

## 05

**Animal Form and Function****Processes and systems involved in coordination**

Coordination between stimuli and responses is needed to maintain constant internal environment inside the body of an organism for existence.

**Systems contributing to coordination**

Animals unlike plants have two different but related systems for coordination of body function. They are the nervous system and the endocrine system.

**Table 5.1: Similarities and differences (in relation to coordination) of the nervous system and endocrine system**

Feature	Nervous coordination	Hormonal coordination
Transmission	through neurons	through blood
Nature of transmitter	chemical and electrical	chemical
Response	localized	diffused
Time taken to start the response	fast acting	slower action
Duration of response	short	long

**Organization of nervous systems in different animal Phyla**

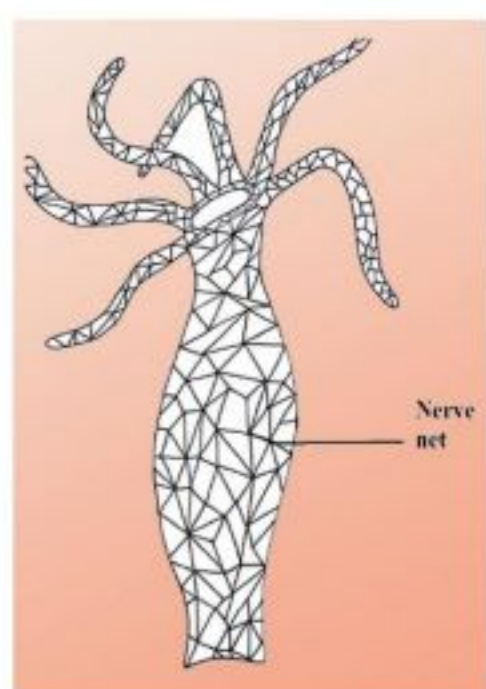
Animals have specialized systems of neurons to sense their surroundings and respond rapidly. In the animal kingdom, cnidarians are the simplest animals having a nervous system. They have a diffuse nerve net which is composed of interconnected individual neurons.

In more complex animals, the nervous systems contain groups of neurons organized into nerves, and often ganglia and a brain. In some platyhelminthes such as Planaria, the nervous system contains a pair of ganglia in the anterior region (brain) and a pair of ventral nerve cords that runs longitudinally. In planarians, the eye spots which are located near the ganglia act as photoreceptors. Annelids and arthropods have a somewhat complicated brains and ventral nerve cords. The ventral nerve cord contains ganglia. They are segmentally arranged. Nervous system

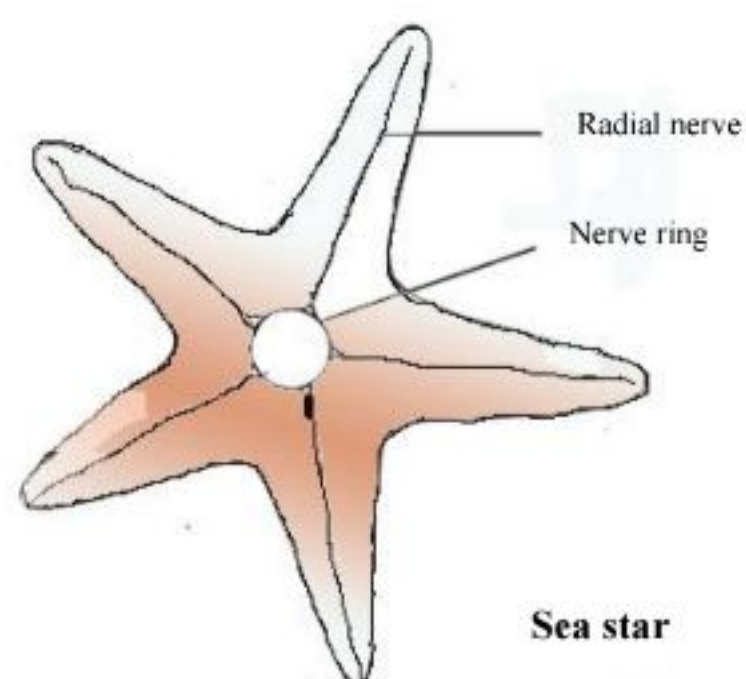
of echinoderms is composed of radial nerves and a nerve ring. Nervous system of the chordates consists of a central nervous system (CNS) and a peripheral nervous system (PNS). The CNS is composed of the brain and the spinal cord. The PNS is composed of nerves and ganglia.

**Table 5.2: Different organism phyla and their nervous organization**

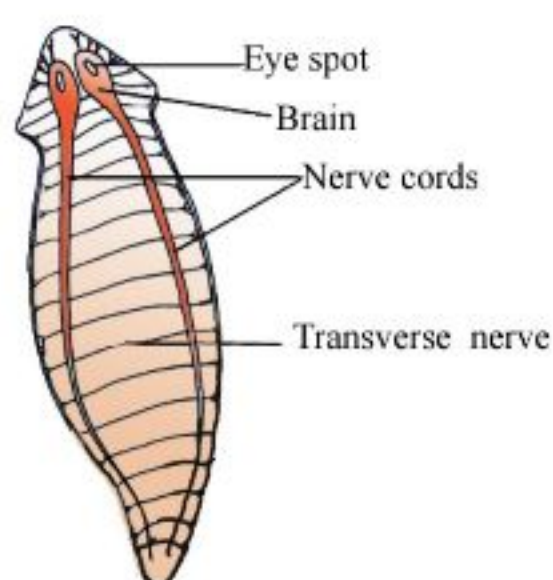
Phylum	Organization	Example
Cnidaria	Nerve net	Hydra
Platyhelminthes	Brain, longitudinal nerve cords	Planaria
Annelida	Brain, ventral nerve cord, segmental ganglia	Leech
Arthropoda	Brain, Ventral nerve cord, Segmental ganglia	Cockroach
Echinodermata	Nerve ring and radial nerves	Sea star
Chordata	Brain, spinal cord (dorsal nerve cord), nerves and ganglia	Gecko



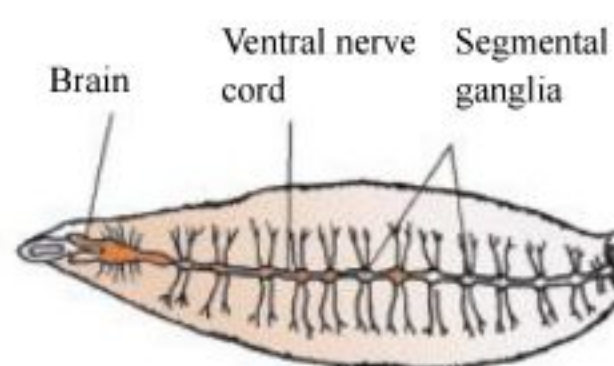
**Hydra**



**Sea star**

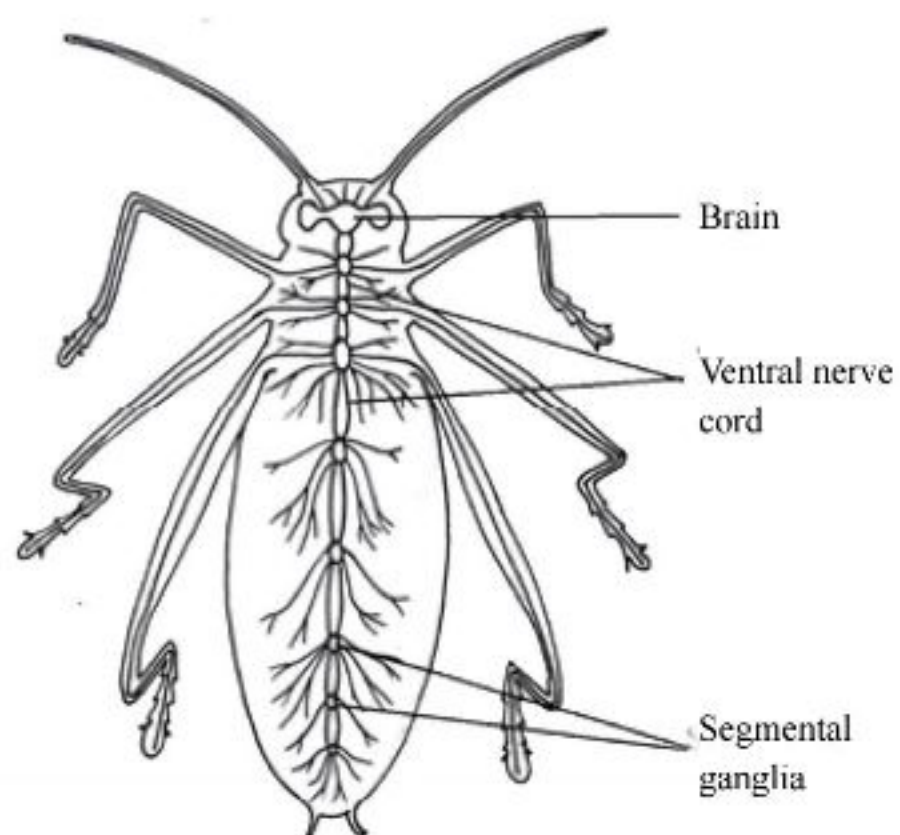
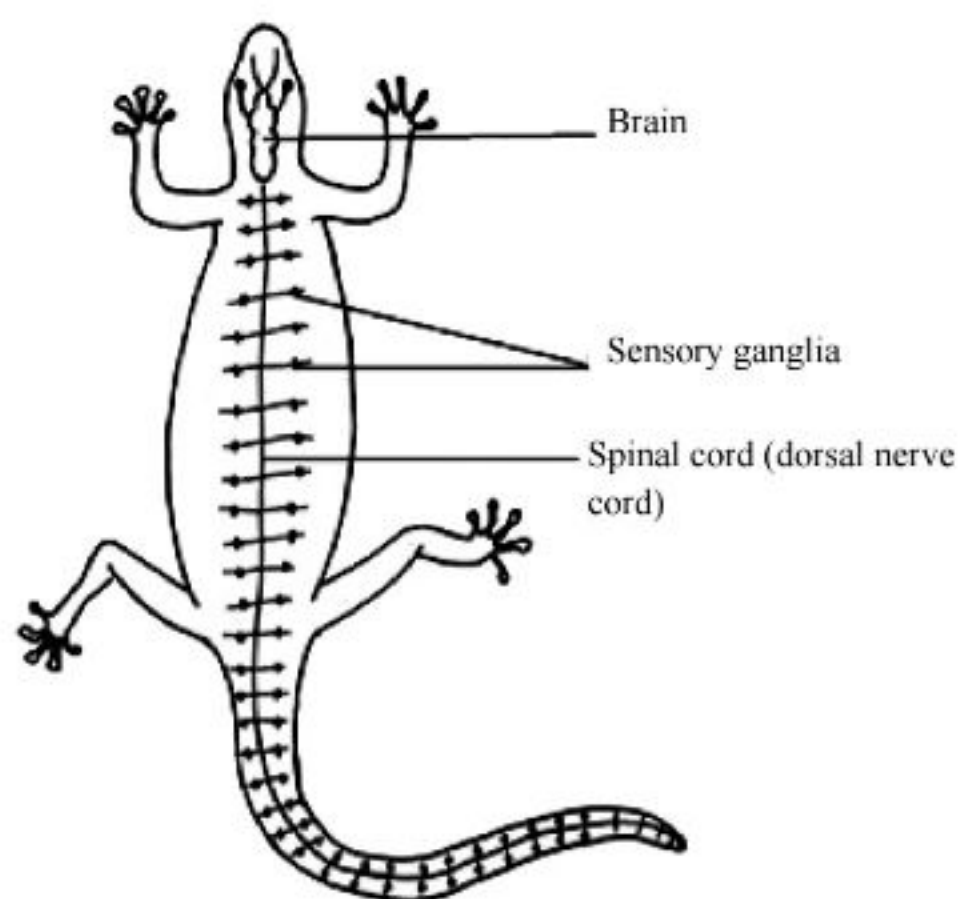


**Planaria**



**Leech**



**Insect****Gecko****Figure 5.1: Organization of nervous systems in different animal phyla**

## The gross structure and the functions of the human nervous system

### Organization and main parts of the human nervous system

Human nervous system consists of central and peripheral nervous systems. In vertebrates, the brain and the spinal cord form the central nervous system. Nerves and ganglia forms the main components of the peripheral nervous system.

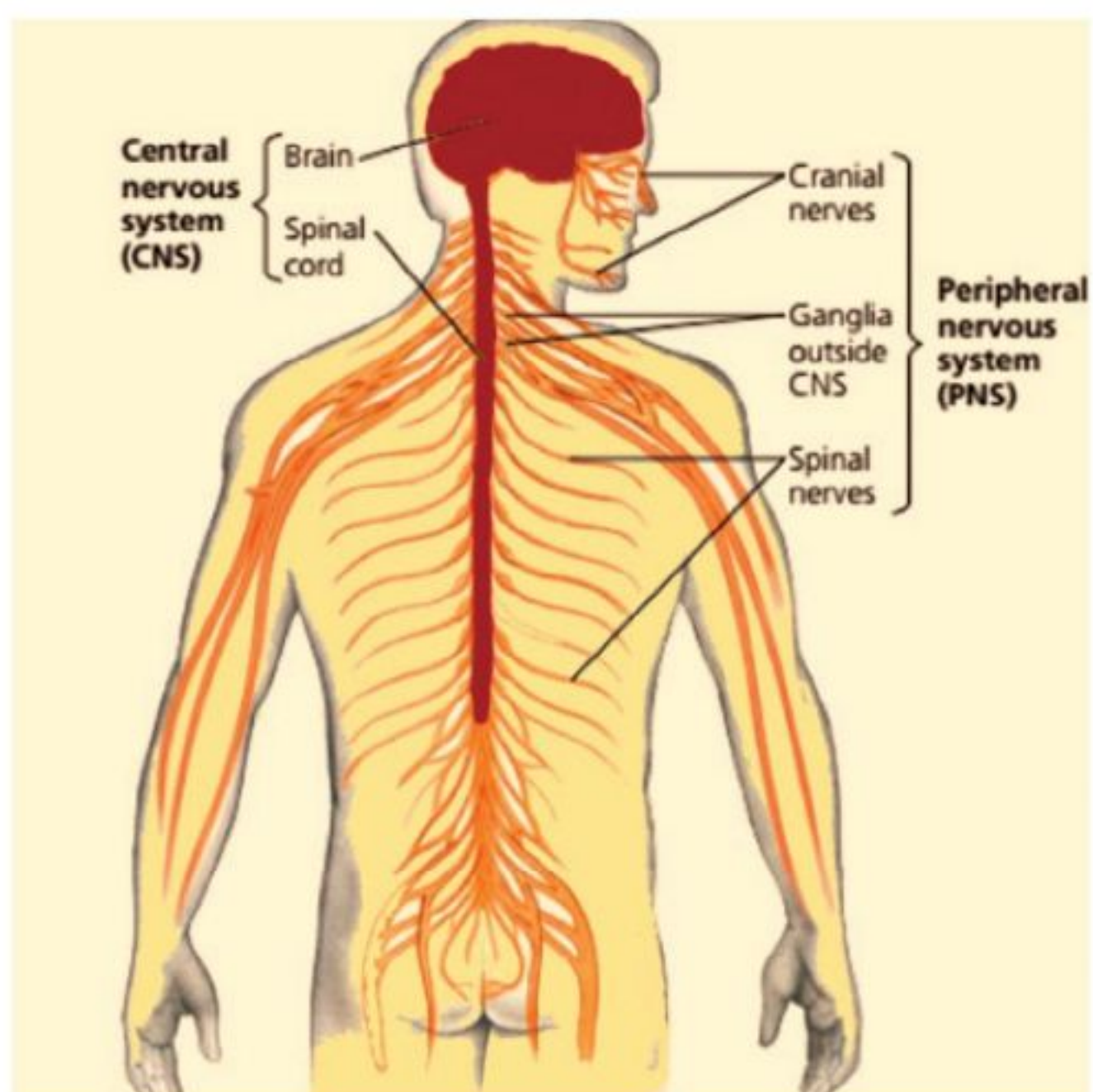
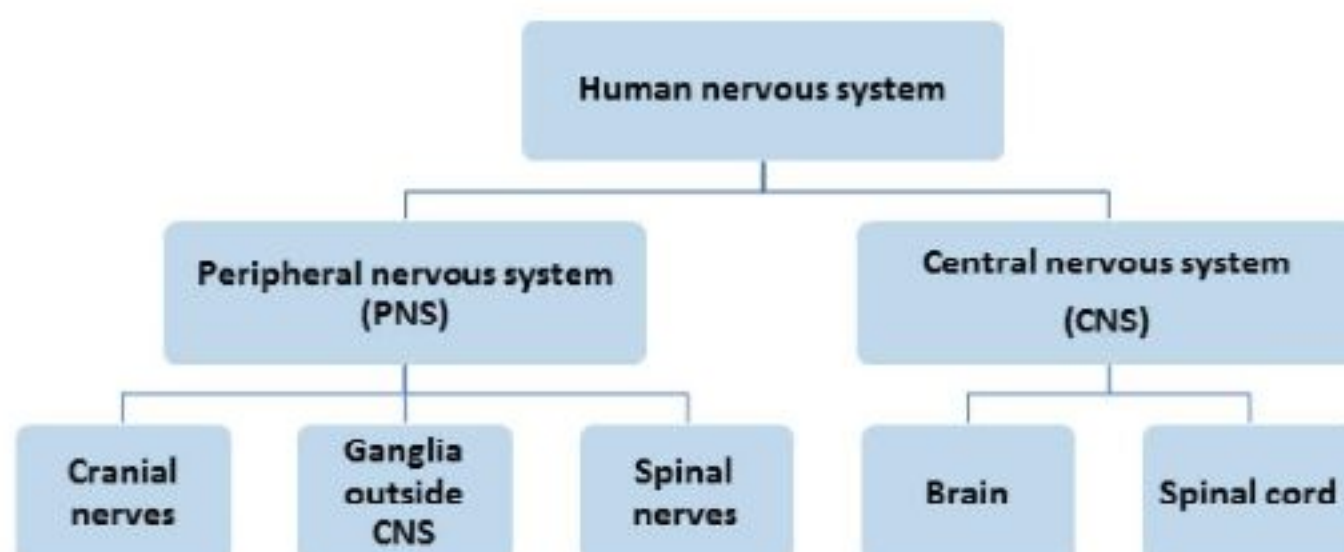


Figure 5.2: The organization of human nervous system



### Central nervous system (CNS)

Central nervous system consists of the brain and the spinal cord. In vertebrates, the CNS develops from the hollow dorsal nerve cord during embryonic development. Anterior part of the central nervous system enlarges and forms the brain which has three major regions: forebrain, midbrain and hindbrain. The central canal in the brain forms four irregular shaped cavities called ventricles. The brain contains four ventricles: three ventricles are present in the fore brain and one ventricle is in the hind brain. This central canal continues in the spinal cord. The ventricles and central canal contains cerebrospinal fluid. This fluid helps to maintain uniform pressure within the CNS and act as a shock absorber between the brain and skull. It also helps to circulates nutrients and hormones as well as to remove waste products.

The brain and the spinal cord have several adaptations to be protected from physical injuries. The brain is enclosed by a skull. The spinal cord is surrounded by vertebrae which forms the vertebral column. Further protection to the CNS is given by three layers of tissues called the meninges. The outermost layer is called the dura mater, the innermost layer as pia mater and in between these two layers is the arachnoid mater.

### Main parts of the human Brain

The forebrain, midbrain and hindbrain of the human embryo develops into the adult brain. The forebrain gives rise to the cerebrum, thalamus, hypothalamus and pineal body. The mid brain gives rise to part of the brain stem. The hind brain gives rise to cerebellum, pons varoli and medulla oblongata. The brain stem consists of the midbrain, pons Varolii and medulla oblongata.

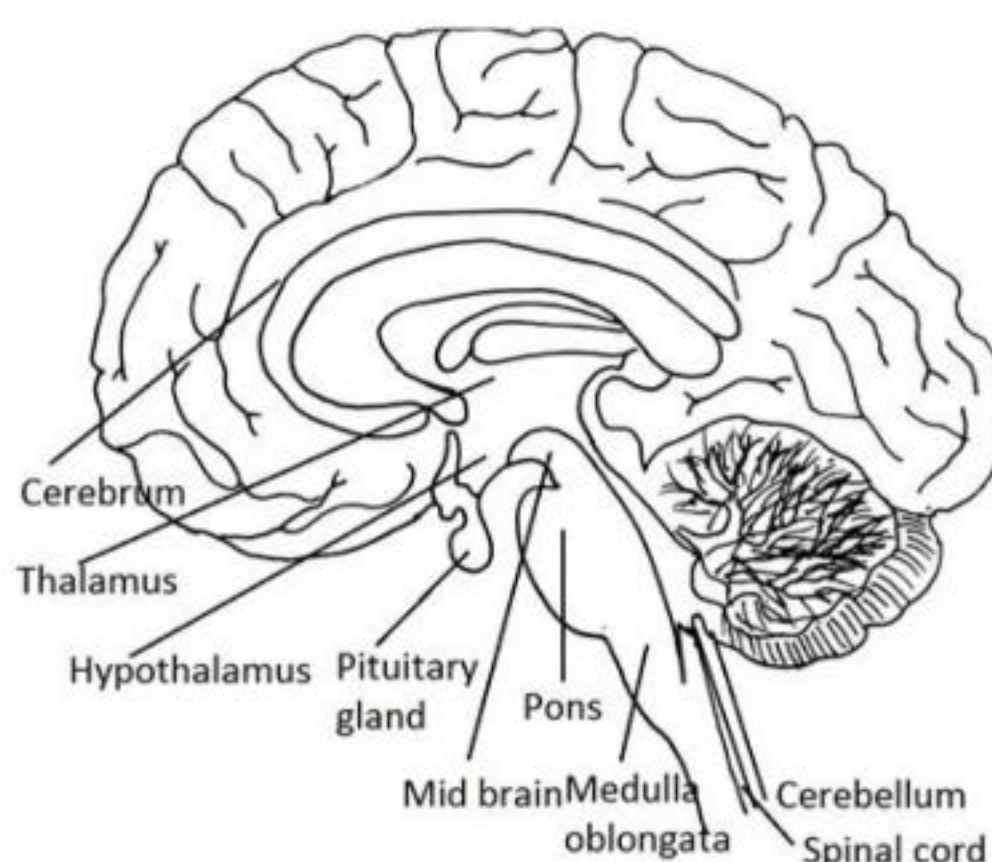
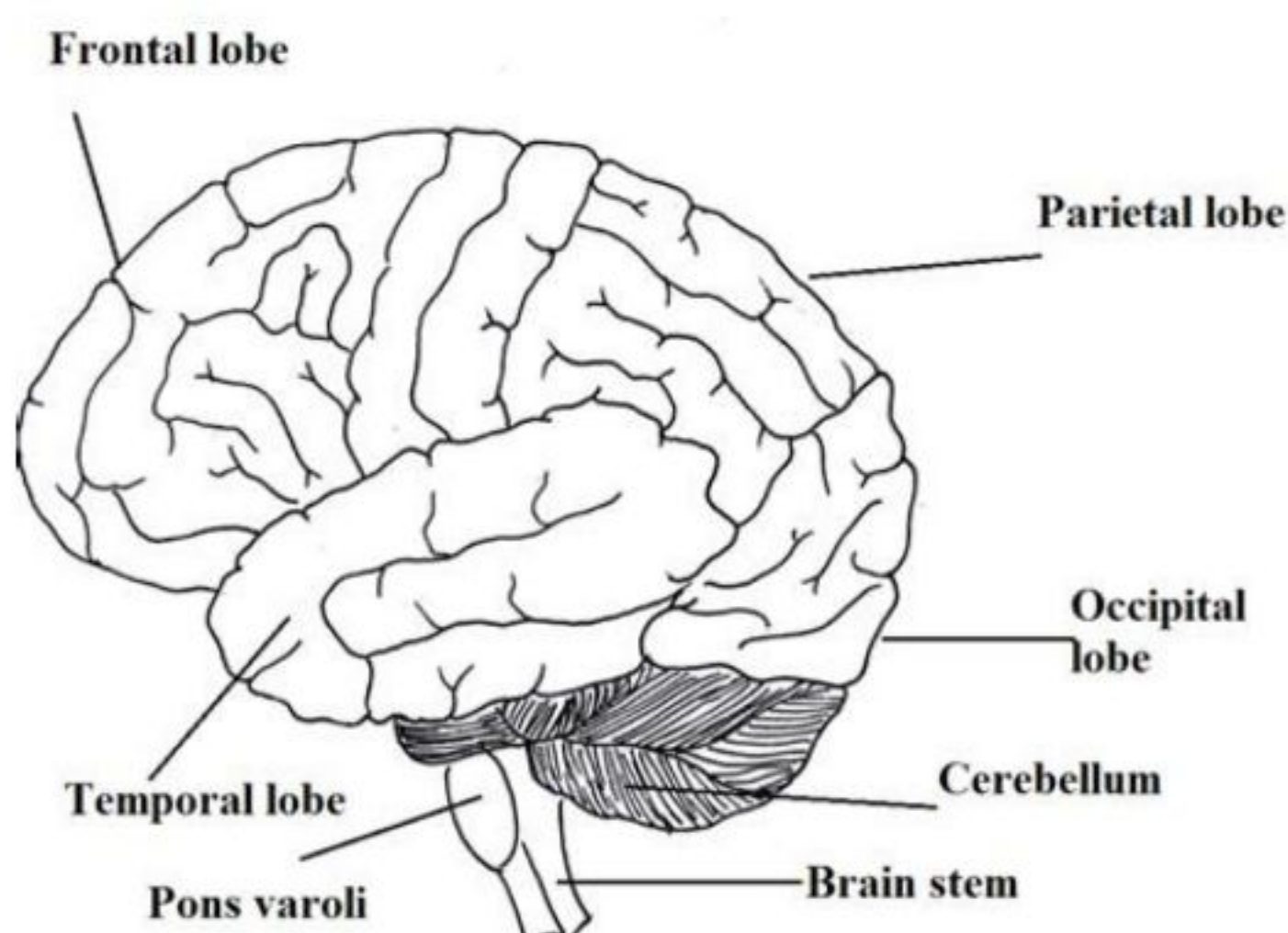


Figure 5.3 : The longitudinal view of the human brain



## Cerebrum

Cerebrum is the largest part of the human brain. It is divided by a deep cleft into right and left cerebral hemispheres. The superficial part of the cerebrum is composed of nerve cell bodies (or grey matter) forming the cerebral cortex and deeper layers consist of nerve fibers (or white matter). The two cerebral hemispheres are connected by corpus callosum which is a mass of white matter. The cerebral cortex shows many infoldings to increase the surface area of the cerebrum. The cortex of each cerebral hemisphere is divided into four lobes: frontal lobe, temporal lobe, parietal lobe and occipital lobe.



**Figure 5.4 : The human cerebral cortex**

Three main functional areas of the cerebral cortex have been identified. They are;

- Sensory areas which receive and process sensory information including the perception of pain, temperature, touch, sight, hearing, taste and smell
- Association areas which are responsible for recognition and interpretation of sensory information and integration and processing of complex mental functions such as memory, intelligence, reasoning, judgment and emotions
- Motor areas which are responsible for directing skeletal (voluntary) muscle movement through the initiation and control of voluntary muscle contraction



**Thalamus**

Thalamus is situated within the cerebral hemispheres just below the corpus callosum. It consists of two masses comprising grey and white matter.

**Functions:**

Thalamus acts as the main input centre of sensory information from special sense organs and sensory receptors in the skin and internal organ. This sensory information is sorted and directed to specific location of the cerebral cortex for further processing and perception. The thalamus relays and redistributes nerve impulses from most parts of the brain to cerebral cortex.

**Hypothalamus**

Hypothalamus is situated below and in front of the thalamus, immediately above the pituitary gland. It is linked to the posterior lobe of the pituitary gland by nerve fibers and to the anterior lobe by a complex system of blood vessels.

**Functions:**

- Regulates body temperature
- Regulates thirst and water balance
- Regulates appetite
- Regulate sleep and wake cycles
- Control of autonomic nervous system
- Initiates fight-or-flight response
- Source for posterior pituitary hormones and releasing hormones that act on anterior pituitary.
- Plays a role in sexual behaviours

**Mid brain**

Mid brain is the upper part of the brain stem. It is situated between the cerebrum above and the pons below surrounding the cerebrospinal fluid filled connection of the third and fourth ventricles. Mid brain contains aggregates of nerve cell bodies and nerve tracts which connect the cerebrum with lower brain and spinal cord.

**Functions:**

- Acts as relay stations for ascending and descending nerve fibers
- Receives and integrates sensory information (auditory and visual) and sends it to particular regions of the forebrain, coordinates auditory and visual reflexes

**Pons Varolii**

Pons Varolii, (a part of the brain stem) is located in front of the cerebellum, below the mid brain and above the medulla oblongata. It contains nerve fibers that form a bridge between the two hemispheres of the cerebellum. It also contains nerve fibers passing between higher levels of brain

and spinal cord. Groups of nerve cell bodies in the pons form centers that regulate respiration. Some nerve cell bodies in the pons act as relay stations.

Functions:

- Transfers information between PNS and the midbrain and forebrain
- Coordinates large scale body movements such as climbing and running
- Together with the medulla oblongata helps regulate respiration.

### **Medulla oblongata**

Medulla oblongata is the lowest part of the brain stem which extends from the pons above and is continuous with the spinal cord below. It consists of cardiovascular centre, respiratory center and reflex centers.

Functions:

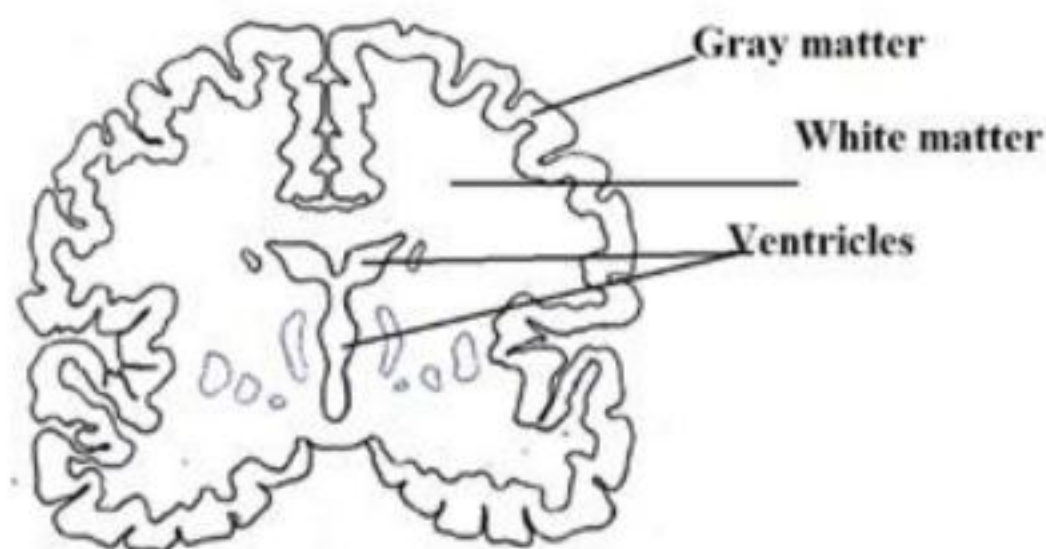
- Transfers information between PNS and the mid brain and the fore brain
- Coordinates various body movements such as running, climbing
- Controls several autonomic, homeostatic functions including breathing, heart and blood vessel activities (contains respiratory centre, cardiovascular centre)
- Controls involuntary reflexes such as vomiting, swallowing, coughing, sneezing through reflex centres

### **Cerebellum**

Cerebellum is located behind the pons Varolii and below the posterior portion of the cerebrum. It is also made up of two hemispheres.

Functions

- Coordinates voluntary muscular movements
- Maintains posture and balance
- Helps in learning and remembering motor skills



**Figure 5.5 : T.S of the human brain**



## Spinal cord

The spinal cord is an elongated cylindrical structure suspended in the vertebral canal. It is continuous with the medulla oblongata. Centre of the spinal cord contains the central canal which is surrounded by grey matter. Outer region of the spinal cord is made up of white matter.

### Functions:

- Links the central nervous systems to sensory and motor neurons and facilitates nerve impulse propagation towards the brain and away the brain
- Coordinates and produces reflexes

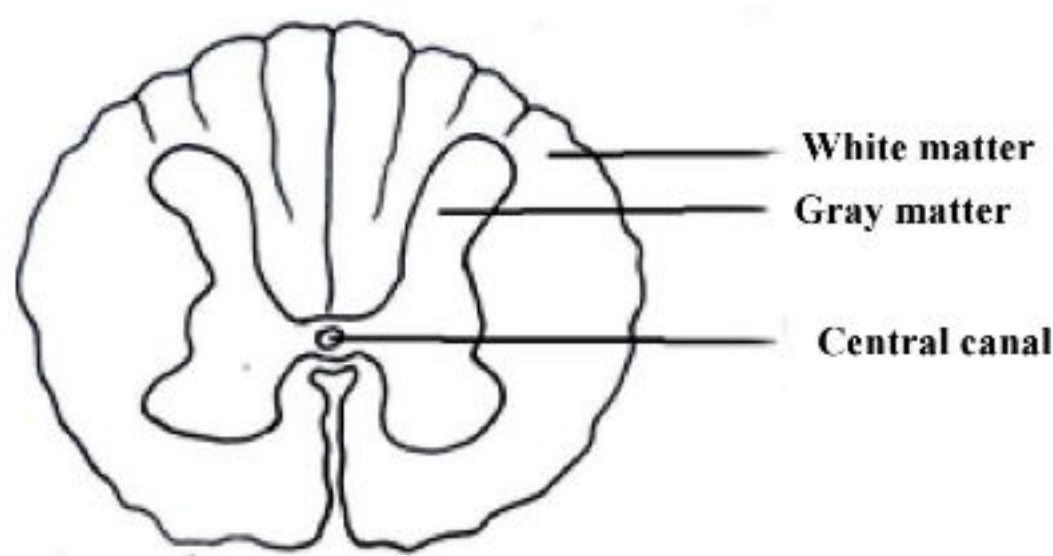


Figure 5.6: T.S of the spinal cord

## Peripheral nervous system (PNS)

Peripheral nervous system is made up of cranial nerves, spinal nerves and autonomic nervous system (with ganglia). It transmits impulses to and from CNS regulating both an animal's movement and its internal environment.

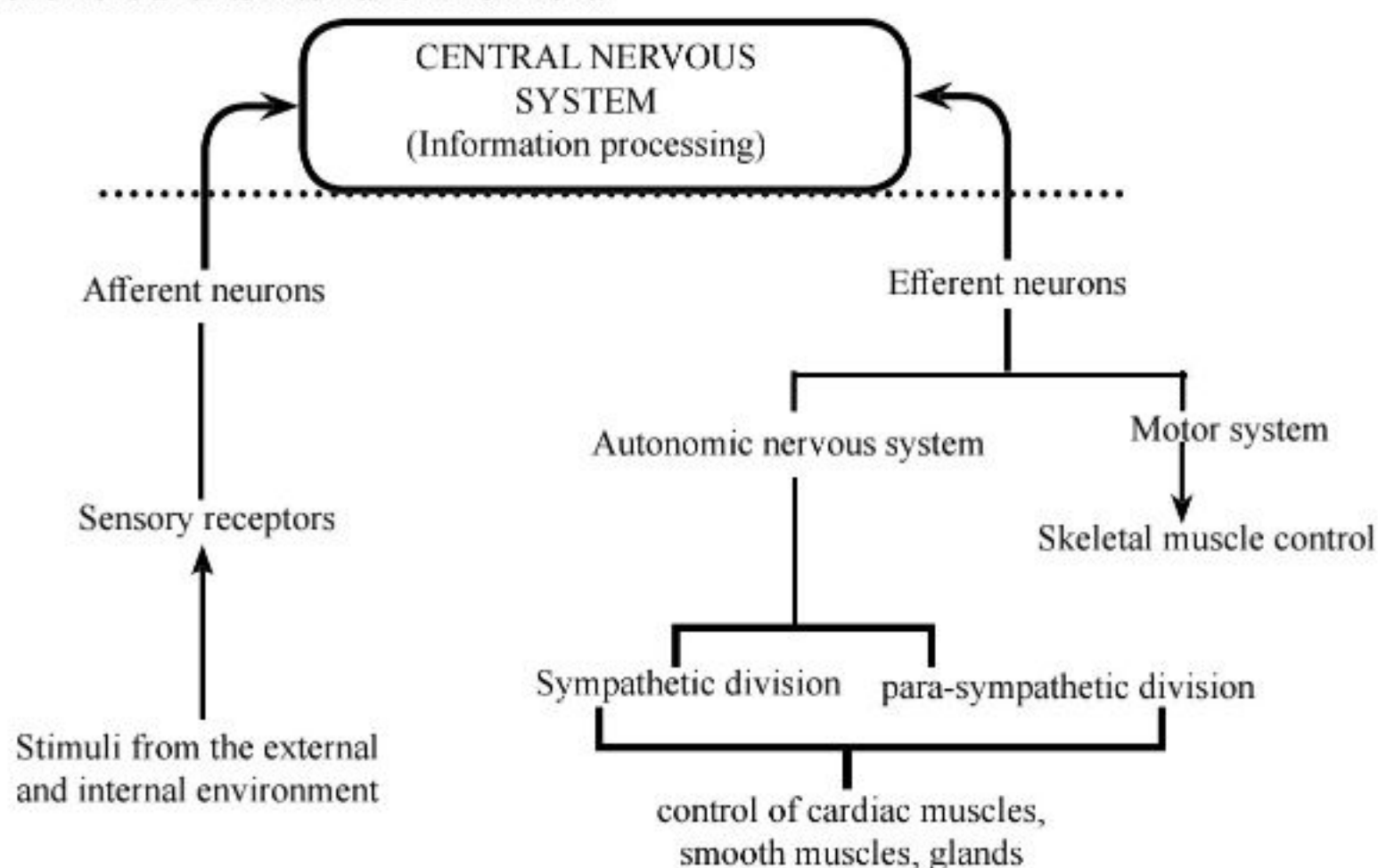


Figure 5.7 : Peripheral nervous system of a vertebrate (Functional hierarchy)

Sensory information from sensory receptors reaches the CNS along PNS neurons referred to as afferent neurons (sensory neurons). Within the CNS this information is processed and instructions are transmitted to effector tissues/organs (muscles, glands and endocrine cells) along PNS neurons referred to as efferent neurons (motor neurons).

