Uttar Pradesh Rajarshi Tandon Open University

UGHN 102- Elementary Anatomy and Physiology

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 UGHN 102- Elementary Anatomy and Physiology

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Uttar Pradesh Rajarshi Tandon Open University

UGHN 102- ELEMENTARY ANATOMY AND PHYSIOLOGY

BLOCK-1	**INTRODUCTION TO HUMAN BODY**
BLOCK-2	**DIGESTIVE, RESPIRATORY, EXCRETORY SYSTEM**
BLOCK-3	**ENDOCRINE, REPRODUCTIVE SYSTEM**
BLOCK-4	**MUSCULO-SKELETAL, CENTRAL NERVOUS SYSTEM**

UNIT 1 HUMAN BODY

Structure

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- 1.2.3 Endoplasmic Reticulum
- 1.2.4 Mitochondria
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1.1 INTRODUCTION

As we all know human being is the most complex well organized single physical structure which are specialized in structure and function to varying degree. Human body is made up of billions of cells. Cells are the basic unit of life which can work independently and perform all vital life processes in unicellular organism. Over the years, human body evolved from unicellular to more advanced multi-cellular organism in which cells are specialized to perform several functions. As you know that in unicellular organism all vital functions such as digestion, respiration, excreation, reproductions are performed by single cell. Although, in multicellular organism, specialized cells are grouped together and depended on one another for various functions such as digestion, excretion, reproduction locomotion, respiration etc. Thus in human, cells are specialized, depended on each other, functions in well organized manner to carry out all life processes. Furthermore, they coordinate their activities, exchange their materials and thus improve the performance of life process. This unit introduces the structure of human body and how those structures relate with each other. In human body, cells unit together in highly organized manner to perform specific functions and forms tissue. Subsequently, these tissues further group together into organs such as liver, stomach, lungs and organs grouped together into organ system like digestive system, respiratory system, excretory system to perform specific function necessary for its everyday living. Although, there are some organs lose their functionality over the evolution are called vestiginal organ. This unit helps us to understand the function of different part of body and how it work together for specific function.

Objectives

After studying this unit, you will be able to:

- explain the levels of structural organization of human body
- describe the basic structure of human cell
- explain the function of different cell organelle
- explain the working of human body at cellular level
- discuss the different types of tissue and its function
- explain different type of organ systems in human body

1.2 CELL AND CELL ORGANELLE

Like all living things, human body is composed of cells. It divided and differentiated into other cells, tissues, numerous body organs and organ systems. Cell is the smallest and fundamental unit of life. The term “Cell” was given by Robert Hooke in 1665, which means a small chamber. He observed the number of small compartments in a cork under the microscopes. Human body is made up of billions of cells and each cell is efficient to perform the essential life process. Therefore, it can be considered as mini- organism consists of many small organs called as organelle.

In the following section, we will study the different types of cell organelle and how they work to perform different life processes.

