General Certificate of Education
(Advanced Level)
BIOLOGY

Handout for Unit 05 (Animal form and function) part II

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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

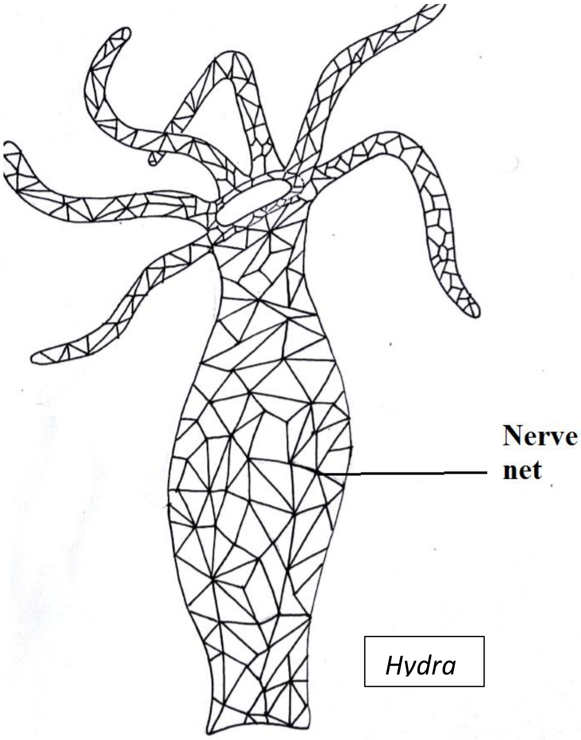
Animals have specialized systems of neurons to sense their surroundings and respond rapidly. In the animal kingdom, cnidarians are the simplest animals having a nervous system. They have a diffuse nerve net which is composed of interconnected individual neurons.

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 echinodermates 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.

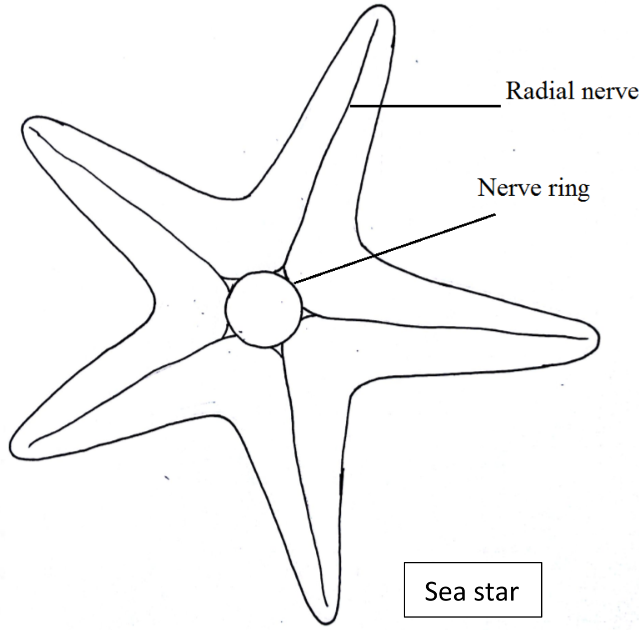
Table : Different organism phyla and their nervous organization

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

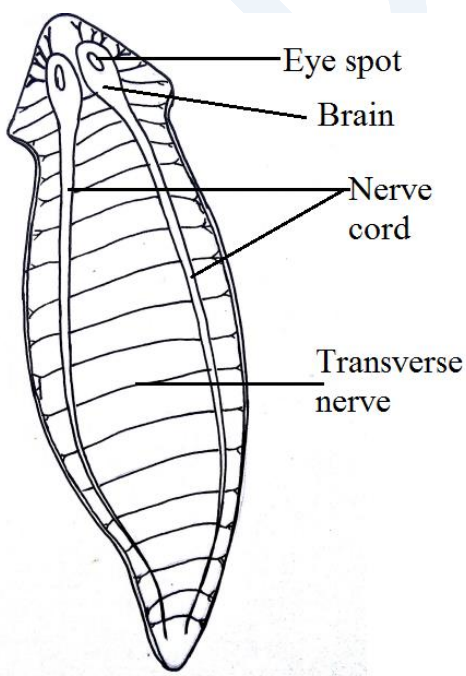
Chordata	Brain, spinal cord (dorsal nerve cord), nerves and ganglia	Gecko



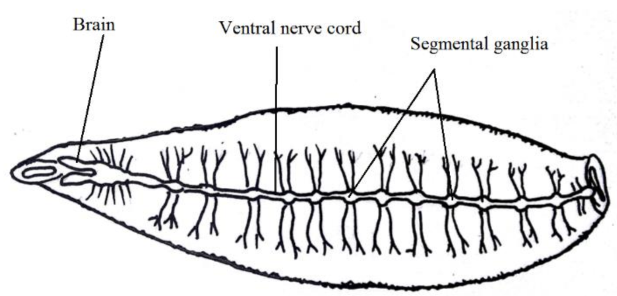
Hydra



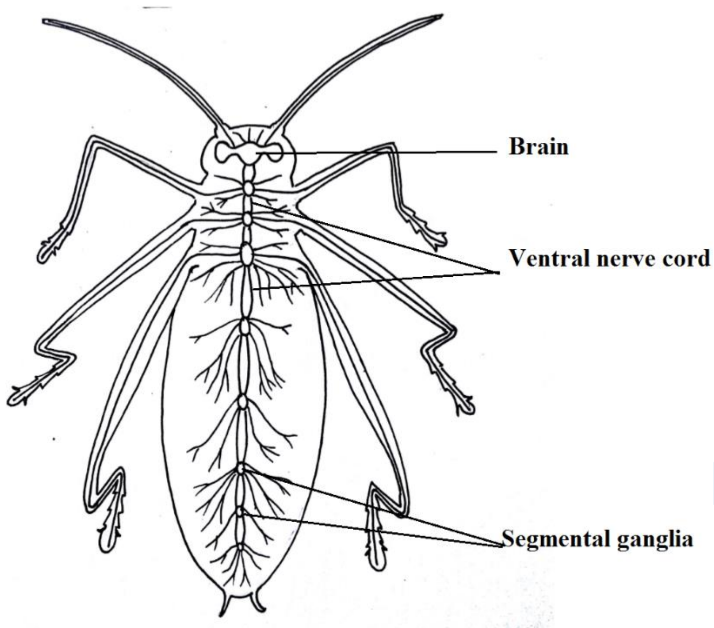
Sea star



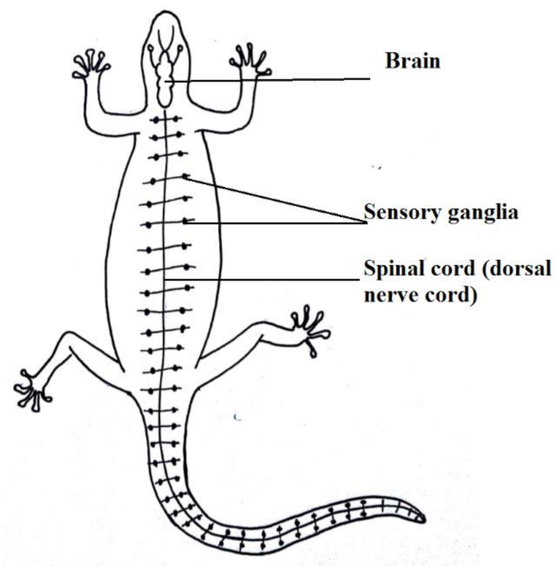
Planaria



Leech



Insect



Gecko

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.

