a post-synaptic neuron, which may or may not be separated by a gap called **synaptic cleft**. There are two types of synapses, namely, electrical synapses and chemical synapses. At electrical synapses, the membranes of pre- and post-synaptic neurons are in very close proximity. Electrical current can flow directly from one neuron into the other across these synapses. Transmission of an impulse across electrical synapses is very similar to impulse conduction along a single axon. Impulse transmission across an electrical synapse is always faster than that across a chemical synapse. Electrical synapses are rare in our system.

At a chemical synapse, the membranes of the pre- and post-synaptic neurons are separated by a fluid-filled space called synaptic cleft (Figure 21.3). *Do you know how the pre-synaptic neuron transmits an impulse (action potential) across the synaptic cleft to the post-synaptic neuron?* Chemicals called neurotransmitters are involved in the transmission of impulses at these synapses. The axon terminals contain vesicles filled with these neurotransmitters. When an impulse (action potential) arrives at the axon terminal, it stimulates the movement of the synaptic vesicles towards the membrane where they fuse with the plasma

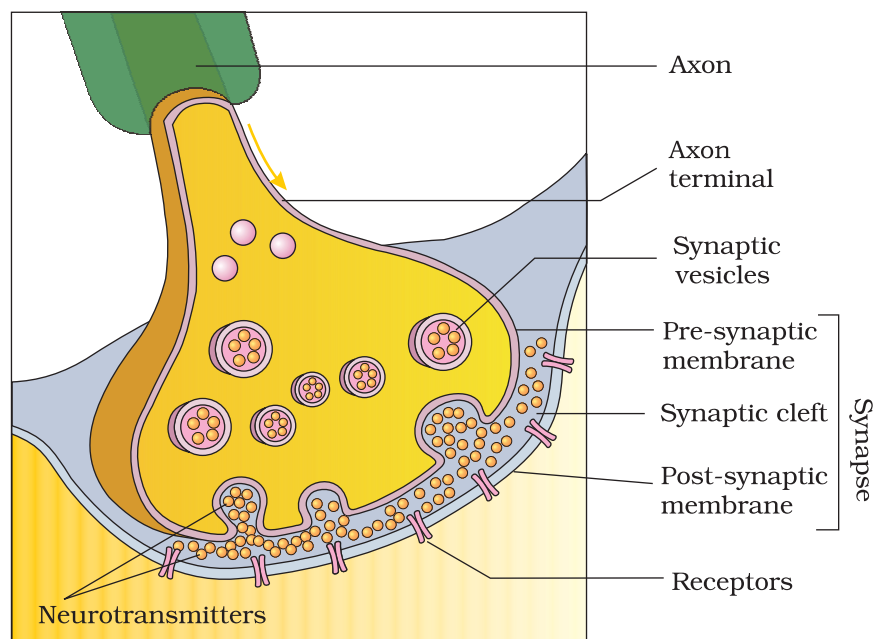


Figure 21.3 Diagram showing axon terminal and synapse

membrane and release their neurotransmitters in the synaptic cleft. The released neurotransmitters bind to their specific **receptors**, present on the post-synaptic membrane. This binding opens ion channels allowing the entry of ions which can generate a new potential in the post-synaptic neuron. The new potential developed may be either excitatory or inhibitory.

21.4 CENTRAL NEURAL SYSTEM

The brain is the central information processing organ of our body, and acts as the 'command and control system'. It controls the voluntary movements, balance of the body, functioning of vital involuntary organs (e.g., lungs, heart, kidneys, etc.), thermoregulation, hunger and thirst, circadian (24-hour) rhythms of our body, activities of several endocrine glands and human behaviour. It is also the site for processing of vision, hearing, speech, memory, intelligence, emotions and thoughts.

The human brain is well protected by the skull. Inside the skull, the brain is covered by **cranial meninges** consisting of an outer layer called **dura mater**, a very thin middle layer called **arachnoid** and an inner layer (which is in contact with the brain tissue) called **pia mater**. The brain can be divided into three major parts: (i) **forebrain**, (ii) **midbrain**, and (iii) **hindbrain** (Figure 21.4).