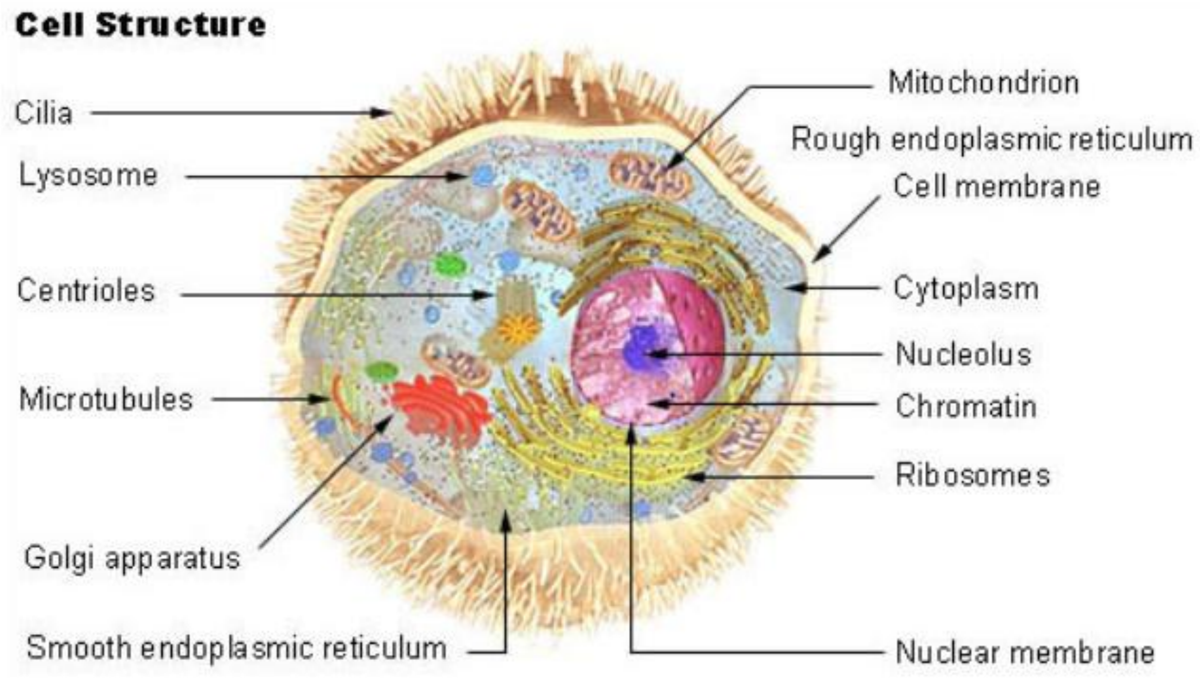

Figure 1.1: Cell structure of eukaryotic cell

1.2.1 Cell membrane

It is the thin membrane surrounds every cells and separate inner material of cells from environment around. It is also known as plasma membrane. . It is semi permeable layer which allows the passage of selected materials. It is outer most covering, made up of double layer of phospholipids and protein molecules in between them. Phospholipid molecules are amphiphilic in nature, containing both hydrophilic and hydrophobic ends. The hydrophilic ends contain the molecules have high affinity for water while hydrophobic ends repel water. Proteins are the carrier molecules that responsible for the selective transport of molecules across the membrane. It also acts as receptors that allow the cell to respond to external signals. In addition, it consist some lipid molecules which regulates the fluidity and permeability of cell membrane. The fluids outside the cell membrane are called extracellular fluid (FCF) and inside the cell membrane is called intracellular fluid (ICF).

The cell membrane, also known as the plasma membrane, is a thin, semi-permeable layer of lipid and protein molecules that surrounds the cell. It separates the inside of the cell from the outside environment, regulates the movement of certain substances into and out of the cell, and is responsible for many cellular functions. The cell membrane is a dynamic structure undergoes a variety of changes which is explained by Singer and Nicholson(1972) and proposed the fluid mosaic model. As shown in figure 1.2, it consists of a double layer of phospholipid molecules, with their hydrophilic heads facing outwards and their hydrophobic tails facing inwards. There are various proteins, including integral proteins and peripheral protein embedded in cell membrane. In the figure 1.2, you can see two integral proteins that extent the entire membrane and peripheral proteins that are attached to the surface.