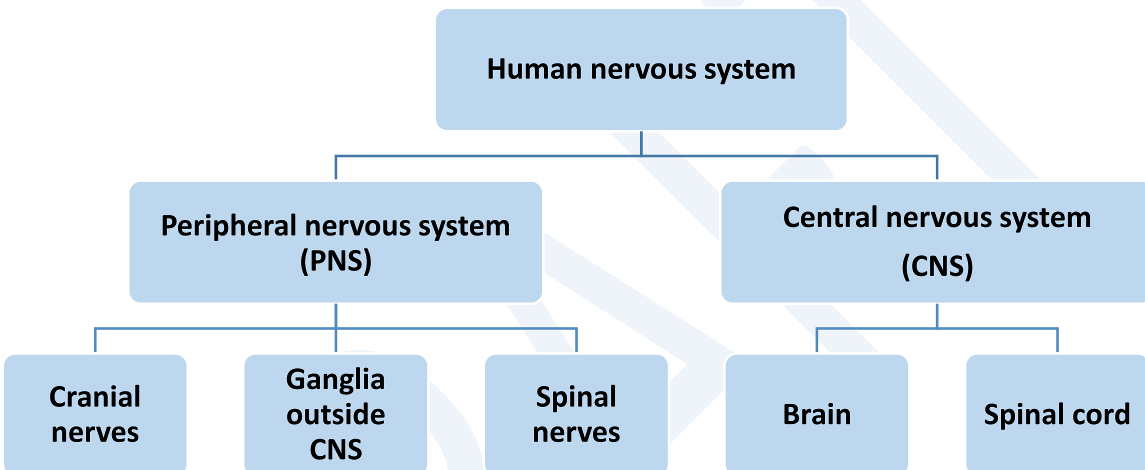


Figure: Organization of the human nervous system

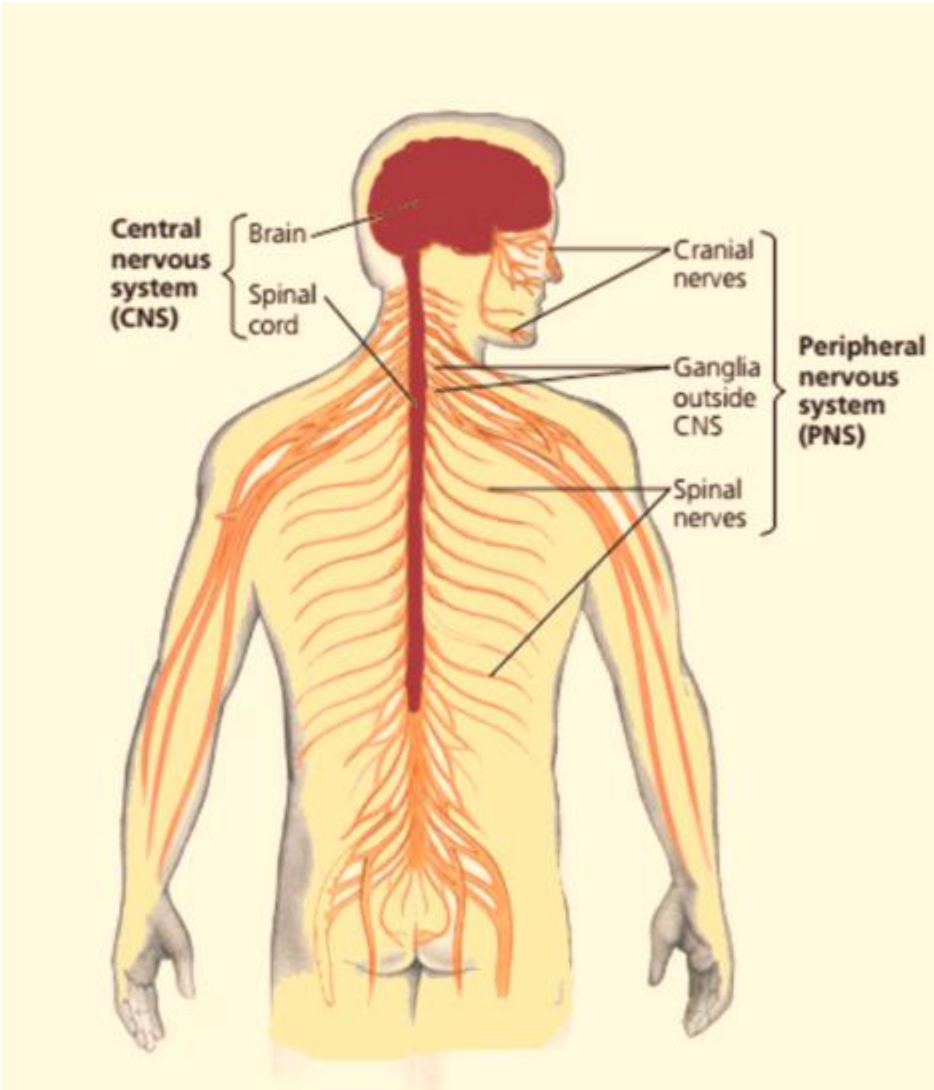


Figure: The organization of human nervous system

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 shock absorber between brain and skull. It also helps to circulates nutrients and hormones as well as to remove waste products.

The brain and the spinal cord has several adaptations to protect 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 outer most layer is called the dura mater, the inner most 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.

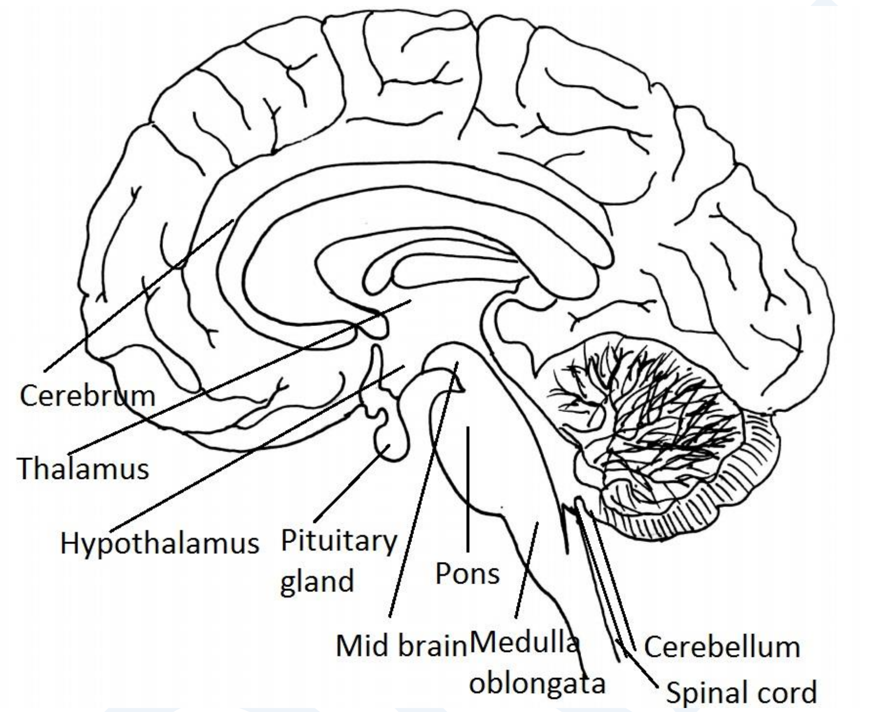


Figure: The longitudinal view of the human brain

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 consists 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.

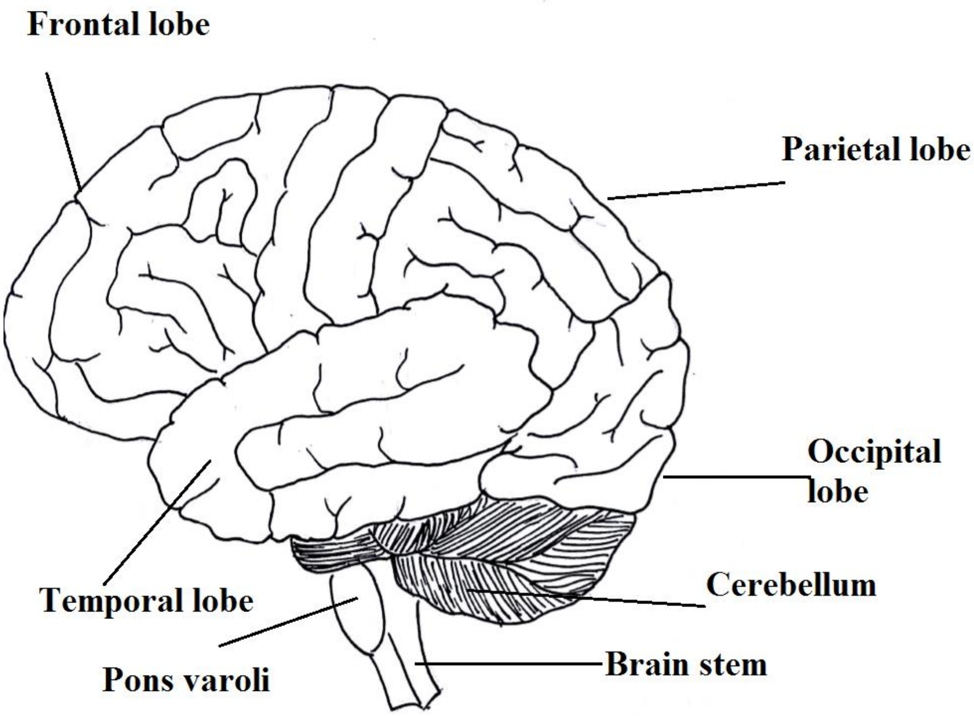


Figure : The human cerebral cortex

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 of gray and white matter.