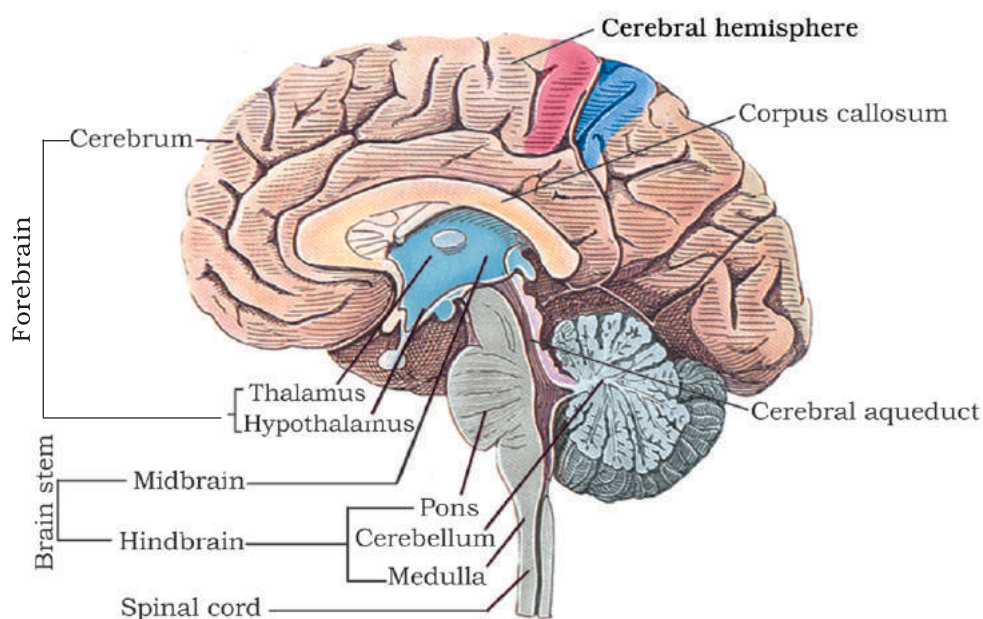


Figure 21.4 Diagram showing sagittal section of the human brain

21.4.1 Forebrain

The forebrain consists of **cerebrum**, **thalamus** and **hypothalamus** (Figure 21.4). Cerebrum forms the major part of the human brain. A deep cleft divides the cerebrum longitudinally into two halves, which are termed as the left and right **cerebral hemispheres**. The hemispheres are connected by a tract of nerve fibres called **corpus callosum**. The layer of cells which covers the cerebral hemisphere is called cerebral cortex and is thrown into prominent folds. The cerebral cortex is referred to as the grey matter due to its greyish appearance. The neuron cell bodies are concentrated here giving the colour. The cerebral cortex contains motor areas, sensory areas and large regions that are neither clearly sensory nor motor in function. These regions called as the **association areas** are responsible for complex functions like intersensory associations, memory and communication. Fibres of the tracts are covered with the myelin sheath, which constitute the inner part of cerebral hemisphere. They give an opaque white appearance to the layer and, hence, is called the white matter. The cerebrum wraps around a structure called thalamus, which is a major coordinating centre for sensory and motor signaling. Another very important part of the brain called **hypothalamus** lies at the base of the thalamus. The hypothalamus contains a number of centres which control body temperature, urge for eating and drinking. It also contains several groups of neurosecretory cells, which secrete hormones called hypothalamic hormones. The inner parts of cerebral hemispheres and a group of associated deep structures like amygdala, hippocampus, etc., form a complex structure called the limbic lobe or limbic system. Along with the hypothalamus, it is involved in the regulation of sexual behaviour, expression of emotional reactions (e.g., excitement, pleasure, rage and fear), and motivation.

21.4.2 Midbrain

The midbrain is located between the thalamus/hypothalamus of the forebrain and pons of the hindbrain. A canal called the **cerebral aqueduct** passess through the midbrain. The dorsal portion of the midbrain consists mainly of four round swellings (lobes) called **corpora quadrigemina**. Midbrain and hindbrain form the brain stem.

21.4.3 Hindbrain

The hindbrain comprises **pons**, **cerebellum** and **medulla** (also called the medulla oblongata). Pons consists of fibre tracts that interconnect different regions of the brain. Cerebellum has very convoluted surface in order to provide the additional space for many more neurons. The medulla of the brain is connected to the spinal cord. The medulla contains centres which control respiration, cardiovascular reflexes and gastric secretions.

21.5 REFLEX ACTION AND REFLEX ARC

You must have experienced a sudden withdrawal of a body part which comes in contact with objects that are extremely hot, cold, pointed or animals that are scary or poisonous. The entire process of response to a peripheral nervous stimulation, that occurs involuntarily, i.e., without conscious effort or thought and requires the involvement of a part of the central nervous system is called a **reflex action**. The reflex pathway comprises at least one afferent neuron (receptor) and one efferent (effector or excitor) neuron appropriately arranged in a series (Figure 21.5). The afferent neuron receives signal from a sensory organ and transmits the impulse via a dorsal nerve root into the CNS (at the level of spinal cord). The efferent neuron then carries signals from CNS to the effector. The stimulus and response thus forms a reflex arc as shown below in the knee jerk reflex. You should carefully study Figure 21.5 to understand the mechanism of a knee jerk reflex.

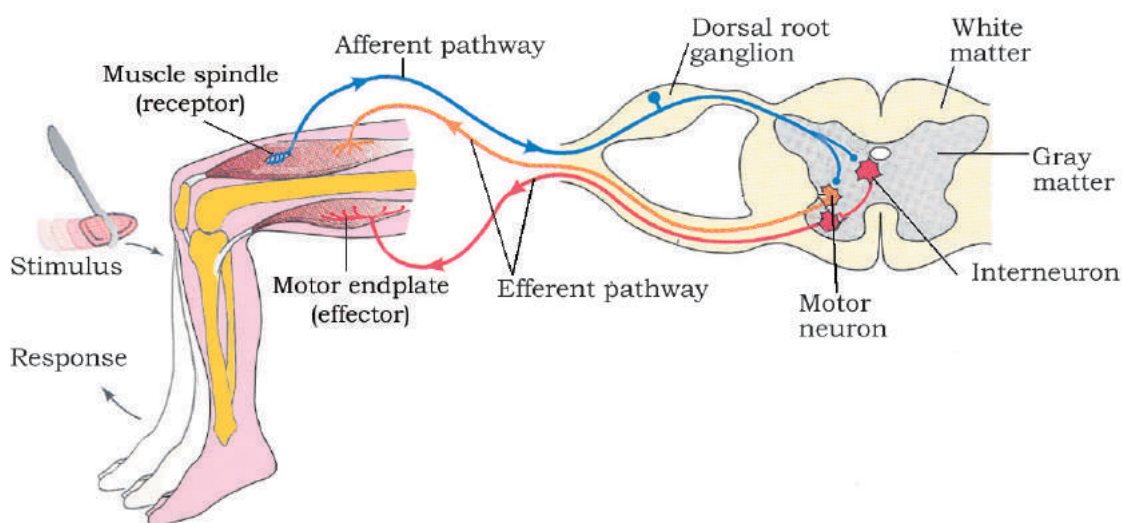


Figure 21.5 Diagrammatic presentation of reflex action (showing knee jerk reflex)

21.6 SENSORY RECEPTION AND PROCESSING

Have you ever thought how do you feel the climatic changes in the environment? How do you see an object and its colour? How do you hear a sound? The sensory organs detect all types of changes in the environment and send appropriate signals to the CNS, where all the inputs are processed and analysed. Signals are then sent to different parts/centres of the brain. This is how you can sense changes in the environment.

In the following sections, you will be introduced to the structure and functioning of the eye (sensory organ for vision) and the ear (sensory organ for hearing).

21.6.1 Eye

Our paired eyes are located in sockets of the skull called **orbits**. A brief account of structure and functions of the human eye is given in the following sections.