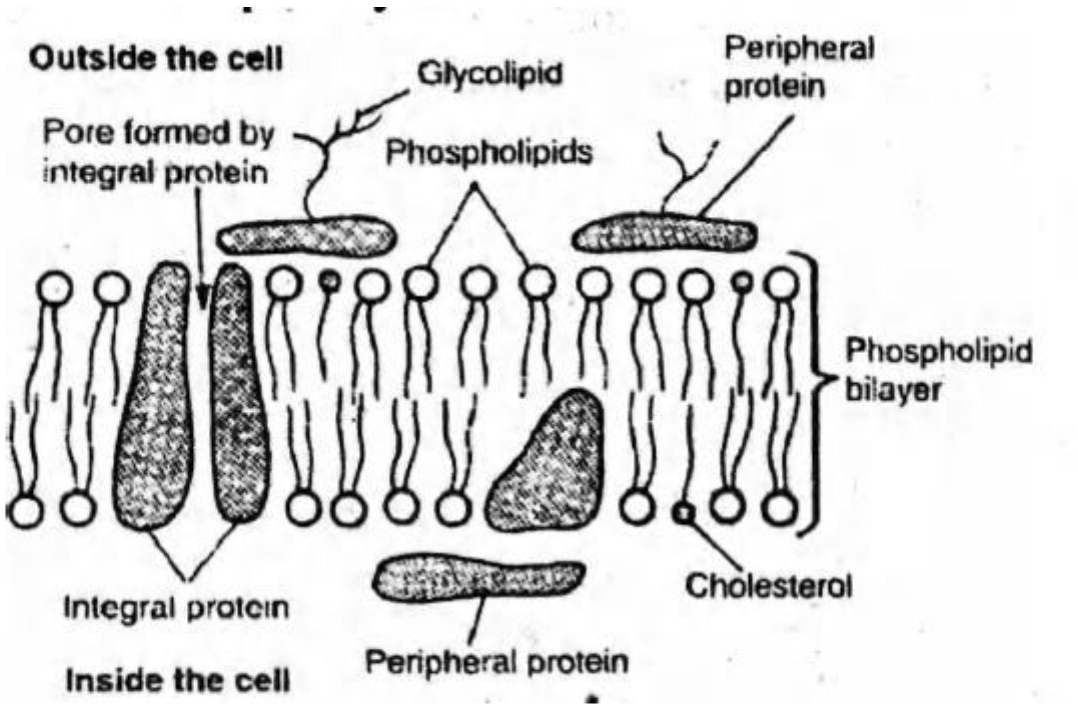

Figure 1.2: Fluid Mosaic Model of Cell membrane

The cell membrane has several important functions, including:

1. Selective permeability: The cell membrane is selectively permeable, which means it allows certain substances to pass through while blocking others. Small, non-polar molecules like oxygen and carbon dioxide can easily diffuse across the membrane, while larger or charged molecules like glucose or ions require transport proteins to move across.

2. Protection and support: The cell membrane provides a protective barrier around the cell, shielding it from the outside environment and helping to maintain its shape.
3. Signal transduction: The proteins embedded in the cell membrane can act as receptors, which can receive signals from other cells or the environment and relay them into the cell.
4. Cell adhesion: The cell membrane can contain proteins that help cells adhere to one another, forming tissues and organs.
5. Cell recognition: The cell membrane contains various carbohydrates that act as markers, allowing cells to recognize one another and distinguish self from non-self.

1.2.2 Nucleus

Nucleus is a spherical shaped organelle controls the cell division and growth. It contains hereditary information of cells and regulates gene expression. Nucleus is the control center of eukaryotic cells, coordinating all cell activities. Nucleus is formed of nuclear envelope, nucleoplasm and nucleolus. Nuclear envelope is the double layered membrane enclosed the nucleus and separates the content of nucleus from cytoplasm of cell. It is also known as nuclear membrane or karyotheca. It is made up of phospholipid bilayer and maintains the shape and integrity of nucleus. There are small pores in between the membrane through which exchange of large molecules between nucleoplasm and cytoplasm was coordinated. Nuclear envelop is connected to the endoplasmic reticulum in such a way that inner content of nuclear envelope is continous with with the lumen of endoplasmic reticulum (ER), which allows the transfer of materials. Nucleoplasm or Karyolymph, is the fluid which lies between the nucleus and nucleolus Nucleolus (plural form is nucleoli) is the site of ribosome synthesis and store house of RNA. Generally, one nucleolus (singular) is present in eukaryotic cell. However, some cell in human body is enucleate i.e. without nucleus for example red blood cell. More than one nucleoli may be present in immature or rapidly dividing stage. The major component of nucleus is chromatin, a thread like structure made up of DNA and protein (chiefly histone). DNA is the double helix strand contains the genetic information in form of genes.