Functions:

Thalamus acts as the main input center of sensory information from special sense organs and sensory receptors in the skin and integral 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:

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

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:

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

Pons Varolli

Pons Varolli, (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 contain 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:

- Transfer information between PNS and the midbrain and forebrain
- Coordinate 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 center, respiratory center and reflex centers.

Functions:

- Transfer information between PNS and the mid brain and the fore brain
- Coordinate various body movements such as running, climbing
- Control several autonomic, homeostatic functions including breathing, heart and blood vessel activities (contains respiratory center, cardiovascular center)
- Control involuntary reflexes such as for vomiting, swallowing, coughing, sneezing through reflex centers

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

- Coordinate voluntary muscular movements
- Maintain posture and balance
- Helps in learning and remembering motor skills.

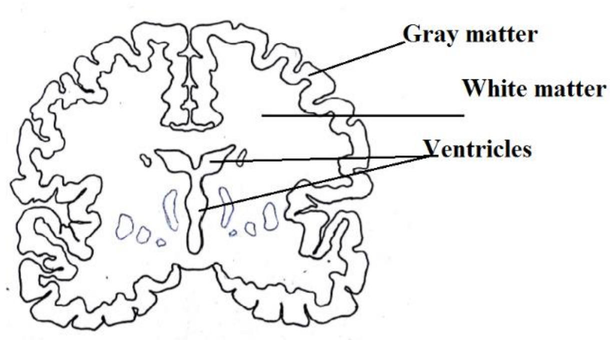


Figure: T.S of the human brain

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 facilitate nerve impulse propagation towards the brain and away the brain
- Coordinate and produce reflexes

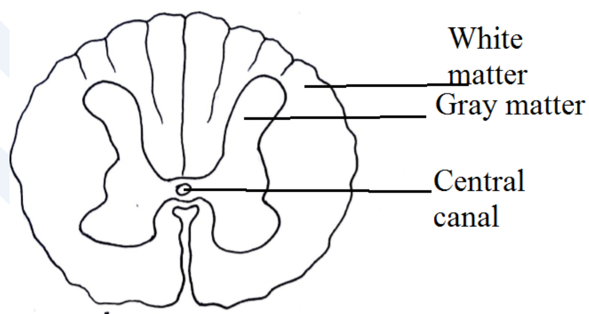


Figure: T.S of the spinal cord

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.

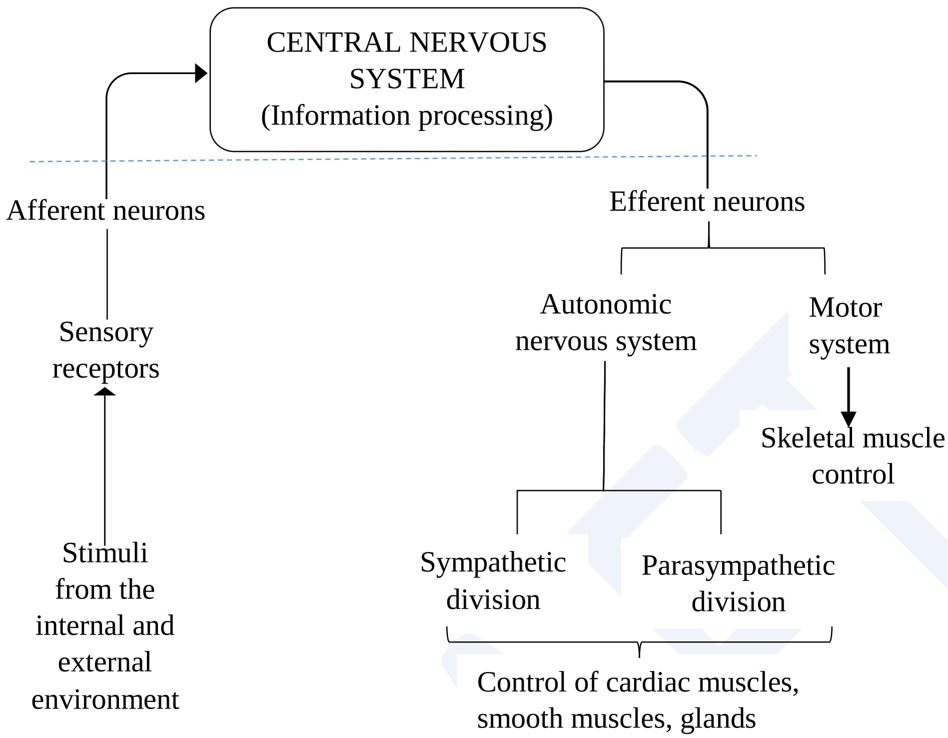


Figure: Peripheral nervous system of the vertebrate (Functional hierarchy)

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 prepares the body to deal with exciting/ stressful situations and energy generating situation (fight- or -flight). Parasympathetic division cause 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.

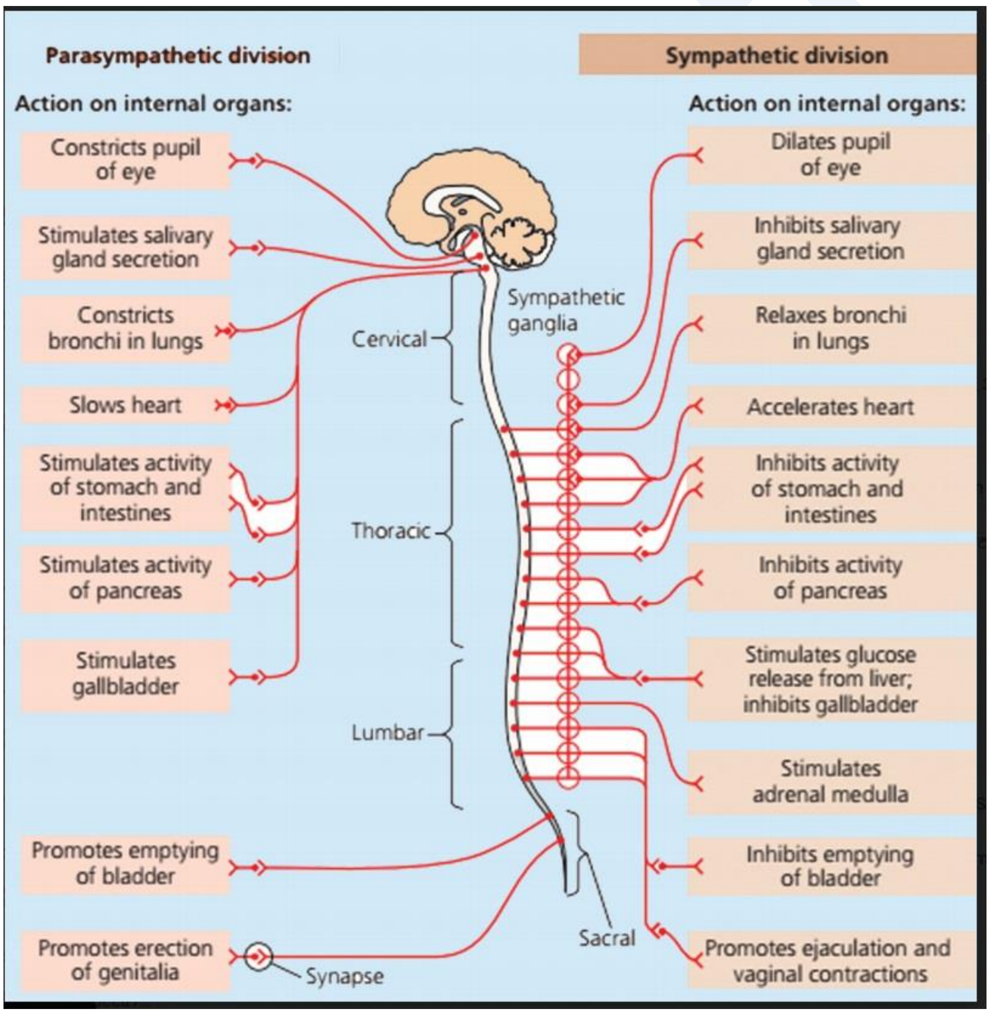


Figure: The autonomic nervous system (Parasympathetic and sympathetic division)

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.