21.6.1.1 Parts of an eye

The adult human eye ball is nearly a spherical structure. The wall of the eye ball is composed of three layers (Figure 21.6). The external layer is composed of a dense connective tissue and is called the **sclera**. The anterior portion of this layer is called the **cornea**. The middle layer, **choroid**, contains many blood vessels and looks bluish in colour. The choroid layer is thin over the posterior two-thirds of the eye ball, but it becomes thick in the anterior part to form the **ciliary body**. The ciliary body itself continues forward to form a pigmented and opaque structure called the **iris** which is the visible coloured portion of the eye. The eye ball contains a transparent crystalline **lens** which is held in place by ligaments attached to the ciliary body. In front of the lens, the aperture surrounded by the iris is called the **pupil**. The diameter of the pupil is regulated by the muscle fibres of iris.

The inner layer is the **retina** and it contains three layers of cells – from inside to outside – ganglion cells, bipolar cells and photoreceptor cells.

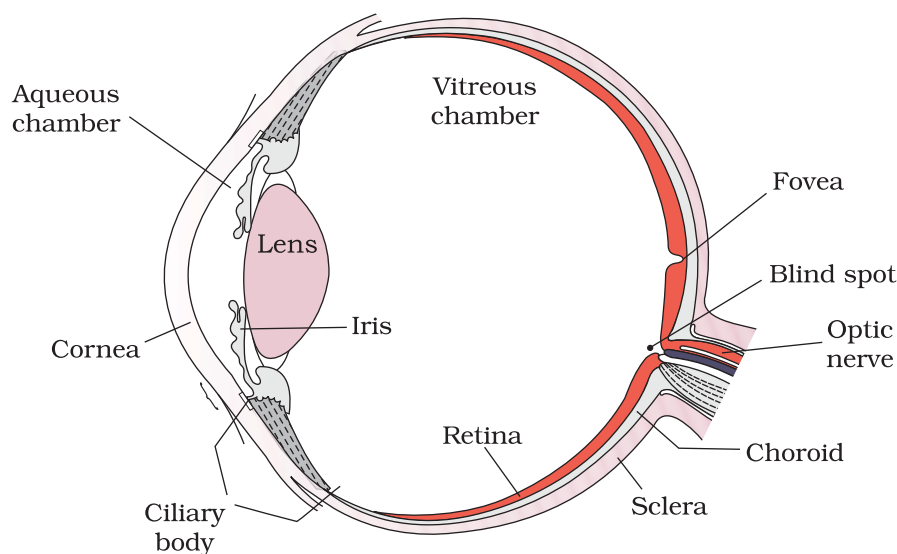


Figure 21.6 Diagram showing parts of an eye

There are two types of photoreceptor cells, namely, **rods** and **cones**. These cells contain the light-sensitive proteins called the photopigments. The daylight (photopic) vision and colour vision are functions of cones and the twilight (scotopic) vision is the function of the rods. The rods contain a purplish-red protein called the rhodopsin or visual purple, which contains a derivative of Vitamin A. In the human eye, there are three types of cones which possess their own characteristic photopigments that respond to red, green and blue lights. The sensations of different colours are produced by various combinations of these cones and their photopigments. When these cones are stimulated equally, a sensation of white light is produced.

The **optic nerves** leave the eye and the retinal blood vessels enter it at a point medial to and slightly above the posterior pole of the eye ball. Photoreceptor cells are not present in that region and hence it is called the **blind spot**. At the posterior pole of the eye lateral to the blind spot, there is a yellowish pigmented spot called macula lutea with a central pit called the **fovea**. The fovea is a thinned-out portion of the retina where only the cones are densely packed. It is the point where the visual acuity (resolution) is the greatest.

The space between the cornea and the lens is called the **aqueous chamber** and contains a thin watery fluid called aqueous humor. The space between the lens and the retina is called the **vitreous chamber** and is filled with a transparent gel called vitreous humor.

21.6.1.2 Mechanism of Vision

The light rays in visible wavelength focussed on the retina through the cornea and lens generate potentials (impulses) in rods and cones. As mentioned earlier, the photosensitive compounds (photopigments) in the human eyes is composed of **opsin** (a protein) and **retinal** (an aldehyde of vitamin A). Light induces dissociation of the retinal from opsin resulting in changes in the structure of the opsin. This causes membrane permeability changes. As a result, potential differences are generated in the photoreceptor cells. This produces a signal that generates action potentials in the ganglion cells through the bipolar cells. These action potentials (impulses) are transmitted by the optic nerves to the **visual cortex** area of the brain, where the neural impulses are analysed and the image formed on the retina is recognised based on earlier memory and experience.

21.6.2 The Ear

The ears perform two sensory functions, hearing and maintenance of body balance. Anatomically, the ear can be divided into three major sections called the **outer ear**, the **middle ear** and the **inner ear** (Figure 21.7). The

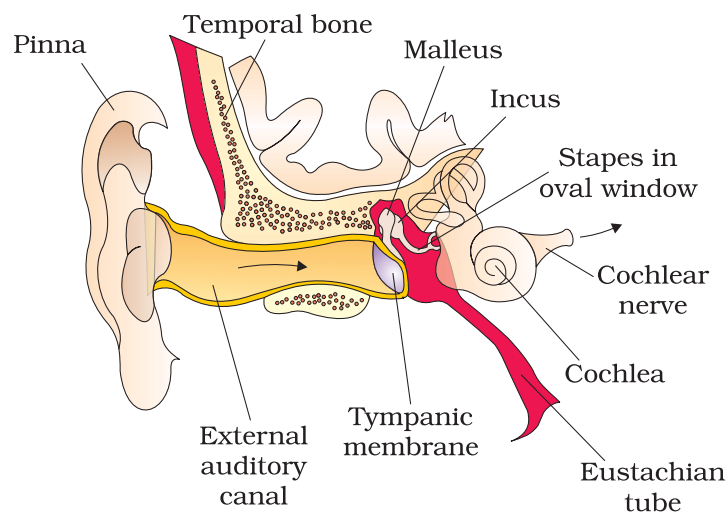


Figure 21.7 Diagrammatic view of ear

outer ear consists of the **pinna** and **external auditory meatus** (canal). The pinna collects the vibrations in the air which produce sound. The external auditory meatus leads inwards and extends up to the **tympanic membrane** (the **ear drum**). There are very fine hairs and wax-secreting sebaceous glands in the skin of the pinna and the meatus. The tympanic membrane is composed of connective tissues covered with skin outside and with mucus membrane inside. The middle ear contains three ossicles called **malleus**, **incus** and **stapes** which are attached to one another in a chain-like fashion. The malleus is attached to the tympanic membrane and the stapes is attached to the **oval window** of the cochlea. The ear ossicles increase the efficiency of transmission of sound waves to the inner ear. An **Eustachian tube** connects the middle ear cavity with the pharynx. The Eustachian tube helps in equalising the pressures on either sides of the ear drum.