PNS consists of two efferent components;

- The motor system- It consists of neurons that carry nerve impulses to skeletal muscles. So it controls voluntary activities.
- Autonomic nervous system- It generally controls the involuntary activities of the body. Autonomic nervous system consists of neurons which carry impulses to control activities of smooth muscles, cardiac muscles and glands.

**Autonomic nervous system consists mainly of two divisions:**

- Sympathetic division
- Parasympathetic division

### **Sympathetic and parasympathetic nervous system**

The majority of the body organs are supplied by both sympathetic and parasympathetic nerves which have antagonistic (opposite) functions. Sympathetic stimulations prepare the body to deal with exciting/ stressful situations and energy generating situations (fight- or -flight). Parasympathetic division causes opposite responses that promote calming or a return to self-maintenance functions (rest and digest).

The two divisions differ in overall functions, organization and the signal released. Parasympathetic nerves exit the CNS at the base of the brain or the spinal cord as cranial nerves or spinal nerves respectively. On the other hand sympathetic nerves exit only from the spinal cord. Different neurotransmitters enable the two systems to bring about two opposite effects in different organs such as lung, heart, intestine and bladder. For example, when the neurotransmitter secreted by the parasympathetic division is acetylcholine, the sympathetic division secretes norepinephrine.



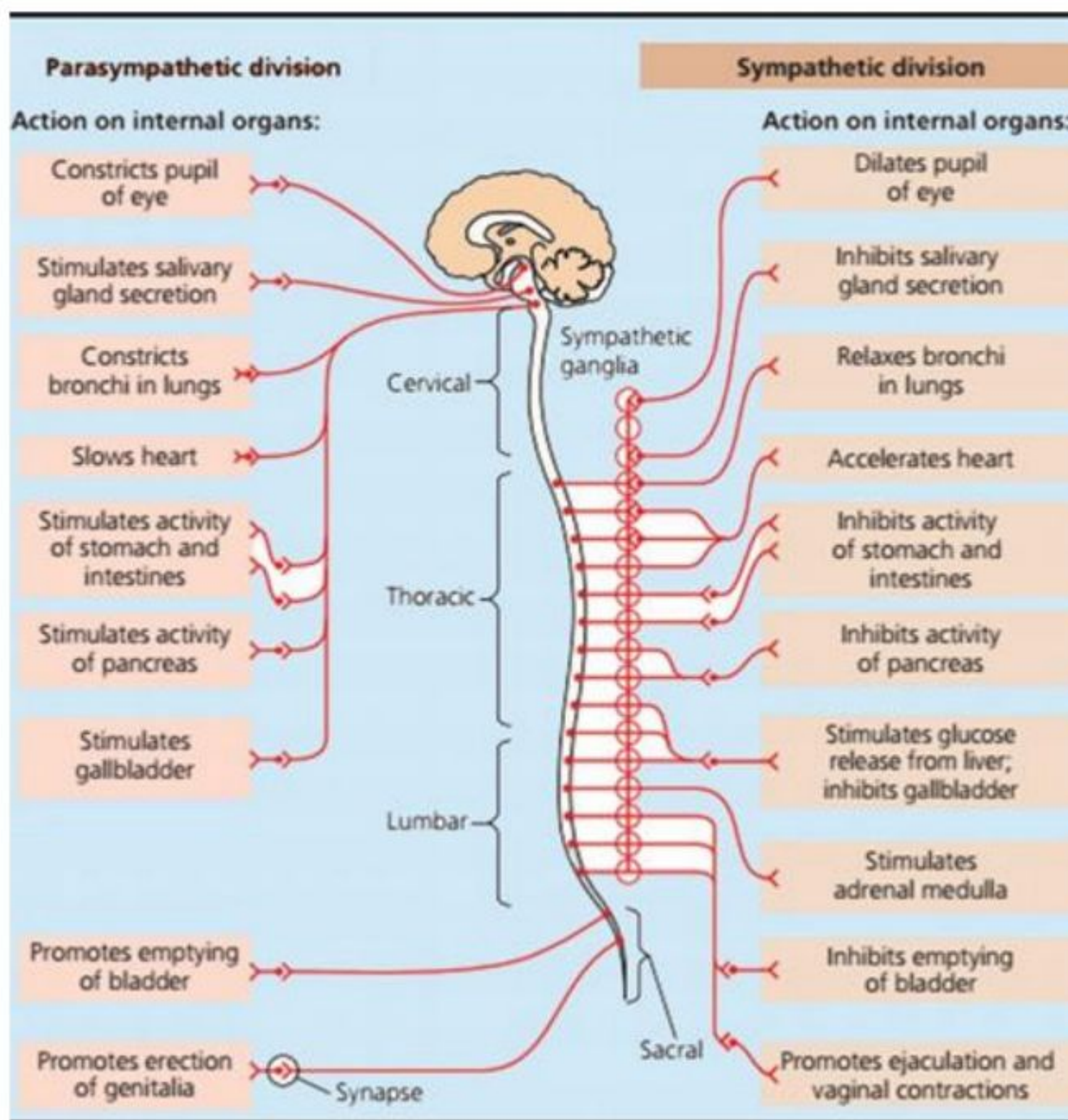


Figure 5.8: The autonomic nervous system (Parasympathetic and sympathetic division)

### How nerve impulses are generated and transmitted

In all cells including neurons, ions are distributed unequally between the cell interior and exterior (extra cellular fluid). Generally the inside of the cell is negatively charged whereas the exterior is positively charged. These opposite charges are attracted across the plasma membrane and as a result it creates a voltage difference across the membrane that is referred to as membrane potential.

### Resting potential

When a neuron is at rest (when not sending a signal/non conducting), the membrane potential is called the resting potential. In a non-conducting neuron the resting potential is typically between -60 mV and -80 mV.



The resting membrane potential is maintained by;

- Distribution of ion concentrations inside and outside of the neuron- In a non conducting neuron the concentration of  $K^+$  is higher inside the cell while concentration of  $Na^+$  is higher outside. In addition there are  $Cl^-$  and other large anions (proteins) inside the cell. As a result a neuron has a negative charge inside the cell and positive charge outside the cell.
- Selective permeability of the plasma membrane to  $K^+$  and  $Na^+$  ions- There are potassium channels and sodium channels, which are membrane bound proteins that are able to open or close in response to stimuli. Potassium channels allows only  $K^+$  ions to pass whereas sodium channels allow only  $Na^+$  to pass. These channels allow  $K^+$  and  $Na^+$  to diffuse according to their concentration gradient. However there are more potassium channels open than sodium channels. As a result there is a net negative charge inside the cell.
- Sodium-potassium pump- This pump helps to maintain  $Na^+$  and  $K^+$  gradient across the membrane by transporting three  $Na^+$  out of the cell for every two  $K^+$  that it transports in. This pump uses ATP to actively transport these ions.

### **Action potential**

An action potential occurs due to a change in membrane potential above a threshold value due to a stimulus. The action potential has the following phases: depolarization, repolarization and hyperpolarization.

**Depolarization:** A change in the cell's membrane potential such that the inside of the membrane is made less negative relative to the outside. Depolarization results due to  $Na^+$  inflow in response to a stimulus.

**Repolarization:** Sodium channels close blocking  $Na^+$  inflow. However most potassium channels open permitting  $K^+$  outflow. This makes the inside of the cell negative.

**Hyperpolarization:** Sodium channels are closed but potassium channels are opened. As a result the inside of the membrane is more negative.

### **Refractory period**

Refractory period is the short time immediately after an action potential in which the neuron cannot respond to another stimulus, owing to the inactivation of sodium channels. This prevents the reverse conduction of an impulse in an axon.



## Generation of action potential

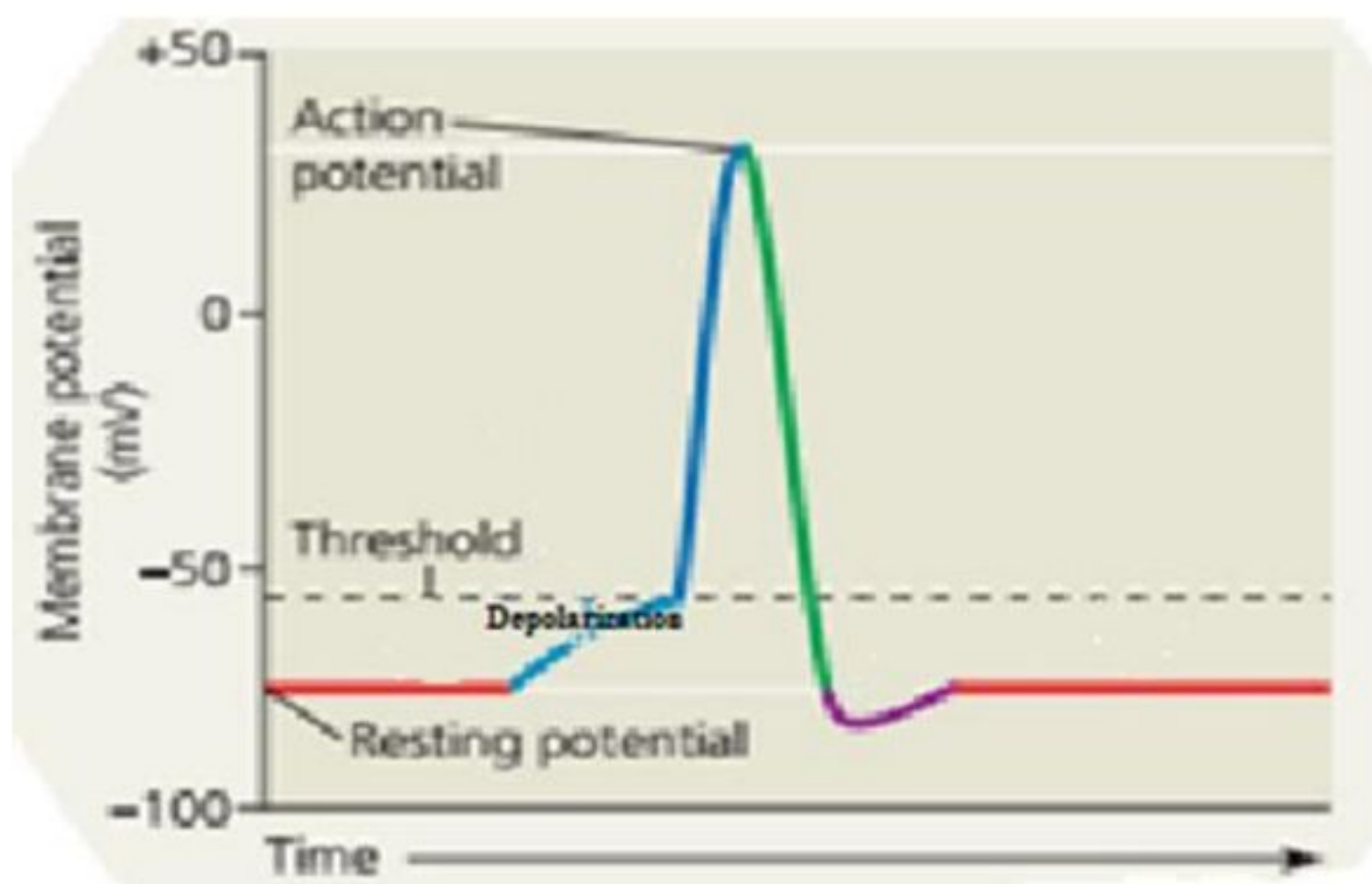


Figure 5.9: Graph of generating action potential

### Conduction of action potential (nerve impulse)

- A series of action potentials that move along an axon is defined as a nerve impulse.
- An action potential is generated due to  $\text{Na}^+$  inflow (depolarization) at one location in the axon.
- This axon potential spreads to the neighboring location while the initial location repolarizes.
- This depolarization-repolarization process is repeated through the axon.

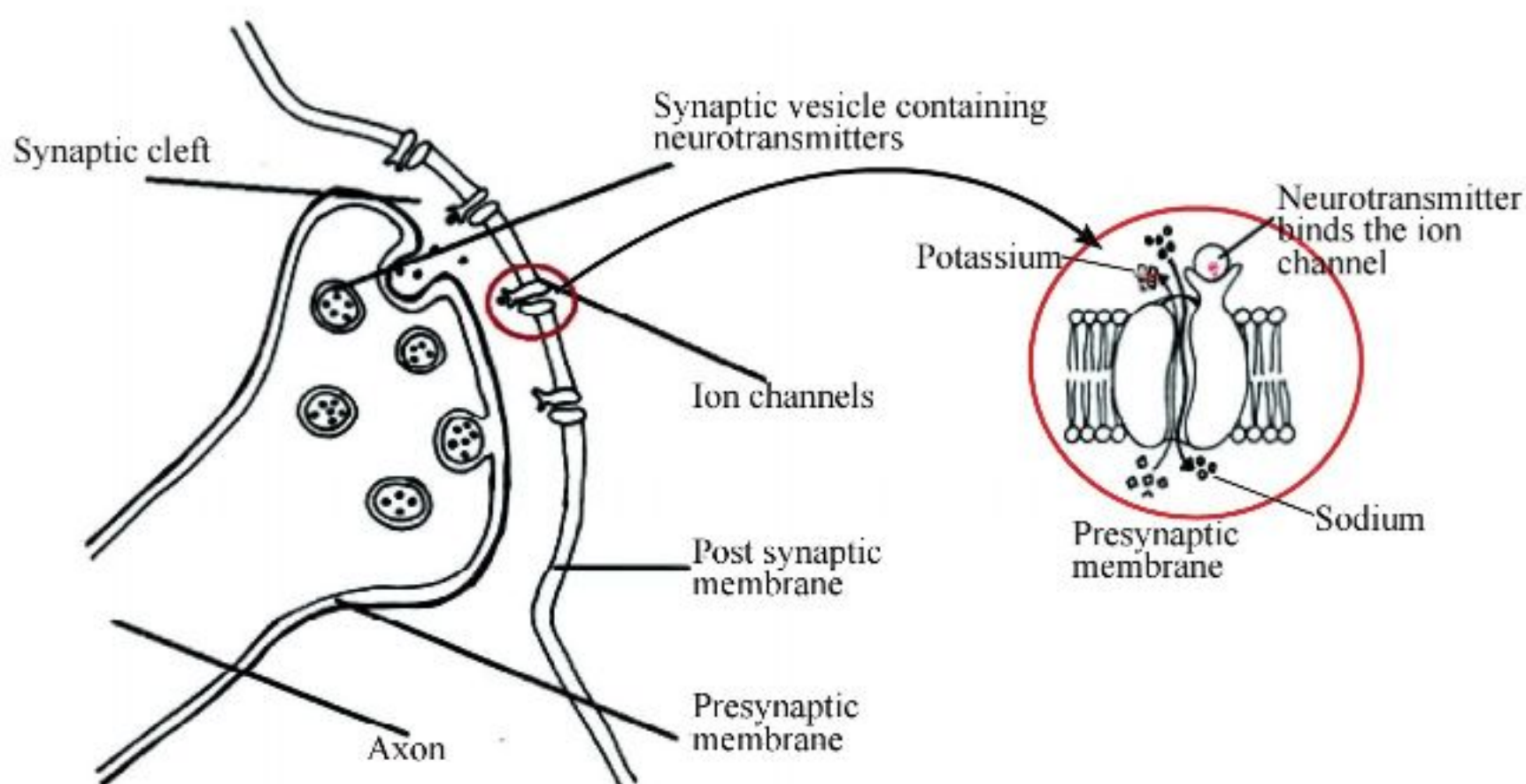
### The speed of conduction depends on:

Diameter of the axon- The conduction speed increases with the increase in axon diameter.

Presence of myelinated axon (in myelinated neuron, axon potential jumps from one node of Ranvier to the next)

### Synapses

A synapse is the junction where a neuron (presynaptic cell) communicates with another cell (postsynaptic cell) across a narrow gap (synaptic cleft). Postsynaptic cell may be another neuron, muscle cell or secretory cell. This junction where one neuron communicates with the next cell using a chemical (neurotransmitter) is called a chemical synapse. Some neurons can also communicate through direct electrical connections (electrical synapse).



**Figure 5.10: A synapse which communicates through a neurotransmitter**

### **Mechanism of transmission of nerve impulses through chemical synapses**

- An action potential at an axon terminal depolarizes the plasma membrane of presynaptic cell.
- Depolarization at the presynaptic terminal causes  $\text{Ca}^{2+}$  to diffuse into the terminals.
- The rise in  $\text{Ca}^{2+}$  causes binding of synaptic vesicles containing neurotransmitters to the presynaptic membrane.
- This results in the release of the neurotransmitters into the synaptic cleft.
- Neurotransmitters diffuse across the synaptic cleft.
- Neurotransmitters bind and activates specific receptors in the postsynaptic cell membrane.
- If acetylcholine is taken for example, the binding of neurotransmitters to the post synaptic membrane allows  $\text{Na}^+$  and  $\text{K}^+$  to diffuse across the post synaptic membrane.
- Depolarization takes place in the post synaptic membrane and it reaches the action potential
- After passing the nerve impulse to the postsynaptic cell, the signal is terminated either by:
  - Enzymatic hydrolysis of neurotransmitters
  - Recapture of neurotransmitter into the presynaptic terminals.

### **Neurotransmitters**

Neurotransmitters are the molecules that are released from the synaptic terminals of presynaptic neuron and diffuse across the synaptic cleft, bind to the receptors at the postsynaptic membrane, triggering a response.

Common neurotransmitters are;



- Acetylcholine
- Some amino acids
- Biogenic amines
- Neuropeptides
- Some gases

**Reflex arc**

Reflex arcs are the functional unit of the vertebrate nervous system. Typically a reflex arc consists of three neurons. They are

1. Afferent/ Sensory neuron
2. Interneuron
3. Efferent/ Motor neuron

A sensory neuron transmits impulses from a sensory receptor to the central nervous system where it synapses with an associated neuron called interneuron. This impulse is transmitted to a motor neuron. The motor neuron conveys the signal to effector tissues/organs.

**Common disorders of the nervous system**

Common disorders of the nervous system are Schizophrenia, Depression, Alzheimer's disease and Parkinson's disease.

- **Schizophrenia:** This is a severe mental disturbance characterized by psychotic episodes in which patients have a distorted perception of reality. They experience voices that only they can hear. They think that others are plotting to harm them. Evidence suggests that this disorder affects neural pathways that use dopamine as a neurotransmitter.
- **Depression:** Depression is likely to be due to a complex combination of factors that include: Changes in neurotransmitter levels in the brain, genetics, psychological, social, environmental factors. People who are suffering from this disorder show depressed mood, abnormalities in sleep, appetite and energy level. In some conditions once enjoyable activities are no longer pleasurable or interesting. Some conditions involve extreme mood swings. Effective therapies are available to increase activity of some neurotransmitters in the brain
- **Alzheimer's disease:** This is a severe mental deterioration (dementia) characterized by confusion and memory loss. Patients are gradually becoming less able to dress, bathe and feed themselves. They lose their ability to recognize people including their immediate family members. Cause of the disease is due to progressive and irreversible degeneration of neurons in the brain especially in cerebral cortex with deteriorating mental functioning. The disease affects elderly people. Genetic factors may be involved. So far, there is no cure for this disease.



- **Parkinson disease:** This is a progressive motor disorder that leads to lack of control and coordination of muscle movements. The patients show slowness of movements, difficulty in initiating movements, poor balance; fixed muscle tone causing lack of facial expression; speech problems and muscle tremor of extremities: e.g. shaking a hand, fingers in one hand, shaking head. This disease is associated with gradual degeneration of dopamine neurotransmitter releasing neurons in the brain (mid brain, basal ganglia). The disease is common in the elderly people. Genetic factors may be involved. Disease can be treated but not cured.

## Human sensory structures and functions

A sensory receptor is a specialized structure which can detect a specific stimulus and convert the stimulus energy to a changing membrane potential to be transmitted to the central nervous system as action potentials for sensory perception and interpretation. Sensory receptor can be a specialized cell or an organ or a subcellular structure that could detect the stimuli. Some sensory cells are specialized neurons. Sensory receptors can inform the central nervous system about the conditions inside and outside the body in order to maintain homeostasis. Specific sensory receptors detect the stimuli that arise in the external environment whereas internal receptors sense the stimuli that arise inside the body.

Basic characteristic of sensory receptors.

- A specialized structure (cell / organ / subcellular structure) designed to receive a specific stimuli.
- Detect the stimulus if the stimulus is at or above threshold level.
- Convert the energy of the stimulus (e.g. light energy, sound energy) into a changing membrane potential to be later transmitted as an action potential.
- Always connected with the nervous system.
- During the conversion of stimulus energy into the action potential, sensory signal can be strengthened which is called amplification.
- If the stimulation is continuous, many receptors show decrease in responsiveness which is called sensory adaptation (For example upon continuous exposure to a strong smell, perception of that smell gradually decreases and stops within few minutes).

### Types of sensory receptors

Sensory receptors can be categorized based on the nature of the stimulus they detect. Several types of sensory receptors are found in the human body. They are chemoreceptors, thermoreceptors, photoreceptors, mechanoreceptors and pain receptors.



- **Chemoreceptors**

These are sensory receptors that respond to chemical stimuli. Chemical substances should always be dissolved in water to stimulate sensory cells. Chemoreceptors include taste receptors and olfactory receptors. These receptors mediate the senses of taste and smell. Some chemoreceptors can detect specific chemicals such as  $\text{CO}_2$  in the circulating blood.

- **Taste receptors:** Five basic sensations of taste have been described: sweet, sour, bitter, salt and umami (savory taste). Receptor cells for taste are modified epithelial cells organized into taste buds. Taste buds are found in papillae which are small projections of the tongue. A taste bud consists of taste cells, supporting cells and sensory nerve endings. Substances to be tasted should be dissolved in the fluid surrounding the sensory cells and diffuse to receptor cells.

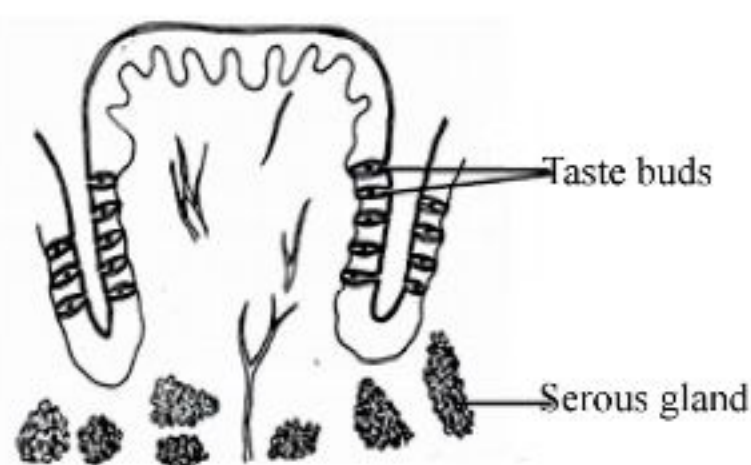


Figure 5.11: A section of a papilla

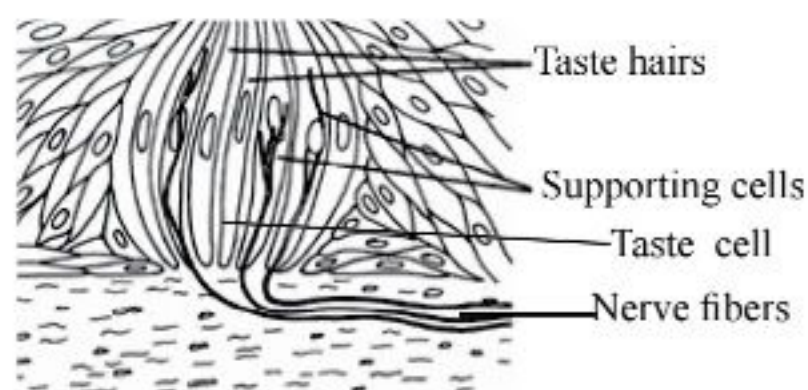


Figure: 5.12-A magnified taste bud

- **Olfactory receptors:** In olfaction, receptor cells are neurons. Olfactory receptor cells are located within the epithelium of the upper portion of the nasal cavity. Receptive ends of the cells extend into the mucus layer of the nasal cavity. When odorants diffuse into this region, receptor cells are stimulated and the nerve impulse is sent along their axons to the olfactory bulb in the brain.
- **Thermoreceptors**

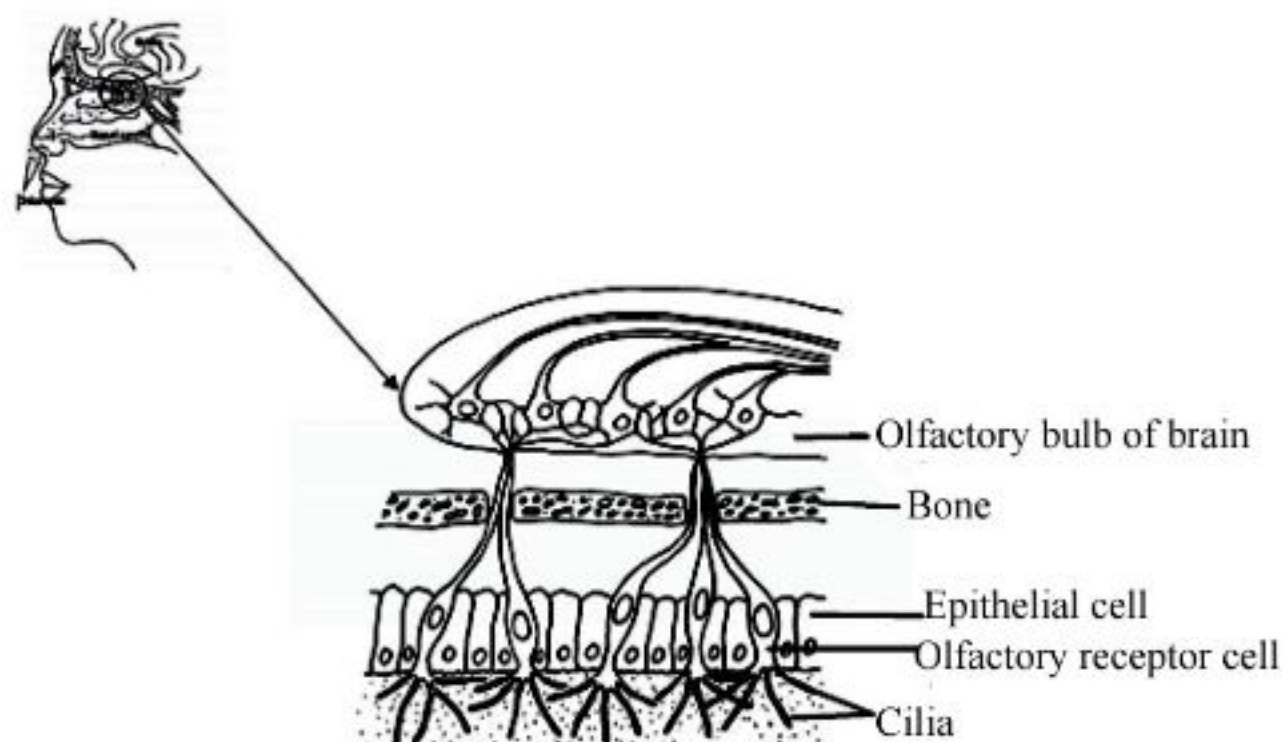


Figure 5.13: Location of olfactory receptors in humans



Thermoreceptors are specialized temperature sensitive receptors which detect heat and cold on the body surface and in the internal environment of the body. Thermoreceptors located in the skin detect the body surface temperature whereas thermoreceptors found in hypothalamus detects the temperature of the blood circulating through the internal organs (core temperature). Thermoreceptors found in the skin are: Krause end bulbs (detect cold), Ruffini corpuscles (detect warmth) and free nerve endings (detect both cold and warmth). Thermoreceptors found in the hypothalamus are specialized neurons.

- **Photoreceptors**

Photoreceptors are sensitive for light. Humans have two main types of photoreceptor cells called rods and cones.

- **Rods:** They are more sensitive to light but do not distinguish colours, they enable us to see at night but only in black and white.
- **Cones:** They provide colour vision. But they contribute very little to night vision as they are not much sensitive. There are three types of cones. Each has a different sensitivity across the visible spectrum providing an optimal response to red, green, or blue light.

- **Mechanoreceptors**

Mechanoreceptors respond to stimuli arising from mechanical energy deformation such as pressure, touch, stretch, motion and sound. Mechanoreceptors in the human body include the following.

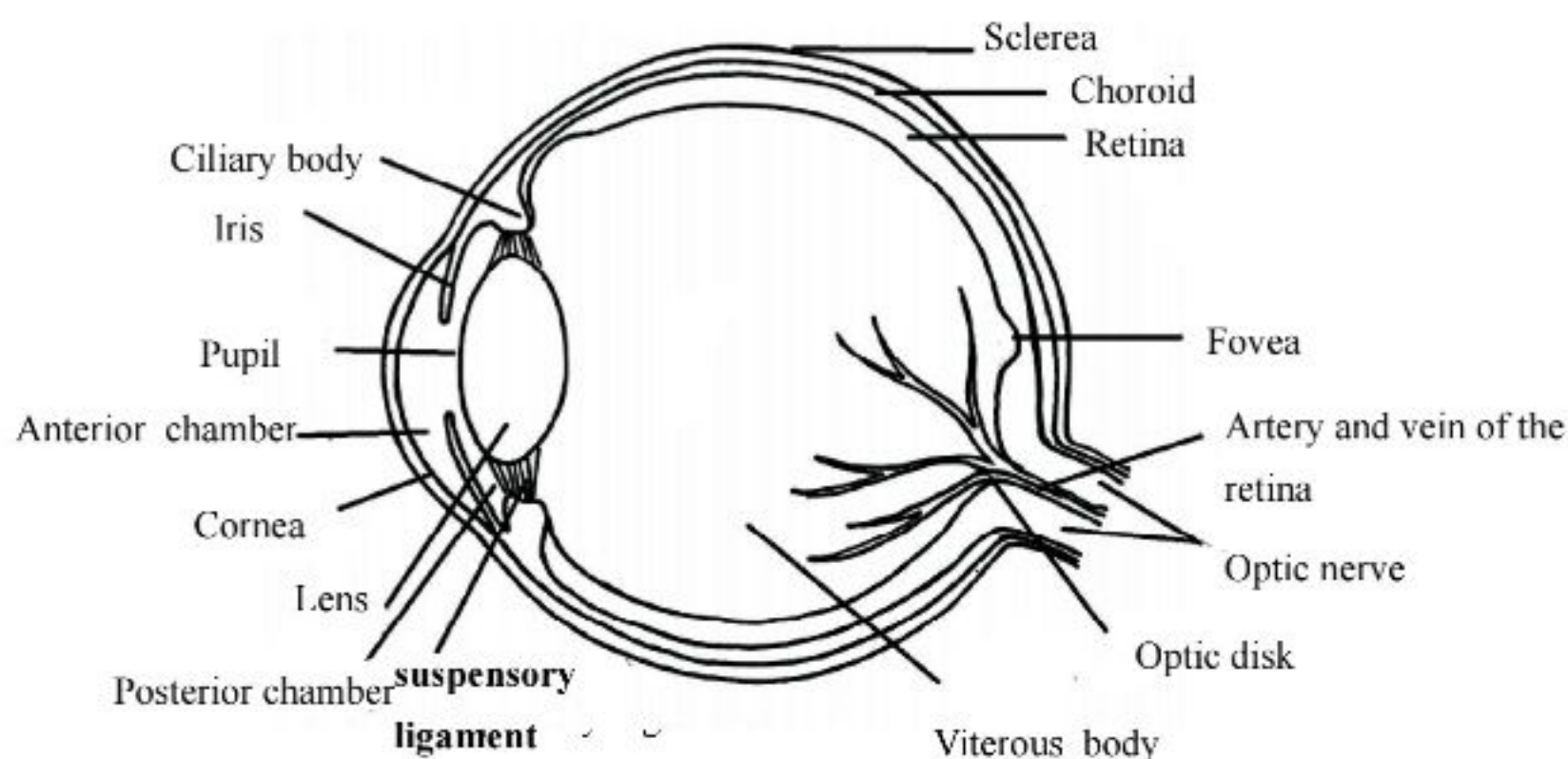
- **Touch receptors:** They are mostly present close to the surface of the skin. Examples for touch receptors are Meissner corpuscles (sensitive to light pressure), Merkel discs (sensitive to light touch) and free nerve endings.
- **Pressure receptors:** Example for pressure receptors are Pacinian corpuscles which are present in the deep skin. They are sensitive to deep pressure.
- **Vibration receptors:** Most of the touch receptors can also detect vibrations (e.g. Meissner corpuscles, Pacinian corpuscles). Specific hair cells in the organ of Corti in the inner ear detect sound vibrations. Hair cells of the vestibule of the inner ear detect the gravity whereas hair cells of the semicircular canals detect the motion.

- **Pain receptors**

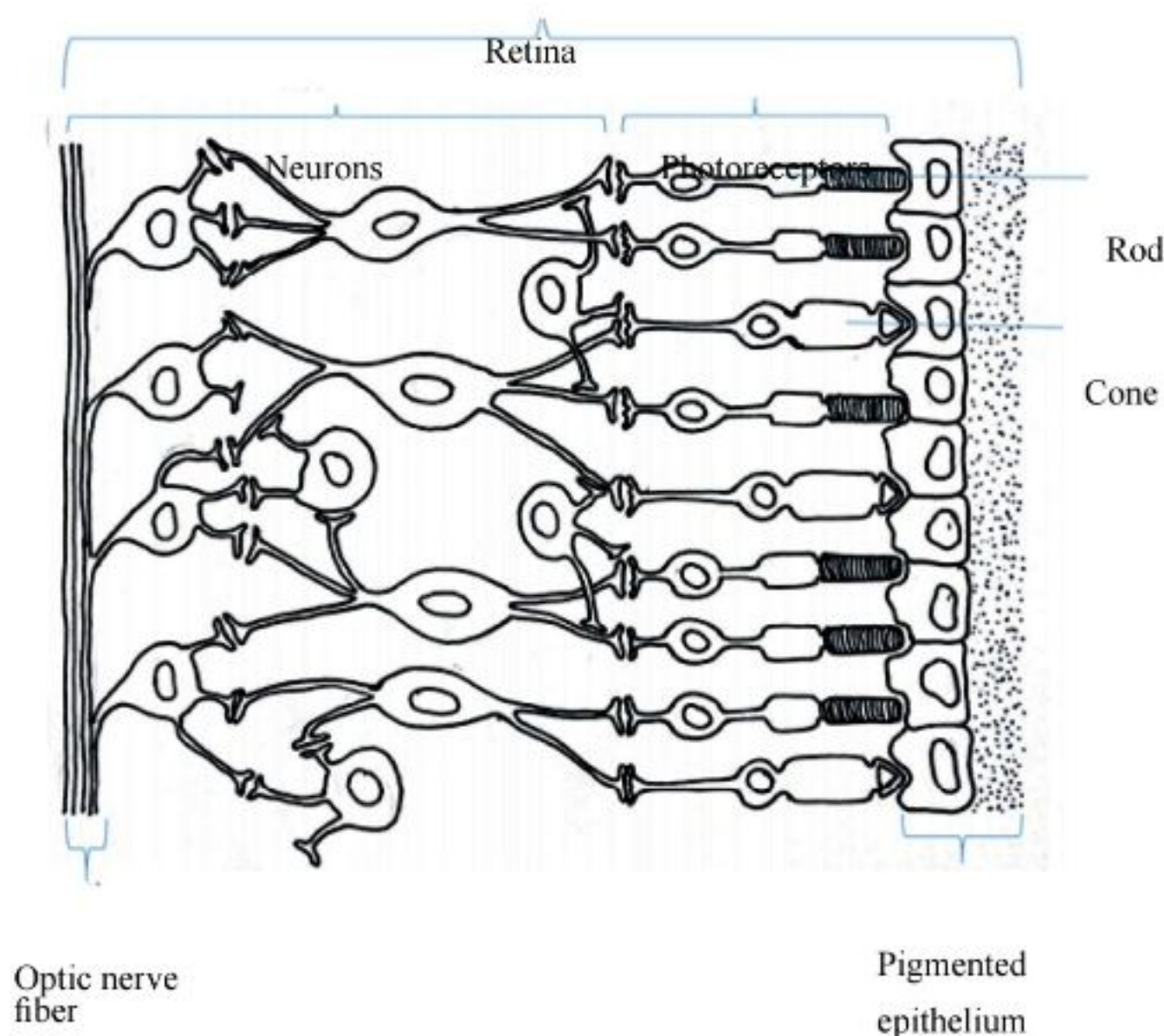
Pain receptors detect stimuli that reflect harmful conditions that could arise from extreme pressure or temperature and certain chemicals that could damage the tissues. Special nerve endings in different parts of the body can detect the tissue damage. Ultimately the pain is perceived by the brain.