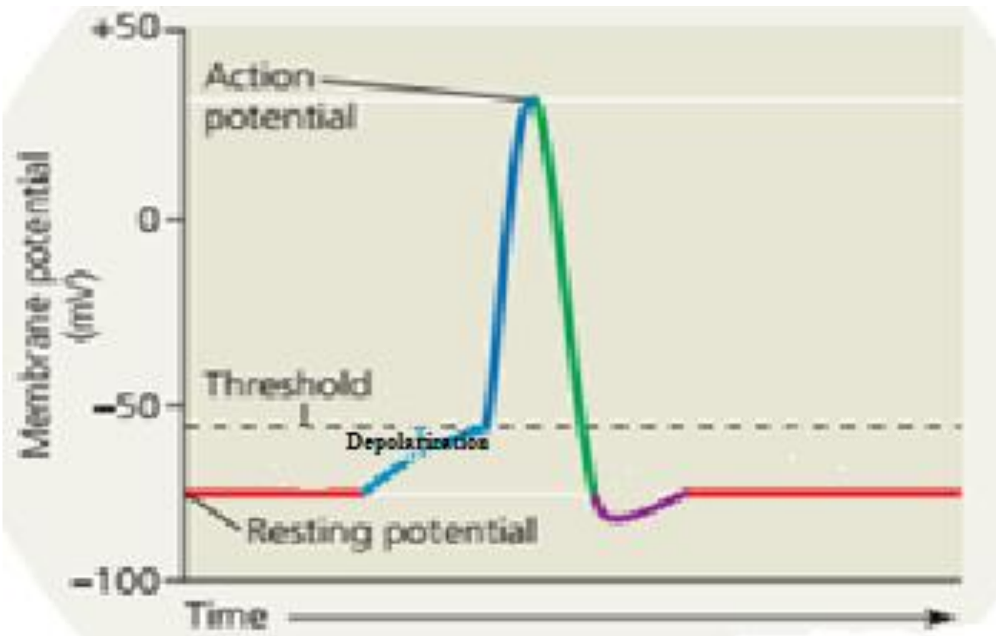
Repolarization: Sodium channels close blocking Na^+ inflow. However most Potassium channels open permitting K^+ outflow. This makes the inside of the cell negative.

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



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 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 increase with the increase in axon diameter.
- Presence of myelinated axon (in myelinated neuron, axon potential is jumped 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).

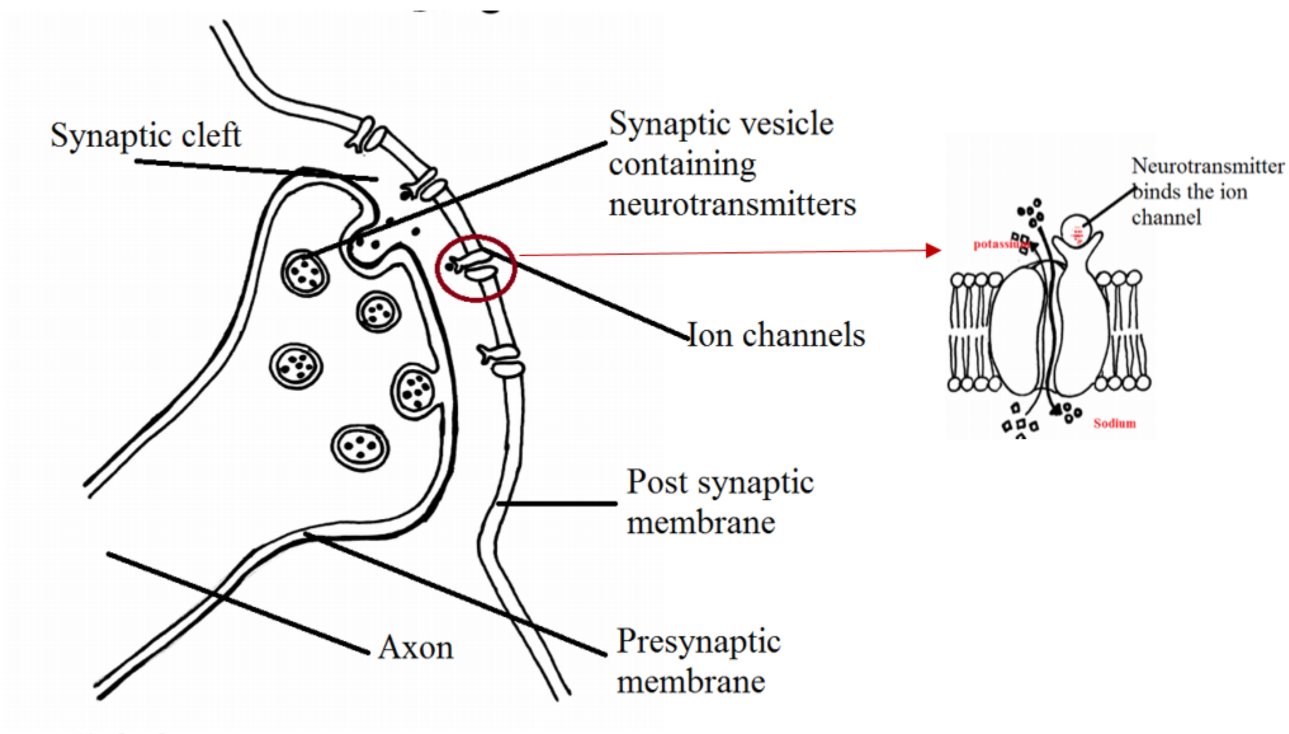


Figure: A synapse which communicates through a neurotransmitter

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 Ca^{2+} to diffuse into the terminals.
- The rise in 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 acetyl choline is taken as for example, the binding of neurotransmitters to the post synaptic membrane allows Na^+ and 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, binds to the receptors at the postsynaptic membrane, triggering a response.

Common neurotransmitters are;

- Acetyl choline
- 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 convey the signal to effector tissues/organs.

Common disorders of 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, 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 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 in to the action potential, sensory signal can be strengthen 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, thermo receptors, 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 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.

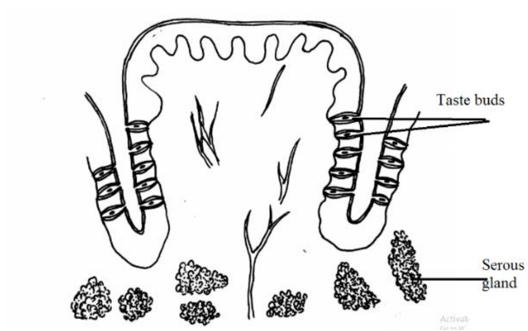


Fig: A section of a papilla

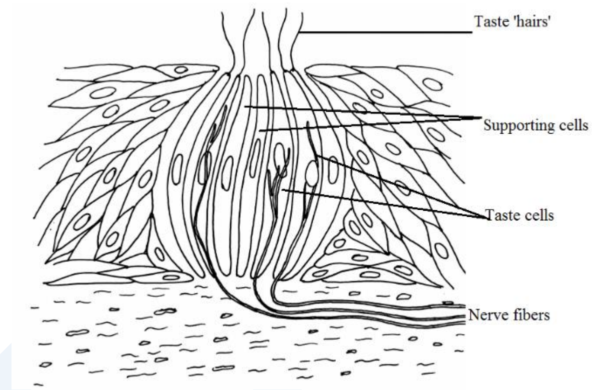


Fig. A magnified taste bud

- **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.