The fluid-filled inner ear called **labyrinth** consists of two parts, the bony and the membranous labyrinths. The bony labyrinth is a series of channels. Inside these channels lies the membranous labyrinth, which is surrounded by a fluid called perilymph. The membranous labyrinth is filled with a fluid called endolymph. The coiled portion of the labyrinth is called **cochlea**. The membranes constituting cochlea, the reissner's and basilar, divide the surrounding perilymph filled bony labyrinth into an upper scala vestibuli and a lower scala tympani (Figure 21.8). The space within cochlea called scala media is filled with endolymph. At the base of the cochlea, the scala vestibuli ends at the oval window, while the scala tympani terminates at the round window which opens to the middle ear.

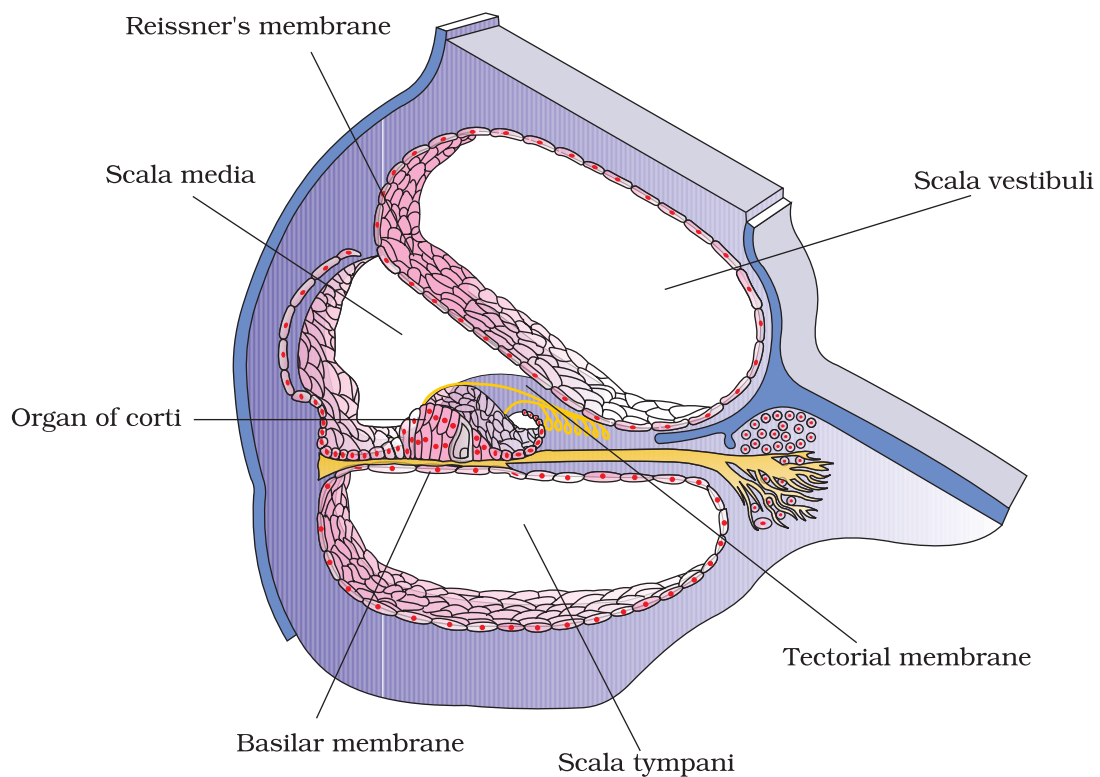


Figure 21.8 Diagrammatic representation of the sectional view of cochlea

The **organ of corti** is a structure located on the basilar membrane which contains **hair cells** that act as auditory receptors. The hair cells are present in rows on the internal side of the organ of corti. The basal end of the hair cell is in close contact with the afferent nerve fibres. A large number of processes called stereo cilia are projected from the apical part of each hair cell. Above the rows of the hair cells is a thin elastic membrane called **tectorial membrane**.

The inner ear also contains a complex system called **vestibular apparatus**, located above the cochlea. The vestibular apparatus is composed of three **semi-circular canals** and the **otolith organ** consisting of the saccule and utricle. Each semi-circular canal lies in a different plane at right angles to each other. The membranous canals are suspended in the perilymph of the bony canals. The base of canals is swollen and is called ampulla, which contains a projecting ridge called **crista ampullaris** which has hair cells. The saccule and utricle contain a projecting ridge called **macula**. The crista and macula are the specific receptors of the vestibular apparatus responsible for maintenance of balance of the body and posture.

20.6.2.1 Mechanism of Hearing

How does ear convert sound waves into neural impulses, which are sensed and processed by the brain enabling us to recognise a sound ?

The external ear receives sound waves and directs them to the ear drum. The ear drum vibrates in response to the sound waves and these vibrations are transmitted through the ear ossicles (malleus, incus and stapes) to the oval window. The vibrations are passed through the oval window on to the fluid of the cochlea, where they generate waves in the lymph. The waves in the lymph induce a ripple in the basilar membrane. These movements of the basilar membrane bend the hair cells, pressing them against the tectorial membrane. As a result, nerve impulses are generated in the associated afferent neurons. These impulses are transmitted by the afferent fibres via auditory nerves to the auditory cortex of the brain, where the impulses are analysed and the sound is recognised.