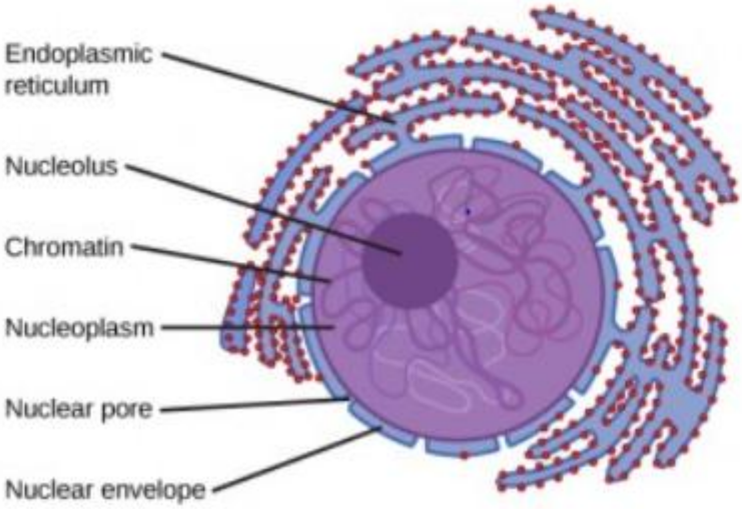

Figure 1.3: Structure of Nucleus

Functions:

a) Regulates the cell division and growth.
b) Storage house of genetic materials and controls the hereditary characteristics of an organism.
c) Nucleolus is the storehouse of RNA and regulates the synthesis of protein and ribosomes.

1.2.3 Endoplasmic Reticulum

As you can see in Figure 1.4, endoplasmic reticulum is a large organelle composed of series of membranous tubular or flattened structure distributed throughout the cytoplasm and play important role in overall functioning of eukaryotic cells. It consists of network of interconnected compartments (sacs) connect cytoplasmic content to the nucleus. The hollow membranous spaces of ER tubules are called the lumen or cisternal space. It is an important site of protein synthesis, lipid metabolism, detoxification and also plays critical role in wide range of essential cellular functions. The outer membrane of the organelle is either rough or smooth.

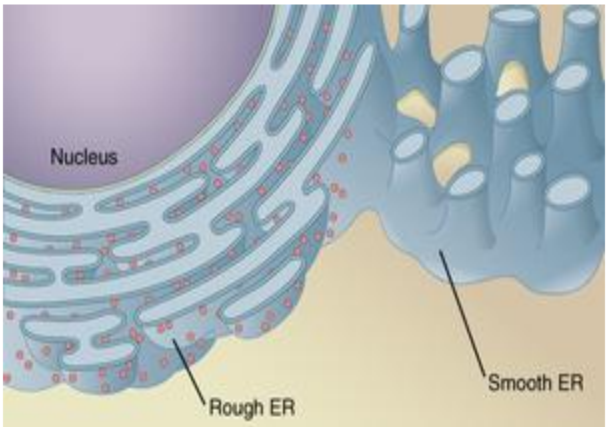

Figure 1.4: Structure of Endoplasmic reticulum

There are two types of endoplasmic reticulum:

a. Smooth endoplasmic reticulum**-** As you can observed in Figure 1.4, smooth endoplasmic reticulum has smooth surface as it is not studded with ribosome. It is abbreviated as SER. It plays important role in synthesis and metabolism of lipids including cholesterol and phospholipids. It is also involved in synthesis of steroids hormones and detoxification of chemicals. It also transport products of the rough ER to other cellular organelles especially the Golgi apparatus.

b. *Rough endoplasmic reticulum-* This endoplasmic reticulum has rough surface due to the presence of ribosome on its outer membrane as depicted in figure 1.4. It appears as dotted structure under microscope and is abbreviated RER; also called *granular endoplasmic reticulum*. It is connected to outer membrane of nuclear envelop. It plays important role in synthesis and metabolism of proteins in the liver, and hormones in the glands.