### Basic structure and functions of the human eye



**Figure 5.14: The basic structure of the human eye**



**Figure 5.15: The retina**

The eye is the organ responsible for sight. There is a fine transparent membrane that lines the iris and front of the eye ball; this is called conjunctiva. The walls of the eye are made up of three layers of tissue: The outer fibrous layer (sclera and cornea), the middle vascular layer (choroid,



ciliary body and iris) and the inner nervous layer (Retina). Inside the eyeball contains the lens, aqueous fluid and vitreous body.

### **Sclera and cornea**

- Sclera is white and opaque. It is the outermost layer of the posterior and lateral aspects of the eye ball. It connects anteriorly with the clear transparent epithelial membrane called cornea. Sclera maintains the shape of the eye and gives attachment of the extrinsic muscles of the eye.
- Cornea is the passage through which light rays reach the retina. It is devoid of blood vessels. The cornea is convex anteriorly and is involved in refracting light rays to focus on the retina.

### **Choroid, ciliary body and iris**

- Choroid is located just beneath the sclera. It is a thin pigmented layer and rich with blood vessels.
- Ciliary body is the anterior continuation of the choroid layer consisting of smooth muscle fibers (ciliary muscle) and sensory epithelial cells. Most of these smooth muscle fibers are circular. Therefore ciliary muscles act as a sphincter. The ciliary body holds the lens in place by suspensory ligaments. The size and thickness of the lens can be controlled by contraction and relaxation of the ciliary muscle fibers attached to these suspensory ligaments. Epithelial cells secrete aqueous humor.
- Iris is a circular coloured body composed of pigment cells. It is located at the front of the eye. It extends anteriorly from the ciliary body and present behind the cornea and in front of the lens. It contains two layers of smooth muscle fibers which are arranged as circular and radial bundles. In the center of iris is a hole called pupil. Iris controls amount of light entering the pupil by changing size which is mediated by the autonomic nervous system. Pigments prevent penetration of excessive light.

### **Lens**

The lens is lying immediately behind the pupil. It is an elastic, biconvex transparent disc made up of protein enclosed within a transparent capsule. It refracts light rays reflected by objects in front of the eye and focuses them on the retina to form the image. By changing the thickness, the lens can vary its refractive power in order to focus rays on the retina.

### **Aqueous fluid (aqueous humour) and vitreous body (vitreous humour)**

In front of the lens, a clear watery substance is present which is called aqueous fluid (Blockage of ducts that drain this fluid can produce glaucoma causing vision loss). Aqueous fluid supplies nutrients and removes wastes from the cornea, lens and lens capsule which have no blood supply. Behind the lens a colourless and transparent jelly like vitreous humour is present. It maintains enough intra ocular pressure to support the retina against choroid and prevents the eye ball from collapsing.



## Retina

- Retina is the innermost lining of the eye. It consists of three layers: Outer pigmented epithelium, middle photoreceptive layer and inner layer with neurons. Photoreceptor layer consists of sensory cells (rods and cones) which contain photosensory pigments that can convert light rays into nerve impulses. Retina is thickest at the back. At the centre of the posterior part of the retina, macula lutea (yellow spot) is present. In the center of the yellow spot there is a little depression called the fovea centralis which contains only cones. Towards the anterior part of the retina there are fewer cones than rods. About 0.5 cm to the nasal side of the macula lutea all the nerve fibers of the retina converge to form the optic nerve. The small area of retina where the optic nerve leaves eye is the blind spot (optic disk). It lacks photoreceptors.
- **Photoreceptor cells:** There are two types: rods and cones. Within the outer segment of these cells is a stack of membranous disks in which visual pigments are embedded. In the retina, more rods are present than cones. In the rods visual pigment is rhodopsin. They are sensitive to light but do not distinguish colours. They enable us to see at night but only in black and white. In the cones, visual pigment is photopsin. They provide colour vision. They contribute very little to night vision as they are less sensitive. There are three types of cones each of which has a different sensitivity across the visible spectrum providing an optimal response to red, green or blue light.
- Neurons in the retina: several types of neurons are present including bipolar cells and ganglion cells.

## Functioning of the human eyes

Light is reflected into the eye by the objects in the field of vision. In order to achieve clear vision, light reflected from the object within the visual field should be refracted mainly by the lens and focused on the retina of each eye. The processes which are involved in producing a clear image on the retina are refraction of light rays, changing the size of the pupil and accommodation. Then photoreceptor cells in the retina convert light energy to voltage changes leading to action potentials which are sent through the optic nerve to the brain for perception of visual objects. In the retina, stimulation of rods leads to black and white vision. Cones are sensitive to light and colour therefore bright light is needed to activate them and give sharp clear colour, vision. The different wavelengths of visible light activate light sensitive pigments in the cones which result in perception of different colours.

- **Refraction of light rays**

Light rays coming from the visual field pass through the conjunctiva first, then successively through cornea, aqueous fluid, lens and vitreous body before reaching the retina. During this



process light rays are refracted (bent) to focus them on the retina as they all are denser than the air. Lens has changing refractory power while all the other parts (conjunctiva, cornea, aqueous fluid and vitreous body) have constant refractory powers. Light rays are mostly refracted by the biconvex lens.

- **Changing the size of the pupil and accommodation**

For clear vision, the amount of light entering the eye is controlled by changing the size of the pupil which is mediated by the autonomic nervous system. Light rays coming from the distant objects need least refraction but as the object comes closer, the amount of refraction needs to be increased to focus light rays on the retina. Hence for near vision the eye must make some adjustments.

- **Constriction of the pupil:** In bright light, pupils are constricted to avoid entering too much light into the eye and damage the sensitive retina. In dim light, the pupils are dilated to allow entering sufficient light to activate photoreceptors which would eventually enable the vision.
- **Movement of the eye ball (convergence):** As light rays from near objects enter the two eyes at different angles, for clear vision they must stimulate corresponding areas of two retina. Muscles attached to the eye ball rotate the eyes to achieve the convergence. This is under autonomic controls.
- **Changing the refractory power of the lens:** Parasympathetic nervous supply to the ciliary body controls the contraction of ciliary muscles and accommodation of eye. Accommodation is important in near vision for focusing on near objects. In near vision the ciliary muscles contract thereby moving the ciliary body inwards towards lens. As a result convexity of the lens is increased due to the reduction of the pull of the suspensory ligaments on the lens. Thus light waves from the near objects are focused on the retina. When seeing a distant object, ciliary muscles relax, then ciliary body moves away from the lens that increases the pull of the suspensory ligaments on the lens so convexity of the lens is reduced. Thus light rays from distant objects are focused on the retina.

**Focusing the image on the retina and converting the light energy to action potential to be transmitted to the brain**

- The light waves coming from the object are bent (refracted) and focused on the retina. This process produces an image on the retina which is upside down. Once light rays reach the retina, chemical changes happen in the photoreceptive cells (rods and cones).
- Bipolar cells receive information from photoreceptor cells and each ganglion cell gathers inputs from several bipolar cells. In addition, specific neurons in the retina can integrate information across the retina. Ganglion cells form the optic nerve fibers that transmit sensation from the eyes as action potential to the brain. This change will generate a nerve impulse.
- The optic nerve transmits this nerve impulse into occipital lobes (visual area) of the cerebrum. There the visual objects are perceived in the correct way (the right way up) by the brain.



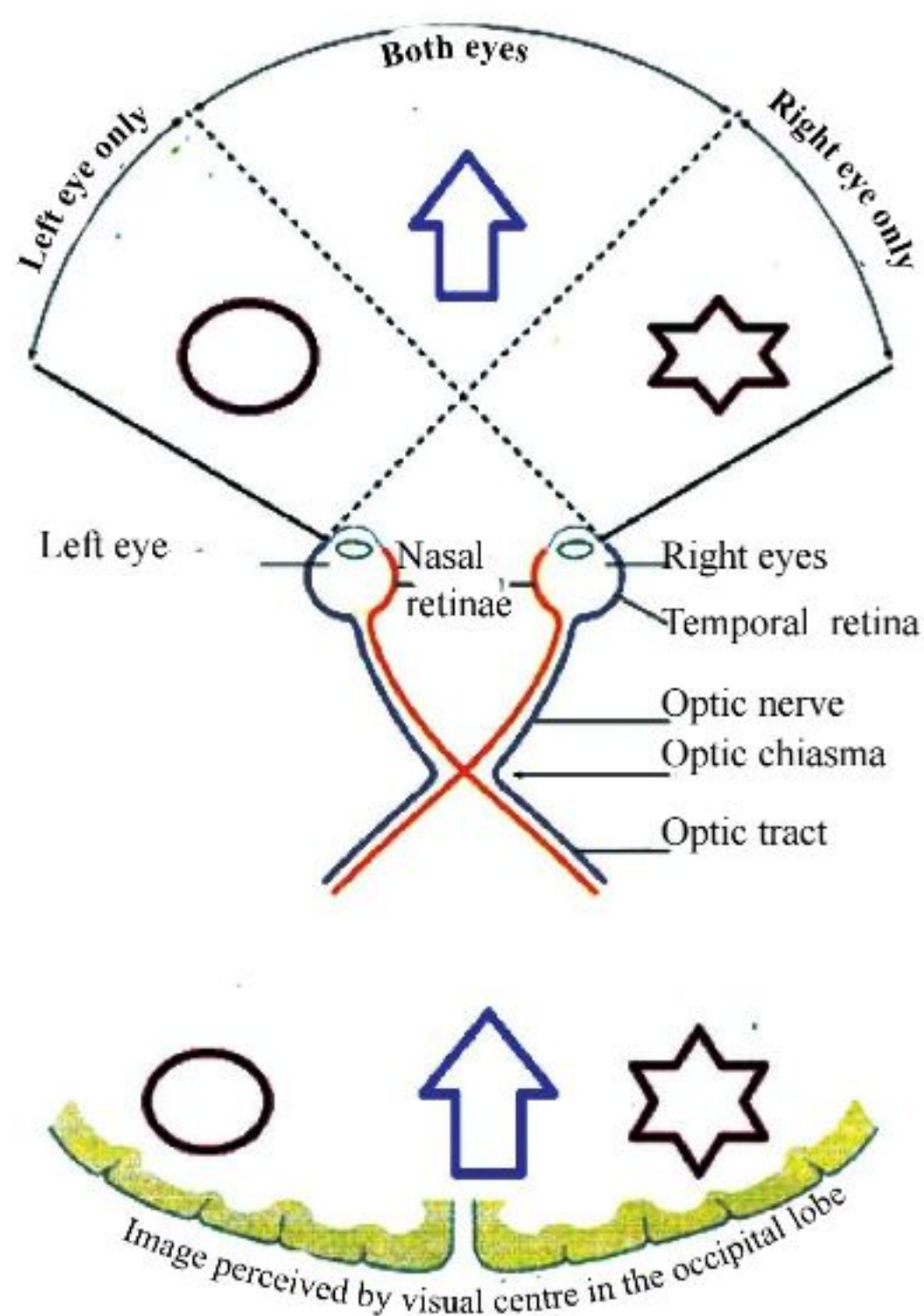
- Choroid functions in absorption of light after the entered light stimulate sensory receptors in the retina.

### **Monocular vision and binocular vision in human**

In humans, both eyes are located in front of the face which facilitates coordinated vision from the two eyes. However it is possible to see visual fields with one eye. Seeing the visual field using only one eye is called monocular vision. However when one eye is used, three dimensional vision is impaired especially in relation to the judgment of speed and distance.

Seeing the visual field using two eyes with greater overlapping fields of view is called binocular vision. The left eye views more on the left of the visual fields. The right eye views more on the right of the visual fields. Even though each eye views a scene from a slightly different angle, in the middle the visual fields are overlapped. However only one image is perceived due to the fusion of left, middle and right of the visual field images from the two eyes in the occipital lobe of the cerebrum.

Unlike monocular vision, binocular vision enables three dimensional views. So binocular vision is very important in judging the speed and distance of an approaching object such as a vehicle. It gives more accurate assessment of one object relative to another in relation to distance, depth, height and width. In some individuals, binocular vision may be impaired. Such individuals face difficulties to judge the speed and distance of an approaching object.



**Figure 5.16: Visual fields**

### Structure of the human ear

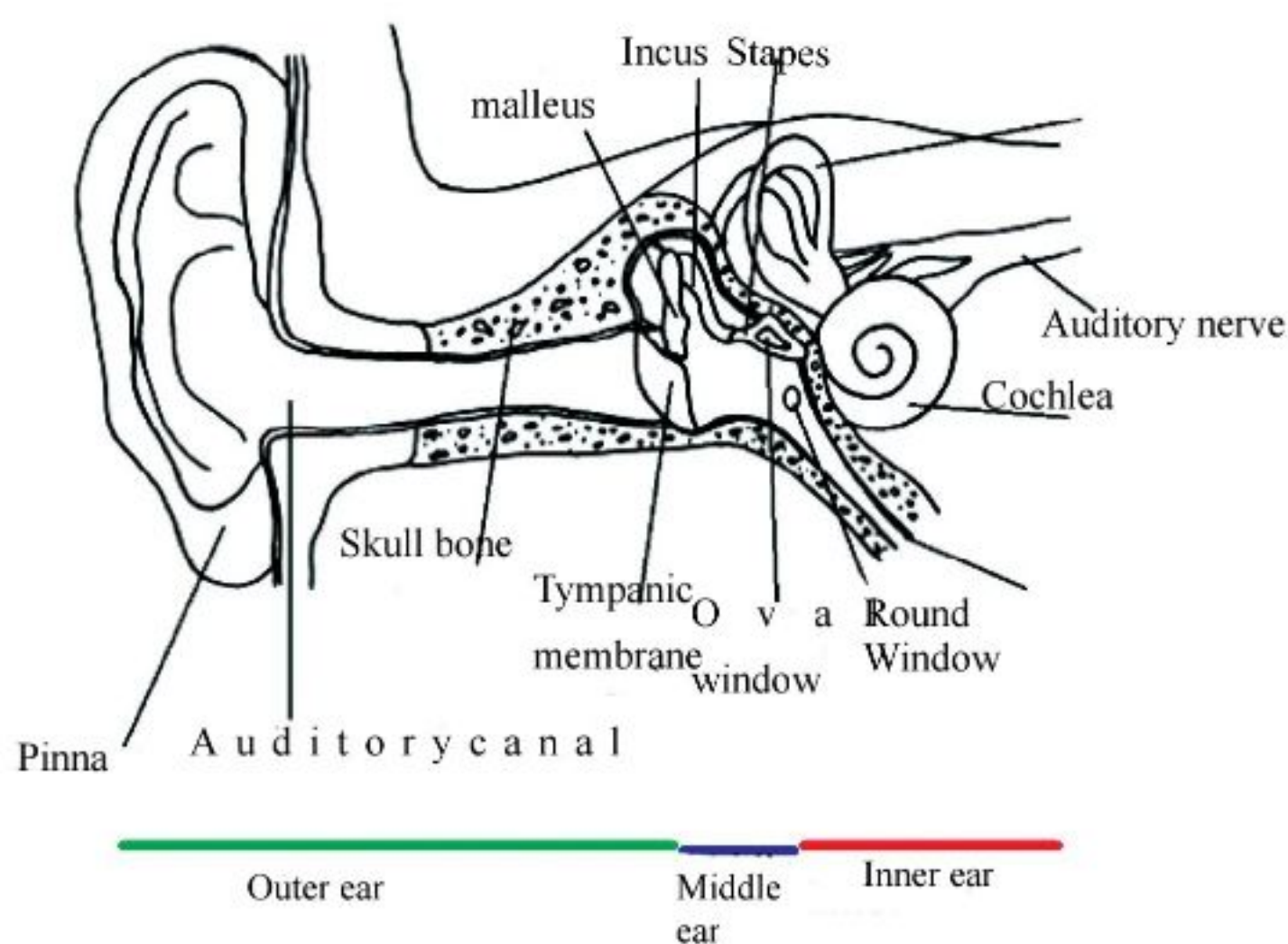
Human ear is divided into three parts; outer ear, middle ear and inner ear.

Outer ear consists of pinna and auditory canal. Auditory canal is a slightly “S” shaped tube and lined by hairy skin with numerous modified sweat glands which secrete ear wax. Auditory canal extends to the tympanic membrane which is located in between the middle and the outer ear.

Middle ear (tympanic cavity) is an air filled cavity within the temporal bone. It is lined by simple epithelium. In the medial wall of the middle ear, there are two openings called oval window and round window. Oval window is covered by a small bone called stapes. Round window is covered by a fine fibrous tissue. Three very small bones (ear ossicles) called malleus, incus and stapes extend across the middle ear from tympanic membrane to the oval window. They form movable joints with each other and the medial wall of the cavity at the oval window. Malleus is in contact with the tympanic membrane and form a movable joint with the incus. Incus articulates with the stapes which fits with the oval window. A long tube called Eustachian tube connects the middle ear to the pharynx.



Inner ear is formed from a network of channels and cavities in temporal bone which are called bony labyrinth. Within the bony labyrinth, a network of fluid filled membranes called membranous labyrinth is present which lines and fills the bony labyrinth. Inner ear is composed of three main regions: vestibule, three semicircular canals and cochlea. Vestibule is the expanded part near the middle ear. Oval and round windows are present in its lateral walls. Vestibule contains two membranous sacs called utricle and saccule. Semicircular canals are three tubes arranged at right angles to one another so that one is situated in each of the three planes of space. They are continuous with the vestibule. Cochlea is a coiled structure with the broad base which is continuous with the vestibule. Cochlea has three compartments: an upper vestibular canal, a lower tympanic canal and middle cochlear duct which is a small canal that separates the upper and lower canals. Vestibular canal originates at the oval window and tympanic canal ends at the round window. The two canals are continuous with each other and filled with perilymph. The cochlear duct is a part of the membranous labyrinth and filled with endolymph. The floor of the cochlear duct is called the basilar membrane which bears the organ of Corti (spiral organ). It contains supporting cells and specialized cochlear hair cells containing mechanoreceptors (auditory receptors) of the ear. Hairs of the cochlear hair cells project into the cochlear duct. Many hairs are attached to the tectorial membrane that hangs over the organ of Corti. Auditory receptors are dendrites of sensory nerves that combine to form the auditory nerve to the brain.



**Figure:5.17-The typical structure of the human ear**

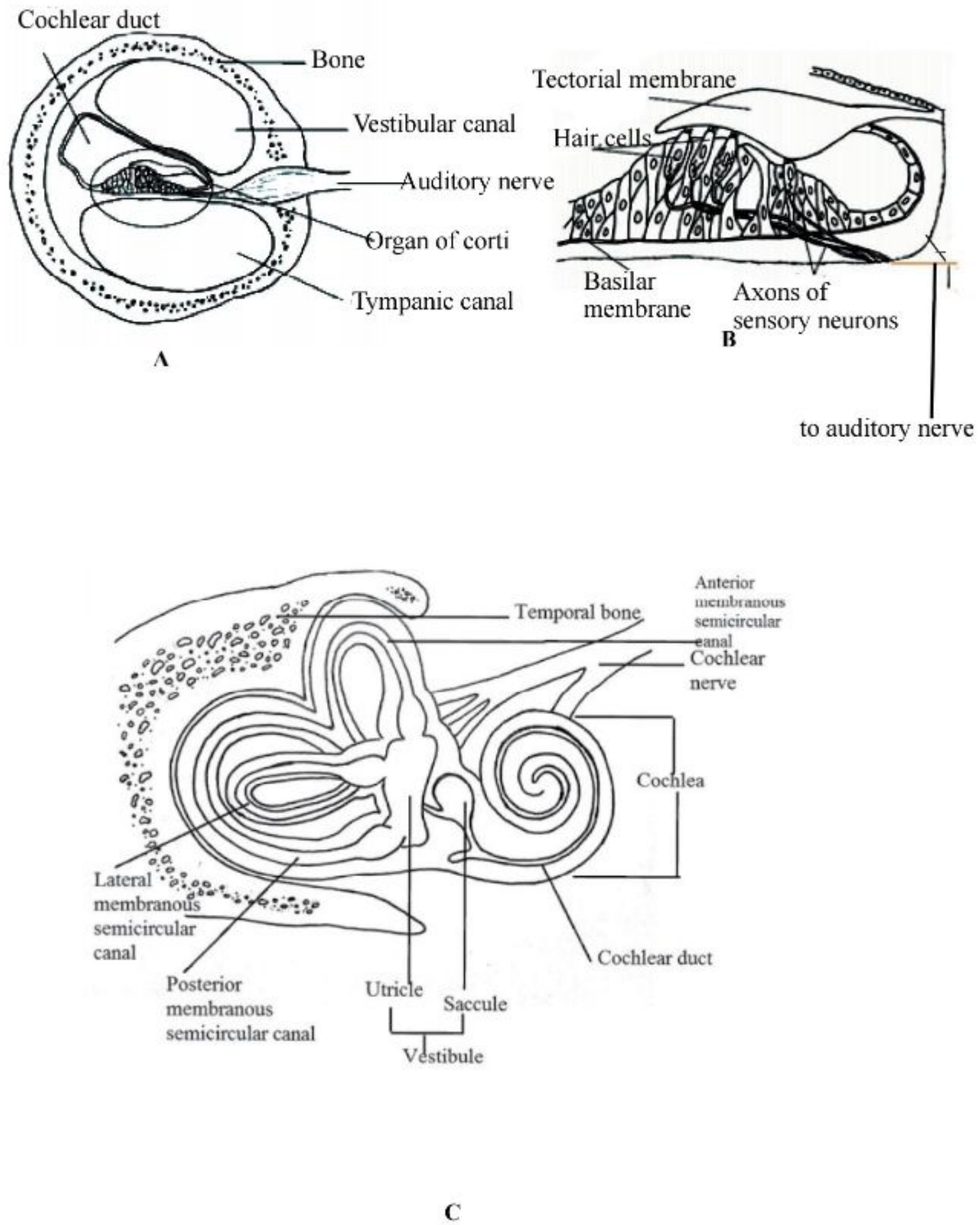


Figure 5.18: (a) . The Cochlea (b) . The organ of Corti (c) The semicircular canals



## **Functions of the human ear**

### **Hearing**

Vibrating objects produce pressure waves in the surrounding air. In hearing, the ear transduces these pressure waves (mechanical stimulus) into nerve impulses that are transmitted to the brain which perceives as sound.

The outer ear collects and concentrates the sound waves and directs them along the auditory canal towards the tympanic membrane. This causes the tympanic membrane to vibrate. Tympanic membrane vibrations are transmitted and amplified through the middle ear by the movement of three jointed ear ossicles.

The ear ossicles transmit the vibrations to the oval window which is located on the membrane of the cochlear surface. When the stapes vibrates against the oval window, pressure waves are created in the perilymph inside the cochlea. When the fluid pressure waves enter the vestibular canal they push down on the cochlea duct and the basilar membrane. As a result, the basilar membrane and attached hair cells vibrate up and down. This causes bending of hair projecting from the hair cell against the fixed tectorial membrane which lies above the hair cells. This results in the stimulation of auditory receptors in the auditory hair cells and generation of nerve impulses. These nerve impulses are passed to the auditory area of the brain (temporal lobe of the cerebrum) for sound perception.

After the sound perception, the fluid wave is finally dissipated into the middle ear by vibration of the membrane of the round window. Eustachian tube maintains the air pressure on both sides of tympanic membrane at the atmospheric pressure level.

### **Equilibrium**

Semicircular canals and vestibule located in the inner ear provide information about the position of the head in space and contribute to maintain the posture and balance.

Utricle and saccule of the vestibule perceive position with respect to gravity or linear movements. Each of these perilymph filled chambers contain hair cells that project into a gelatinous material in which small calcium carbonate particles (otolith) are embedded. When the head is tilted otoliths press on the hairs projecting into the gels. Hair cell receptors transform this deflection into an electrical signal and pass into cerebellum.

The semicircular canals, arranged in three spatial planes detect angular movements of the head. Within each canal, hair cells form a cluster with the hairs projecting into a gelatinous cap. Changes in the position of the head causes movements in the perilymph and endolymph. As a result hair cells are stimulated and resulting nerve impulses are transmitted to the brain.



**Basic structures and functions of the human skin**

In the human body skin is the largest organ. It consists of two main layers which are the epidermis and the dermis. The layer underneath the skin is called subcutaneous layer which is composed of adipose tissue and areolar tissue.

**Epidermis**

Epidermis is the outermost layer of the skin which consists of stratified keratinized squamous epithelium. Epidermis is not supplied with blood vessels. But its deeper layers are provided with nutrients and oxygen by the interstitial fluid of the dermis finally drained away as lymph. There are several layers of cells in the epidermis. The deepest layer is the germinative layer from which epidermal cells are originated constantly. These cells undergo gradual changes as they progress towards the surface of the skin. The cells on the surface are flat, thin, non-nucleated and dead, in which the cytoplasm has been replaced by keratin which is a fibrous protein. The surface cells are constantly rubbed off and replaced by the cells underneath. In areas where the skin is subjected to wear and tear, the epidermis is thicker (e.g. palms and fingers of the hand, sole of the foot)

Melanocytes in the deep germinative layer secrete a dark pigment called melanin contribute to the skin colour. In addition extent of oxygen saturation in the circulating blood in the dermis, excessive levels of bile pigments and carotenes in the fat layer can affect the skin colour.

**Dermis**

Dermis is composed of areolar connective tissue. The matrix contains collagen fibers interlaced with elastic fibers. Collagen fibers bind water and give the skin its tensile strength. Fibroblasts, macrophages and mast cells are the main cells found in the dermis.

The structures present in dermis are

- blood and lymph vessels
- sensory nerve endings
- sweat glands
- sebaceous glands
- hair, arrector pili muscles
- sensory receptors (Meissner's corpuscle, Pacinian corpuscle, free nerve endings, bulb of Krause, organ of Ruffini, Merkle discs)

**Functions of the human skin**

- **Protection:** skin act as a defensive barrier against invasion by microorganisms, entrance of chemicals and physical agents and dehydration. The skin contains keratinized epithelium which is relatively water proof. This layer can protect deeper and more delicate structures. The skin contains specific immune cells which can phagocytose foreign invasions. The melanin pigments protect against the harmful effects of UV radiations.



- **Regulation of the body temperature:** The skin contributes to regulation body temperature as it provides passage through which heat can be lost or gained depending on the body requirements. When body temperature is increased above the normal range, sweat glands secrete sweats onto the skin surface. Evaporation of sweat cools the body surface. When heat stressed, heat loss can be promoted by increasing the blood flow through the skin capillaries by dilating arterioles. When the body temperature falls beyond the normal range heat loss through the skin capillaries can be minimized by constricting arterioles in the dermis. When cold stressed, contraction of erector pili muscles attached to the hair can generate body heat and contribute to the heat production.
- **Cutaneous sensation:** Skin contains sensory receptors which are sensitive to touch, pressure, temperature and pain. Upon stimulation, nerve impulses are generated which are transmitted to the brain for sensory perception.
- **Synthesis of vitamin D:** Exposure to the sunlight can convert a lipid based substances in the skin to vitamin D.
- **Excretion:** Skin serve as a minor excretory organ. Sodium chloride, urea, and aromatic substances such as garlic can be excreted in sweat.

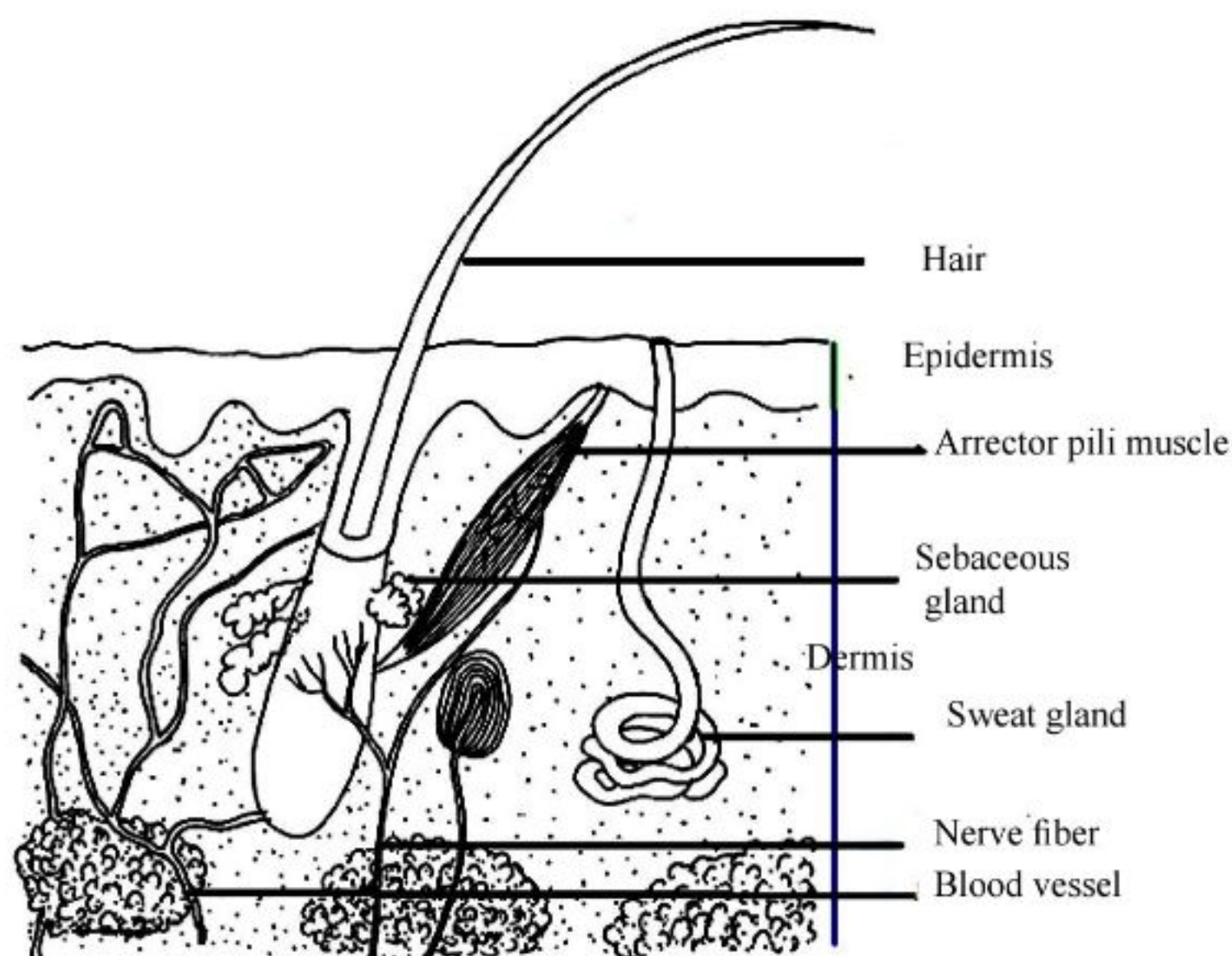


Figure 5.19: Typical structure of the skin



## The role of human endocrine system

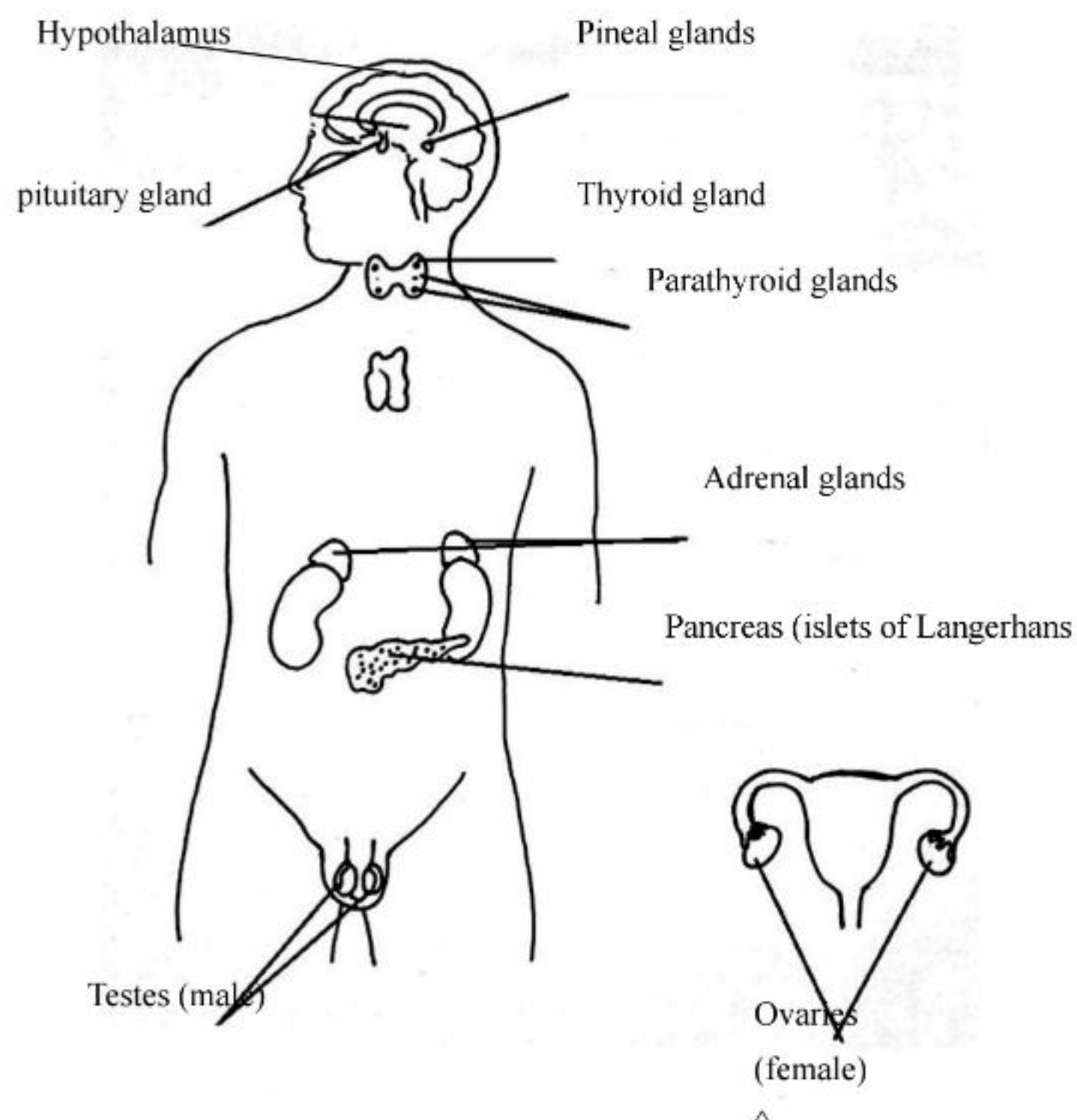
Endocrine system is one of the two basic systems for coordination and regulation of activities in the human body. Compared to the nervous system, endocrine control is mainly involved in slower but more precise adjustments in maintaining homeostasis in the body. The endocrine system functions through “chemical signaling” by hormones which are secreted by specific endocrine glands or endocrine cells.

**Endocrine glands** are ductless glands consisting of groups of specialized cells which secrete hormones (chemical messengers) that diffuse directly into the bloodstream and reach the specific target organs/tissues that may be located quite distantly. Diffusion of hormones from these endocrine glands to the bloodstream is facilitated by the extensive capillary networks surrounding the glands.