SUMMARY

The neural system coordinates and integrates functions as well as metabolic and homeostatic activities of all the organs. Neurons, the functional units of neural system are excitable cells due to a differential concentration gradient of ions across the membrane. The electrical potential difference across the resting neural membrane is called the 'resting potential'. The nerve impulse is conducted along the axon membrane in the form of a wave of depolarisation and repolarisation. A synapse is formed by the membranes of a pre-synaptic neuron and a post-synaptic neuron which may or may not be separated by a gap called synaptic cleft. Chemicals involved in the transmission of impulses at chemical synapses are called neurotransmitters.

Human neural system consists of two parts : (i) central neural system (CNS) and (ii) the peripheral neural system. The CNS consists of the brain and spinal cord. The brain can be divided into three major parts : (i) forebrain, (ii) midbrain and (iii) hindbrain. The forebrain consists of cerebrum, thalamus and hypothalamus. The cerebrum is longitudinally divided into two halves that are connected by the corpus callosum. A very important part of the forebrain called hypothalamus controls the body temperature, eating and drinking. Inner parts of cerebral hemispheres and a group of associated deep structures form a complex structure called limbic system which is concerned with olfaction, autonomic responses, regulation of sexual behaviour, expression of emotional reactions, and motivation. The midbrain receives and integrates visual, tactile and auditory inputs. The hindbrain comprises pons, cerebellum and medulla. The cerebellum integrates information received from the semicircular canals of the ear and the

auditory system. The medulla contains centres, which control respiration, cardiovascular reflexes, and gastric secretions. Pons consist of fibre tracts that interconnect different regions of the brain. The entire process of involuntary response to a peripheral nervous stimulation is called reflex action.

Information regarding changes in the environment is received by the CNS through the sensory organs which are processed and analysed. Signals are then sent for necessary adjustments. The wall of the human eye ball is composed of three layers. The external layer is composed of cornea and sclera. Inside sclera is the middle layer, which is called the choroid. Retina, the innermost layer, contains two types of photoreceptor cells, namely rods and cones. The daylight (photopic) vision and colour vision are functions of cones and twilight (scotopic) vision is the function of the rods. The light enters through cornea, the lens and the images of objects are formed on the retina.

The ear can be divided into the outer ear, the middle ear and the inner ear. The middle ear contains three ossicles called malleus, incus and stapes. The fluid filled inner ear is called the labyrinth, and the coiled portion of the labyrinth is called cochlea. The organ of corti is a structure which contains hair cells that act as auditory receptors and is located on the basilar membrane. The vibrations produced in the ear drum are transmitted through the ear ossicles and oval window to the fluid-filled inner ear. Nerve impulses are generated and transmitted by the afferent fibres to the auditory cortex of the brain. The inner ear also contains a complex system located above the cochlea called vestibular apparatus. It is influenced by gravity and movements, and helps us in maintaining balance of the body and posture.

EXERCISES

1. Briefly describe the structure of the following:
(a) Brain (b) Eye (c) Ear
2. Compare the following:
(a) Central neural system (CNS) and Peripheral neural system (PNS)
(b) Resting potential and action potential
(c) Choroid and retina
3. Explain the following processes:
(a) Polarisation of the membrane of a nerve fibre
(b) Depolarisation of the membrane of a nerve fibre
(c) Conduction of a nerve impulse along a nerve fibre
(d) Transmission of a nerve impulse across a chemical synapse
4. Draw labelled diagrams of the following:
(a) Neuron (b) Brain (c) Eye (d) Ear

5. Write short notes on the following:
(a) Neural coordination (b) Forebrain (c) Midbrain
(d) Hindbrain (e) Retina (f) Ear ossicles
(g) Cochlea (h) Organ of Corti (i) Synapse
6. Give a brief account of:
(a) Mechanism of synaptic transmission
(b) Mechanism of vision
(c) Mechanism of hearing
7. Answer briefly:
(a) How do you perceive the colour of an object?
(b) Which part of our body helps us in maintaining the body balance?
(c) How does the eye regulate the amount of light that falls on the retina.
8. Explain the following:
(a) Role of Na^+ in the generation of action potential.
(b) Mechanism of generation of light-induced impulse in the retina.
(c) Mechanism through which a sound produces a nerve impulse in the inner ear.
9. Differentiate between:
(a) Myelinated and non-myelinated axons
(b) Dendrites and axons
(c) Rods and cones
(d) Thalamus and Hypothalamus
(e) Cerebrum and Cerebellum
10. Answer the following:
(a) Which part of the ear determines the pitch of a sound?
(b) Which part of the human brain is the most developed?
(c) Which part of our central neural system acts as a master clock?
11. The region of the vertebrate eye, where the optic nerve passes out of the retina, is called the
(a) fovea
(b) iris
(c) blind spot
(d) optic chiasma
12. Distinguish between:
(a) afferent neurons and efferent neurons
(b) impulse conduction in a myelinated nerve fibre and unmyelinated nerve fibre
(c) aqueous humor and vitreous humor
(d) blind spot and yellow spot
(f) cranial nerves and spinal nerves.

CHAPTER 22

CHEMICAL COORDINATION AND INTEGRATION

22.1 *Endocrine
Glands and
Hormones*

22.2 *Human
Endocrine
System*

22.3 *Hormones of
Heart, Kidney
and
Gastrointestinal
Tract*

22.4 *Mechanism of
Hormone Action*

You have already learnt that the neural system provides a point-to-point rapid coordination among organs. The neural coordination is fast but short-lived. As the nerve fibres do not innervate all cells of the body and the cellular functions need to be continuously regulated; a special kind of coordination and integration has to be provided. This function is carried out by hormones. The neural system and the endocrine system jointly coordinate and regulate the physiological functions in the body.

22.1 ENDOCRINE GLANDS AND HORMONES

Endocrine glands lack ducts and are hence, called ductless glands. Their secretions are called hormones. The classical definition of hormone as a chemical produced by endocrine glands and released into the blood and transported to a distantly located target organ has current scientific definition as follows: **Hormones are non-nutrient chemicals which act as intercellular messengers and are produced in trace amounts.** The new definition covers a number of new molecules in addition to the hormones secreted by the organised endocrine glands. Invertebrates possess very simple endocrine systems with few hormones whereas a large number of chemicals act as hormones and provide coordination in the vertebrates. The human endocrine system is described here.