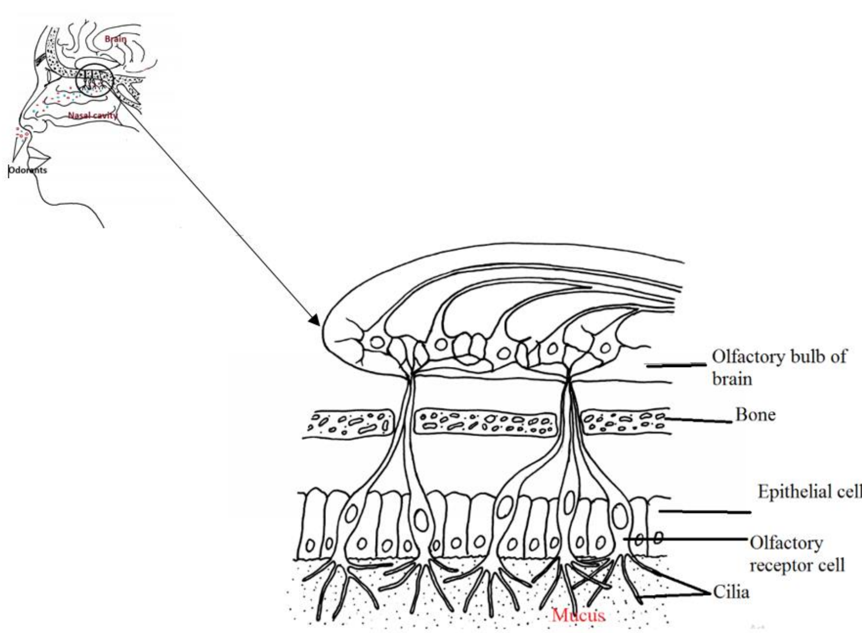


Figure: Location of olfactory receptors in humans

- **Thermoreceptors**

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. Human 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

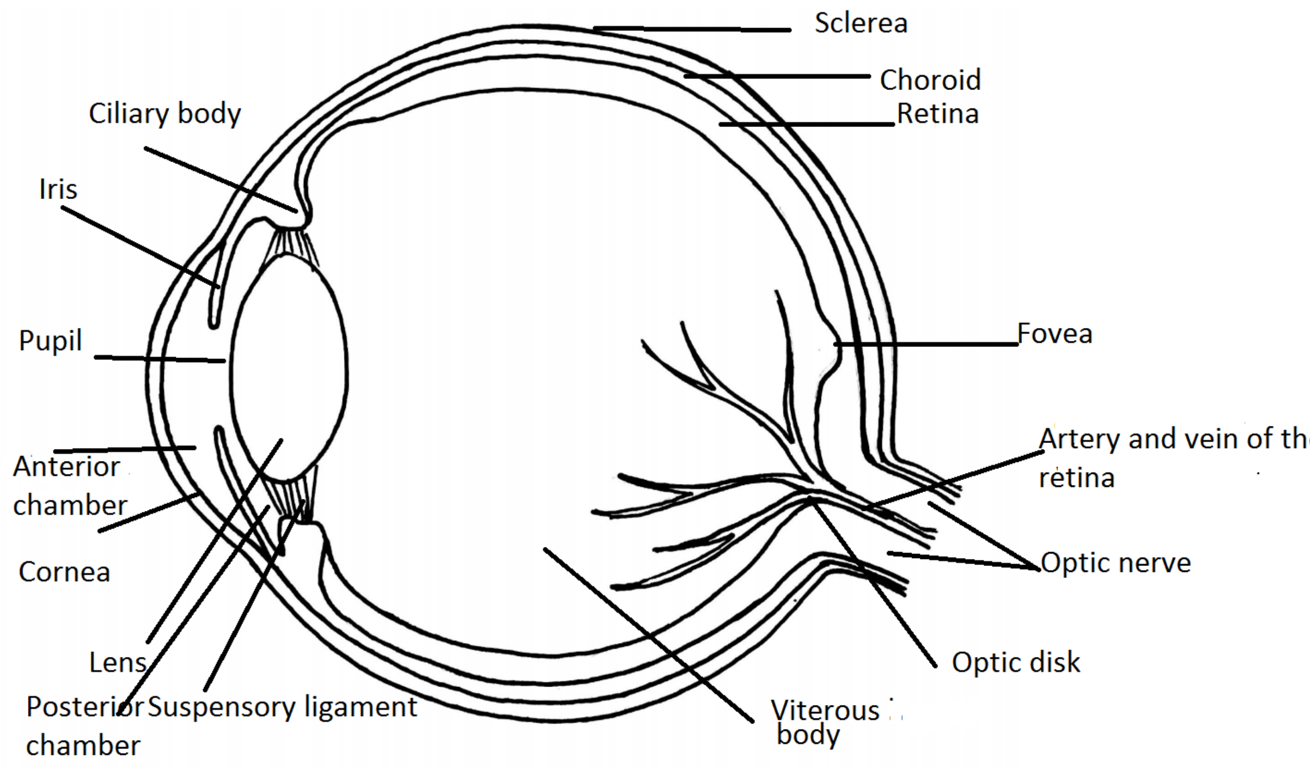


Figure: The basic structure of the human eye

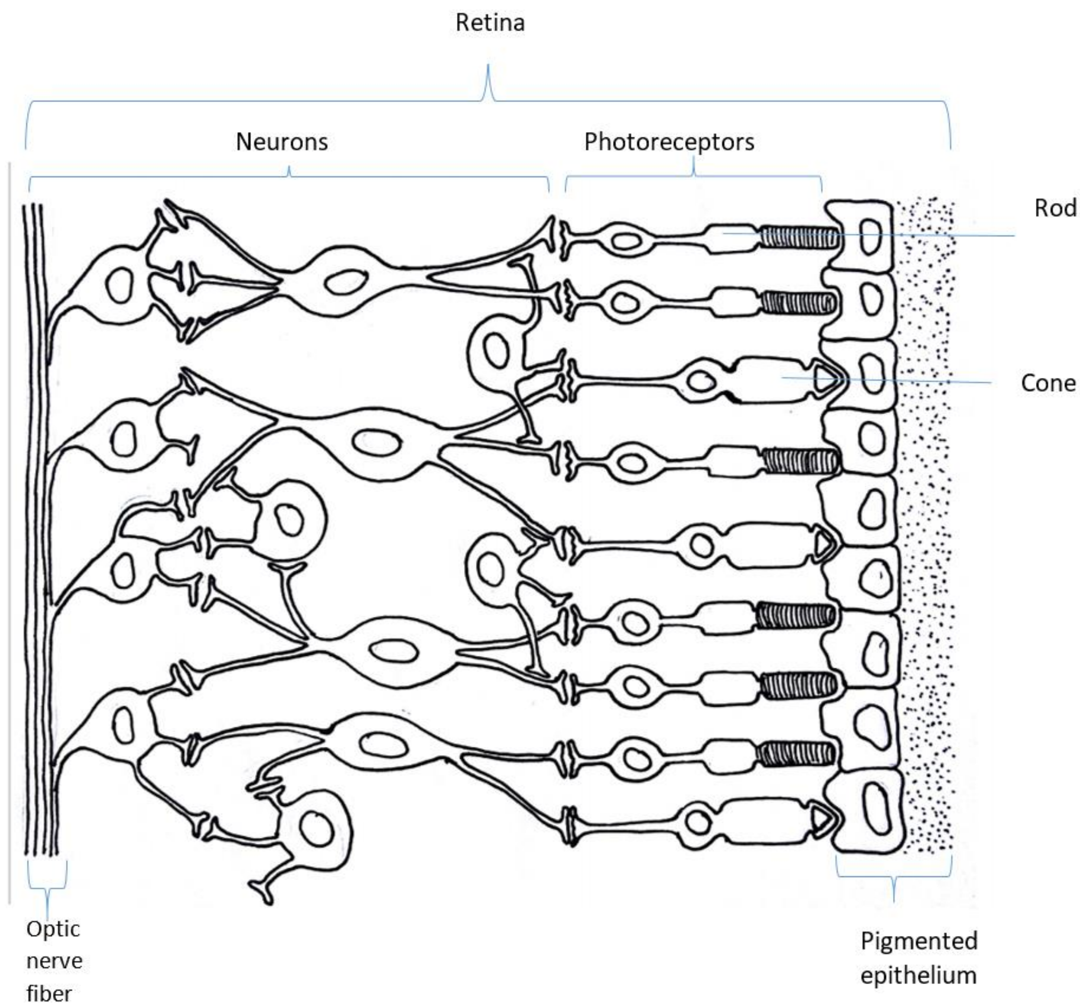


Fig: The retina

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, cilliary 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 muscle 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 them 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.
  - Cilliary 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 ligament. The size and thickness of the lens can be controlled by contraction and relaxation of the ciliary muscle fibers attach 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 control 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 focus on the retina to form the image. By changing the thickness, the lens can vary its refractive power in order to focus on the retina.

- **Aqueous fluid (aqueous humor)** and **vitreous body (vitreous humor)**

  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 humor 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 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 the 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 wavelength of visible light activate light sensitive pigments in the cones which results 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 come closer, the amount of refraction need 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 in to 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 attach 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 muscle 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 increase the pull of the suspensory ligaments on the lens and 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 produce 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 gather input 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 transmit 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 stimulated 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.