**Hormone** is a specific type of signaling molecules secreted by an endocrine gland/endocrine cells and travels in the blood and acts on specific target cells elsewhere in the body, changing the target cell functioning. Although a specific hormone can reach all body cells, only the cells (target cells) which have matching receptors for that hormone are responsive to the chemical signal. When the hormone binds to the specific receptor of the target cell, it act as a switch influencing chemical/metabolic reactions within the cell. Through chemical signals, hormones can communicate regulatory messages throughout the body.

**Human endocrine system** mainly consists of specific endocrine glands that are widely separated from each other. Location of endocrine glands of the human endocrine system is shown in the **Figure (Location of human endocrine glands)**. Endocrine glands of the human endocrine system include hypothalamus, pituitary gland, thyroid gland, parathyroid glands, adrenal glands, islets of Langerhans (in the pancreas), gonads, thymus gland and pineal gland. In addition to these endocrine glands, isolated endocrine cells are found in some organs and tissues (e.g. stomach, small intestine, kidneys etc.) which secrete specific hormones (e.g. isolated endocrine cells in the stomach secrete the hormone, gastrin).





**Figure 5.20: Location of human endocrine glands**

### **Hypothalamus**

Hypothalamus is located at the base of the fore brain just below the thalamus and connected to the pituitary gland. Seven hormones that are produced and released by the hypothalamus (five releasing hormones and two release inhibiting hormones), act on the anterior pituitary (target site). These hypothalamic hormones regulate the secretion of anterior pituitary hormones (Table Hypothalamic hormones that act on the anterior pituitary gland). Two other hormones produced

by the hypothalamus (oxytocin and antidiuretic hormone) are stored in the posterior pituitary until they are released into the bloodstream and act on specific target sites.

**Table 5.3: Hypothalamic hormones that act on the anterior pituitary gland**

Hypothalamic hormone	Function
Growth hormone releasing hormone (GHRH)	Stimulates the secretion of growth hormone (GH) from anterior pituitary
Thyrotropin releasing hormone (TRH)	Stimulates the secretion of thyroid stimulating hormone (TSH) from anterior pituitary
Corticotropin releasing hormone (CRH)	Stimulates the secretion of adrenocorticotrophic hormone (ACTH) from anterior pituitary
Gonadotropin releasing hormone (GnRH)	Stimulates the secretion of follicle stimulating hormone (FSH) and luteinizing hormone (LH) from anterior pituitary
Prolactin releasing hormone (PRH)	Stimulates the secretion of prolactin hormone from anterior pituitary
Prolactin inhibiting hormone (PIH)	Inhibits the secretion of prolactin hormone from anterior pituitary
Growth hormone release inhibiting hormone (GHRH)	Inhibits the secretion of GH and TSH from the anterior pituitary

### Pituitary gland

Pituitary gland is situated in the fore brain just below the hypothalamus to which it is attached by a stalk. Pituitary gland consists of two main parts (anterior pituitary and posterior pituitary) which are actually two fused glands that perform different functions.

The anterior pituitary synthesizes specific hormones (**Table 5.4: Anterior pituitary hormones, their target sites and functions**). The anterior pituitary connects with the hypothalamus through portal blood vessels. In response to specific releasing hormones secreted from the hypothalamus (Table: Hypothalamic hormones that act on the anterior pituitary gland), anterior pituitary secretes its specific hormones to the blood stream. Some hormones secreted by the anterior pituitary redirect the chemical signals from hypothalamus to other endocrine glands. These anterior pituitary hormones are called tropic hormones (TSH, ACTH, FSH and LH) as their specific target site is another endocrine gland or endocrine cell. The hormone prolactin which is secreted by the anterior pituitary is not a tropic hormone as its target sites are non-endocrine tissues. Prolactin promotes only non-tropic effects. Growth hormone (GH) secreted by the anterior pituitary has a “tropic as well as non-tropic effects” as its target sites can be endocrine cells as well as non-endocrine cells. GH is the most abundant hormone synthesized by the anterior pituitary.



**Table 5.4: Anterior pituitary hormones, their target sites and functions**

Hormone	Target site	Function
Growth hormone (GH)	All body cells	Promotes tissue growth (especially bones and muscles) by stimulating protein synthesis; Regulates metabolism
Thyroid stimulating hormone (TSH)	Thyroid	Stimulates secretion of thyroid hormones (triiodothyronine and thyroxine); Stimulates growth of thyroid gland,
Prolactin	Mammary gland	Stimulates milk production; Together with other hormones promotes milk secretion by the mammary glands.
Adrenocorticotrophic hormone (ACTH)	Adrenal cortex	Stimulates secretion of adrenal cortex hormones (Glucocorticoid hormones)
Follicle stimulating hormone (FSH)	Ovary	Stimulates growth and development of ovarian follicle
	Testis	Stimulate spermatogenesis
Luteinizing hormone (LH)	Ovary	Ovulation; promote formation of corpus luteum in the ovary (structure formed after ovulation) and stimulates progesterone hormone secretion by the corpus luteum.
	Testis	Stimulates secretion of testosterone hormone

The posterior pituitary which is an extension of the hypothalamus connecting via axons, does not synthesize hormones but secretes two hypothalamic hormones (oxytocin and antidiuretic hormone) to the bloodstream. Oxytocin and antidiuretic hormone (ADH) synthesized in the hypothalamic neurons travel through the long hypothalamic axons that reach into the posterior pituitary. These hormones are stored in the axon ends located in the posterior pituitary until they are released into the blood stream in response to nerve impulses transmitted from the hypothalamus. The target sites and functions of the hormones secreted by the posterior pituitary are given in the Table 5.5 (**Posterior pituitary hormones, their target sites and functions**).



**Table 5.5: Posterior pituitary hormones, their target sites and functions**

Hormone	Target site	Function
Antidiuretic hormone (ADH)	Distal convoluted tubules of the nephrons and collecting ducts in the kidney	Stimulates resorption of water by increasing permeability to water
Oxytocin	Mammary gland	Stimulates milk ejection by stimulating contraction of smooth muscles
	Uterine muscles	Promotes parturition by contraction of smooth muscles

**Thyroid gland**

Thyroid gland is located in the neck just below the larynx and in front of the trachea. It has two lobes. Thyroid gland secretes triiodothyronine (T3) and thyroxine (T4) which are collectively called thyroid hormones. Thyroid hormones increase the basal metabolic rate and heat production; regulate the metabolism of carbohydrates, proteins and fats. Thyroid hormones are needed for normal growth and development of especially the skeletal and nervous systems. Thyroid hormones also help maintain normal blood pressure, heart rate and muscle tone and regulate digestive and reproductive functions. Calcitonin is another hormone secreted by the thyroid gland. Calcitonin helps to lower blood calcium ion level if it is raised above the normal limit. This hormone acts on bone cells and promotes storage of calcium within bone tissues. The hormone also acts on kidney tubules and inhibit calcium reabsorption enhancing calcium excretion.

**Parathyroid glands**

Parathyroid glands (a set four small glands) are embedded in the posterior surface of the thyroid gland located in the neck. Two glands are embedded in each lobe of the thyroid gland. Parathyroid glands secrete parathyroid hormone (PTH). Main function of the PTH is to promote high calcium levels in the blood by stimulating calcium reabsorption from the kidney tubules and calcium absorption through the small intestine. If these sources supply inadequate calcium, PTH acts on bone destroying cells and promotes release of calcium from the bones into the blood. PTH has the opposite effect of calcitonin hormone (released by the thyroid gland) on the blood calcium level.

**Thymus gland**

Thymus gland is located in the upper part of the chest, directly behind the sternum and between the lungs. Thymus gland secretes the hormone thymosin. Thymosin acts on the lymphocytes (originated from the stem cells in the bone marrow) and regulates development and maturation of T lymphocytes which are important components of specific immunity.



**Pineal gland**

Pineal gland is located in the brain. Melatonin secreted by the pineal gland is involved in the regulation of biological rhythms related to reproduction and daily activity levels. Melatonin seems to be associated with coordination of circadian and diurnal rhythms of many tissues and inhibition of growth and development of sex organs before puberty.

**Adrenal glands**

Adrenal glands are paired structures, one of which lies superior to each kidney. Each gland consists of two parts: adrenal cortex (outer) and adrenal medulla (inner). The structure and functions of these two parts are different. Hormones secreted by the adrenal cortex and the adrenal medulla can mediate the stress responses in the body.

The hormones mainly produced by the adrenal cortex are glucocorticoids and mineralocorticoids. These hormones mediate “long term stress responses” and participate in homeostatic regulation of metabolism. Glucocorticoids have a main effect on glucose metabolism and promote glucose synthesis from non-carbohydrate sources such as protein and fat so that more glucose is available in the blood circulation for cellular energy production. These hormones can promote breakdown of skeletal muscle proteins for synthesis of glucose when the body requires more glucose. Cortisol is the main glucocorticoid produced by the adrenal gland. Main mineralocorticoid produced by the adrenal gland is aldosterone which is involved in maintaining water and electrolyte balance. Aldosterone stimulates the reabsorption of sodium ions by the kidney tubules and excretion of potassium ions in the urine. As sodium reabsorption is accompanied by the water retention, blood volume and blood pressure can be increased. Hence aldosterone hormone is also involved in the regulation of blood volume and blood pressure.

The hormones produced in the adrenal medulla are adrenaline (epinephrine) and noradrenaline (norepinephrine) which could mediate ‘short term stress responses’. Upon extensive sympathetic nervous stimulation, adrenal medulla secretes these hormones which can potentiate the “fight or flight response” by increasing the heart rate and blood pressure, diverting blood to essential organs (i.e heart, brain, skeletal muscles) and increasing metabolic rate etc. The hormones secreted by adrenal medulla are mainly involved in increasing the availability of chemical energy for immediate use. These hormones promote glucose release into the circulating blood by increasing the rate of glycogen breakdown (in liver and skeletal muscles) and fatty acids release (from fat cells) for energy production within the body cells.



**Islets of Langerhans in the pancreas**

Pancreases can be considered an endocrine gland as well as an exocrine gland. It is located behind the stomach in the curve of the duodenum. The endocrine part of the pancreas is the islets of Langerhans which are clusters of cells scattered throughout the pancreas. These pancreatic islets mainly secrete two hormones, glucagon and insulin which control the blood glucose level by opposing actions. Alpha cells of the pancreatic islets secrete glucagon which mainly promote the blood glucose level increase. Beta cells of the pancreatic islets secrete insulin which promotes lowering of blood glucose level. Liver and skeletal muscles are the main target sites of these hormones (Refer the section on homeostatic control of blood glucose).

**Gonads**

Paired female gonads (ovaries) are located in the pelvic cavity. Paired male gonads (testes) lie in the scrotum. In addition to the reproduction, ovaries and testes have endocrine functions. (Refer the section on human male and female reproductive systems for more details).

Ovarian follicle produces the hormone estrogen. Corpus luteum (the structure formed from the ovarian follicle after ovulation) produces progesterone. These female sex hormones along with FSH and LH from the anterior pituitary regulate menstrual cycle, maintain pregnancy and prepare mammary glands for lactation. They also help establish and maintain feminine sexual characteristics. The ovaries also produce the hormone inhibin that inhibits secretion of FSH from anterior pituitary.

The main hormone produced and secreted by the testes (interstitial cells) is the male sex hormone, testosterone. Testosterone regulates production of sperm and stimulates the development and maintenance of masculine secondary sex characteristics. In addition, the testes (Sertoli cells) produce inhibin that inhibits secretion of FSH.

**Feedback mechanisms related to the endocrine system**

Variety of physiological processes in the human body including the actions of hormones on target cells are regulated by feedback mechanisms. Feedback refers to the regulation of a process by its output or end product.

Most hormonal controls in the human body use negative feedback mechanisms where accumulation of an end product of a process (the response to the stimulus) slows that process (reduces the effect of the initial stimulus). The endocrine gland will release its hormone into the blood only when the gland is stimulated and the response at the target site will in turn reverse or reduce the stimulus through the negative feedback. In the absence of stimulation, the blood level of hormone will



decrease. Some hormone levels in the blood can be directly controlled by the blood levels of the stimulus (e.g. insulin or glucagon by blood glucose levels). For example high blood glucose levels stimulate the release of insulin hormone (from the pancreas) to the circulating blood which acts on specific target tissues to lower the blood glucose level. When glucose level in the blood reaches normal range, blood glucose level can in turn directly control the secretion of insulin levels from the pancreas and prevent further lowering of the glucose level in the blood. (Refer the section on homeostatic control of blood glucose level).

A few hormonal regulatory systems operates using “positive feedback mechanism” which is a form of regulation in which an output (or end product) of a process speeds up that process thereby reinforcing or amplifying the change. Positive feedback mechanisms involving oxytocin hormone operate in childbirth and breast milk ejection. During labour, contractions of uterus are stimulated by oxytocin hormone released by the posterior pituitary. These contractions force the baby’s head into the uterine cervix stimulating its stretch receptors. In response to stimulation of stretch receptors, sensory neurons are stimulated again triggering more oxytocin release from the posterior pituitary enhancing contractions of the uterus. This process repeats until the baby is born. Afterwards oxytocin secretion stops as the stimulus (stretching of the cervix) is no longer present. Another positive feedback mechanism involving oxytocin hormone operates when releasing milk from the mammary glands (**Figure 5.21: Positive feedback mechanism related to oxytocin hormone action**). During suckling, sensory neurons send the nerve impulses to the posterior pituitary triggering release of oxytocin hormone to the circulating blood. Then oxytocin acts on the mammary glands and induces contractions of smooth muscles in the mammary glands to release milk. Milk release increases the sensory stimulus forming a positive feedback that amplifies the stimulus. In response to the positive feedback, more oxytocin is released enhancing milk ejection



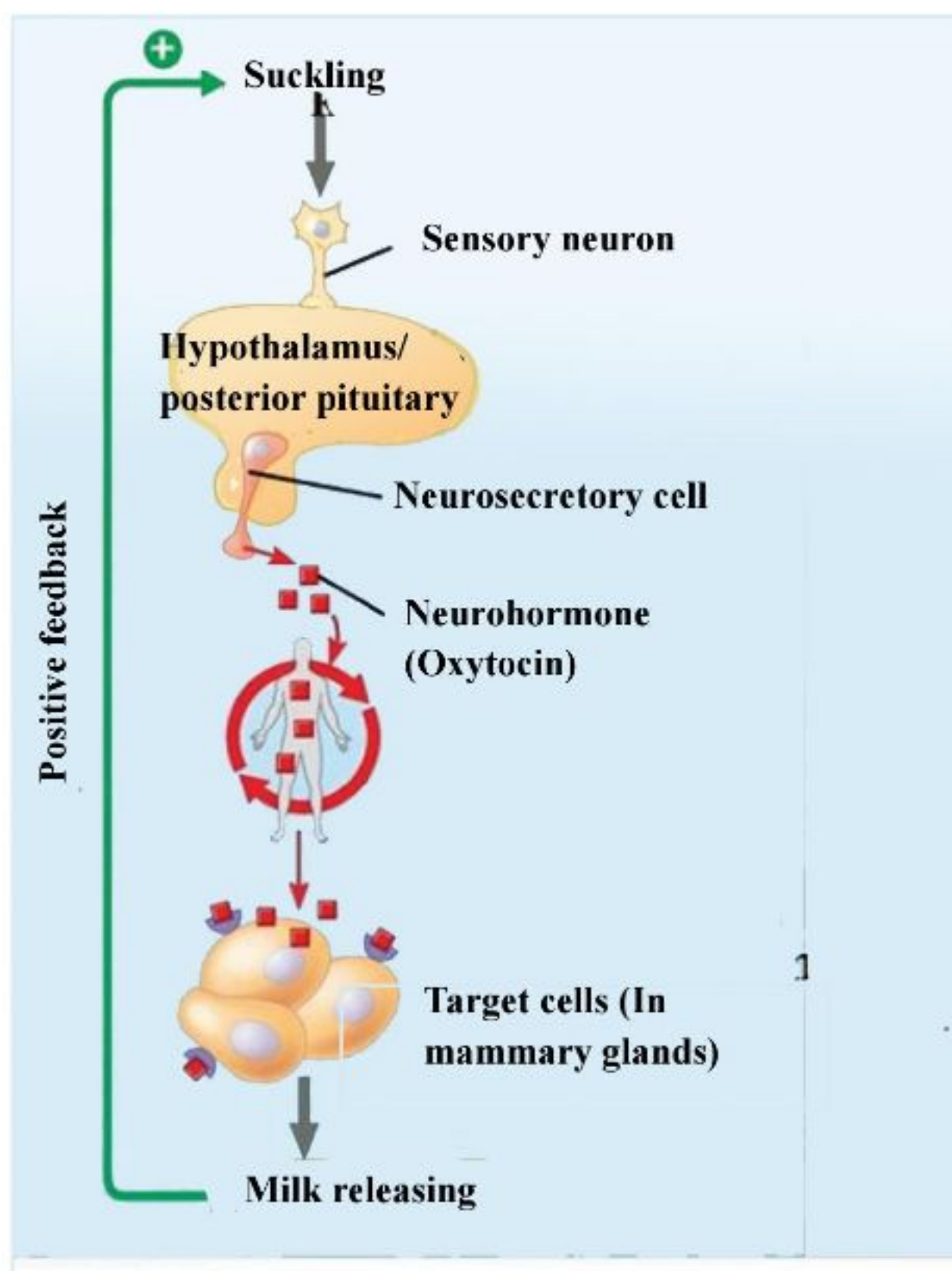


Figure 5.21: Positive feedback mechanism related to oxytocin hormone action

#### Some endocrine disorders in human

- **Diabetes mellitus:** Diabetes mellitus is a common disorder associated with insulin hormone produced by the pancreatic islets of Langerhans. Primary sign of this disorder is the increase in blood glucose levels above the normal limits. High blood glucose levels lead to excretion of glucose with urine, excessive production of urine and the thirst. Diabetes mellitus is mainly classified into two types: Type 1 diabetes and Type 2 diabetes.

Type 1 diabetes was known as insulin dependent diabetes mellitus. This disorder usually appears in children and young adults. This is an autoimmune disorder caused by the destruction of beta cells of the islets of Langerhans by the immune system in the body. As



a result, insulin secretion is severely deficient or absent in the affected individuals. Genetic factors and environment factors seem to be associated with this disorder. Type 1 diabetes may be controlled by taking meals with less carbohydrates and fats, regular monitoring of blood glucose levels and periodic insulin injections.

Type 2 diabetes was known as non-insulin dependent diabetes mellitus. This condition is not dependent on insulin production. Even though insulin is produced and secreted into the blood, target cells fail to take up glucose from the blood. Hence blood glucose levels remain elevated but glucose may be deficient inside the body cells. The cause for this type of diabetes is multifactorial. Predisposing factors include obesity, lack of exercise (sedentary lifestyle), increasing age and genetic factors. Type 2 diabetes may be controlled by the diet with less carbohydrates and fats, balancing sugar intake with exercise and taking suitable medicine.

- **Hyperthyroidism and hypothyroidism:** These conditions are associated with abnormal secretion of thyroid hormones (T<sub>3</sub> and T<sub>4</sub>) which may occur due to abnormal functioning of the thyroid gland and disorders of pituitary or hypothalamus. Persistence of these conditions may lead to enlargement of the thyroid gland (goiter).

**Hyperthyroidism:** This condition occurs due to exposure of body tissues to excessive levels of T<sub>3</sub> and T<sub>4</sub>. Common effects include increased basal metabolic rate, weight loss, warm, sweaty skin and diarrhea. Some conditions lead to bulging of eyes (exophthalmos) and goiter. Treatment may include surgical removal of part or all of the thyroid gland and using medicine to block thyroid hormone synthesis.

**Hypothyroidism:** Insufficient secretion of thyroid hormones (T<sub>3</sub> and T<sub>4</sub>) from the thyroid gland causes hypothyroidism. This can be due to lack of TSH production by anterior pituitary or iodine deficiency in diet. Common effects include low basal metabolic rate, weight gain, lethargy, dry, cold skin and constipation. The condition may be controlled by increasing dietary iodine intake or/and oral thyroid hormone treatment.



## **Maintenance of constant internal environment within limits in the human body**

### **Homeostasis**

**Homeostasis** is a steady state condition where body's internal environment remains relatively constant within narrow physiological limits despite significant changes in the external environment. Surroundings outside of the body are referred to as the external environment. Internal environment is the immediate surroundings of the body cells which provides the cells with the medium in which they have to live. Examples for the internal environment of the body are interstitial fluid and the blood. Many animals and humans exhibit homeostasis for a range of physical and chemical properties. For example, humans maintain a fairly constant body temperature, blood pH, blood glucose and blood osmolality within narrow physiological limits. Homeostasis is important for maintaining the internal environment in a steady and balance state and to establish optimum conditions for the human body.

Homeostatic control systems in the human body mainly depend on negative feedback mechanisms to maintain a constant level thereby preventing serious changes in the internal environment. Homeostasis is achieved by maintaining a variable (e.g. body temperature, blood glucose) at or near a particular value (set point). A fluctuation in the variable above or below the set point serves as the stimulus detected by a sensor (detector). When a signal is received from the sensor, a control center generates output that triggers a response, a physiological activity that helps to return the variable towards the set point level. The set point level is achieved by the negative feedback control of the stimulus by the response.

### **Homeostatic regulation of body temperature in humans**

As the temperature affects the rate of chemical reactions, homeostatic control keeps the human body at optimum operating temperature. The normal body temperature of man is typically 37°C (36.5°C – 37.5°C). Human body temperature is controlled by negative feedback mechanisms. If the body temperature is outside the normal range, a group of nerve cells in the hypothalamus of the brain ("body's temperature control center") functions as a thermostat and responds to the temperature increase or decrease by activating heat loss mechanisms or promoting heat gain mechanisms respectively until the body temperature reaches the preset level.



High peripheral temperature (e.g. when the person is in hot surroundings) is detected by warm receptors in the skin. High deep body temperature (e.g. due to high body heat generation after exercise) is detected by hypothalamic temperature sensitive nerve endings when warm blood pass through the hypothalamus. These nerve impulses are sent to the “body’s temperature control center” (thermostat) in the hypothalamus. In response to the increase in body temperature above the preset level, the ‘thermostat’ in the hypothalamus sends impulses to activate heat loss mechanisms and to inhibit heat gain mechanisms that lower the body temperature until the set point.

The following heat loss mechanisms promote the decrease in body temperature.

- dilation of blood vessels in the skin which causes filling of blood capillaries with warm blood and radiating heat from the skin surface
- increase sweat secretion from the sweat glands which promotes heat dissipation through evaporative cooling

When body temperature is within the normal range again, the warm temperature sensitive receptors are no longer stimulated and their signals to the ‘hypothalamic thermostat’ stops due to the negative feedback mechanism. Then, additional heat loss mechanisms stop and blood flow to the peripheries returns to normal.

Low peripheral temperature (when in cold surroundings) is detected by cold receptors in the skin. Low deep body temperature (due to more heat loss and low heat generation in the body) is detected by temperature sensitive nerve endings in the hypothalamus. These nerve impulses are sent to the body’s temperature control center (thermostat) in the hypothalamus. If the body temperature decreases below the preset level, the thermostat in hypothalamus sends impulses to activate heat gain mechanisms and inhibit the heat loss mechanisms thereby increasing the body temperature until the preset point.

The following heat conservation and heat gain mechanisms promote the increase in body temperature.

- constriction of blood vessels in the skin which divert the blood from the skin to deeper tissues thereby reducing heat loss through the skin surface
- shivering: rapid repetitive contractions of skeletal muscles to generate heat
- contracting hair erector muscles to generate heat to some extent
- stimulating secretions of more thyroid hormones (e.g. thyroxin) and adrenalin into the blood which increase the metabolic rate and cellular metabolism (especially oxidation of fat in the liver) to produce more heat



When body temperature returns to the normal range, the cold temperature sensitive receptors are no longer stimulated and their signals to the hypothalamic thermostat stop due to negative feedback mechanism. Then, additional heat generating mechanisms in the body stop and blood flow to the peripheries returns normal.

### **Homeostatic regulation of blood glucose level**

In humans, normal blood glucose level is 70 – 110 mg/100 mL (while fasting) which is sufficient for immediate needs of the body cells. The blood glucose levels can fluctuate throughout the day within physiological limits in non-diabetic persons. In the human body, blood sugar levels are homeostatically controlled by opposing actions of two hormones secreted by the pancreas: insulin and glucagon.

High blood glucose levels exceeding the normal limits, stimulate the secretion of insulin hormone from beta cells of the islets of Langerhans into the circulating blood. Insulin acts on specific target tissues to promote lowering of the blood glucose level. Insulin in the circulating blood stimulates transport of glucose into the body cells and use of glucose by body cells for ATP production (glucose may be broken down into carbon dioxide and water), conversion of glucose to glycogen in liver and skeletal muscle cells for storage, and conversion of glucose to fatty acids and storage of fat in adipose tissues. When glucose level in the blood reaches normal range, blood glucose level can in turn directly control the secretion of insulin levels from the pancreas through negative feedback. This mechanism prevents further lowering of the glucose level in the blood beyond the normal limits.

Low blood glucose levels below the normal limit, stimulate the secretion of glucagon from alpha cells of the islets of Langerhans into the circulating blood. Glucagon acts on specific target tissues to promote increase of the blood glucose level. Glucagon promotes the breakdown of glycogen in the liver and skeletal muscles and release of glucose into blood. When glucose level in the blood reaches normal range, blood glucose level can in turn directly control the secretion of glucagon levels from the pancreas through negative feedback which prevents further increasing of the glucose level in the blood beyond the normal limits.

### **Osmoregulation**

Osmoregulation is the process of maintaining water and salt balance (osmotic balance) across membranes within the body's fluids relative to the surrounding. When there is osmotic balance, amount of water and concentration of salts is same inside and outside the cells. Osmoregulation is important for organisms to keep a constant, optimal osmotic pressure within the body. In the humans, osmoregulation ensures that the total blood volume and the concentration of dissolved substances in the plasma and tissue fluids remain constant within a favourable range.



In the human body, osmotic balance is achieved by two ways: controlling the amount of water and controlling the amount of salt gained and lost by the body. Blood water homeostasis is controlled by the hypothalamus. Hypothalamus contains osmoreceptors which can detect the osmolarity of the blood passing through the brain. In response to the osmolarity (or osmotic pressure) of the blood, the hypothalamus controls the sensation of thirst, and secretion of the hormone ADH from the posterior pituitary.

When blood osmolarity is increased beyond the physiological limits, it is sensed by the osmoreceptors in the hypothalamus which stimulates the posterior pituitary to release ADH to the blood circulation. ADH acts on the kidney tubules and stimulates the reabsorption of water through distal convoluted tubules of the nephrons and collecting ducts producing concentrated urine. When blood osmolarity is decreased, ADH is not secreted, so water reabsorption through distal convoluted tubules of the nephrons and collecting ducts stop thereby producing diluted urine. In addition, low blood volume and low blood sodium ions stimulate the kidneys to produce angiotensin II which stimulates the adrenal cortex to secrete aldosterone hormone. Aldosterone stimulates the reabsorption of sodium ions by the kidney tubules which is accompanied by the water retention, thereby increasing blood volume and blood pressure. Hence, kidneys play a major role in osmoregulation in the human body.

#### **Role of the liver in homeostasis.**

Liver is an active organ and plays an important role in maintaining homeostasis of the human body. The functions of the liver include the following.

- **Carbohydrate metabolism:** The liver plays an important role in maintaining blood glucose levels within normal ranges. When blood glucose is increased (e.g. after a meal), glucose is stored as glycogen under the stimulation of insulin. If blood glucose level is reduced (e.g. starvation), glycogen is converted back to glucose under the influence of glucagon hormone.
- **Fat metabolism:** When the body needs excess energy, fats that are stored in the liver cells are metabolized to produce ATP
- **Protein metabolism:** In the liver cells, nitrogen part of some amino acids that are not needed for new protein synthesis are removed (deamination) and excreted in urine or transferred to carbohydrates to synthesize new nonessential amino acids (transamination). Liver also synthesizes plasma proteins (e.g. albumin, globulins) from amino acids.
- **Breakdown of erythrocytes and defense against microbial infections:** In humans, liver is a site for red blood cell breakdown. Macrophages located in the liver are involved in microbial defense.
- **Detoxification of drugs and toxicants:** The liver plays an important role in detoxification.
- **Production of heat:** Liver is the major heat producing organ of the body as it has a high metabolic rate.



- **Storage of nutrients:** Glycogen, fat soluble vitamins (A, D, E,K), some water soluble vitamins- B12 and essential metals such as iron, copper are stored in liver.
- **Inactivation of hormones:** Some hormones are inactivated by the liver after their biological action.
- **Secretion of bile:** Liver cells synthesize the components present in the bile which is important in fat digestion and excretion of bilirubin (a breakdown product of red blood cells).



## Reproduction

### Modes of reproduction seen among animals

Reproduction is a biological process through which a new generation of individuals is produced from the existing organisms. Two modes of reproduction are found among the animals: Asexual reproduction and Sexual reproduction. For the most animals, reproduction is mainly or entirely sexual. Several forms of asexual reproduction are also seen especially among invertebrates.

### Asexual reproduction

Asexual reproduction is a mechanism through which new individuals are generated from a single parent without the fusion of egg and sperm. Asexual reproduction relies entirely on mitotic cell division. Asexual reproduction allows the rapid multiplication of individuals from single parents. Hence no time or energy is spent in searching the mates for the reproduction. The produced offspring are genetically identical to each other and to the single parent. Several methods of asexual reproduction are found among invertebrates. They include budding, fragmentation and regeneration, and parthenogenesis.

- **Budding:** Budding is a form of asexual reproduction in which new individuals arise from outgrowths of the animal. e.g. Hydra – A localized mass of mitotically dividing cells, develops into a small Hydra, which can eventually detach from the parent.
- **Fragmentation and regeneration:** This is a form of asexual reproduction which involves breaking of the body or part of the body into several pieces, followed by the growth of a separate individual from each piece. Each fragment develops into a complete animal by regrowth of lost body parts (regeneration). e.g. Certain annelid worms, numerous sponges, cnidarians.
- **Parthenogenesis:** This is an unusual form of asexual reproduction in which an egg develops into a complete individual without being fertilized. Among invertebrates, parthenogenesis occurs in some animals such as bees, ants, aphids and wasps. The progeny can be haploid or diploid. In honey bees – males (drones) are fertile haploid adults that develop through parthenogenesis, whereas females including both sterile workers and the fertile queen, are diploid adults that developed from fertilized eggs. Parthenogenesis has also been observed very rarely among vertebrates (e.g. some lizards and fish).



## Sexual reproduction

Sexual reproduction is a mechanism through which a new individual is developed from a diploid zygote as a result of the fusion of two haploid gametes (the sperm and the egg) which are produced by two individuals (the male and the female parents respectively). The female gamete, the egg, is large and non-motile, while the male gamete, the sperm, is generally much smaller and motile. The fusion of the female and male gametes forms a diploid cell called the zygote. The animal that develops mitotically from a zygote can in turn give rise to gametes by meiosis. For the most animals, reproduction is mainly or entirely sexual.

- **Gamete formation:** In animals, reproductive cells called gametes (sperms and eggs) are the vehicles that transmit genes from one generation to the next. Each gamete is a haploid, unicellular reproductive cell. Gametes in animals are formed by meiosis in special organs called gonads.
- **Bisexual organism and Unisexual organism:** In a bisexual organism (Hermaphrodite), one individual has both female and male reproductive structures and therefore is able to produce both male and female gametes by the same individual. e.g. Earthworms. In unisexual organisms (dioecious), one individual bears either male or female reproductive structures. Therefore production of male or female gametes occurs in separate organisms. e.g. Humans
- **Fertilization:** Union of egg and sperm (gametes) culminating in fusion of their nuclei is called fertilization. Fertilization can be either external or internal.

**External fertilization** occurs in aquatic environments. In species with external fertilization, the female releases eggs while the male releases sperm into the external environment and fertilization occurs in the water. A moist habitat is almost always required for external fertilization both to prevent the gametes from drying out and to allow the sperm to swim toward the eggs. e.g. Many invertebrates, amphibians, most bony fish.

**In internal fertilization**, sperms are deposited in or near the female reproductive tract and fertilization occurs within the female reproductive tract. e.g. insects, reptiles, mammals. Internal fertilization is an adaptation that enables sperm to reach an egg even when the environment is dry. The male copulatory organ delivers sperm and the female reproductive tract often has receptacles for storage and delivery of sperm to mature eggs. Internal fertilization is typically associated with the production of fewer gametes than external fertilization but results in the survival of a higher fraction of zygotes. Internal fertilization often provides greater protection to the embryos. Many animals show parental care. Internally fertilized eggs of birds and other reptiles possess shells and internal membranes that protect against water loss and physical damage. Some retain the embryo for a portion of any development within the female reproductive tract.



### **Significance of asexual reproduction and sexual reproduction**

Asexual reproduction and sexual reproduction are important biological processes to ensure existence of a species.

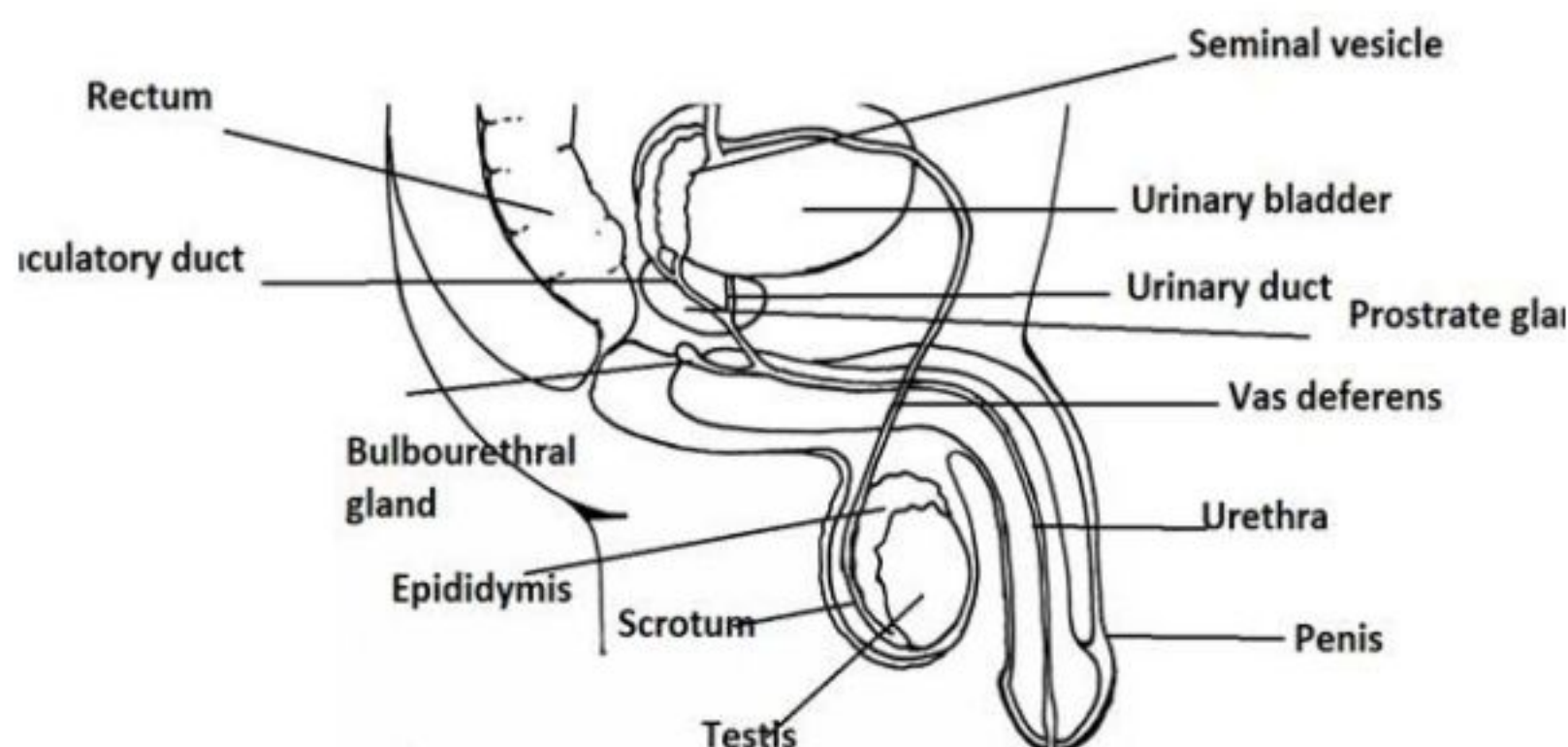
Asexual reproduction allows rapid multiplication of individuals from single parents. Hence no time or energy is needed to be spent in searching mates for the reproduction. In asexual reproduction, there is no or very little genetic variation within a population as the produced offspring are genetically identical to each other and to the single parent. Therefore, asexual reproduction would be more advantageous in stable, favorable environments as it can propagate successful genotypes specifically. However, any mutation in the parent cell, can cause harmful effects on the survival ability of the offspring in changing environments. If there is a harmful mutation in the organisms, environment changes could be deadly to all the individuals in the population.