22.2 HUMAN ENDOCRINE SYSTEM

The endocrine glands and hormone producing diffused tissues/cells located in different parts of our body constitute the endocrine system. Pituitary, pineal, thyroid, adrenal, pancreas, parathyroid, thymus and gonads (testis in males and ovary in females) are the organised endocrine bodies in our body (Figure 22.1). In addition to these, some other organs, e.g., gastrointestinal tract, liver, kidney, heart also produce hormones. A brief account of the structure and functions of all major endocrine glands and hypothalamus of the human body is given in the following sections.

22.2.1 The Hypothalamus

As you know, the hypothalamus is the basal part of diencephalon, forebrain (Figure 22.1) and it regulates a wide spectrum of body functions. It contains several groups of neurosecretory cells called nuclei which produce hormones. These hormones regulate the synthesis and secretion of pituitary hormones. However, the hormones produced by hypothalamus are of two types, the releasing hormones (which stimulate secretion of pituitary hormones) and the inhibiting hormones (which inhibit secretions of pituitary hormones). For example a hypothalamic hormone called Gonadotrophin releasing hormone (GnRH) stimulates the pituitary synthesis and release of gonadotrophins. On the other hand, somatostatin from the hypothalamus inhibits the release of growth hormone from the pituitary. These hormones originating in the hypothalamic neurons, pass through axons and are released from their nerve endings. These hormones reach the pituitary gland through a portal circulatory system and regulate the functions of the anterior pituitary. The posterior pituitary is under the direct neural regulation of the hypothalamus (Figure 22.2).

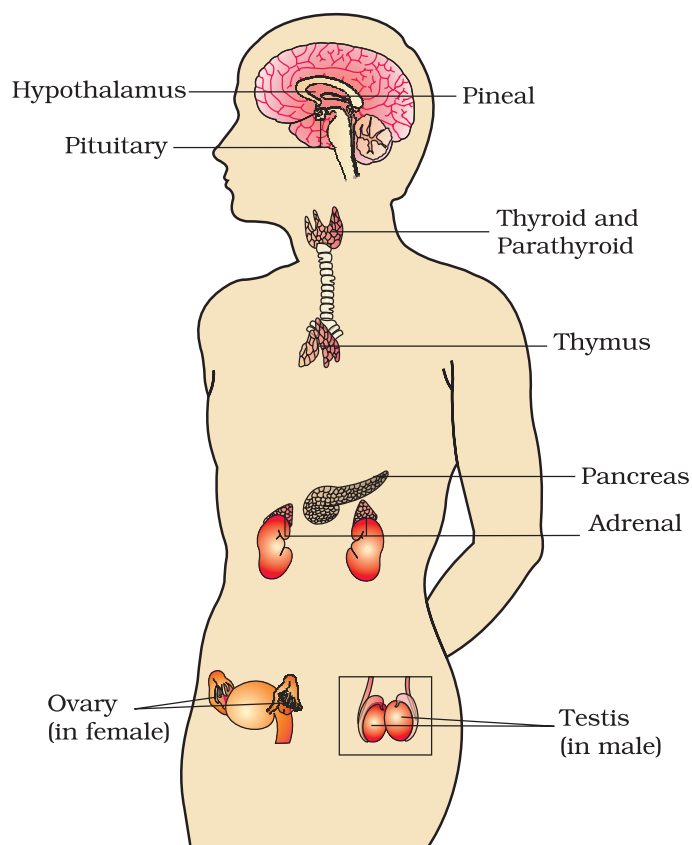


Figure 22.1 Location of endocrine glands

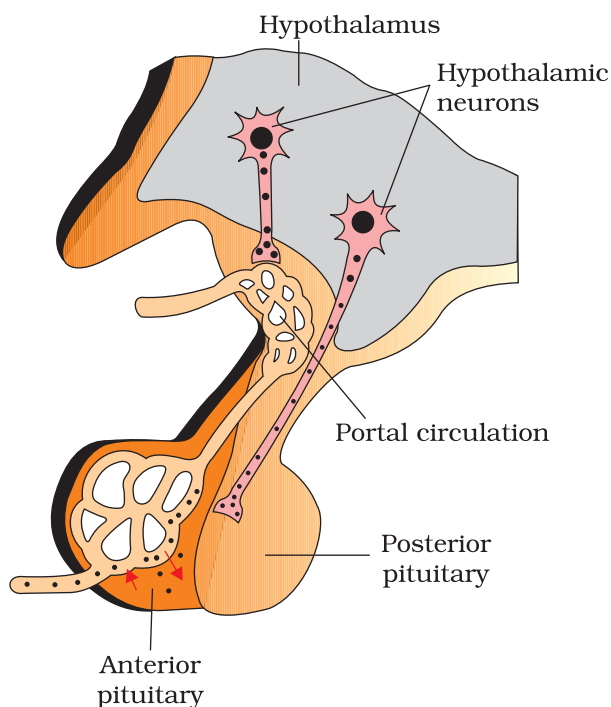


Figure 22.2 Diagrammatic representation of pituitary and its relationship with hypothalamus

22.2.2 The Pituitary Gland

The pituitary gland is located in a bony cavity called sella tursica and is attached to hypothalamus by a stalk (Figure 22.2). It is divided anatomically into an **adenohypophysis** and a **neurohypophysis**. Adenohypophysis consists of two portions, pars distalis and pars intermedia. The pars distalis region of pituitary, commonly called anterior pituitary, produces **growth hormone** (GH), **prolactin** (PRL), **thyroid stimulating hormone** (TSH), **adrenocorticotrophic hormone** (ACTH), **luteinizing hormone** (LH) and **follicle stimulating hormone** (FSH). Pars intermedia secretes only one hormone called **melanocyte stimulating hormone** (MSH). However, in humans, the pars intermedia is almost merged with pars distalis. Neurohypophysis (pars nervosa) also known as posterior pituitary, stores and releases two hormones called **oxytocin** and **vasopressin**, which are actually

synthesised by the hypothalamus and are transported axonally to neurohypophysis.