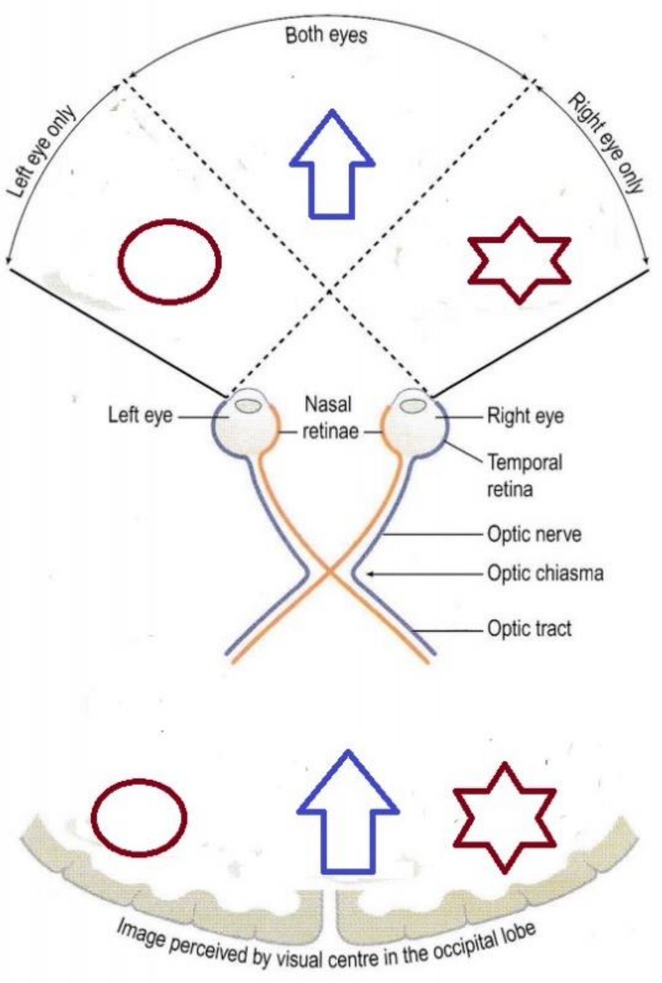


Figure: Visual fields

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 middle and 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 medial wall of the cavity at the oval window. Malleus is in contact with 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.

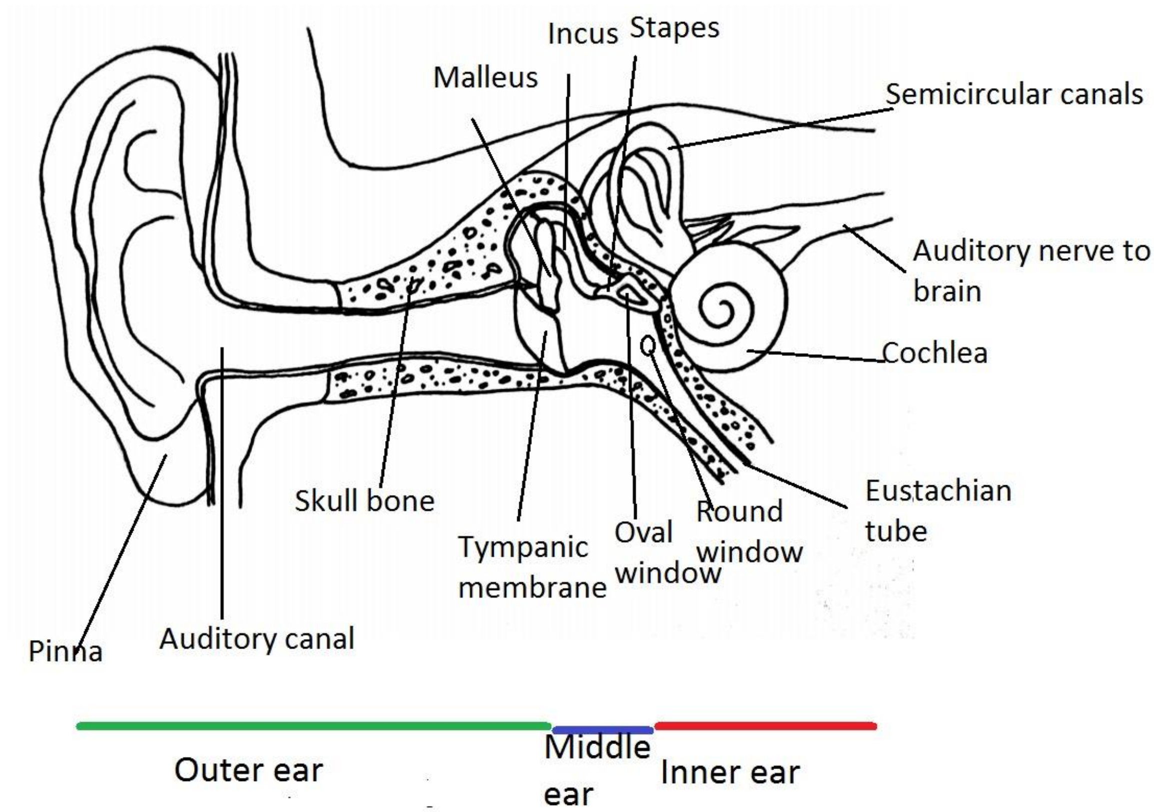
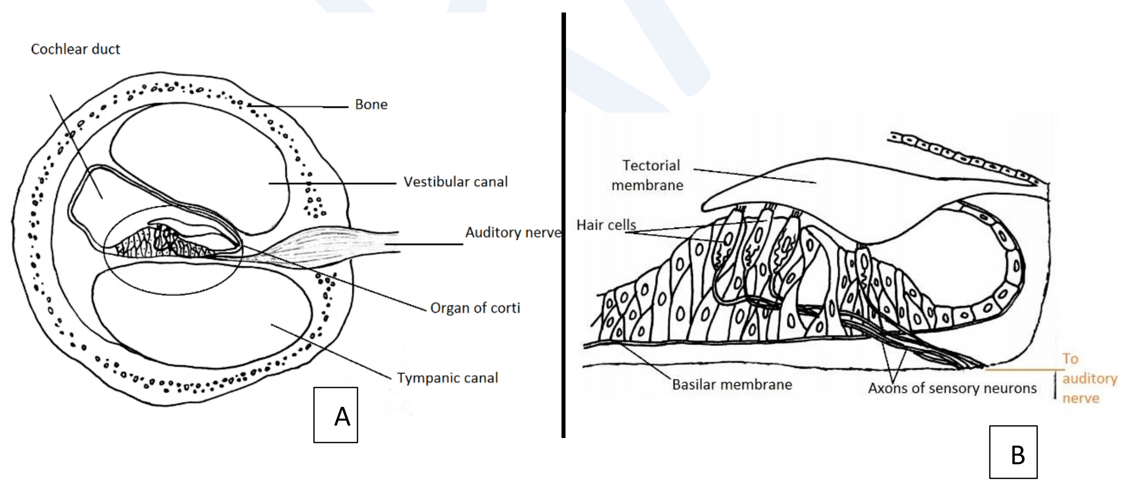