Unlike asexual reproduction, sexual reproduction results in the production of a unique offspring by combining genetic materials from two parents. Meiotic recombination during sexual reproduction helps produce varied genotypes. Unique gene combinations formed during sexual reproduction would be advantageous as this can enhance reproductive success and survival of a species in changing environments. Beneficial gene combination arising through recombination may speed up adaptation. During sexual reproduction, shuffling of genes might allow a population to clear sets of harmful genes more readily which would enhance the survival of the species.

### **Structure and Function of the Human Male Reproductive System**

Main internal reproductive structures of a male consist of gonads (testes) which produce sperm and reproductive hormones, epididymis which store mature sperms, accessory glands that secrete products required for sperm movement and ducts that transport the mature sperm and glandular secretions. The external reproductive organs of a male are the scrotum and penis.





**Figure 5.22: The gross structure of male reproductive system. (For orientation, some non-reproductive structures are also labelled)**

**Scrotum:** Scrotum is a pouch formed by a fold of the body wall. Scrotum is divided into two compartments. Each compartment contains one testis, one epididymis and part of the spermatic cords which suspend the testis in the scrotum.

- Testes:** The testes are found within the scrotum which allows the maintenance of the testis temperature  $2^{\circ}\text{C}$  below the core body temperature. Sperms are produced properly only when the testes are cooler than the rest of the body. The testes develop in the abdominal cavity and descend into the scrotum just before birth. The testes are cooled by their position outside the abdominal cavity and the thin covering of the scrotum. Each testis contains many lobules. Within each lobule there are highly coiled (convoluted) loops called **seminiferous tubules**. Sperms are produced within these tubules. Different cells that undergo spermatogenesis are surrounded and connected to special type of supporting cells (**Sertoli cells**) located in the seminiferous tubule. Sertoli cells extend from the wall of the seminiferous tubules to the lumen. These cells secrete the hormone inhibin and nourish and provide attachment for cells that are in different stages of spermatogenesis. Groups of cells called Leydig cells (or interstitial cells) are present in the connective tissue between the seminiferous tubules. **Leydig cells** secrete the hormone testosterone and other androgens after puberty which promote spermatogenesis in the tubules. The seminiferous tubules combine to form a single tubule (duct) at the upper part of the testes.
- Epididymis:** Epididymis is the tightly packed mass that is formed by the repeatedly folded long duct originated from combined seminiferous tubules in the testis. From the seminiferous tubules, the sperm pass into the epididymis. Since it is very long (about 6 m



in length), it takes about 3 weeks for sperm to travel the length of this duct. During this time the sperms become matured and motile. Matured sperms are stored within the epididymis until ejaculation.

- **Vas deference, ejaculatory duct, urethra and penis:** During ejaculation, sperm are propelled from each epididymis through a muscular duct, the **vas deferens**. Each vas deferens (one from each epididymis) extends around and behind the urinary bladder, where it joins a duct from a seminal vesicle, forming a short **ejaculatory duct**. The ejaculatory ducts open into the urethra which is the passageway for both urinary excretion and delivery of sperms in semen into the female reproductive tract. The urethra runs through the penis and opens to the outside at the tip of the penis which contains erectile tissues derived from modified veins and capillaries.

### Spermatogenesis

Spermatogenesis is the process of male gamete formation which includes formation of spermatocytes from a spermatogonium, meiotic division of the spermatocytes, and transformation of the four resulting spermatids (from each spermatocyte) into spermatozoa (sperm). Spermatogenesis occurs within the seminiferous tubules of the testes. The time taken to produce mature sperm cells from a specific spermatogonia in a seminiferous tubule is about seven weeks from start to finish.

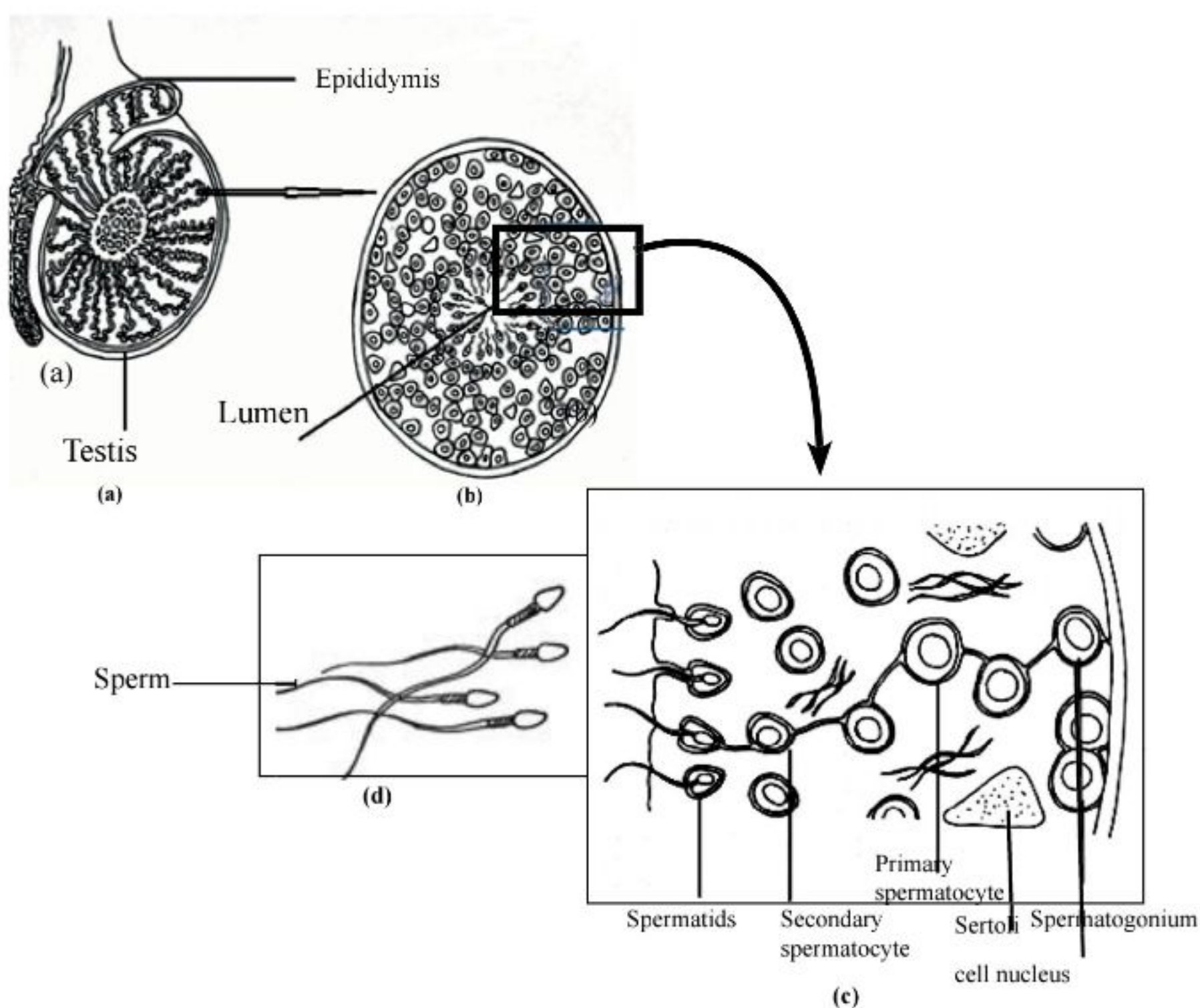
The formation and development of sperms is continuous and inexhaustible in adult human males. Cell division and maturation during gametogenesis occur throughout the seminiferous tubules. Hundreds of millions of sperm are produced each day by spermatogenesis. In contrast to oogenesis (discussed later), in spermatogenesis all four cells produced during meiosis of each spermatocyte develop into mature gametes. Spermatogenesis starts at puberty and occurs throughout life. Spermatogenesis produces mature sperms from precursor cells in a continuous sequence.

### Main steps in Spermatogenesis

- The stem cells ( $2n$ ) that give rise to sperms (Spermatogonial stem cells) arise from mitotic division and differentiation of primordial germ cells in the embryonic testes. These stem cells are situated near the edge of the seminiferous tubules. In mature testis, their progeny moves inward as they pass through the different stages of maturation.
- In mature testes, the stem cells divide mitotically to form Spermatogonia ( $2n$ ), which in turn generate primary spermatocytes ( $2n$ ) by mitosis.
- Each primary spermatocyte gives rise to four spermatids ( $n$ ) through meiosis (meiosis I and II), reducing the chromosome number from diploid ( $2n=46$  in humans) to haploid ( $n=23$ ).
- These spermatids differentiate into sperms with its characteristic head, midpiece and tail.
- The sperms are released into the fluid-filled lumen of the tubule and they travel along the tubule into the epididymis, where they become mature and motile.

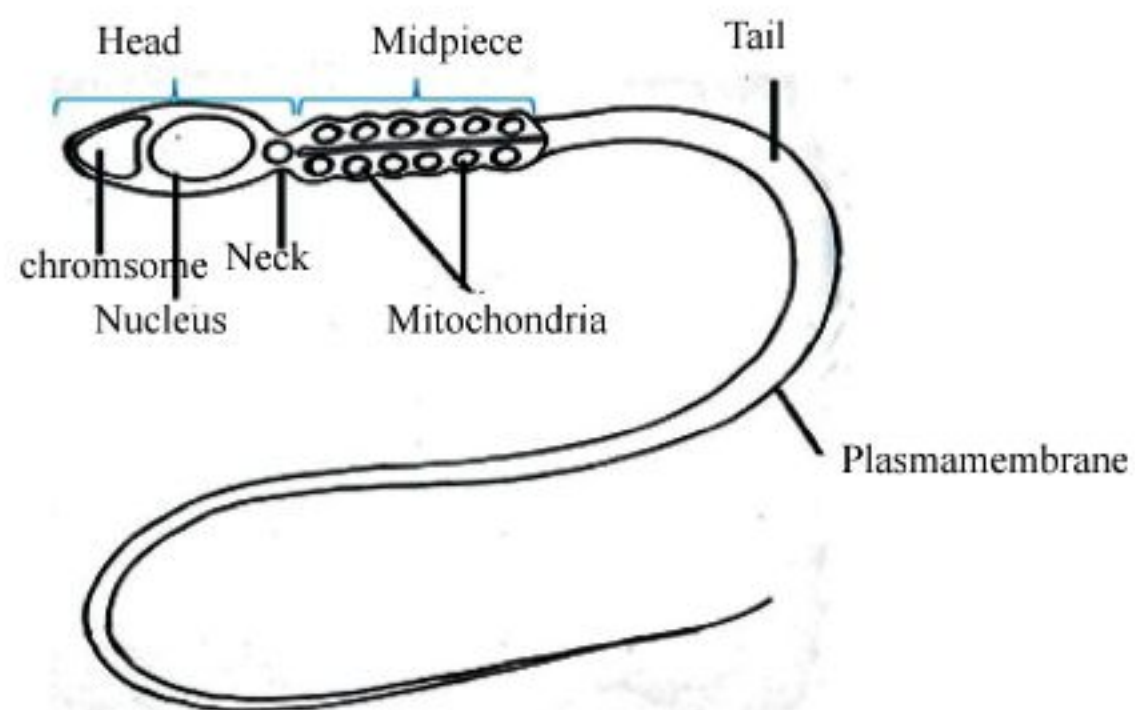
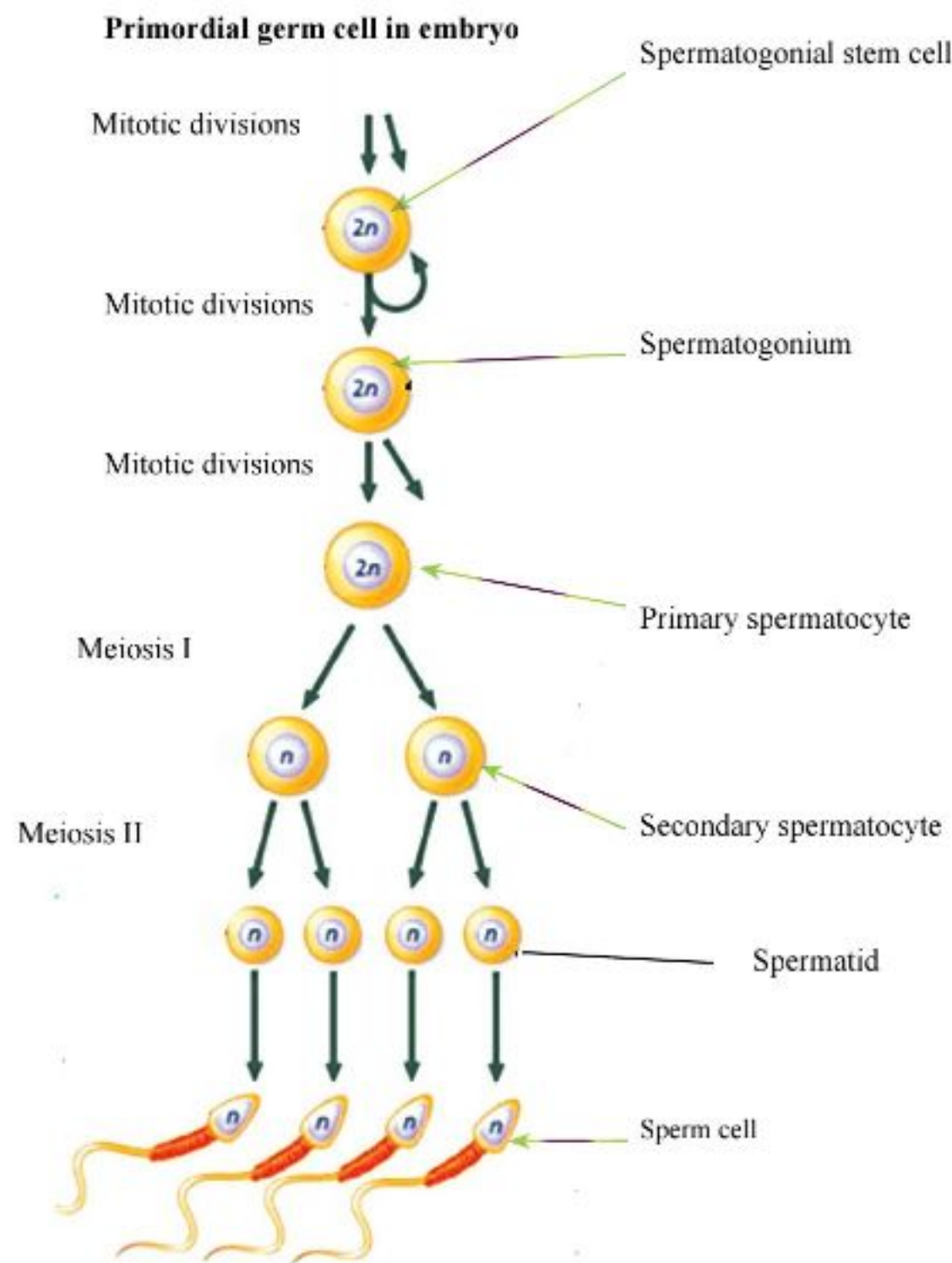


After puberty, Leydig cells present between the seminiferous tubules secrete the hormone testosterone which promotes spermatogenesis. Different cells that undergo spermatogenesis are surrounded and connected to special type of supporting cells called Sertoli cells. These cells extend from the wall of the seminiferous tubules to the lumen. These cells secrete inhibin hormone and nourish and provide attachment for cells that are in different stages of spermatogenesis.



**Figure 5.23:** (a) T.S of testis (b) T.S of Seminiferous tubule (c) spermatogenesis  
(d) mature sperm released into lumen of seminiferous tubule





**Figure 5.24: -Basic structure of the sperm**



Each sperm is made up of three main parts, the head, midpiece (body) and tail.

Head of the sperm contains the haploid nucleus carrying the paternal genetic material. A special vesicle called the acrosome is present at the anterior end of the head. It contains hydrolytic enzymes such as trypsin and hyaluronidase that help the sperm to penetrate the outer layers of the ovum. Midpiece of the sperm contains many mitochondria that provides ATP necessary for the movement of the tail.

The tail of the sperm contains a long flagellum with typical 9+2 arrangement of microtubules. It is produced by the centriole found near the base of the nucleus. The tail enables the sperm to swim along the female reproductive tract towards an ovum.

### **Semen**

The semen is the fluid that contains a mixture of sperms and the secretions of three sets of accessory glands. The semen is discharged from the urethra during ejaculation. Usually a normal ejaculate contains about 2-5 mL of semen and the sperm count in the semen may be in the range of 40-100 million/mL. Normally, the sperms comprise less than 10% of the final ejaculate. Main fraction of the semen is made up of secretions from seminal vesicles and the prostate gland.

The semen contains several components such as mucus, enzymes, prostaglandins, ascorbic acid, citrate and fructose which promote the survival of sperm. The semen provides a liquid medium for the sperm movement and also helps to neutralize the acidity in the female reproductive tract. The life expectancy of a sperm is about 48-72 hours after ejaculation.

### **Accessory glands associated with the male reproductive system**

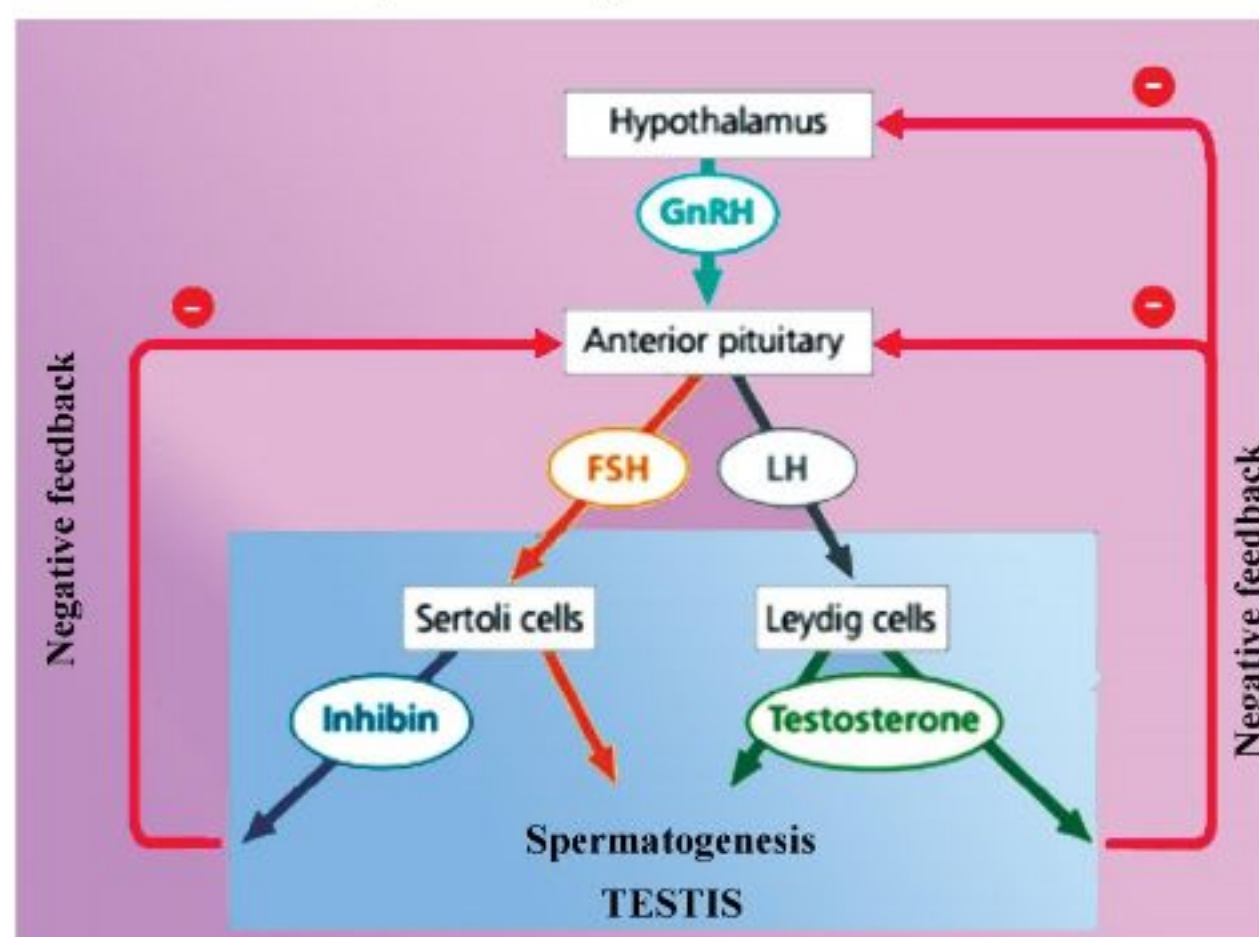
There are three sets of accessory glands that produce secretions necessary for sperm survival and movement. They are seminal vesicles, prostate gland and bulbourethral glands.

- **Seminal vesicles:** They are a pair of two small pouches that produce a thick, yellowish fluid that is expelled during ejaculation. Seminal fluid is alkaline to protect the sperm in the acidic environment of the vagina. It contains mucus, fructose (that provides most of the sperm's energy), a coagulating enzyme (helps semen coagulates after ejaculation), ascorbic acid and local regulators called prostaglandins. This fluid contributes to about 60% of the volume of semen. Each seminal vesicle opens into a short duct that joins the corresponding vas deference to form an ejaculatory duct.



- **Prostate gland:** This gland is found below the urinary bladder. It secretes a thin, milky fluid directly into the urethra through small ducts. This milky secretion contains coagulants, anticoagulant enzymes and citrate which is a sperm nutrient. This fluid contributes to about 30% of the volume of semen.
- **Bulbourethral glands:** They are a pair of small glands found along the urethra below the prostate. These glands secrete a clear alkaline mucus that is able to neutralize any acidic urine remaining in the urethra and lubricates the lining of the urethra.

### Hormonal control of the male reproductive system



**Figure 5.25: Hormonal control of the male reproductive system**

- In males, in response to the release of GnRH from the hypothalamus (just before puberty), results in the release of FSH and LH by the anterior pituitary. Rising levels of the FSH and LH hormones at puberty promotes mature functioning of the male reproductive organs. The hormones regulate the development, growth, pubertal maturation and reproductive processes of the body.
- FSH and LH hormones direct spermatogenesis by acting on different types of cells in the testis.
  - FSH stimulates Sertoli cells to nourish the developing sperm.
  - LH causes Leydig cells to produce testosterone and other androgens to promote spermatogenesis.
- Two negative-feedback mechanisms control sex hormone production in males.



- Testosterone inhibits GnRH, FSH and LH in blood through its effect on the hypothalamus and anterior pituitary.
- Additionally inhibin produced by Sertoli cells, acts on anterior pituitary gland to reduce FSH secretion.
- These negative-feedback circuits maintain testosterone and other androgen levels in the normal range.

### Structure and Function of the Human Female Reproductive System

Main internal structures of the female reproductive system consists of two ovaries (female gonads), two oviducts, uterus and vagina.

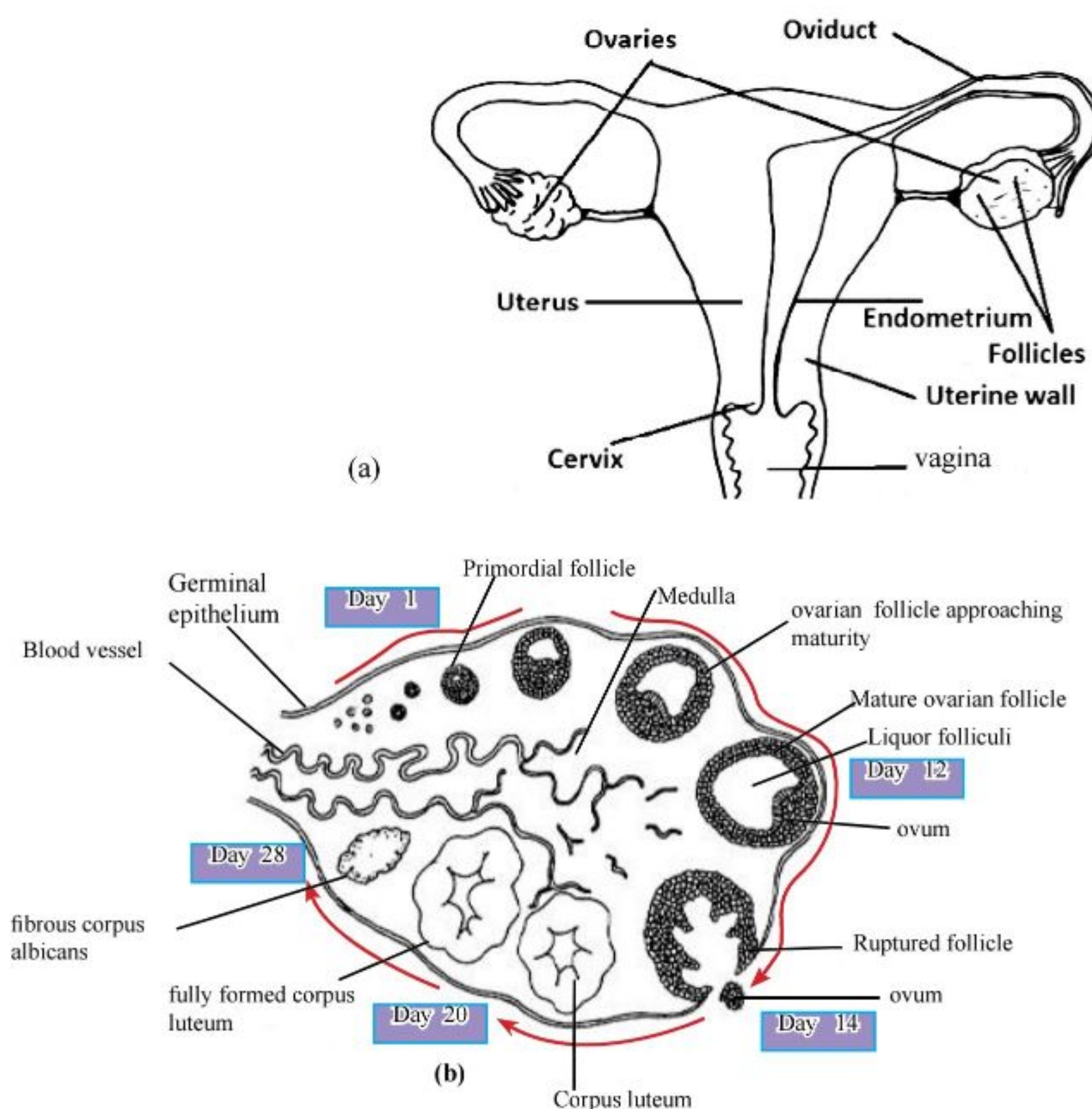


Figure 5.26: (a) The gross structure of the female reproductive system



**Ovaries:** The female gonads are the two ovaries. They are found on either side of the uterus and are held in place in the abdominal cavity by ligaments. In the ovary, female gametes are stored and developed prior to ovulation. Ovaries also produce female sex hormones that are needed for physiological changes during the reproductive cycle.

The ovaries have two tissue layers: outer the cortex and inner the medulla. The outer layer of each ovary consists of connective tissues covered by germinal epithelium. The outer layer contains ovarian follicles in various stages of maturity. Each follicle consists of an oocyte, which is a partially developed egg surrounded by support cells. Support cells protect and nourish the oocyte during its development. The ovum is discharged from the ovary at secondary oocyte stage of oogenesis with the first polar body. This secondary oocyte divides into the mature ovum (egg) and a second polar body if a sperm penetrates the secondary oocyte. Human ovum is a round cell with 23 maternal chromosomes and relatively large cytoplasm and is surrounded by numerous supporting cells. In addition, there is a clear layer present between plasma membrane of the ovum and the supporting cells.

**Oviducts:** The oviduct or the fallopian tube extends from the uterus toward a funnel like opening at each ovary. The dimensions of this tube vary along its length (near the uterus is narrow as a human hair). After ovulation, cilia on the inner epithelial lining of the oviduct help collect the egg by drawing fluid from the body cavity into the oviduct. Then with the help of wave like contractions of the oviduct the cilia convey the egg down the oviduct to the uterus.

**Uterus:** The uterus or the womb is a thick, pear shaped chamber. Its walls are muscular, which allows it to expand during pregnancy to accommodate the fetus and its inner lining (endometrium) is highly vascularized. The distal end of the uterus narrows to form a neck, called the cervix that opens into the vagina.

**Vagina:** This is a muscular but elastic chamber with a stratified epithelium. The vagina connects external and internal organs of reproduction. It is the site where sperm is deposited and also serves as the birth canal.

### **Oogenesis**

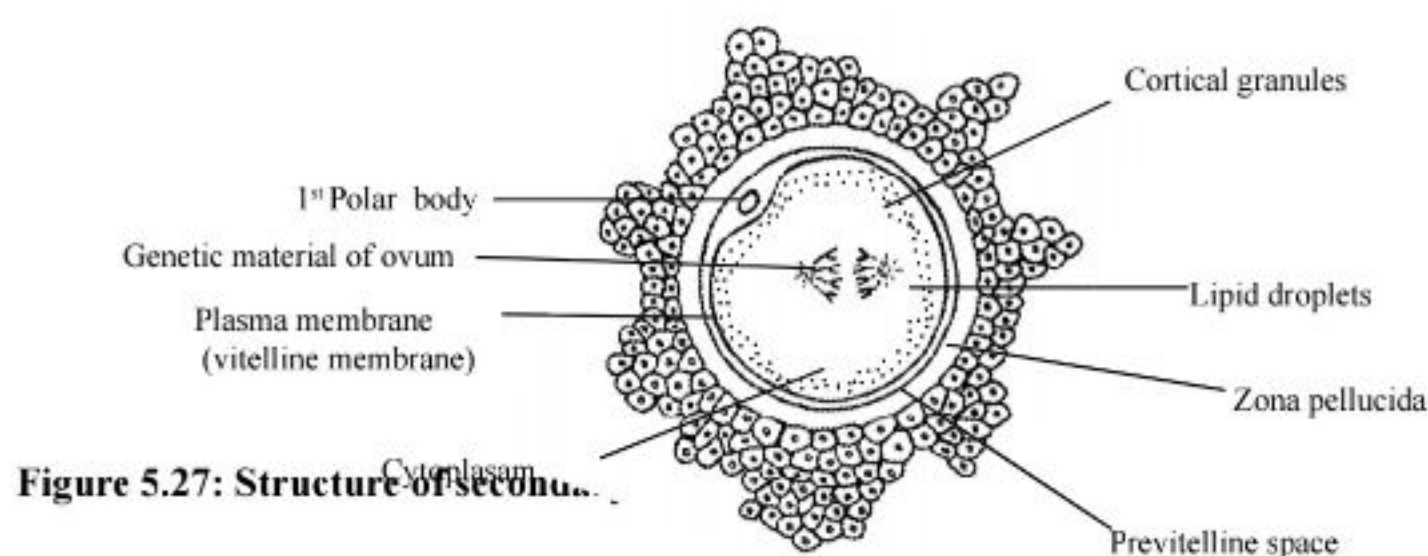
In the human female, the development of mature oocytes takes a long time. Immature eggs are formed in the ovary of a developing female embryo. But these eggs complete their development many years or even decades later. In oogenesis, cytokinesis during meiosis is unequal, with almost all the cytoplasm segregated to a single daughter cell. This large cell develops to become the egg. The other products of meiosis, which are smaller cells are known as polar bodies. These polar bodies eventually degenerate. Unlike spermatogenesis, the mitotic divisions that occur during



oogenesis in human females are thought to be complete before birth and the production of mature gametes ceases at about the age 50 years. Unlike in spermatogenesis, during oogenesis there are also long interruptions.

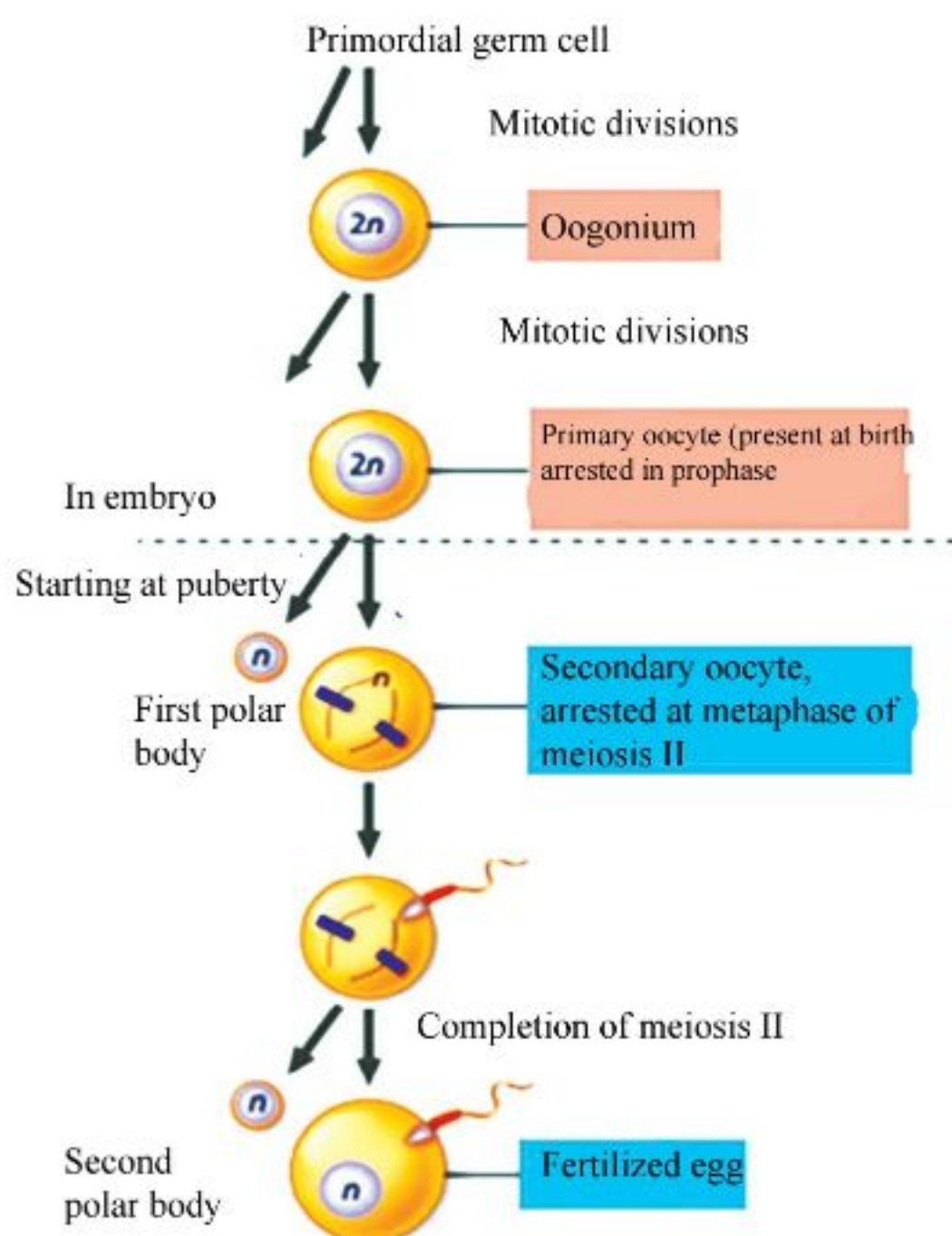
#### Main steps in oogenesis

- Oogenesis begins in the female embryo with the mitotic division of primordial germ cells that give rise to oogonia.
- Then oogonia divide by mitosis to form cells that begin meiosis, but stops at prophase I before birth.
- Each of these developmentally arrested cell is called a primary oocyte. Each primary oocyte is found within a small follicle, a cavity lined with protective cells. At birth, the ovaries together contain about 1-2 million primary oocytes. Out of these about 500 fully mature between the puberty and the menopause.
- Beginning at puberty, follicle stimulating hormone (FSH) periodically stimulates a small group of follicles to resume growth and development. Out of these only one follicle fully matures each month. During this time the primary oocyte within the follicle completes meiosis I and produces a secondary oocyte and the first polar body. Then the meiosis II starts, but stops at the metaphase.
- The secondary oocyte arrested in meiosis II is released at ovulation (with the first polar body), when its follicle breaks open.
- If a sperm penetrates the secondary oocyte, meiosis II completes and the secondary oocyte divides into the mature ovum and a second polar body. Both meiotic divisions involve unequal cytokinesis, with the smaller cells becoming polar bodies which will degenerate eventually. If a sperm penetrates, there is a single mature egg (ovum) containing a sperm head at the end of oogenesis. The fusion of the haploid nuclei of the sperm and the ovum is called fertilization.
- The ruptured follicle left behind after ovulation develops into the corpus luteum. Corpus luteum secretes estradiol and progesterone hormones which help to maintain the uterine lining during pregnancy.
- If the egg is not fertilized, the corpus luteum degenerates and leaves a small, permanent scar of fibrous tissue called corpus albicans on the ovary surface.
- A new follicle matures during the next cycle.