Over-secretion of GH stimulates abnormal growth of the body leading to gigantism and low secretion of GH results in stunted growth resulting in pituitary dwarfism. Prolactin regulates the growth of the mammary glands and formation of milk in them. TSH stimulates the synthesis and secretion of thyroid hormones from the thyroid gland. ACTH stimulates the synthesis and secretion of steroid hormones called **glucocorticoids** from the adrenal cortex. LH and FSH stimulate gonadal activity and hence are called **gonadotrophins**. In males, LH stimulates the synthesis and secretion of hormones called **androgens** from testis. In males, FSH and androgens regulate spermatogenesis. In females, LH induces ovulation of fully mature follicles (graafian follicles) and maintains the corpus luteum, formed from the remnants of the graafian follicles after ovulation. FSH stimulates growth and development of the ovarian follicles in females. MSH acts on the melanocytes (melanin containing cells) and regulates pigmentation of the skin. Oxytocin acts on the smooth muscles of our body and stimulates their contraction. In females, it stimulates a vigorous contraction of uterus at the time of child birth, and milk ejection from the mammary gland. Vasopressin acts mainly at the kidney and stimulates

resorption of water and electrolytes by the distal tubules and thereby reduces loss of water through urine (diuresis). Hence, it is also called as **anti-diuretic hormone** (ADH).

22.2.3 The Pineal Gland

The pineal gland is located on the dorsal side of forebrain. Pineal secretes a hormone called **melatonin**. Melatonin plays a very important role in the regulation of a 24-hour (diurnal) rhythm of our body. For example, it helps in maintaining the normal rhythms of sleep-wake cycle, body temperature. In addition, melatonin also influences metabolism, pigmentation, the menstrual cycle as well as our defense capability.

22.2.4 Thyroid Gland

The thyroid gland is composed of two lobes which are located on either side of the trachea (Figure 22.3). Both the lobes are interconnected with a thin flap of connective tissue called isthmus. The thyroid gland is composed of **follicles** and **stromal tissues**. Each thyroid follicle is composed of follicular cells, enclosing a cavity. These follicular cells synthesise two hormones, **tetraiodothyronine** or **thyroxine** (T_4) and **triiodothyronine** (T_3). Iodine is essential for the normal rate of hormone synthesis in the thyroid. Deficiency of iodine in our diet results in **hypothyroidism** and enlargement of the thyroid gland, commonly called **goitre**. Hypothyroidism during pregnancy causes defective development and maturation of the growing baby leading to stunted growth (cretinism), mental retardation, low intelligence quotient, abnormal skin, deaf-mutism, etc. In adult women, hypothyroidism may cause menstrual cycle to become irregular. Due to cancer of the thyroid gland or due to development of nodules of the thyroid glands, the rate of synthesis and secretion of the thyroid hormones is increased to abnormal high levels leading to a condition called **hyperthyroidism** which adversely affects the body physiology.

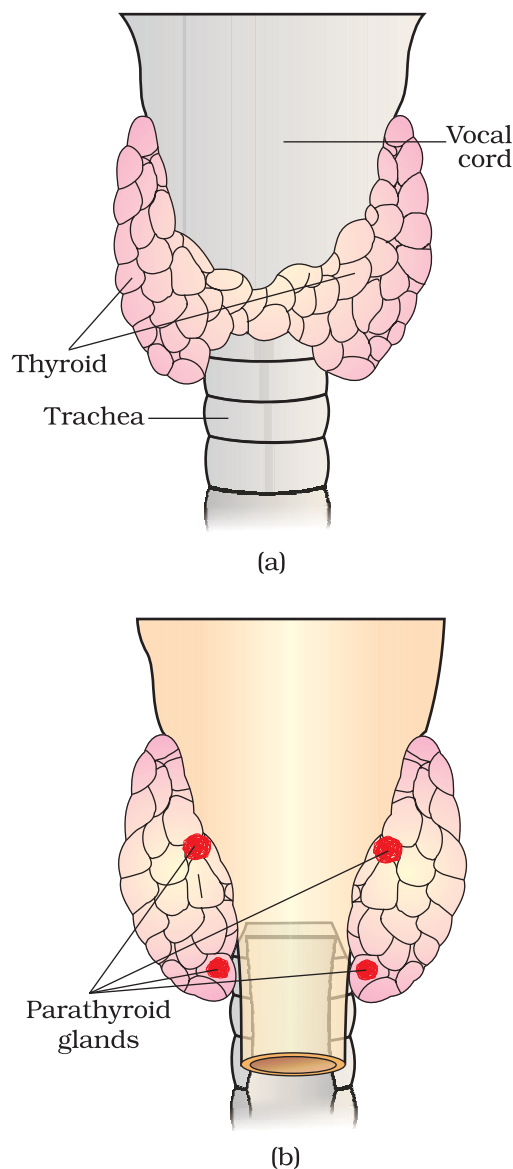


Figure 22.3 Diagrammatic view of the position of Thyroid and Parathyroid
(a) Ventral side
(b) Dorsal side

Thyroid hormones play an important role in the regulation of the basal metabolic rate. These hormones also support the process of red blood cell formation. Thyroid hormones control the metabolism of carbohydrates, proteins and fats. Maintenance of water and electrolyte balance is also influenced by thyroid hormones. Thyroid gland also secretes a protein hormone called thyrocalcitonin (TCT) which regulates the blood calcium levels.

22.2.5 Parathyroid Gland

In humans, four parathyroid glands are present on the back side of the thyroid gland, one pair each in the two lobes of the thyroid gland (Figure 22.3b). The parathyroid glands secrete a peptide hormone called **parathyroid hormone** (PTH). The secretion of PTH is regulated by the circulating levels of calcium ions.

Parathyroid hormone (PTH) increases the Ca^{2+} levels in the blood. PTH acts on bones and stimulates the process of bone resorption (dissolution/demineralisation). PTH also stimulates reabsorption of Ca^{2+} by the renal tubules and increases Ca^{2+} absorption from the digested food. It is, thus, clear that PTH is a hypercalcemic hormone, i.e., it increases the blood Ca^{2+} levels. Along with TCT, it plays a significant role in calcium balance in the body.