Figure: The typical structure of the human ear



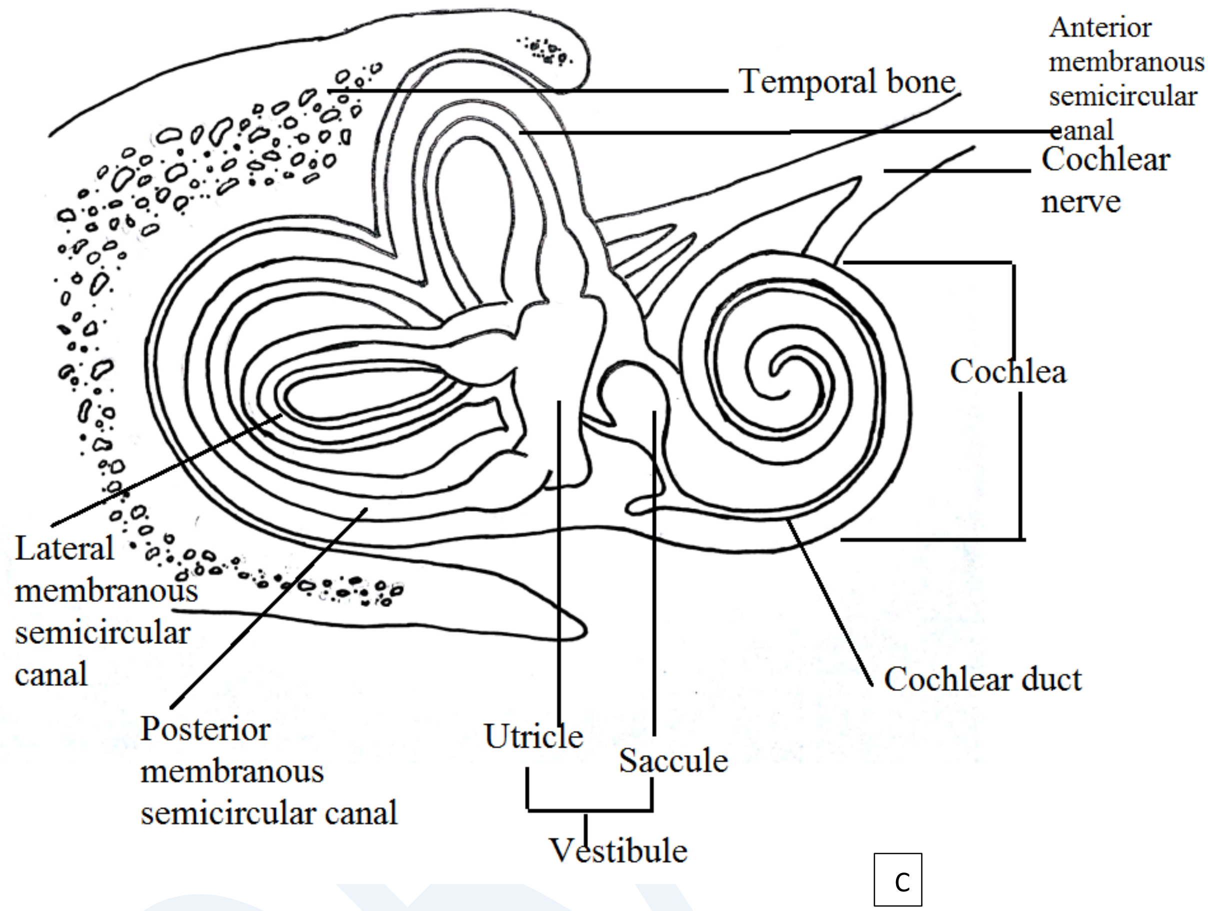


Figure: A. The Cochlea B. The organ of Corti C. The semicircular canals

Functions of the human ear

- **Hearing**

Vibrating objects produce pressure waves in the surrounding air. In hearing, the ear transduce 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 atmospheric pressure level.

- **Equilibrium**

Semicircular canals and vestibule located in the inner ear provide information about the position of the head in the 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 otolith press on the hairs projecting into the gels. Hair cell receptors transform this deflection into an electrical signal and passed 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 secretes 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 layer. 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 on to 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 arrector 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.

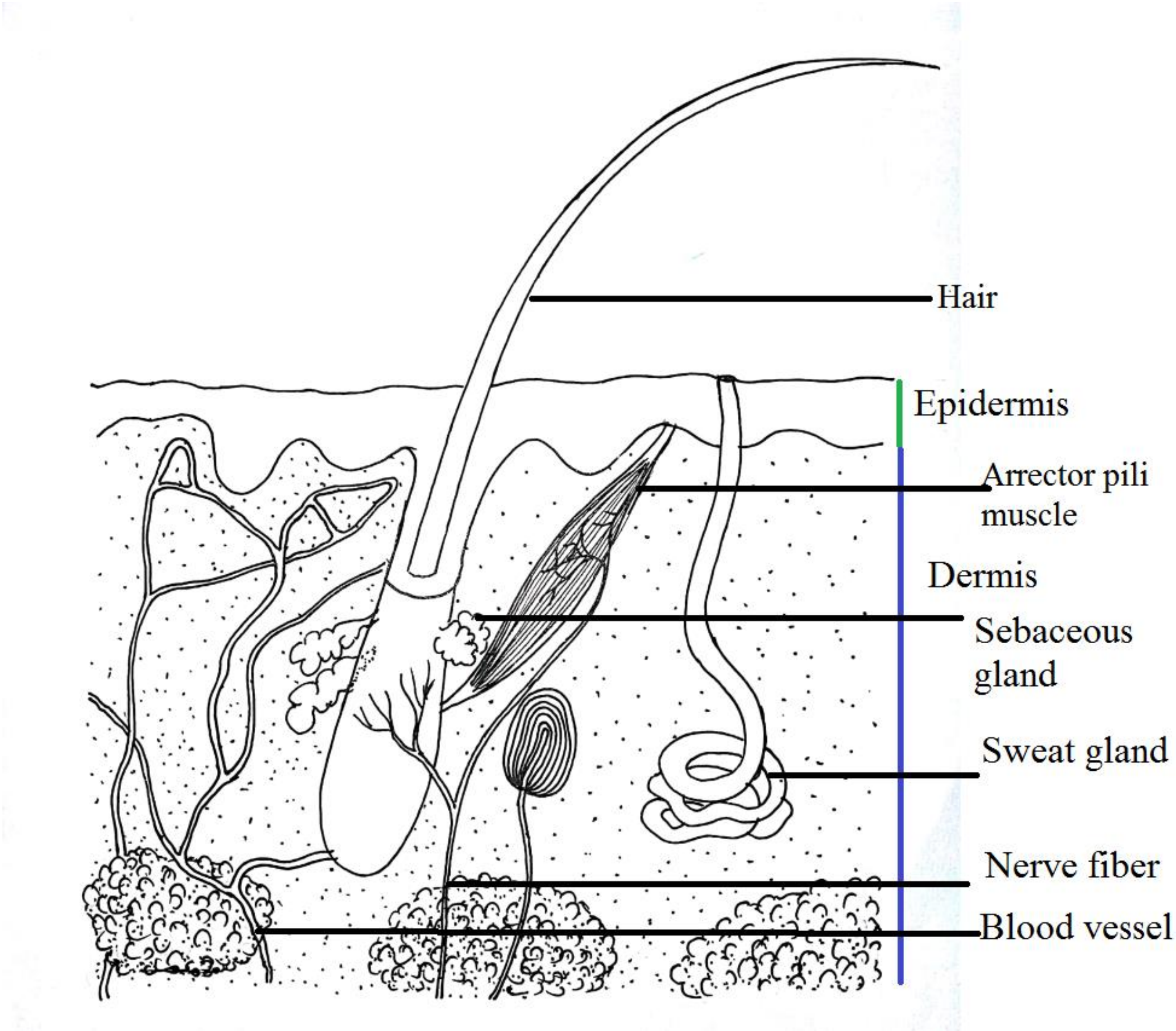


Figure: typical structure of the skin

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).