**Figure 5.27: Structure of second...**

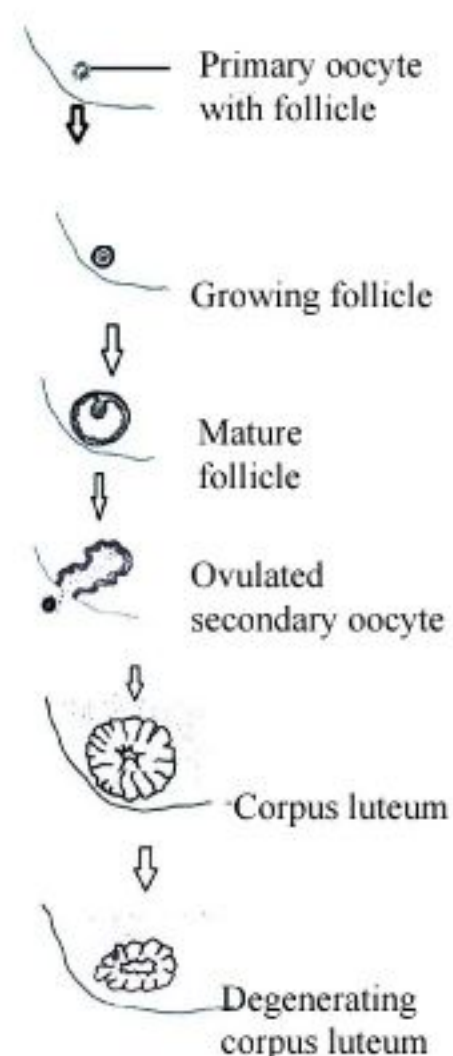




**Figure 5.28: The process of oogenesis**

### Hormonal control of the human female reproductive cycles

Although males produce sperms continuously, females produce ova in cycles. There are two linked reproductive cycles in a human female during their reproductive years; the ovarian cycle and the uterine cycle (or the menstrual cycle). The uterine cycle consists of changes that occur about once a month in the uterus and these cyclic changes in the uterus are controlled by the ovarian cycle, which is cyclic events that occur in the ovaries. Both of these cycles are regulated by hormonal activities which link the two cycles, synchronizing ovarian follicle growth and ovulation with the establishment of a uterine lining which supports the development of embryo.





## 1. Ovarian cycle

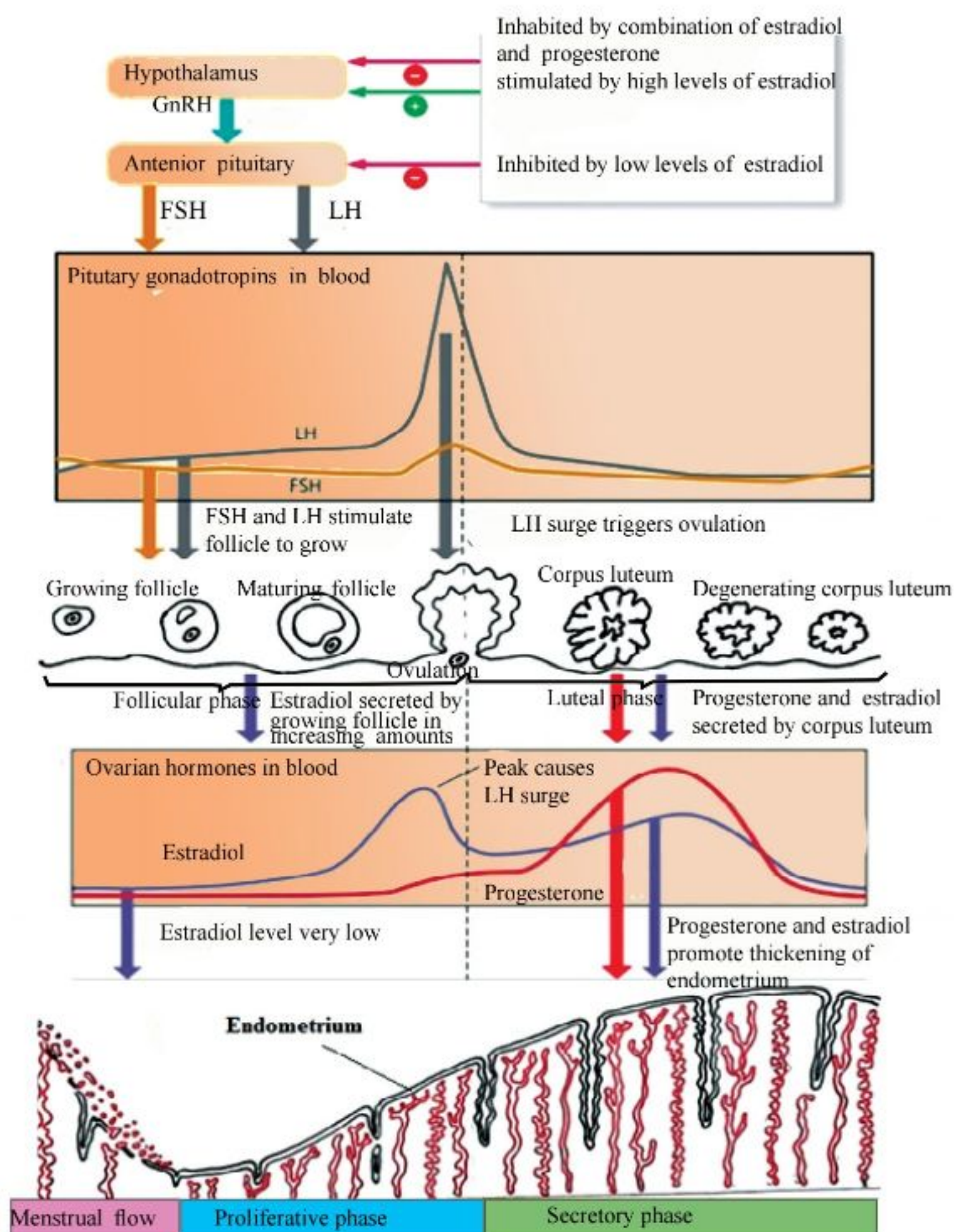
- Ovarian cycle comprises follicular phase and luteal phase.
- The period during which the follicle grows and the oocyte matures is referred to as the follicular phase. At the beginning of follicular phase, GnRH from the hypothalamus stimulates the anterior pituitary to secrete small amounts of FSH and LH.
- FSH stimulates follicle growth, aided by LH.
- Cells of the growing follicle start to make estradiol hormone. Therefore the estradiol level rises slowly during the follicular phase. The low levels of estradiol inhibit the secretion of gonadotropin hormones from the anterior pituitary (negative feedback) so that LH and FSH are kept at relatively low levels in the follicular phase.
- When estradiol secretion by the growing follicle starts to increase sharply, high levels of estradiol stimulate the hypothalamus to increase GnRH secretion which in turn stimulates the anterior pituitary to sharply rise the FSH and LH secretion especially producing a LH surge (through positive feedback mechanism).
- By this time the maturing follicle, containing a fluid-filled cavity has enlarged, forming a bulge at the surface of the ovary. About a day after the LH surge, the follicular phase ends at ovulation. In response to both FSH and the peak in LH level, the follicle and adjacent wall of the ovary rupture, releasing the secondary oocyte which is called ovulation.
- The luteal phase of the ovarian cycle takes place after ovulation. In the luteal phase, LH stimulates the follicular tissue within the ovary to transform into a glandular structure called the corpus luteum.
- The corpus luteum secretes progesterone and estradiol, which then exert negative-feedback on the hypothalamus and pituitary. This feedback reduces LH and FSH secretion to very low levels and thereby prevents the maturation of another egg in the ovary.
- If there is no pregnancy, the low gonadotropin levels at the end of luteal phase promotes disintegration of the corpus luteum.
- Disintegration of corpus luteum leads to the sharp decline in hormones. As a result the negative-feedback of estradiol and progesterone on the hypothalamus and pituitary are removed. This enables the pituitary to produce FSH to stimulate the growth of a new follicles thereby starting the next ovarian cycle.

## 2. Uterine (menstrual) cycle

Uterine cycle consists of proliferative phase, secretory phase and menstrual flow phase.

- Proliferative phase: Before ovulation, steroid hormones of the ovary stimulate the uterus to prepare for support of an embryo. Growing follicles secrete estradiol that stimulates the endometrium to thicken. This is referred to as the proliferative phase in the uterine cycle. Therefore the follicular phase of the ovarian cycle coordinates with the proliferative phase of the uterine cycle.
- The secretory phase starts after ovulation. After ovulation, estradiol and progesterone that are secreted from the corpus luteum stimulate the maintenance and further development of the lining of the uterus by enlarging the arteries and growth of the endometrial glands.





**Figure 5.29: The reproductive cycles of human female showing how ovarian cycle and uterine cycle are regulated by changing hormone levels in the blood.**



These glands secrete nutrient fluid that can sustain an early embryo if fertilization occurs. Hence, the luteal phase of the ovarian cycle is coordinated with the secretory phase of the uterine cycle.

- **Menstrual flow phase:** If implantation of an embryo does not occur, the corpus luteum disintegrates which results in the drop in ovarian hormones. This brings about the end of the secretory phase. As a result, arteries constrict and thereby the uterine lining disintegrates and causes the shedding of endometrial tissues and fluid. This is the menstrual flow phase of the uterine cycle. The cyclic shedding of the blood-rich endometrium from the uterus, a process that occurs in a flow and which lasts for a few days through the cervix and vagina is called menstruation.

### **Menopause**

This is the cessation of ovulation and menstruation in a woman. Usually menopause takes place between the ages of 45 and 55 years. During this time the ovarian supply of oocytes runs out and the estrogen production by the ovary decreases. Ovaries become less responsive to the hormones FSH and LH produced by the anterior pituitary.

### **Human Development**

Growth of a new human being starts when an ovum is fertilized by a sperm usually in the oviduct. During the development of the individual within the mother's uterus, a sequence of events occurs from fertilization to the birth which normally ends in 38 weeks or roughly 9 months. The first 8 weeks of human development is called the embryonic period and thereafter the developing individual is called a fetus.

- **Fertilization/conception and the formation of a human zygote**

During ovulation a secondary oocyte arrested at metaphase II enters the oviduct. During fertilization a sperm enters the secondary oocyte penetrating the epithelial cells surrounding the oocyte, the glycoprotein layer present between the oocyte's plasma membrane and the surrounding cells. Once the sperm enters the secondary oocyte, meiosis II of the oocyte is completed producing the mature ovum. Subsequently, the two haploid pronuclei of the mature ovum and the sperm fuse to produce a diploid, single cell referred to as the zygote. The fusion of the haploid nuclei of the sperm and the ovum is called fertilization. Fertilization takes place in the upper reaches of the oviduct within 12 to 24 hours after ovulation.

- **Cleavage of the zygote, blastocyst formation and implantation**

About 24 hours after fertilization, a series of rapid mitotic cell divisions called 'cleavage' take place in the zygote. Cleavage of zygote begins in the oviduct as it moves forward towards the uterus by ciliary and peristaltic movements. Cleavage continues forming a



solid ball of cells (morula) by the time the embryo reaches the uterus (about 3-4 days after fertilization).

Morula floats within the uterine cavity and gets nutrition by endometrial secretions. About five days after fertilization, a large fluid filled cavity is formed surrounding the ball of cells. With the formation of the cavity, this developing stage is referred to as the blastocyst. Further rearrangements of the cells in the blastocyst results in two distinct structures: the inner cell mass and the trophoblast. Inner cell mass is located internally and eventually develops into the embryo and the membranes enclosing the embryo are called the amniotic sac. The trophoblast which is the outer layer of cells will ultimately develop into the fetal portion of the placenta.

Around 7 days after fertilization, the blastocyst attaches to the endometrium of the mother's uterus. This is called implantation. As the blastocyst implants, the inner cell mass orients towards the endometrium. The trophoblast grows outward and invades the endometrium. This is initiated by the enzyme secreted by the trophoblast to breakdown the uterine lining. Then the trophoblast extends finger like projections into the endometrium. Trophoblast begins to secrete human chorionic gonadotropin (hCG) hormone which has the action similar to LH. The hormone hCG rescues the corpus luteum from degeneration and sustains its secretion of progesterone and estrogen which maintain the uterine lining preventing menstruation.

After implantation, three germ layers are formed in the developing embryo at the end of the gastrulation stage. Extra-embryonic membranes begin to appear which surround the embryo. The placenta is formed by the cells of trophoblast and the adjacent endometrial tissues.

- **Embryonic members / fetal membranes**

Four new extra embryonic membranes appear after implantation. They are chorion, amnion, yolk sac and allantois. They provide a life support system for further embryonic/fetal development.

Chorion becomes the main embryonic portion of the placenta which is the structure for exchange of materials between the fetus and mother. It also protects the embryo/fetus from immune responses of the mother. Chorion produces hCG, an important hormone of pregnancy.

Amnion is a protective membrane surrounding the embryo/fetus creating a fluid filled cavity which serves as a shock absorber and helps prevent desiccation.

Yolk sac contributes to the cells that will become blood cells until the fetal liver takes over. It also is the source of primordial germ cells that migrate to the developing gonads.

Allantois is a small outer-pouching of the yolk sac that serves as an early site for blood formation and is associated with the development of the urinary bladder.



- **Placenta and umbilical cord**

During the first 2-4 weeks of embryonic development, the embryo obtains nourishment directly from the endometrium. Eventually, the embryonic trophoblast and the mother's endometrium intermingles and form the placenta. The placenta is a disc shaped organ formed by two parts: embryonic/fetal portion formed by chorionic villi of the chorion and maternal portion formed by the endometrium. The placenta contains both embryonic/fetal and maternal blood vessels. However maternal and fetal blood vessels do not join and the blood they carry do not normally mix. The placenta mediates the exchange of material (nutrients, respiratory gases, metabolic wastes) between the embryonic/fetal and the mother's circulatory systems. The placenta supplies oxygen and nutrients to the fetus from the maternal blood stream and excrete waste products from the fetus to the maternal blood stream. The placenta also helps to provide immune protection to the developing embryo/fetus. The placenta produces hormones (e.g. hCG, progesterone etc.) needed to sustain the pregnancy.

Umbilical cord is a flexible cord-like structure containing blood vessels and attaches embryo/fetus to the placenta during gestation. Oxygen poor blood from the embryo/fetus travels to the placenta through the two arteries of the umbilical cord and passes through fingerlike projections (chorionic villi) of the placenta where oxygen and nutrients are acquired. Fetal blood (oxygen rich blood) leaves the placenta through the umbilical vein leading back to the embryo/fetus.



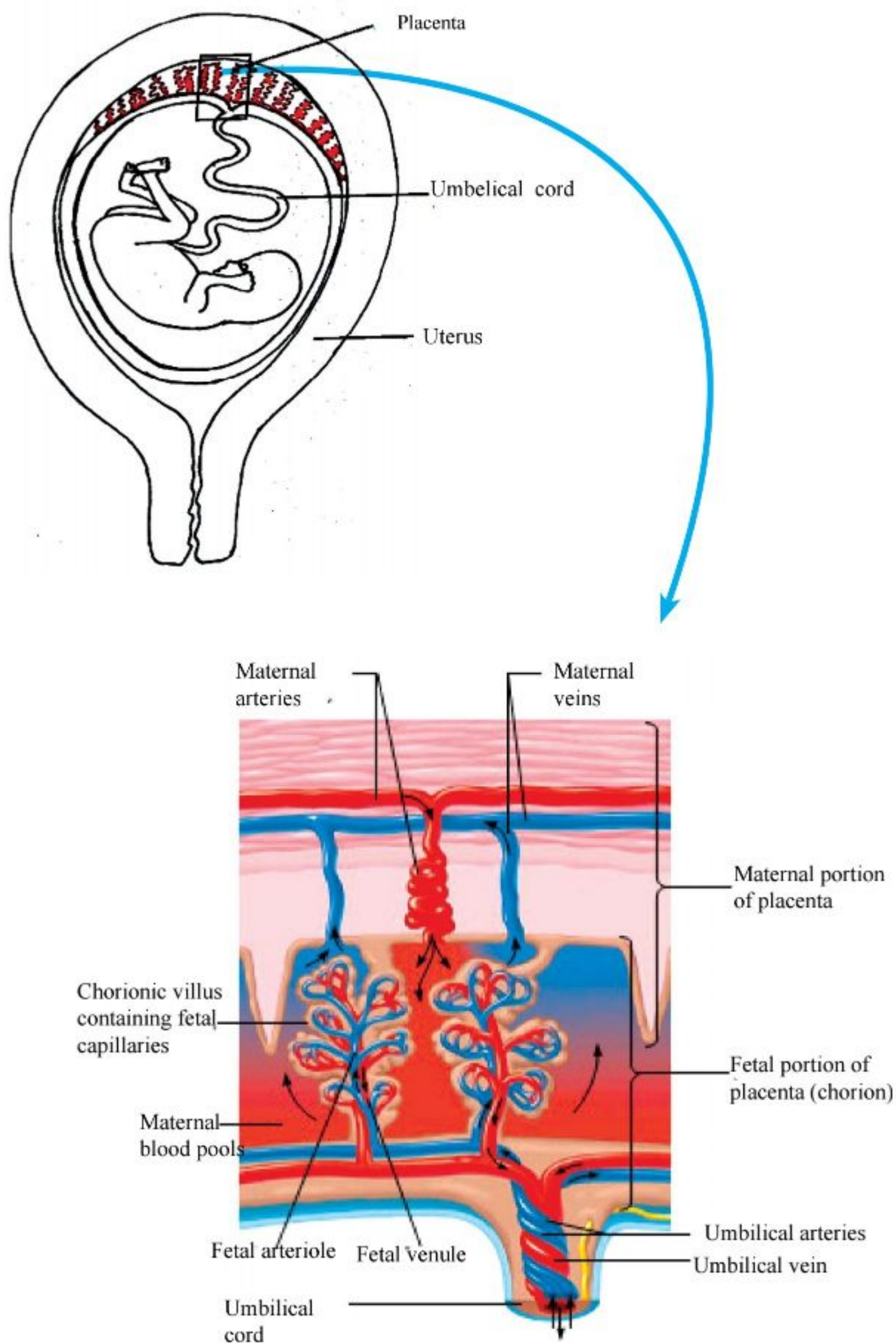


Figure 5.30: Placenta and umbilical cord



## **Pregnancy and its duration**

Pregnancy or gestation is the condition of carrying one or more developing offspring inside the uterus of a female. Human pregnancy period is usually 38 weeks from fertilization to birth or roughly 9 months (or 40 weeks from the last menstruation to birth). The nine months of pregnancy are divided into three trimesters of about three months each.

During the first trimester, the implanted embryo secretes hormones to regulate the mother's reproductive system and to indicate its presence. The hCG hormone secreted by the embryo, maintains the corpus luteum in the ovary to secrete progesterone and estrogen. Some amount of this hCG passes from the maternal blood to the urine. The presence of hCG in pregnant mother's blood and urine can be easily detected and therefore is used as an early pregnancy detection test. High levels of progesterone brings about rapid changes in the mother. Both ovulation and menstrual cycles stop, the maternal side of the placenta grows, and the breasts and the uterus get larger. Mucus in the cervix of the mother forms a plug which prevents the fetus from infections. Most mothers experience nausea (morning sickness) during the first trimester.

By the second trimester, the level of hCG declines and as a result the corpus luteum deteriorates. But the placenta takes over the production of progesterone and estrogens which helps to maintain the pregnancy. Mother can feel fetal movements. As the fetus grows, mother's abdominal organs become compressed and displaced. In the third trimester of pregnancy this may lead to digestive blockage and frequent urination.

## **Major fetal changes in each trimester**

- **First trimester**

The first trimester is the most critical stage of development during which the rudiments of all major organ systems appear. This is the main period of organogenesis (the development of the body organs). The heart begins to beat by the 4<sup>th</sup> week (can be detected at 8-10 weeks). By the 8<sup>th</sup> week, embryo is said to be the fetus as all the parts of an adult are present in rudimentary form. At the end of the 1<sup>st</sup> trimester, the fetus is well differentiated and about 5 -7 cm long.

- **Second trimester**

By the end of second trimester, the fetus assumes distinctively human features. Organ systems are completely developed in this stage. During the second trimester, the fetus grows to about 30 cm in length and is very active so that the mother may feel the fetal movements.



- **Third trimester**

The third trimester represents a period of rapid fetal growth. During the early stage of this period, most of the organ systems become fully functional. During the third trimester, the fetus grows to about 50 cm in length and weighs about 3-4 kg. Fetal activity decrease as it fills the space within the uterus.

**Maternal immune tolerances of the embryo and fetus**

During pregnancy the overall regulation of the mother's immune system changes. These changes allow the mother to keep the embryo in her uterus without rejecting as a foreign body even though half the embryo's genes are inherited from the father and many chemical markers on the surface of the embryo are foreign to the mother.

**Process of parturition**

Child birth begins with the labor. The labor is a series of strong, rhythmic uterine contractions that push the fetus and placenta out of the body. When labor begins, local regulators (prostaglandins) and hormones (mainly estradiol and oxytocin) induce and regulate further contractions of the uterus. This is a positive feedback mechanism as uterine contractions stimulate secretion of oxytocin which stimulates further contractions of the uterus.

The labor can be divided into three stages. The first stage is the thinning and opening up (dilation) of the cervix. The second stage is the delivery of the baby. In this stage, continuous and strong contractions force the fetus out of the uterus and expell through the vagina. Delivery of the placenta is the final stage of labor.

**Lactation**

The lactation which is unique to mammals begins as post natal care. Lactation is the secretion and ejection of mother's milk from the mammary glands. Lactation is subjected to nervous and hormonal regulation. The main hormone in promoting milk synthesis and secretion is prolactin. In response to suckling by the new born baby (which initiates nerve impulses from touch receptors in the nipples) and decrease in estradiol and progesterone levels in the mother's blood after birth, the hypothalamus send impulses to the anterior pituitary to secrete prolactin hormone which stimulates the mammary glands to produce milk. Suckling also stimulates the secretion of oxytocin hormone from the posterior pituitary gland and triggers the release (ejection) of milk from the mammary glands. This is a positive feedback mechanism as milk availability encourages continuous suckling, so touch sensation on the nipple and oxytocin release continue further ejecting milk from the mammary glands.



**Composition of human milk and significance of breast feeding**

During the first few days after birth, the mammary glands secrete a fluid called 'colostrum' until appearance of true milk. Human milk is a sterile solution that contain nutrients such as lactose, fatty acids, amino acids, minerals, vitamins, and water that are ideal for baby's digestion, brain development and growth. Human milk includes proteins such as casein, lactalbumin and immunoglobulins.

Colostrum and true milk provide nutrients for the baby and contain important antibodies that protect the infant. Several types of white blood cells are also present in the breast milk which help the baby to resist microbial infections. Compared to the true milk, colostrum contains less nutrients (less lactose and no fat) but they are adequate for the early nutritional needs.

Breast feeding supports optimal infant growth, enhances intellectual development and fosters mother-infant relations by establishing early and prolonged contact between them. Compared to cow's milk, the fat, iron and the proteins in the breast milk are more readily metabolized. Lower sodium content of breast milk is more suited to the baby's needs. The baby is less likely to have allergic reactions to mother's milk than the milk from another source.

**Birth control methods**

The deliberate prevention of pregnancy is called contraception. This can be achieved in several ways. Some contraceptive methods prevent gamete development or releasing gametes. Some contraceptive methods prevent fertilization of gametes. Some methods are available to prevent implantation of an embryo. Unwanted pregnancies are avoided by birth control methods.

**Common temporary birth control methods:**

- Oral contraceptives for females: Most oral contraceptives contain high concentration of synthetic estrogen and progesterone. High levels of these hormone inhibit GnRH release from hypothalamus and FSH and LH secretions from anterior pituitary through negative feedback. Prevention of LH release blocks ovulation. Inhibition of FSH secretion prevents follicle maturation. Some oral contraceptives contain only high levels of synthetic progesterone (progestin) which thickens cervical mucus so that it blocks entering sperms to the uterus. If fertilization occurs it can interfere with implantation as well.
- Condoms for males: Barrier devices which prevent sperm entry
- IUD (loop ) for females: A device placed in the uterus which interferes with fertilization and prevents implantation of a fertilized ovum
- Depo-Provera injection for females: Periodic injection of a synthetic progesterone which thicken cervical mucus and prevents sperm entry. If fertilization occurs it prevents implantation by making the endometrium thin.



**Surgical Sterilization (preventive methods of gamete release)**

- Vasectomy for males- Prevents release of sperms
- Tubal ligation for females- Prevents ovum from entering uterus

**Abortion**

- Abortion is the premature termination of a pregnancy in progress.
- Miscarriage: Spontaneous abortion which occurs naturally.
- Induced abortion is intentionally performed (surgical or nonsurgical). Certain drugs can induce abortion non-surgically within the first 7 weeks after conception. They block progesterone receptors in the uterus thereby preventing progesterone from maintaining the pregnancy.

**Table 5.6: Sexually transmitted infections**

Infection	Pathogen	Main mode of transmission	Main symptoms
Gonorrhea	<i>Neisseria gonorrhoeae</i> bacterium	<ul style="list-style-type: none"> <li>• Sexual contact,</li> <li>• Mother to child at birth</li> </ul>	In males-burning feeling/discomfort when passing urine, yellow discharge with pus from genito-urinary tract.
Syphilis	<i>Treponema pallidum</i> bacterium	<ul style="list-style-type: none"> <li>• Sexual contact,</li> <li>• Mother to child at birth</li> </ul>	Accompanied by fever, headache.
AIDS (acquired immunodeficiency syndrome)	HIV(Human immunodeficiency virus)	<ul style="list-style-type: none"> <li>• Sexual contact</li> <li>• Transfer of body fluids (blood, serum)</li> <li>• Use of unsterilized needles</li> <li>• Mother to fetus/child :during pregnancy, at birth and during lactation</li> </ul>	Sores or painless ulcers on any part of the body (vagina, lips, fingers, nipples), fever, skin rashes Loss of appetite and weight, fever, persistent dry cough, Lymphoma (cancer in lymphatic system), pneumonia and other disease resulting from breakdown of the immune system
Genital herpes	Herpes simplex 2 virus	Sexual contact	Itchy, painful sores around genital area, fever in some cases



**Detecting disorders during pregnancy**

- Many development problems and genetic disorders can be diagnosed during the gestation period.
- Ultrasound images can be used to analyze the size and condition of the fetus.
- Amniocentesis and chorionic villi sampling –a needle is used to obtain fetal cells from amniotic fluid or tissue surrounding the embryo. Genetic analysis can be done with these samples.
- Newest method is to use a pregnant mother's blood to analyze the genome of the fetus as the mother's blood contains fetal DNA
- But all detectable disorders are untreatable when the embryo is in the uterus and many cannot be corrected even after birth. However, parents can take informed decisions with the help of these tests.

**Infertility**

Infertility is the inability to conceive offspring. Both men and women can have reproductive defects leading to infertility. The number of couples facing this problem appears to be increasing in the modern society. Certain forms of infertility are treatable.

**Modern reproductive technology for resolving infertility problems**

- Some infertility problems are resolved by recent scientific and technological advances. This includes hormone therapy, surgery and assisted reproductive technology.
- Hormone therapy– Sometimes, hormone therapy can increase sperm production in the infertile male or egg production in the infertile female.
- Surgery: The ducts in the reproductive system that are formed improperly or have become blocked can be corrected surgically to resolve infertility.
- Assisted reproductive technology

**In vitro fertilization (IVF):** In vitro fertilization is a series of procedures used to treat infertility problems and assist with the conception of a child. The process involves removal of oocyte(s) from a female ovary and obtaining sperm from a male and combining the oocyte and the sperm to achieve the fertilization under laboratory conditions. The fertilized eggs are incubated until they reach at least 8 cells and then these embryos are transferred to the woman's uterus for implantation and to continue its development. Conventional IVF needs between 50 and 100 thousands of sperm from the male per one oocyte in order to achieve the fertilization. This is due to the fact that in IVF, acrosome reaction has to take place and thousands of sperm cells have to be involved.

**Intra-cytoplasmic sperm injection (ICSI):** This is also a type of in vitro fertilization method which is used to address male infertility. If mature sperm are defective or low in number, a whole sperm or a spermatid nucleus is injected directly into the cytoplasm of an oocyte that has been removed from the woman's ovary. For insemination, ICSI needs only one sperm per oocyte. Unlike in conventional IVF, the sperm which will be inserted into a particular oocyte is already selected in ICSI. The fertilized egg can then be returned to the woman's uterus for implantation.



## Support and Movement

### The structure and functions of the skeletal systems of animals

In the animal kingdom, three major types of skeletons are found. They are hydrostatic skeletons, exoskeletons and endoskeletons.

**Hydrostatic skeleton** is a fluid filled body cavity which is enclosed by the body wall. In cnidarians, gastrovascular cavity acts as the hydrostatic skeleton. In some animals such as nematodes and annelids, the fluid filled cavity enclosed by the body wall (e.g., pseudocoelom in Nematoda, coelom in Annelida) consists of two muscle layers (longitudinal and circular muscles) which act antagonistically. The combined effect of muscle contraction and fluid pressure aids in locomotion and maintain the shape and form of the animal. In many animals, the spaces between cells are filled with fluid called interstitial fluid which provides support to these cells.

**Exoskeleton** is a rigid outer covering of the body of the animal which acts as a skeleton. Different types of exoskeletons are seen in the animal kingdom: Chitinous exoskeleton, calcium carbonate exoskeleton and bony plates. Arthropods possess the exoskeleton which is mainly composed of a non-cellular material, chitin. The chitinous exoskeleton is hardened by proteins or calcium carbonate. Exoskeletons that are made up of calcium carbonate are seen in the molluscs. In some reptiles, bony plates serve as the exoskeleton.

**Endoskeleton** is a hard skeleton which is buried in the soft tissues of the animal. Different types of endoskeletons are seen in the animal kingdom. These include plates of calcium carbonate (in echinodermites), bones and cartilage (in chordates).

### Common functions of the skeletal systems in animals

- Support – All skeletons provide a rigid framework for the body and are resistant to compression and tension forces. They help to maintain the shape of body.
- Protection – The skeleton protects the delicate internal organs.
- Movement – Most skeletons are composed of rigid materials which provide a means of attachment for the muscles of the body. Parts of the skeleton operate as levers on which the muscles can pull. When this occurs, movement takes place.

### Functions of the human skeletal systems

- Support
- Protection
- Movement



- Storage and release of calcium under the influence of some hormones (refer competency level 5.7.1)
- Storage and release of phosphates under the influence of some hormones (refer competency level 5.7.1)
- Production of blood cells in the bone marrow

***How animals move through water and air?***

***Swimming:*** Different groups of animals swim in different ways. Some animals use their legs as oars to push against the water (e.g. insects and four legged vertebrates). Some animals are jet propelled taking water into the body and squirting it out in bursts (e.g. squids). Fishes swim by moving their body and tail from side to side. Aquatic mammals move by undulating their body and tail up and down (e.g. whales and dolphins). Fusiform body shape is a common adaptation for fast swimming animals.

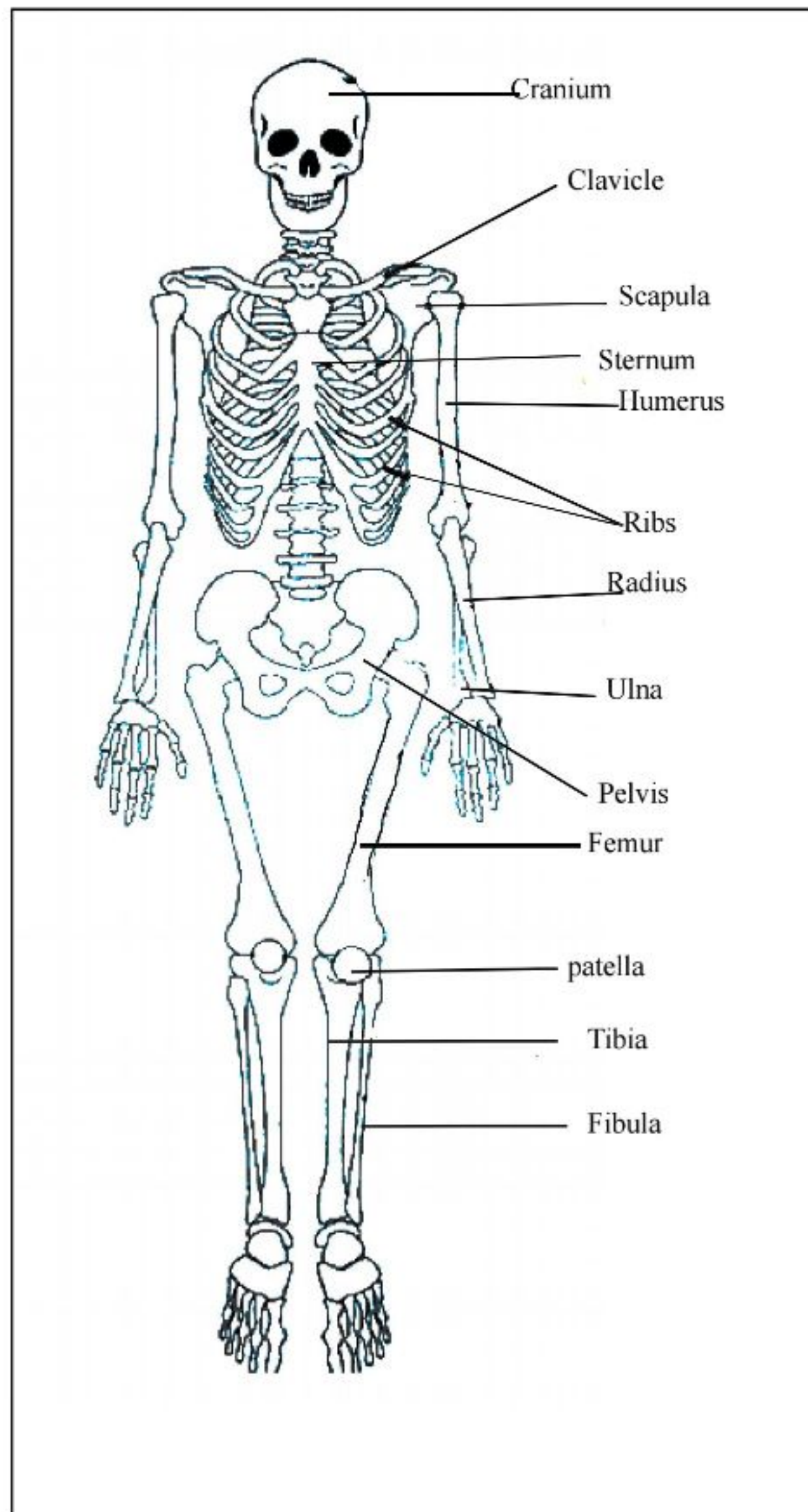
***Movement through air:*** Animals move through air mostly by flying. Gliding downward can occur in some instances. Flying animals use wings to lift the body against the gravity. Wings act as air foil: their shapes alter air currents in a way that helps flying. Fusiform shape of the wings helps to reduce drag force in air.

**The human skeleton**

Human skeleton is divided into two main parts: axial skeleton and appendicular skeleton.

- Axial skeleton consists of skull, vertebral column, sternum and ribs.
- Appendicular skeleton consists of girdles (pectoral and pelvic) and limb bones.





**Figure 5.31: The anterior view of the human skeleton**



## Organization of the human axial skeletal system

### Skull

In humans, the skull rests on the upper end of the vertebral column. The human skull consists of 21 bones which are mostly connected together by ossified joints (sutures). Skull is divided into the cranium (brain case) and the face. The bones in the cranium are the frontal bone, two parietal bones, the occipital bone, two temporal bones, the ethmoid bone and the sphenoid bone. In addition to the frontal bone, thirteen other bones form the skeleton of the face. They are two zygomatic bones (cheek), the maxilla (upper jaw bone), two nasal bones, two lacrimal bones, the vomer, two palatine bones, two inferior conchae and the mandible (lower jaw bone).

Human cranial capacity is nearly 1.5 L. Cranium protects and encloses the brain. It also protects the inner ear, middle ear, olfactory organs and eyes. Bony eye sockets provide attachment to the eye muscles that move them. On the inferior surface of the cranium there is foramen magnum to provide passage to spinal cord. Two smooth rounded knobs (Occipital condyles) on either side of the foramen magnum articulates with the first vertebrae (atlas vertebrae) which permits nodding movements.