22.2.6 Thymus

The thymus gland is a lobular structure located between lungs behind sternum on the ventral side of aorta. The thymus plays a major role in the development of the immune system. This gland secretes the peptide hormones called **thymosins**. Thymosins play a major role in the differentiation of **T-lymphocytes**, which provide **cell-mediated immunity**. In addition, thymosins also promote production of antibodies to provide **humoral immunity**. Thymus is degenerated in old individuals resulting in a decreased production of thymosins. As a result, the immune responses of old persons become weak.

22.2.7 Adrenal Gland

Our body has one pair of adrenal glands, one at the anterior part of each kidney (Figure 22.4 a). The gland is composed of two types of tissues. The centrally located tissue is called the **adrenal medulla**, and outside this lies the **adrenal cortex** (Figure 22.4 b).

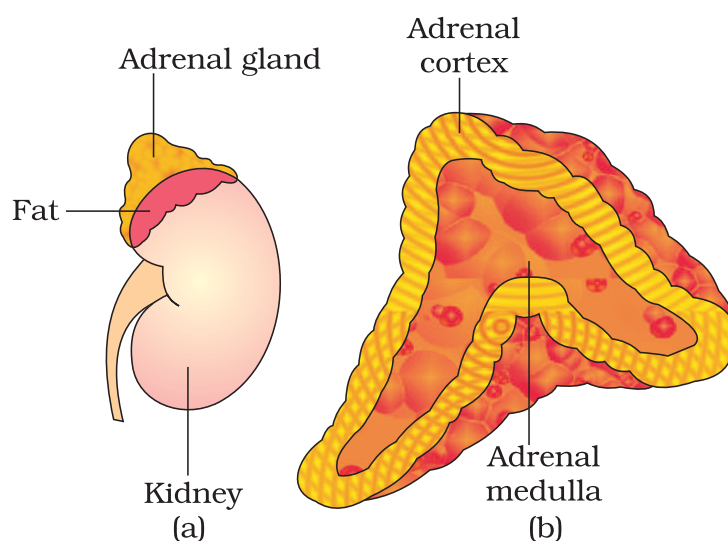


Figure 22.4 Diagrammatic representation of : (a) Adrenal gland above kidney
(b) Section showing two parts of adrenal gland

The adrenal medulla secretes two hormones called **adrenaline** or **epinephrine** and **noradrenaline** or **norepinephrine**. These are commonly called as **catecholamines**. Adrenaline and noradrenaline are rapidly secreted in response to stress of any kind and during emergency situations and are called **emergency hormones** or **hormones of Fight or Flight**. These hormones increase alertness, pupillary dilation, piloerection (raising of hairs), sweating etc. Both the hormones increase the heart beat, the strength of heart contraction and the rate of respiration. Catecholamines also stimulate the breakdown of glycogen resulting in an increased concentration of glucose in blood. In addition, they also stimulate the breakdown of lipids and proteins.

The adrenal cortex can be divided into three layers, called **zona reticularis** (inner layer), **zona fasciculata** (middle layer) and **zona glomerulosa** (outer layer). The adrenal cortex secretes many hormones, commonly called as **corticoids**. The corticoids, which are involved in carbohydrate metabolism are called glucocorticoids. In our body, cortisol is the main glucocorticoid. Corticoids, which regulate the balance of water and electrolytes in our body are called mineralocorticoids. Aldosterone is the main mineralocorticoid in our body.

Glucocorticoids stimulate gluconeogenesis, lipolysis and proteolysis; and inhibit cellular uptake and utilisation of amino acids. Cortisol is also involved in maintaining the cardio-vascular system as well as the kidney functions. Glucocorticoids, particularly cortisol, produces anti-inflammatory reactions and suppresses the immune response. Cortisol

stimulates the RBC production. Aldosterone acts mainly at the renal tubules and stimulates the reabsorption of Na^+ and water and excretion of K^+ and phosphate ions. Thus, aldosterone helps in the maintenance of electrolytes, body fluid volume, osmotic pressure and blood pressure. Small amounts of androgenic steroids are also secreted by the adrenal cortex which play a role in the growth of axial hair, pubic hair and facial hair during puberty.

22.2.8 Pancreas

Pancreas is a composite gland (Figure 22.1) which acts as both exocrine and endocrine gland. The endocrine pancreas consists of 'Islets of Langerhans'. There are about 1 to 2 million Islets of Langerhans in a normal human pancreas representing only 1 to 2 per cent of the pancreatic tissue. The two main types of cells in the Islet of Langerhans are called **α -cells** and **β -cells**. The α -cells secrete a hormone called **glucagon**, while the β -cells secrete **insulin**.

Glucagon is a peptide hormone, and plays an important role in maintaining the normal blood glucose levels. Glucagon acts mainly on the liver cells (hepatocytes) and stimulates glycogenolysis resulting in an increased blood sugar (**hyperglycemia**). In addition, this hormone stimulates the process of gluconeogenesis which also contributes to hyperglycemia. Glucagon reduces the cellular glucose uptake and utilisation. Thus, glucagon is a **hyperglycemic hormone**.

Insulin is a peptide hormone, which plays a major role in the regulation of glucose homeostasis. Insulin acts mainly on hepatocytes and adipocytes (cells of adipose tissue), and enhances cellular glucose uptake and utilisation. As a result, there is a rapid movement of glucose from blood to hepatocytes and adipocytes resulting in decreased blood glucose levels (**hypoglycemia**). Insulin also stimulates conversion of glucose to glycogen (**glycogenesis**) in the target cells. The glucose homeostasis in blood is thus maintained jointly by the two – insulin and glucagons.

Prolonged hyperglycemia leads to a complex disorder called **diabetes mellitus** which is associated with loss of glucose through urine and formation of harmful compounds known as ketone bodies. Diabetic patients are successfully treated with insulin therapy.

22.2.9 Testis

A pair of testis is present in the scrotal sac (outside abdomen) of male individuals (Figure 22.1). Testis performs dual functions as a primary