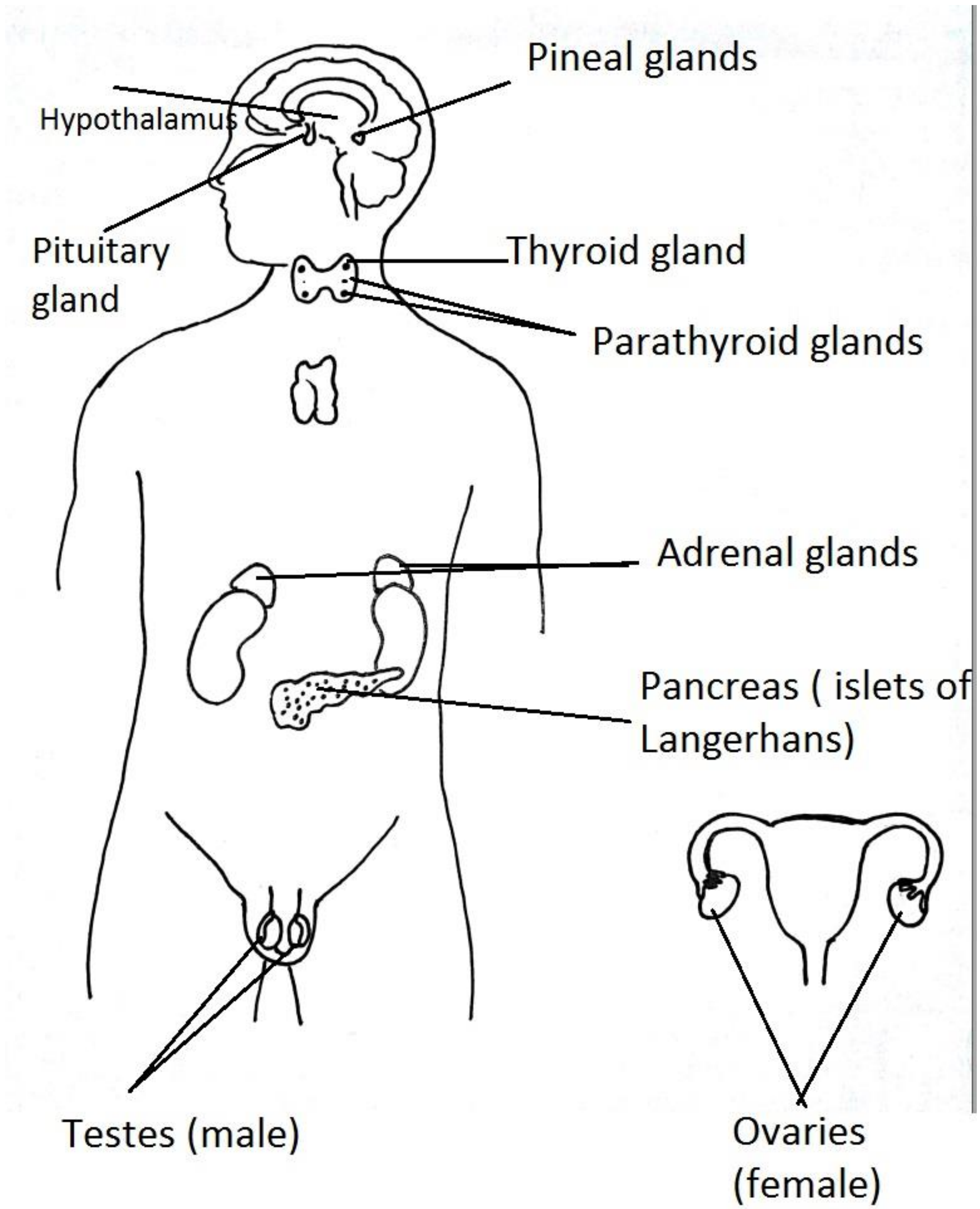


Figure: Location of human endocrine glands

- **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: Hypothalamic hormones that act on the anterior pituitary gland

Hypothalamic hormone	Function
Growth hormone releasing hormone (GHRH)	Stimulate the secretion of growth hormone (GH) from anterior pituitary
Thyrotropin releasing hormone (TRH)	Stimulate the secretion of thyroid stimulating hormone (TSH) from anterior pituitary
Corticotropin releasing hormone (CRH)	Stimulate the secretion of adrenocorticotropic hormone (ACTH) from anterior pituitary
Gonadotropin releasing hormone (GnRH)	Stimulate the secretion of Follicle stimulating hormone (FSH) and Luteinizing hormone (LH) from anterior pituitary
Prolactin releasing hormone(PRH)	Stimulate the secretion of prolactin hormone from anterior pituitary
Prolactin inhibiting hormone(PIH)	Inhibit the secretion of prolactin hormone from anterior pituitary
Growth hormone release Inhibiting hormone (GHRIH)	Inhibit 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: Anterior pituitary hormones, their target sites and functions**). The anterior pituitary connects to 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: 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 thyroxin); Stimulate growth of thyroid gland,
Prolactin	Mammary gland	Stimulates milk production; Together with other hormones promotes milk secretion by the mammary glands.
Adrenocorticotropic hormone (ACTH)	Adrenal cortex	Stimulate secretion of adrenal cortex hormones (Glucocorticoid hormones)
Follicle stimulating hormone (FSH)	Ovary	Stimulate 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	Stimulate 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 (**Posterior pituitary hormones, their target sites and functions**).

Table 3. 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	Stimulate resorption of water by increasing permeability to water
Oxytocin	Mammary gland	Stimulate 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 (T_3) and thyroxin (T_4) which are collectively called as **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 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 is consisted 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 as 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 labor, 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: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 induce 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.

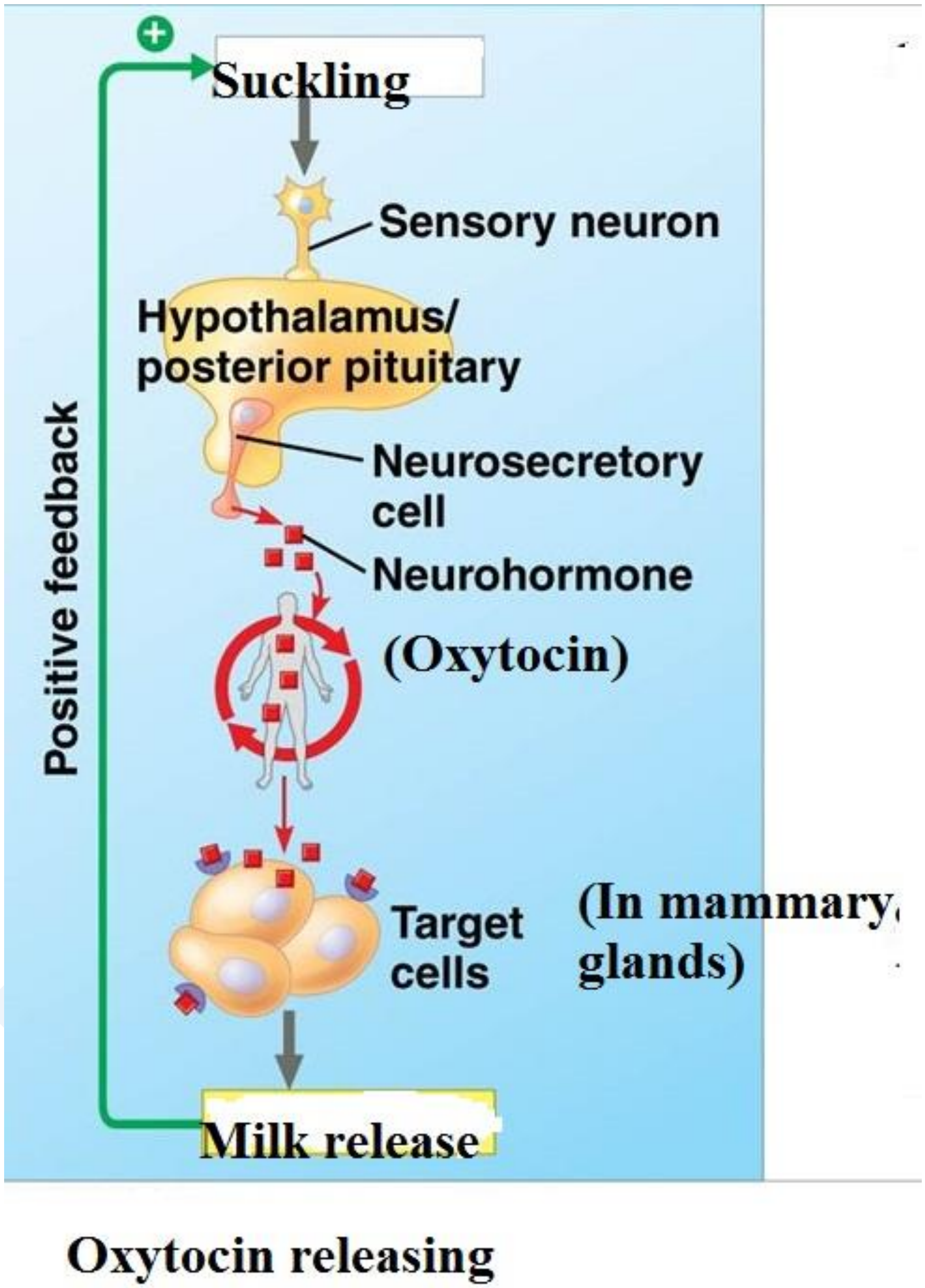


Figure: positive feedback mechanism related to oxytocin hormone action

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_3 and T_4) 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 thyroid gland (goiter).

  Hyperthyroidism: This condition occurs due to exposure of body tissues to excessive levels of T_3 & T_4. 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_3 and T_4) 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 37^0C (36.5^0C – 37.5^oC). 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") function as a thermostat and respond 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 lowers the body temperature until the set point.

The following heat loss mechanisms promotes 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 return 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 promotes 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 return 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 stimulate 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 favorable 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 stimulate 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 play 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- B_{12} 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)