In the cranium, soft membranous regions called fontanelles are present which allow slight compressions at birth facilitating parturition. Fontanelles become replaced by bones within 1-2 years of life. Immovable joints (sutures) are present between the skull bones to provide more protection. Several air filled cavities lined by ciliated mucous membrane are present in the skull (in the sphenoid, ethmoid, maxillary and frontal bones). They are called sinuses. They all communicate with the nasal cavity. Sinuses provide resonance to voice and reduce the weight of the skull.

Facial region is situated below the cranium. Some facial bones form the walls of the posterior part of the nasal cavity and form the upper part of the air passages. Maxilla and mandible provide ridges in which teeth are embedded. Upper jaw (maxilla) is fused with cranium. Lower jaw (mandible) is movable. Hard palate (bony) and soft palate (cartilaginous) separate the buccal cavity from nasal cavity. Lower jaw articulates with the cranium. Zygomatic arch (formed from parts of zygomatic bone and temporal bone) provides the surface for muscular attachment for moving the lower jaw. Lower jaw (mandible) contains two processes: Condylod process which articulates with the temporal bone to form the temporal-mandibular joint; Coronoid process which gives attachment to muscles and the ligaments. At the base of the skull, occipital condyles (1 pair) are present on the two occipital bones to form a hinge joint with atlas vertebrae. Temporal bone contains three processes: zygomatic process (which forms part of the zygomatic arch), mastoid process and styloid process. They provide surfaces for muscle attachment.



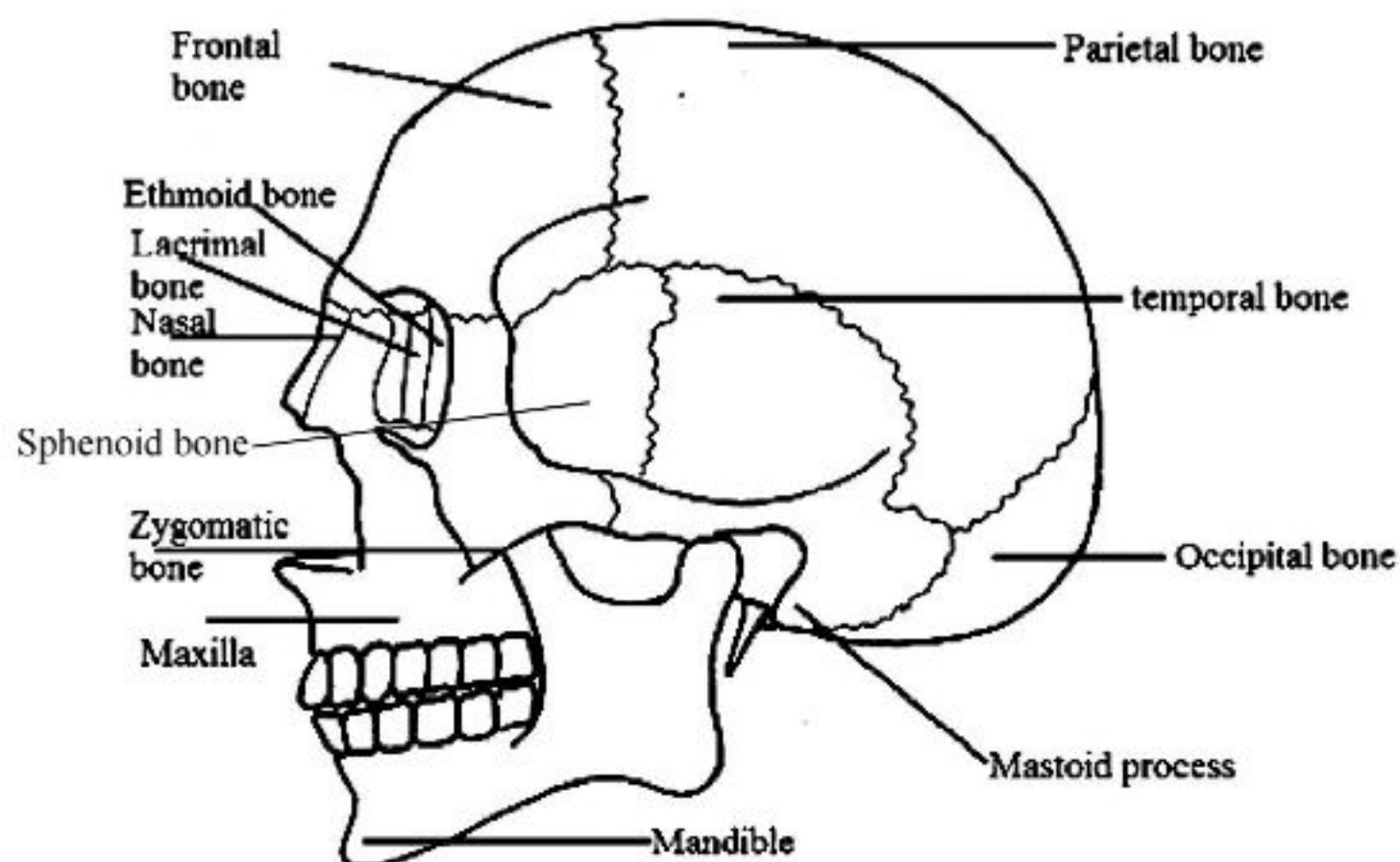


Figure 5.32: The bones of the human skull

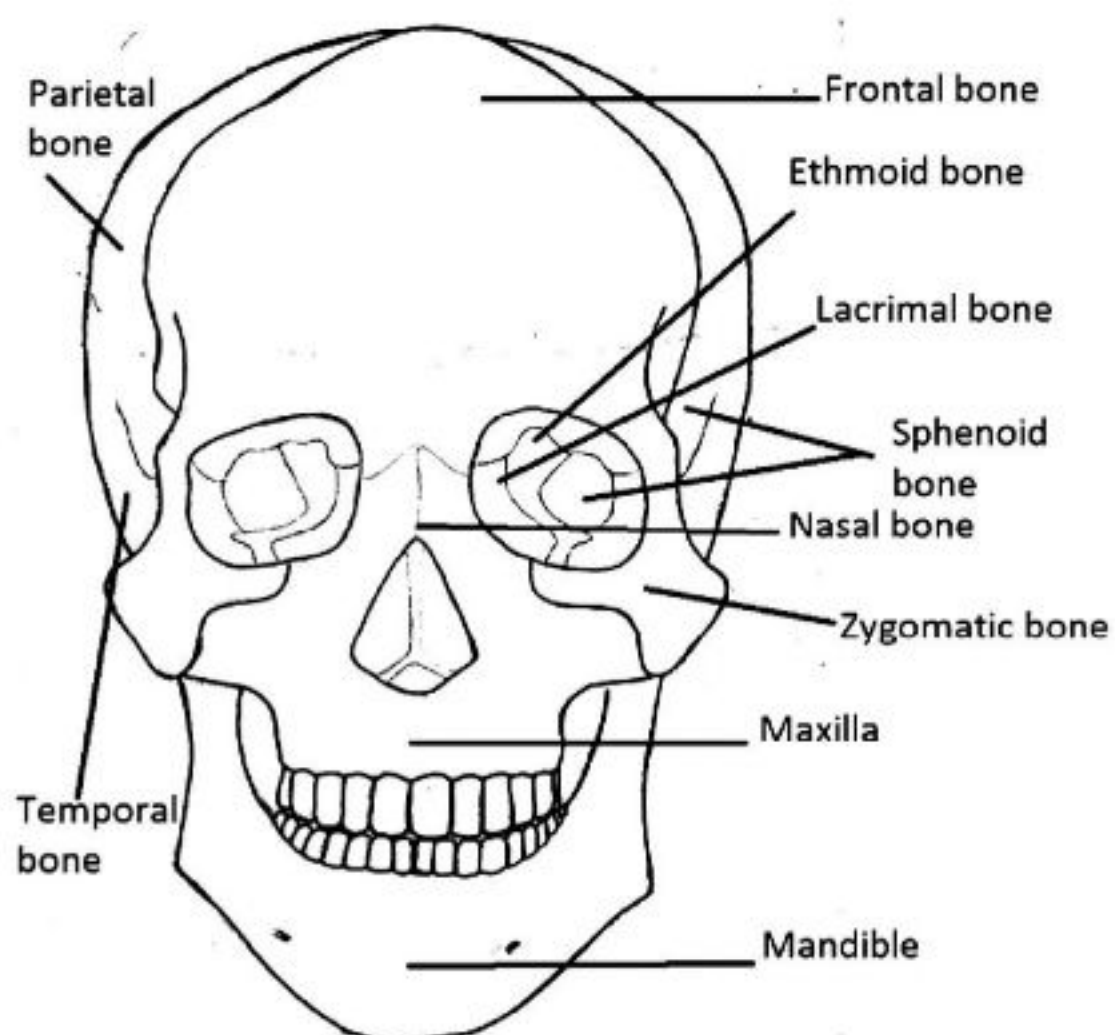


Figure 5.33: The anterior view of the human face ( bones in the face)



## Vertebral column

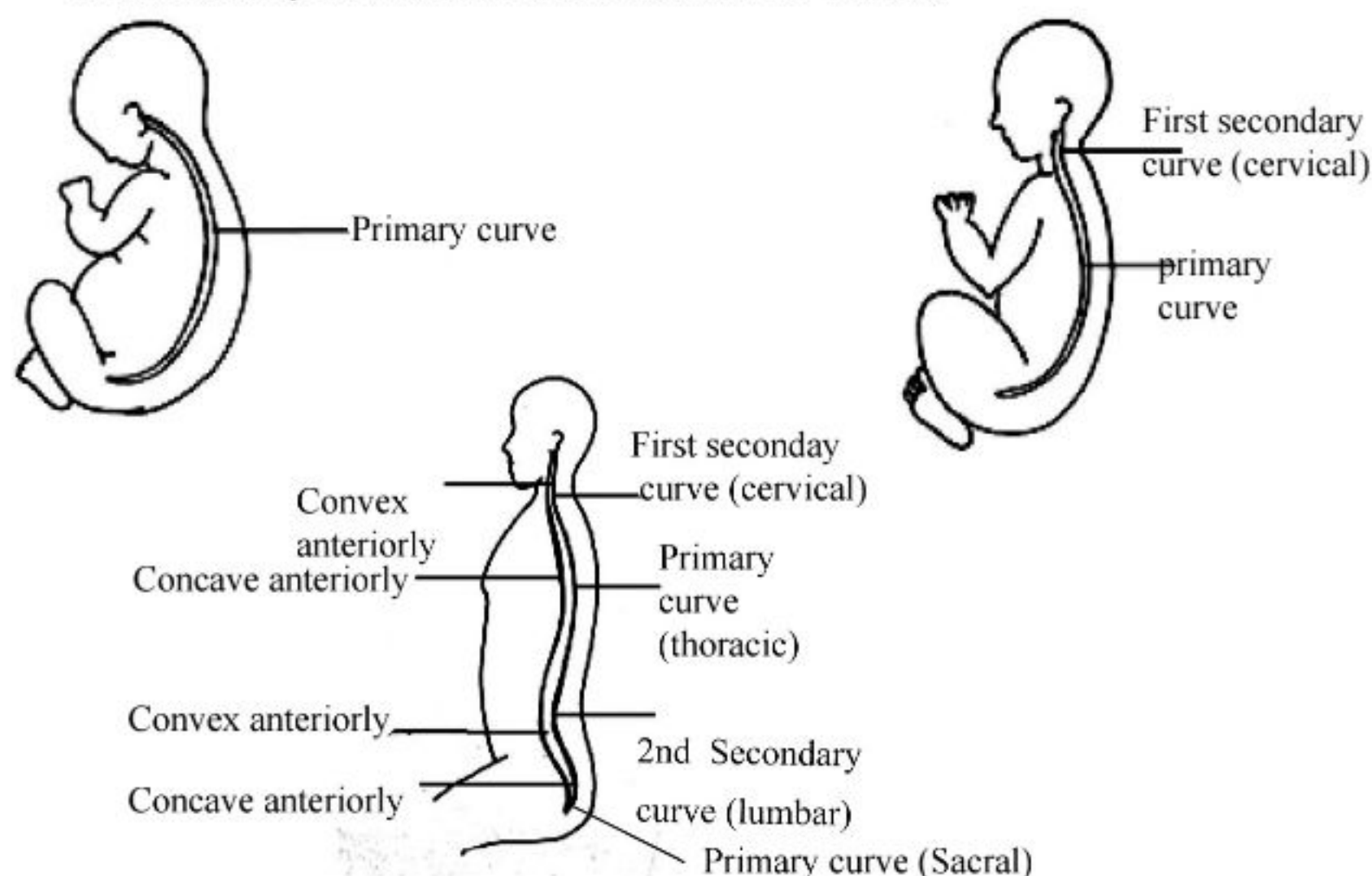
Vertebral column is a strong flexible rod consisting of 26 linearly arranged bones. It consists of 24 separate vertebrae extending downwards from the occipital bone of the skull, the sacrum (formed from 5 fused vertebrae) and coccyx (formed from 4 small fused vertebrae). The vertebral column is divided into different regions. There are 4 distinct regions: cervical spine (formed by 7 vertebrae in the neck), thoracic spine (formed by next 12 vertebrae), lumbar spine (formed by next 5 vertebrae), and the sacrum to which the lowest vertebrae of lumbar spine is articulated; the coccyx is situated at the end.

## Curvatures of the vertebral column

In humans, there are four curves in the vertebral column: cervical, thoracic, lumbar and sacral. They can be categorized into two main types: two primary curvatures and two secondary curvatures. Main function of the curvatures is the maintenance of the erect posture.

**Primary curvatures:** In the foetus, there is only one curvature in the vertebral column. When secondary curvatures are formed the primary curvature is retained only in thoracic and sacral regions which are known as primary curvatures. They are concave anteriorly.

**Secondary curvatures:** Formed after birth, first cervical curvature develops at about 03 months of birth. Then the child can hold his head upright. Second, lumbar curvature develops when the child is around 7-8 months. Then the child can hold his body upright. These secondary curvatures are convex towards the anterior.



**Figure 5.34: The clear development of curves in the human vertebral column**

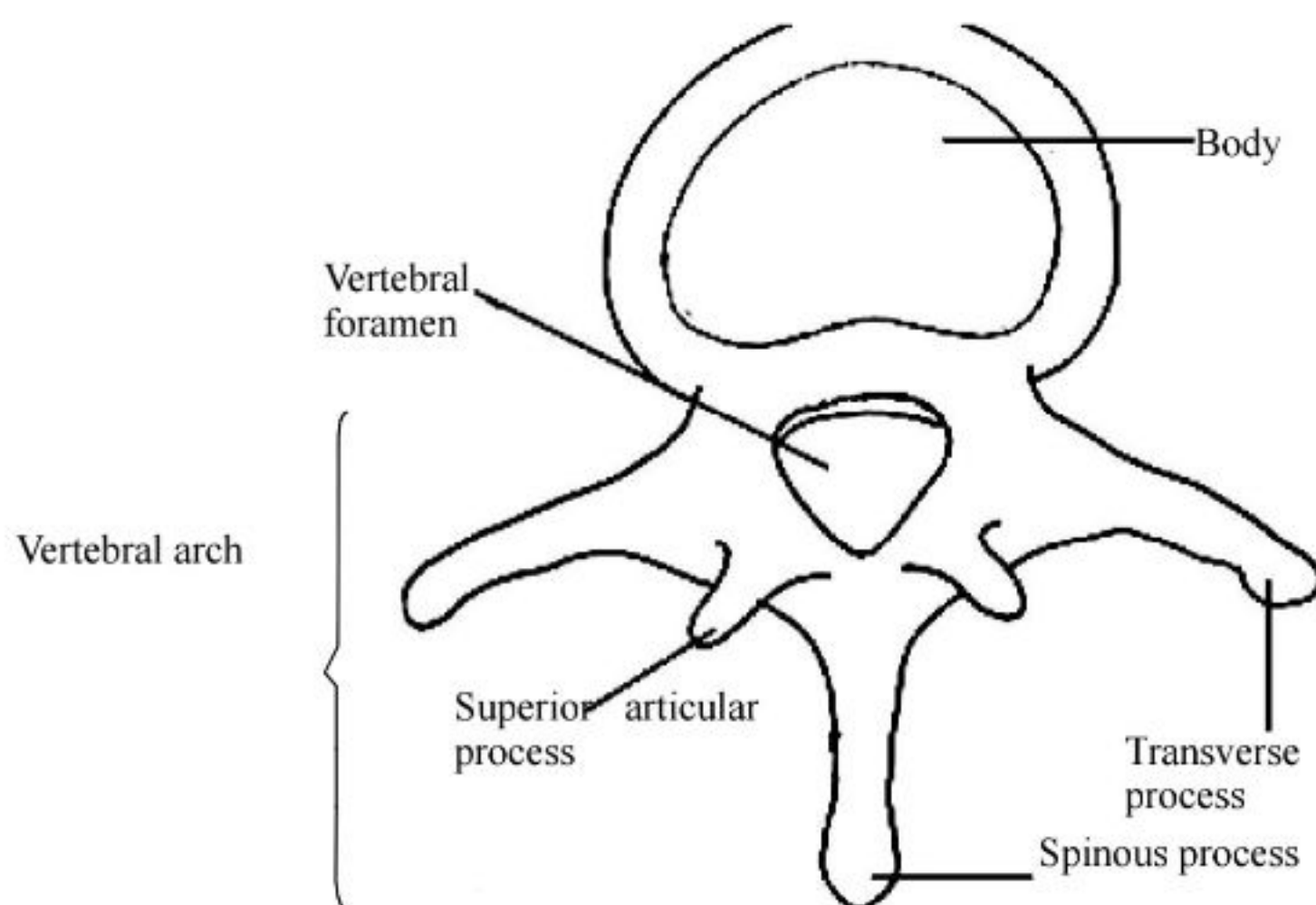


## Types of vertebrae

### Structure of a typical vertebra

A lumbar vertebra can be considered a typical vertebra. A typical vertebra consists of the body and the vertebral arch. The body is the largest, broad and flattened part of the vertebrae. The flattened surface of the body of each vertebra articulates with the corresponding surface of the adjacent vertebra so that vertebrae are stacked together in the vertebral column. However the adjacent two vertebrae are not in direct contact with each other as there is a tough pad of cartilage called intervertebral disc between the two vertebrae. The size of the body of the vertebra increases downwards of the vertebral column to support the body weight.

Vertebral arch encloses vertebral foramen which provides passage way for the spinal cord. Processes arising from the neural arch provide surfaces for muscle attachment. Two lateral processes are called transverse processes and the posterior process is called spinous process. The vertebral arch has four articular surfaces: two superior articular surfaces (articulate with the adjacent vertebrae above) and two inferior articular surfaces (articulate with the adjacent vertebrae below).



**Figure 5.35: The structure of a typical vertebra (lumbar vertebra)**



### Region specific vertebral characteristics

**Cervical vertebrae:** Cervical vertebrae are the first seven vertebrae in the vertebral column. When compared to the other types of vertebra, cervical vertebrae are the smallest. Body of the cervical vertebra is smaller compared to the other vertebrae. In addition, transverse processes of a cervical vertebra have a foramen on each side to provide passage for the vertebral artery. The spinous process of these vertebrae is bifid.

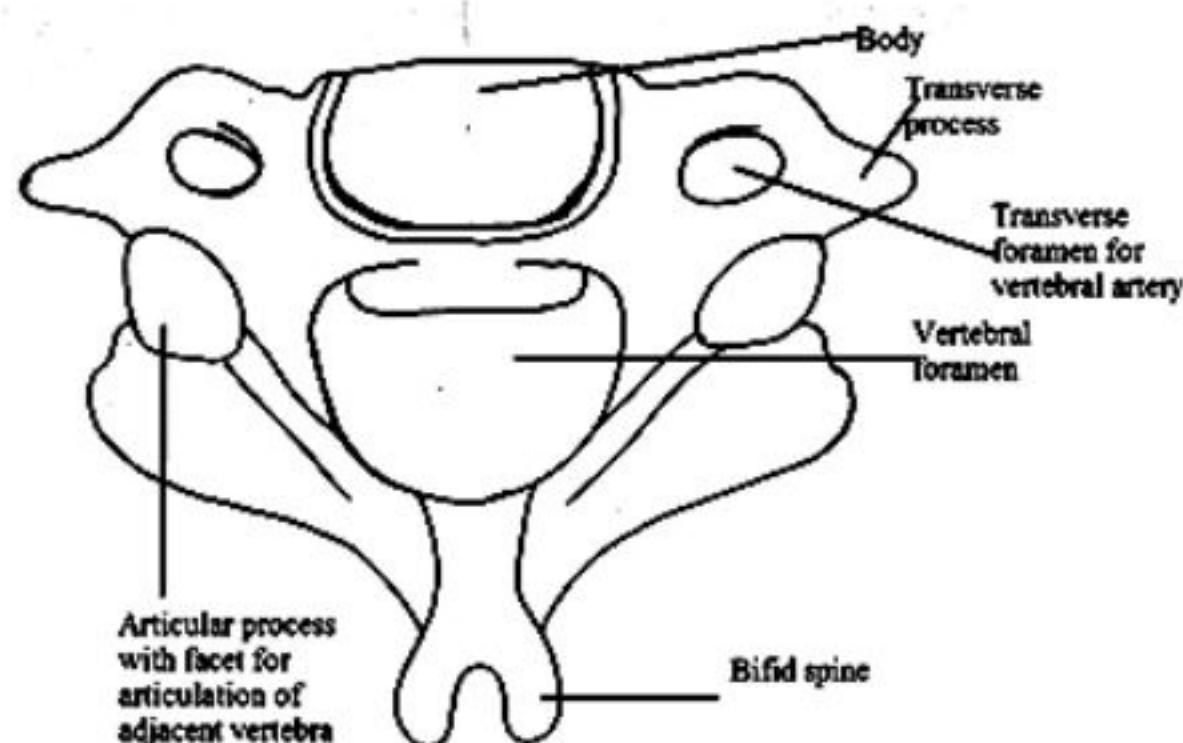


Figure 5.36: The structure of the typical cervical vertebra

The first cervical vertebra is the atlas which is the bone on which the skull rests. It is a ring shaped vertebra with no distinct body or spinous processes. It has two short transverse processes. The atlas contains two flattened facets which articulate with the occipital bone of the skull (condyloid joints), permitting nodding movements. Vertebral foramen of this vertebra is relatively larger to provide the passage of the larger anterior part of the spinal cord.

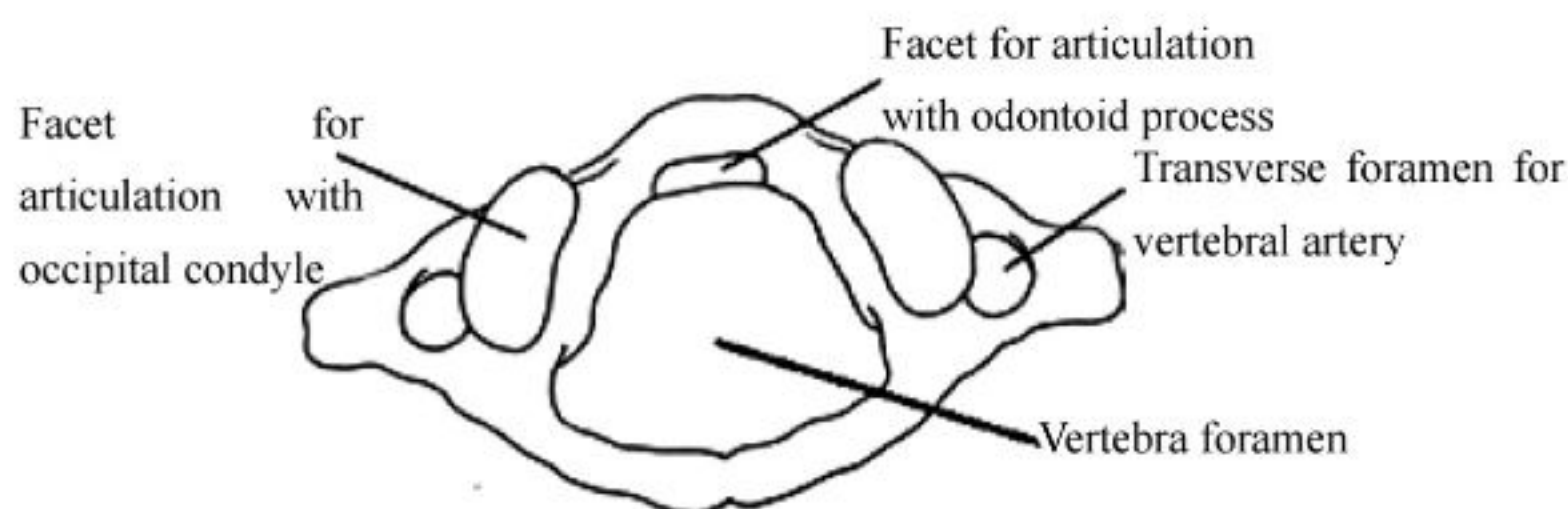
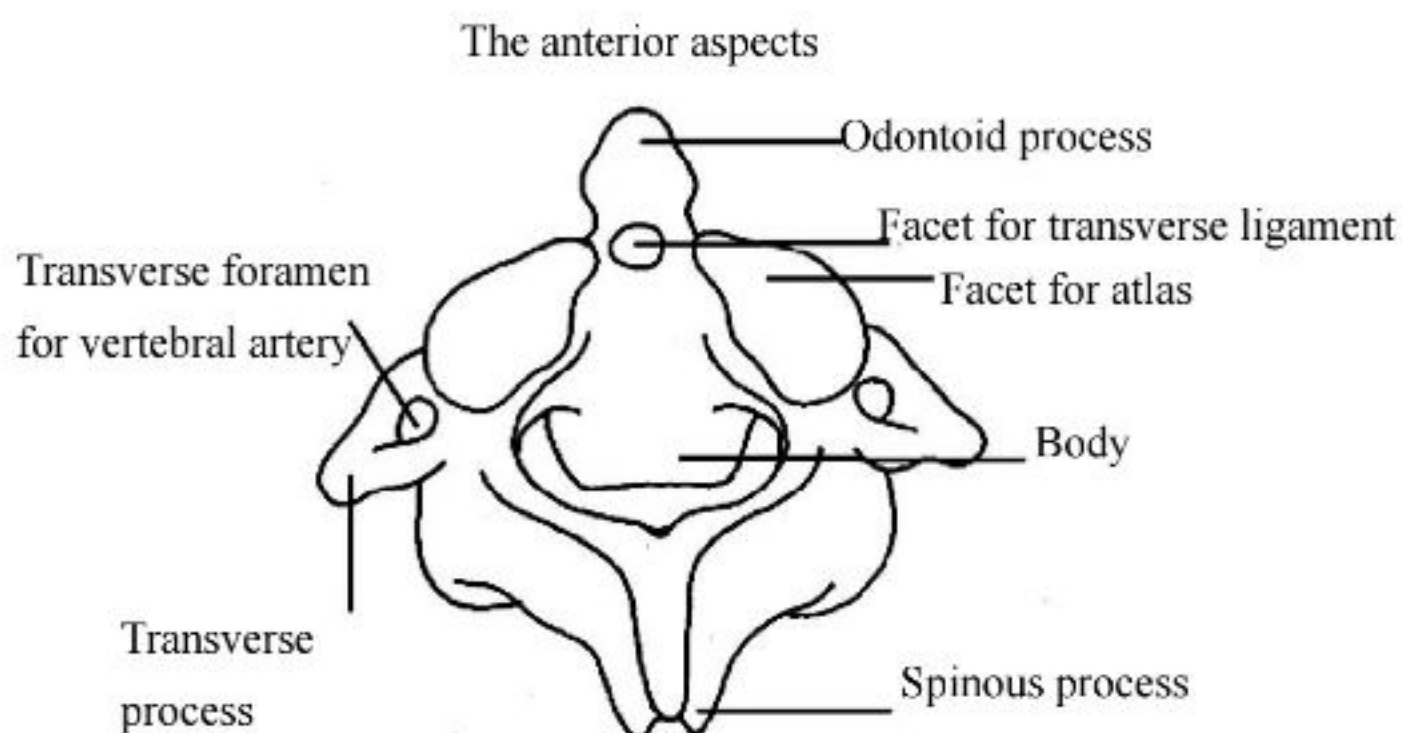


Figure 5.37: The structure of the atlas vertebra

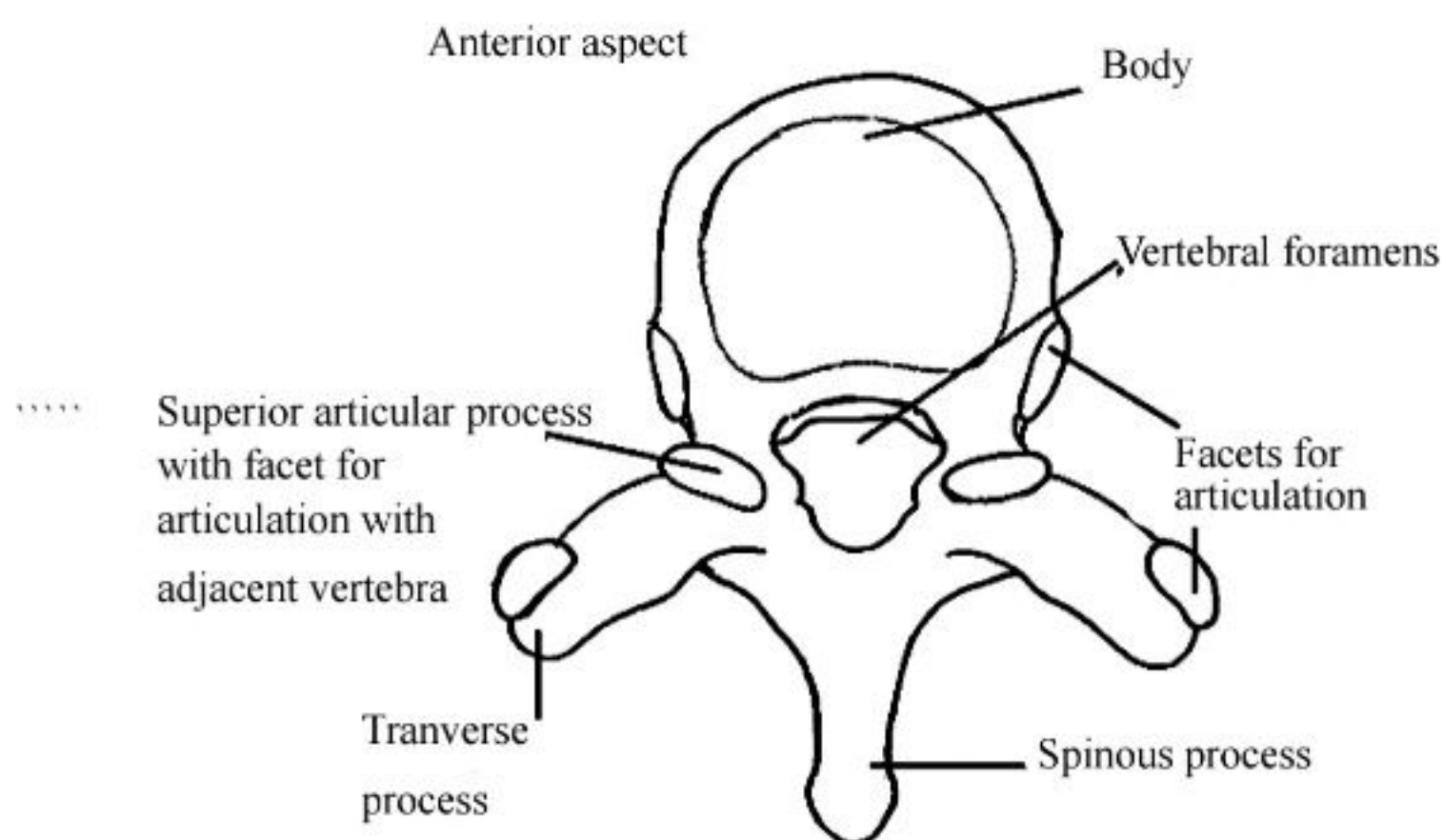


The second cervical vertebra is the axis. It has a small body with a superior projections called odontoid process which articulates with the atlas vertebra above. The head pivots (turns on side to side) on this joint.



**Figure 5.38: The structure of the axis vertebra**

**Thoracic vertebra:** The twelve thoracic vertebrae are larger than cervical vertebrae as this region of the vertebral column has to support more body weight. The body and transverse processes of thoracic vertebrae have facets for articulation with the ribs

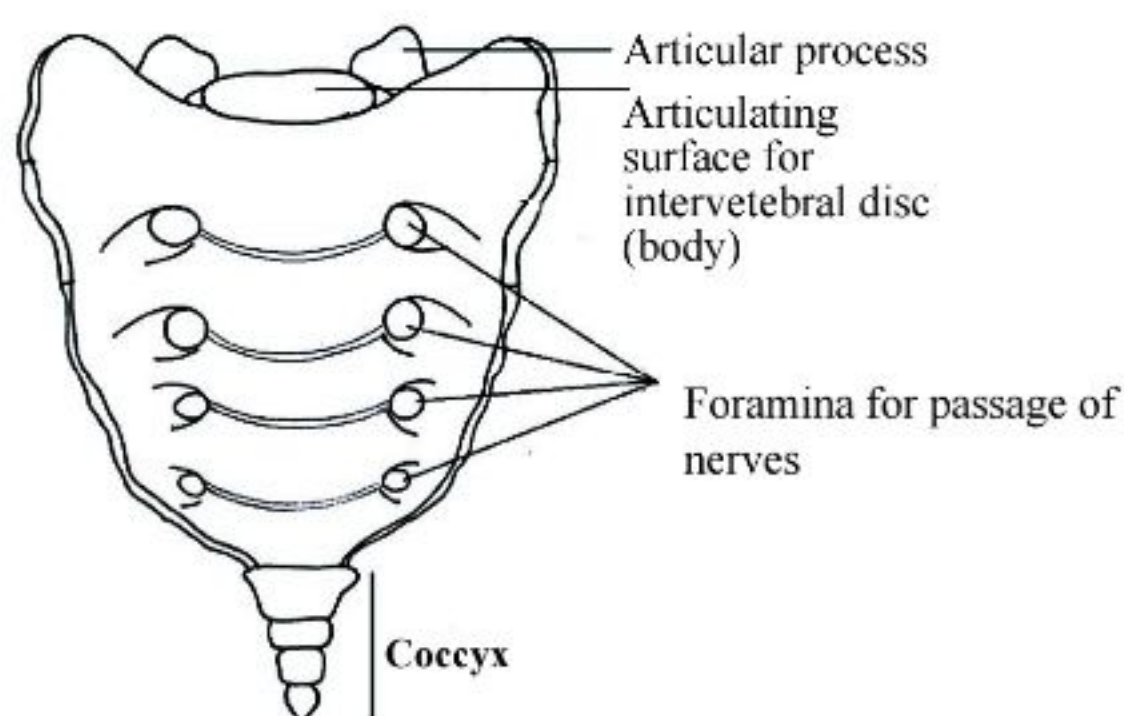


**Figure 5.39 : The structure of thoracic vertebra**



**Lumbar vertebrae:** The five lumbar vertebrae are the largest of the vertebrae because they have to support the weight of the upper body. The size of the body of the lumbar vertebrae is larger compared to the other vertebrae. For attachment of the muscles of lower back, the lumbar vertebrae have relatively large spinal processes.

**Sacrum and Coccyx:** Sacrum is a triangular shaped large bone consisting of five fused rudimentary vertebrae. It has a concave anterior surface. The upper part articulates with the fifth lumbar vertebrae. On each side, sacrum articulates with the pelvic girdle. Inferior tip of the sacrum articulates with coccyx. A series of vertebral foramina are present on each side for passage of nerves. Coccyx consists of fused four terminal vertebrae to form a small triangular bone. The broad base of the coccyx articulates with the tip of the sacrum.



**Figure 5.40: The anterior view of the sacrum and coccyx**

### Common functions of the human vertebral column

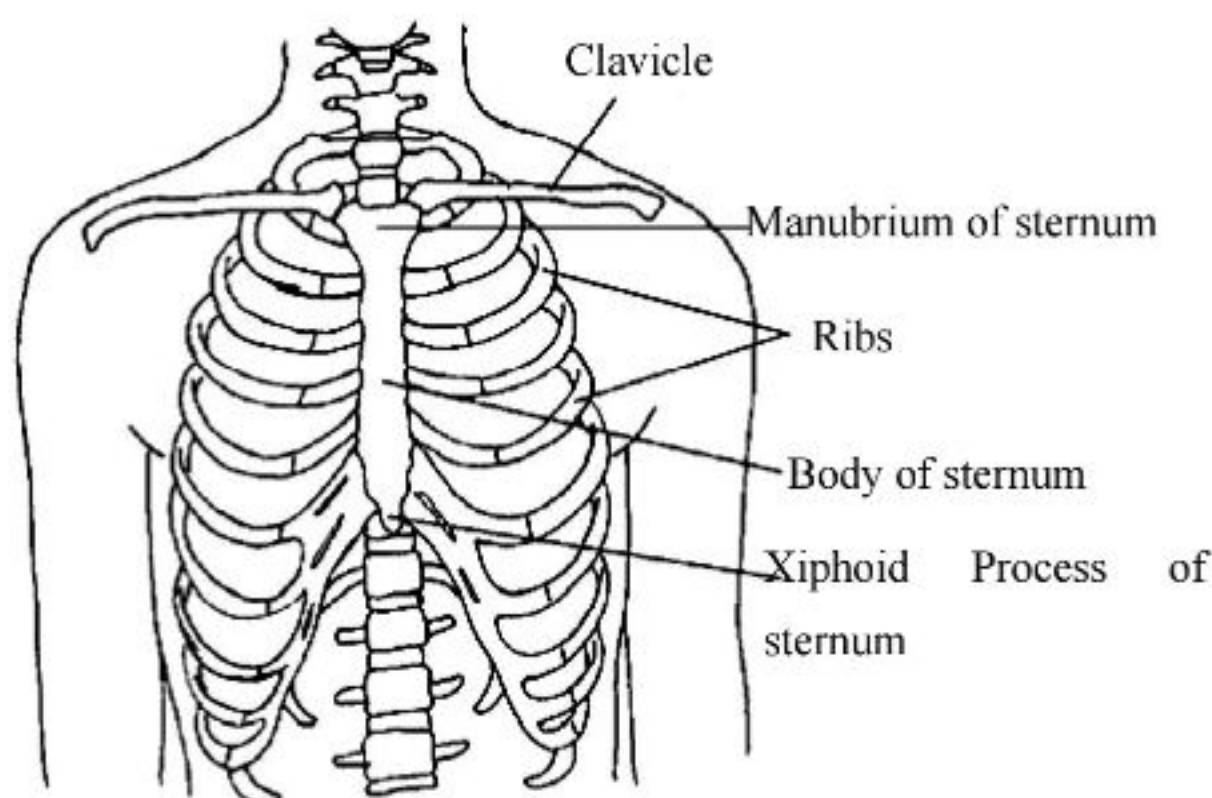
The vertebral column helps to maintain the erect posture. It supports the skull and gives attachment to ribs and girdles. It also provides the protection for the spinal cord. Vertebral foramina provide spaces for spinal nerves and blood vessels and lymph vessels. The vertebral column allows flexibility in the body movements. The intervertebral discs act as shock absorbers and protect the spinal cord.

### Sternum

Sternum is a long flat bone that forms anterior part of the thoracic cage (which is made up of sternum, ribs and thoracic vertebrae). The uppermost section of the sternum is the manubrium which articulates with the clavicles in the pectoral girdles and the first two pairs of ribs. The body, which is the middle part of the sternum gives attachment to the rest of the ribs. The xiphoid process is the tip of the bone which gives attachment to the diaphragm and muscles of the anterior



abdominal wall. The sternum provides protection to the organs and blood vessels that lie behind it (heart and lungs) from physical damage. The red bone marrow in the sternum is one of the main sites for production of blood cells.



**Figure 5.41: The thoracic cage and the location of the sternum**

## Ribs

The twelve pairs of ribs form the lateral walls of the thoracic cage. They are elongated curved bones. They articulate posteriorly with the thoracic vertebrae of the vertebral column. Anteriorly 7 pairs of ribs articulate with the sternum (true ribs), next 3 pairs articulate with sternum indirectly. In both cases costal cartilages attach the ribs to the sternum. The lowest 2 pairs do not join the sternum (floating ribs). Head of the rib articulates with vertebral bodies, facets of tubercle articulate with transverse process of vertebrae. The thoracic cage which includes the ribs and sternum plays an important role in the mechanism of breathing. Between each ribs intercostal muscles are present which move the rib cage during breathing. The first rib is firmly fixed to the sternum and to the first thoracic vertebra. Therefore it does not move during inspiration. Because it is a fixed point when the intercostal muscle contract they pull the entire rib cage upwards and towards the first ribs. Presence of 12 pairs of ribs and sternum provides protection to the organs such as lungs and heart in the thoracic cavity.

## Contribution of human axial skeleton to maintain the upright posture

- Presence of two primary curvatures and two secondary curvatures in the vertebral column. Development of the two secondary curvatures in the vertebral column mainly contribute to maintain the erect posture. (Refer the section on curvatures of vertebral column).

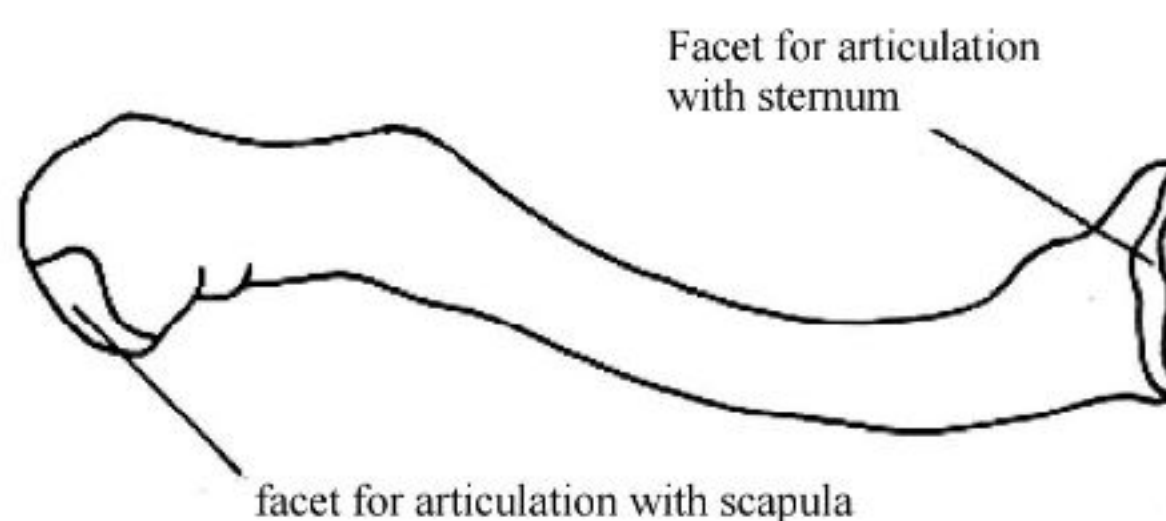


- The size of the vertebrae (especially the body of the vertebrae) become larger towards the end of the vertebral column as they have to support the weight of the upper body (Refer the section on vertebrae).
- The sacral vertebrae are fused to form a triangular shaped large sacrum to support the weight of the vertebral column and internal organs of the body.
- The two occipital condyles (and the foramen magnum) are located inferiorly at the base of the skull close to the center. In the upright position, this arrangement permits proper balancing of the skull on the vertebral column.

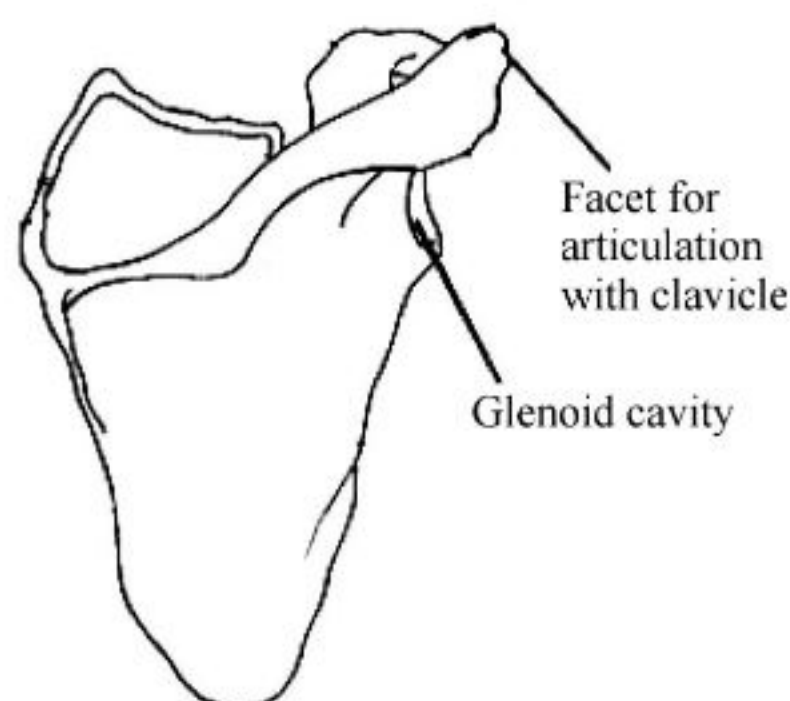
## The structure and functions of the human appendicular skeleton

### Appendicular skeleton

The appendicular skeleton consists of upper limbs with pectoral (shoulder) girdle and lower limbs with the pelvic girdle. Through the pectoral girdle the upper limb forms the joints with the trunk. Pectoral girdle connects upper limb with the axial skeleton. Pectoral girdle consists of two scapulae (shoulder blades) and two clavicles (collar bones). The lower limb forms a joint with the trunk at the pelvic girdle. Pelvic girdle is formed from two hip bones and it is associated with the sacrum.



**Figure:5.37 -The right clavicle**

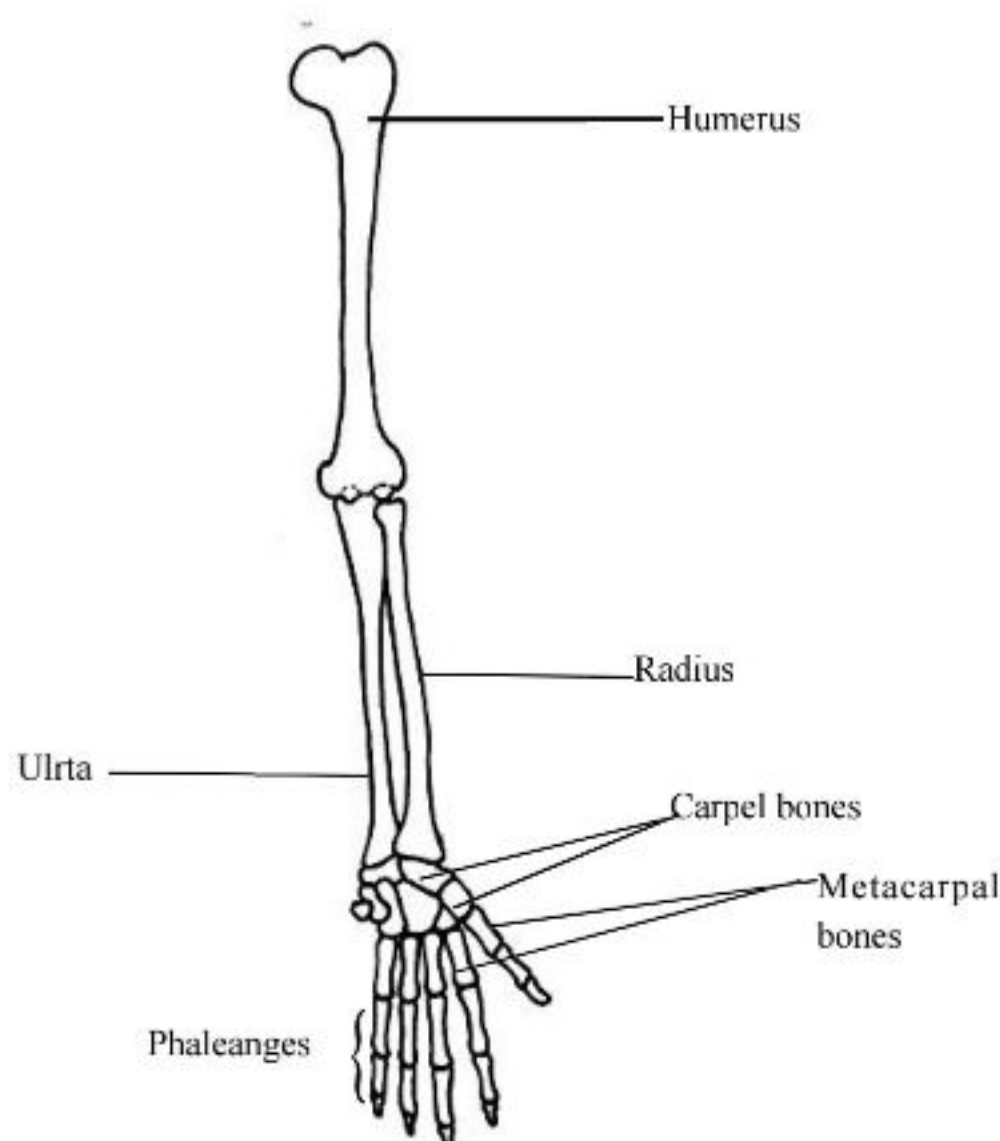


**Figure 5.42: The right scapula**



### Upper limb

Upper limb consists of humerus, radius, ulna, eight carpal bones, five metacarpal bones and fourteen phalanges. Humerus is the bone of the upper arm.



**Figure 5.43: Bones of the upper limb**

### The adaptation of the human upper limb for movement through a wide range

Structure of upper limb is adapted for grasping, weight lifting and movement over a wide range.

Head of the humerus (the bone of the upper arm) forms an incomplete ball and socket joint (shoulder joint) in glenoid cavity of the scapula permitting a vast range of movements. The joint allows for flexion, extension, adduction, abduction, rotation and circumduction.

The distal end of the humerus has two articular surfaces. Through these surfaces, radius and ulna articulate with the humerus at the elbow joint. They articulate with the carpal bones at the wrist joint. Further ulna and radius are articulated with each other at the proximal and distal radio-ulna joints. In addition a fibrous joint connects the bones along their shafts which stabilize their association and maintain their relative position in spite of forces applied from the elbow or wrist. The elbow joint acts as a hinge joint which permits only flexion and extension of the fore arm.

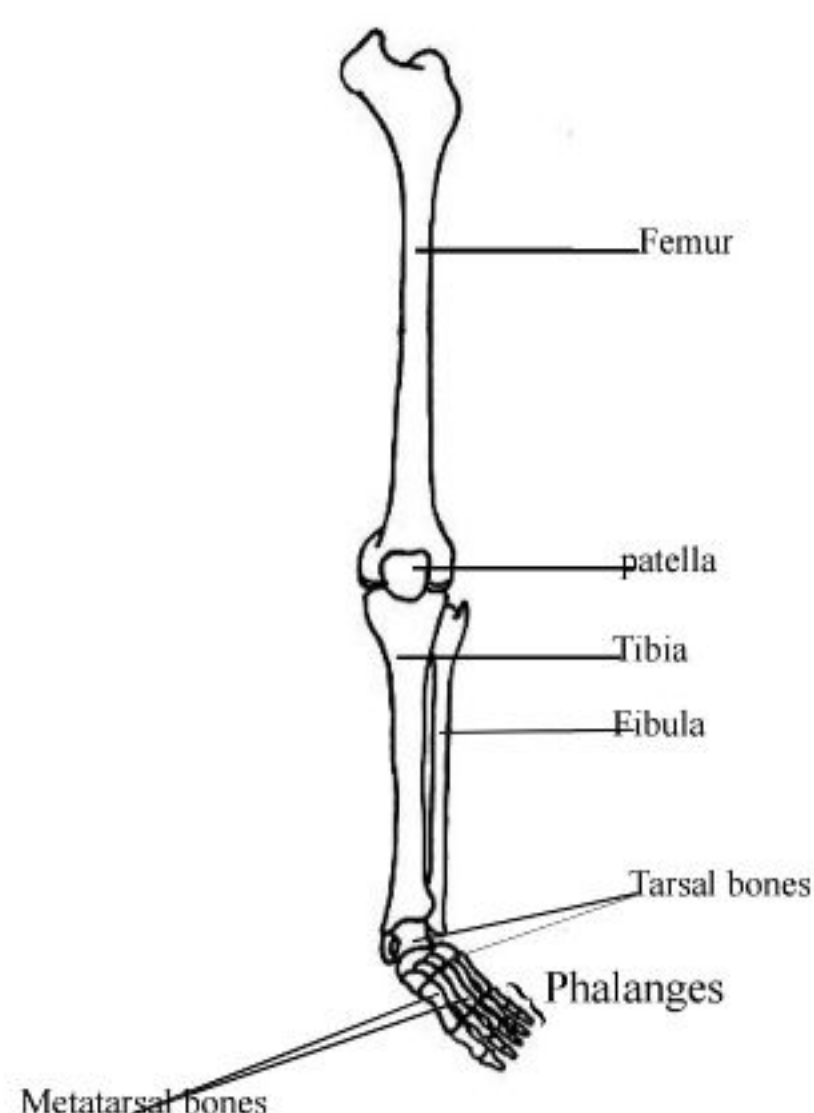


The carpal bones which are arranged in two rows (proximal row and distal row) are closely fitted together so that there is limited amount of movement between them. Proximal row bones are associated with the wrist joint and distal row bones form joints with metacarpal bones. Wrist joint is present between the distal end of radius and three proximal carpal bones. This arrangement allows pronation (palm down) and supination (palm up) of the lower part of the upper limb. In addition the wrist can be flexed, extended, abducted and adducted.

The proximal ends of metacarpal bones in the palm articulate with carpal bones and their distal ends articulate with phalanges. The joints between metacarpal and phalanges allow movement of the fingers and permit the power grip. Fingers may be flexed extended, adducted, abducted and circumducted with the first finger more flexible than the other. The joint present at the base of the thumb between a specific carpal bone and the first metacarpal bone allows more mobility to the thumb than the other fingers. This leads to opposable nature of the thumb which permits the thumb to move perpendicular to the other fingers. This articulation permits precision grip which is unique to man.

### Lower limb

Lower limb consists of femur (thigh bone), tibia (shin bone), fibula, patella (knee cap), seven tarsal bones (ankle bones), five metatarsal bones (bones of the foot) and fourteen phalanges (toe bones).



**Figure 5.44: Adaptations of the lower limb for the erect posture, bearing of body weight and walking**



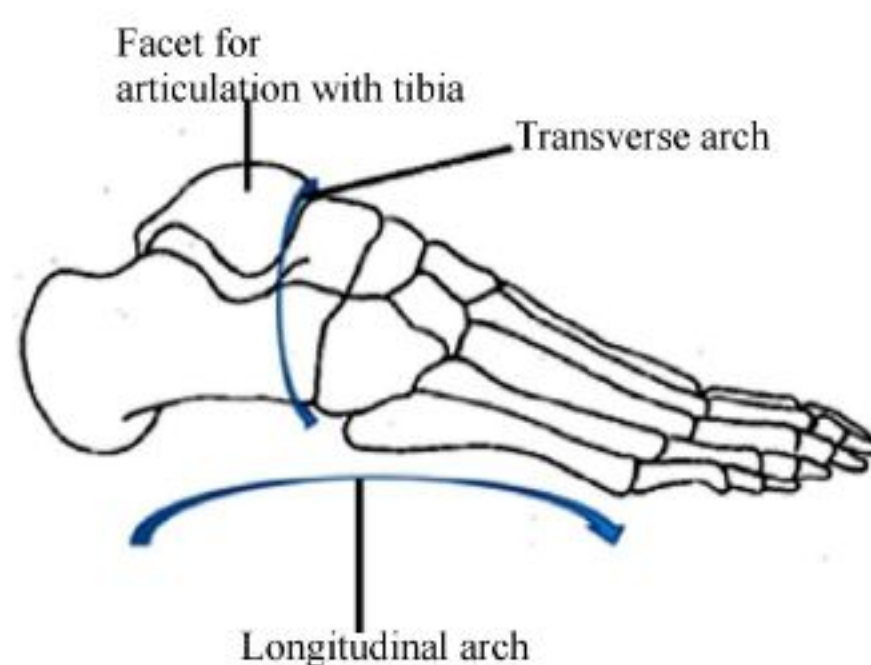
Structure of the lower limb is adapted for strength, erect body posture, bearing body weight and walking.

Femur is the longest, heaviest and the strongest bone of the body. Head of the femur forms the hip joint (ball and socket joint) with the acetabulum of the hip bone of the pelvis. This hip joint is very sturdy and powerful as it bears all body weight when standing. The lower limb can be extended, flexed, abducted, adducted, rotated and circumducted at the hip joint.

Lower end of femur articulates with tibia and patella to form the knee joint. Tibia is the medial of the two bones. Possible movements at the knee joint are flexion, extension and a rotatory movement that locks the joint when it is fully extended. When this joint is locked it is possible to stand upright for a long period of time.

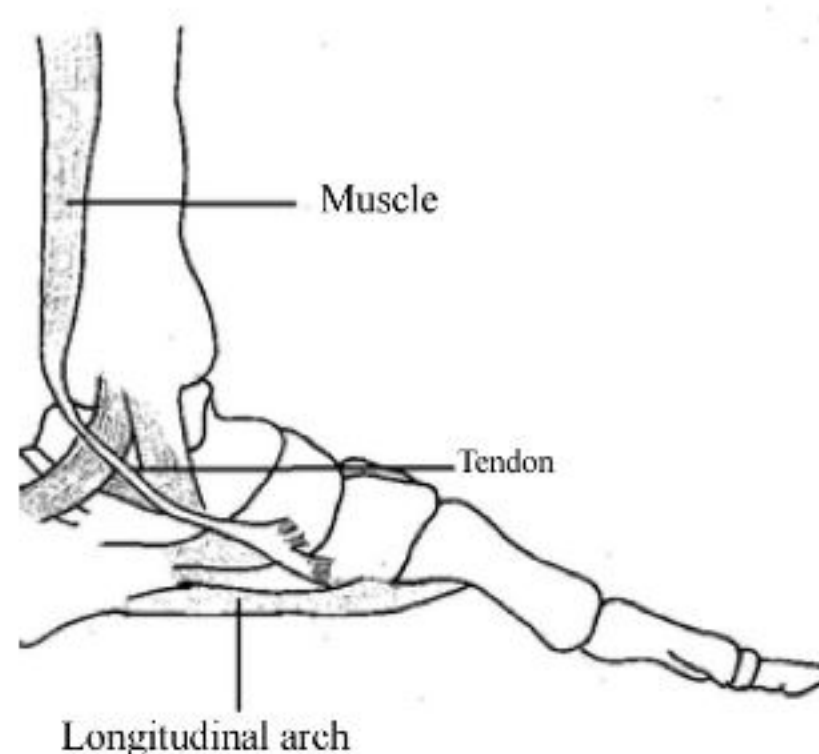
Femur transmits the weight of the body through the bones below the knee to the foot. All the lower ends of both tibia and fibula articulate with a specific tarsal bone to form the ankle joint. The ankle joint allows rising in tip toe and lifting toes towards the calf.

The arrangement of bones in the foot supported by associated ligaments and muscles gives the sole of the foot an arched or a curved shape. There are two longitudinal arches and one transverse arch in the foot. Curve running heel to toe is called the longitudinal arch and the curve running across the foot is called the transverse arch. In the upright position, these arches of the foot are important in distributing the weight of the body evenly whether stationary or moving.



**Figure 5.45 :The arches of foot**





**Figure 5.46 :The tendons and ligaments in the foot**

### **Some disorders and abnormalities associated with human skeletal system**

#### **Osteoporosis**

Osteoporosis is a condition associated with the reduction of bone density due to the exceedance of the bone reabsorption rate over the deposition rate. This gives in fragility to the bone tissue. This condition leads to immobility in joints and may cause fractures, skeletal deformities and bone pain. Factors causing osteoporosis include hormonal imbalances (especially at menopause), calcium deficiency and environmental factors.

#### **Osteoarthritis**

Osteoarthritis is a degenerative non-inflammatory disease that causes pain and restricted movements in the affected joints. Articular cartilage at the joints gradually become thinner so that articular surfaces of the bones come in contact and eventually the bones begin to degenerate; the outcome is pain. The cause of osteoarthritis is unknown. But risk factors include excessive use of affected joints, female gender, increasing age, heredity and obesity.

#### **Slipped disc**

The bodies of adjacent vertebrae are separated by intervertebral discs which serve as shock absorbers. These intervertebral discs consist of an outer ring of cartilage and a central core of soft gelatinous material. An injury or weakness can cause the inner portion of the intervertebral disc to protrude through the outer ring. This condition is called 'slipped disc'. This leads to pain and discomfort. If the slipped disc compresses a spinal nerve, there can be numbness and pain along the affected nerve. Slipped disc condition can arise when lifting heavy weights without bending knees.



**Main types of joints in the human skeletal system**

Main types of the joints in the human skeletal system are ball and socket joint, hinge joint and pivot joint.

- **Ball and socket joints**

In these joints, ball shaped head is connected with the cup shaped socket and allows for wide range movements such as flexion, extension, adduction, abduction, rotation and circumduction. There are two ball and socket joints available in the human body: Shoulder joint and hip joint. (Refer upper limb and lower limb)

- **Hinge Joints**

The articulating ends of the bone fit together in such a way so it looks like a hinge of a door. This allows only restricted movements such as flexion and extensions. Examples for hinge joints are elbow joint, knee joint, ankle joint and joints between the phalanges of the fingers and toes. (Refer upper limb and lower limb)

- **Pivot joints**

One bone fits into a hoop shaped ligament that holds it close to another bone and allows it to rotate in the ring formed by the ligament. These joints allow a bone or limb to rotate. For example head rotates by the pivot joint formed by the axis vertebrae within the transverse ligament ring and odontoid process of the atlas. (Refer vertebral column)

**Skeletal muscle and mechanism of contraction****Features of skeletal muscle tissue**

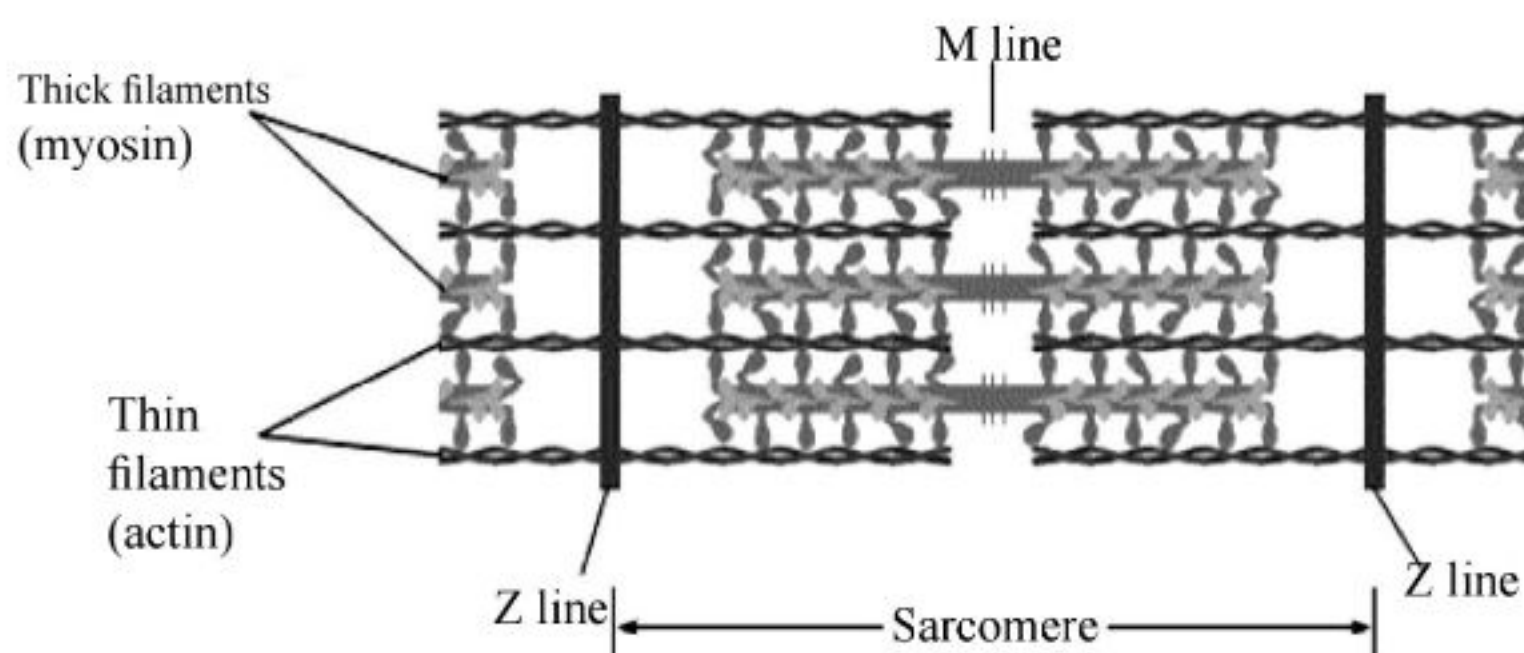
The skeletal muscles are generally attached to the skeletal system and mainly cause voluntary body movements. Skeletal muscle tissue is composed of bundles of long cylindrical cells. These cells are aligned parallel to each other along the length of the muscle. Each cell contain multiple nuclei close to the cell membrane. Inside the cell, bundles of myofibrils containing contractile microfilaments are located longitudinally along the length of the cell. Myofibrils in the muscle cell form repeating sections called sarcomeres. The repeating arrangement of sarcomeres within the skeletal muscle cell gives its striated appearance under the microscope. Sarcomeres are the basic contractile units of the striated muscle cell. Like smooth muscle cells and cardiac muscle cells, skeletal muscle cells show excitability or irritability (ability to receive and respond to stimuli), contractility (ability to contract or shorten), extensibility (ability to stretch or contract) and elasticity (ability to return to its original length after being stretched or contracted). The skeletal muscle is under the voluntary control of the somatic nervous system.



### Structure of the sarcomere, basic mechanism of skeletal muscle movement

Sarcomeres are the repeating contractile units present within a striated muscle cell. The sarcomere is composed of myofibrils containing contractile thick filaments and thin filaments which are made up of specific proteins. The thin filaments (formed mainly from actin protein) attached at the Z line, a dense stripe which forms the borders of the sarcomere. The thick filaments (formed from myosin protein) are fixed (at the M line) in the middle region of the sarcomere. Sarcomeres are found repeatedly between two Z lines in a skeletal muscle cell. At the resting stage of myofibrils, thick and thin filaments are partially overlapped. At the edge of the sarcomere there are only thin filaments while at the center of the sarcomere only thick filaments are present. Such arrangement of thick and thin filaments in the sarcomeres permits the shortening of the skeletal muscle cell during contraction and return to the original state during relaxation. The mechanical function arising from sarcomeres is produced by actin (found in thin filaments) and myosin (found in thick filaments) proteins.

The skeletal muscle contraction is mainly voluntary and under the control of the somatic nervous system. Upon stimulation, individual muscle cells in the skeletal muscle shortens due to the shortening of its sarcomeres, and thus the whole muscle may contract. Converting muscle contraction to movement needs a skeleton to which the muscles attach. Skeletal muscle contractions pull on the tendons attached to the bones. If contraction of the muscle causes the muscle to shorten, the bone and the body part will move. When the nervous stimulation is stopped, the muscles will return to the original length after being contracted.



**Figure 5.46: The arrangement of a sarcomere**

**Sliding filament theory** is the currently accepted model of striated muscle contraction. According to this theory, when a skeletal (or cardiac) muscle cell contracts, the thick (myosin) filaments and thin (actin) filaments in each sarcomere slide past each other pulling the Z lines at each end of the sarcomere closer to one another shortening the sarcomeres and thus the muscle cell, while the two

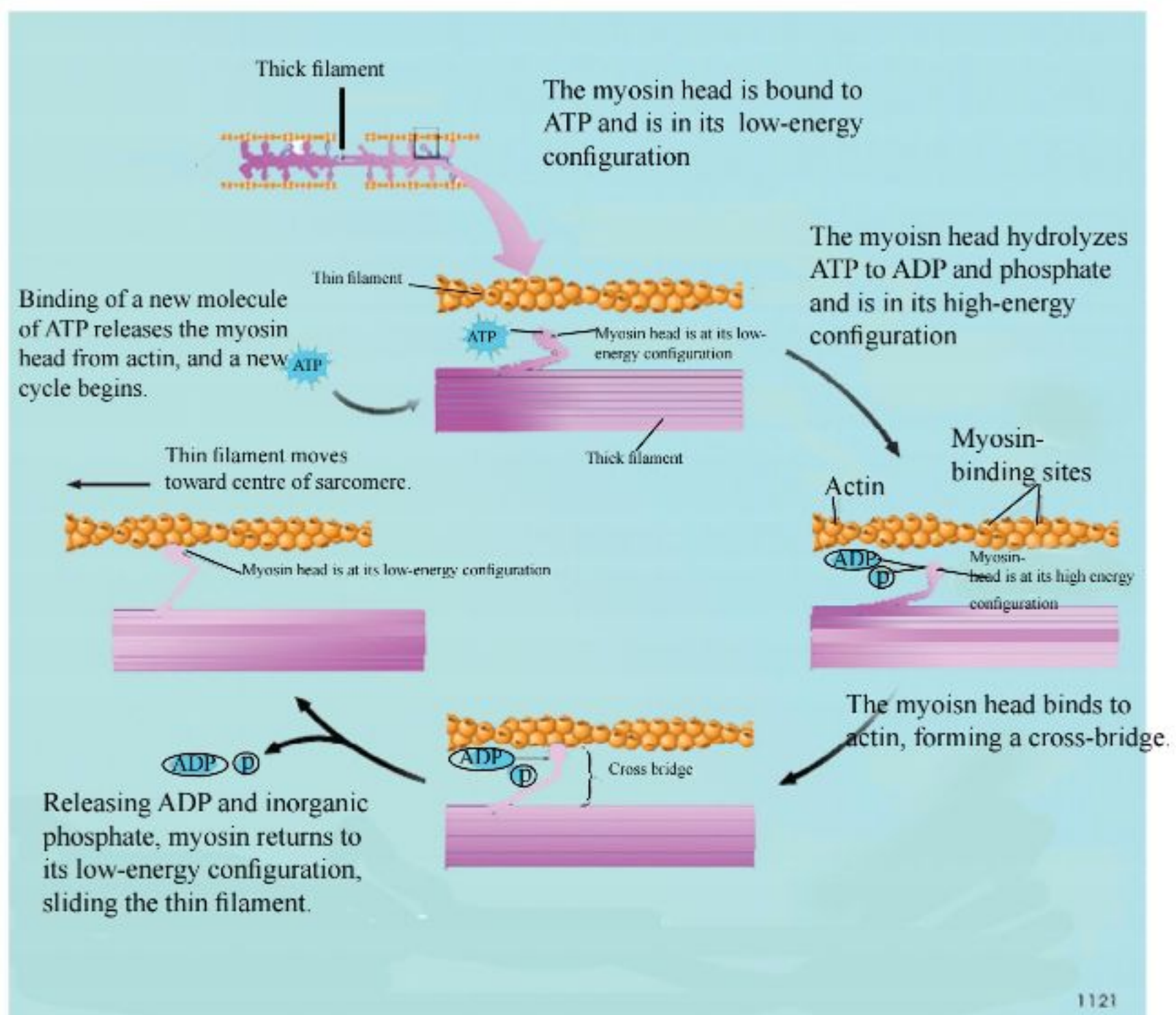


groups of filaments in the sarcomere remain at a relatively constant length. Myosin is the motor protein that does muscle contraction by pulling on thin filaments (actin) in muscle cells. Each myosin molecule is composed of 'tail' region and 'head' region. In the thick filaments, these 'tail' regions are bundled together while the 'heads' are sticking out. The thin filaments are composed of actin molecules which have binding sites for the 'head' region of the myosin molecules. The head region of the myosin can also bind with an ATP molecule when its 'low energy state'.

When the ATP molecule is hydrolyzed to form ADP and phosphate while releasing energy, the myosin head enters into the 'higher energy state'. At this state, the myosin head binds to myosin binding site of actin forming a cross bridge. Thereafter the myosin head returns to its lower energy state by releasing ADP and phosphate, which pulls (slides) the thin filament toward the centre of the sarcomere and so shortening the sarcomere. When a new molecule of ATP binds to the myosin head, the cross bridge is broken, myosin head detaches from actin. A new cross bridge cycle begins again. The contraction of muscles requires many number of repeated cycles of binding and releasing. In each cycle, the myosin head is released from the cross bridge and newly bound ATP is hydrolyzed which promotes binding of myosin again to a new actin molecule. This process occurs along the entire length of every myofibril in the muscle cell. Since in the earlier cycle the thin filament has moved towards the centre of the sarcomere, a new binding site for the myosin head region is exposed in the thin filament. The entire process causes the thick and thin filaments in the muscle cell to slide past each other pulling the Z lines at each end of the sarcomere closer to one another shortening the sarcomere.

Many myosin heads can be found in one thick filament. Within one second, each of these heads can form cross bridges.  $\text{Ca}^{2+}$  and some other proteins also play a major role in muscle contraction. Myosin can only bind to actin when the binding sites on actin are exposed by the action of calcium ions.





**Figure 5.47: Interaction of actin and myosin in skeletal muscle cell contraction**