1.2.4 Mitochondria

The term 'mitochondrion' is derived from the Greek words "*mitos*" which means "**thread**" and "*chondrion*" "**granules-like**", respectively. It is small rod shaped organelle present in cytoplasm. Mitochondria are organelles found in eukaryotic cells that are responsible for generating most of the cell's energy in the form of ATP (adenosine triphosphate) through a process called cellular respiration. They are known as the powerhouse of the cell because they produce ATP, the energy currency of the cell. Mitochondria are found in all eukaryotic cells, including plants, animals, fungi, and protists.

The longitudinal section of mitochondria in the figure 1.5 shows that it consists of an outer membrane and an inner membrane, with an inter-membrane space in between. As you can observe in figure 1.5, the outer membrane of mitochondria is smooth and porous, while the inner membrane is highly folded into cristae, which increase the surface area available for the chemical reactions involved in cellular respiration. The space inside the inner membrane is called the mitochondrial matrix, which contains the enzymes and molecules necessary for the metabolic processes of the mitochondria. The primary function of mitochondria is to produce ATP through oxidative phosphorylation, a process that involves the transfer of electrons from molecules like glucose to oxygen, generating a proton gradient across the inner mitochondrial membrane. This gradient is then used to power the ATP synthase enzyme, which synthesizes ATP from ADP and inorganic phosphate.

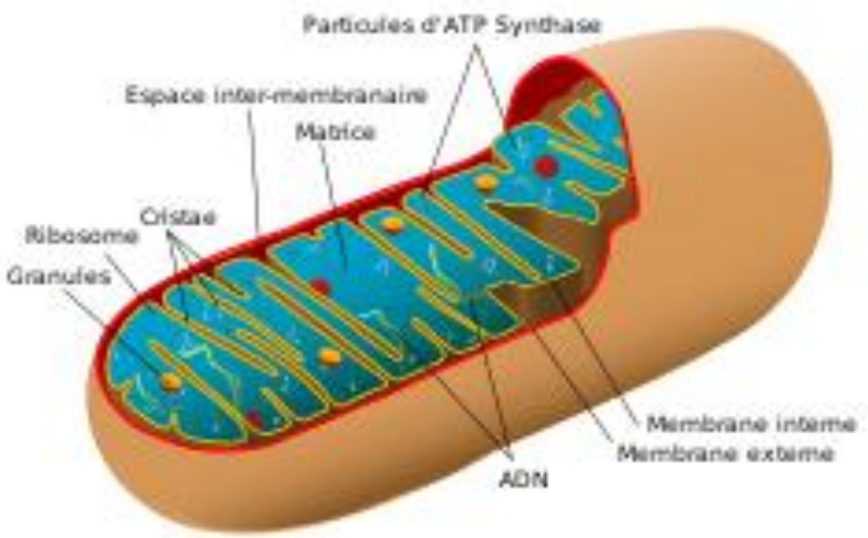

Figure 1.5: Structure of endoplasmic reticulum

1.2.5 Ribosomes

Ribosomes are small organelles found in the cytoplasm of cells. They are responsible for protein synthesis, which is the process of assembling amino acids into polypeptide chains to form proteins. Ribosomes can be found either free in the cytoplasm or attached to the endoplasmic reticulum (ER).

As you can see in figure 1.6**,** Ribosomes are composed of two subunits, a large subunit and a small subunit, which are made up of ribosomal RNA (rRNA) and proteins. The small subunit binds to the mRNA molecule, which carries the genetic information for the protein being synthesized, while the large subunit catalyzes the formation of the peptide bonds that link the amino acids together. Ribosomes play a vital role in the growth and maintenance of cells. They are responsible for the synthesis of all the proteins needed for cellular functions, including enzymes, hormones, and structural proteins. Ribosomes are also involved in the synthesis of proteins for export outside the cell.

Because ribosomes are involved in the synthesis of proteins, they are of great interest to researchers studying genetic disorders and diseases related to protein synthesis. Drugs that target ribosomes have also been developed as potential treatments for diseases such as cancer and bacterial infections.

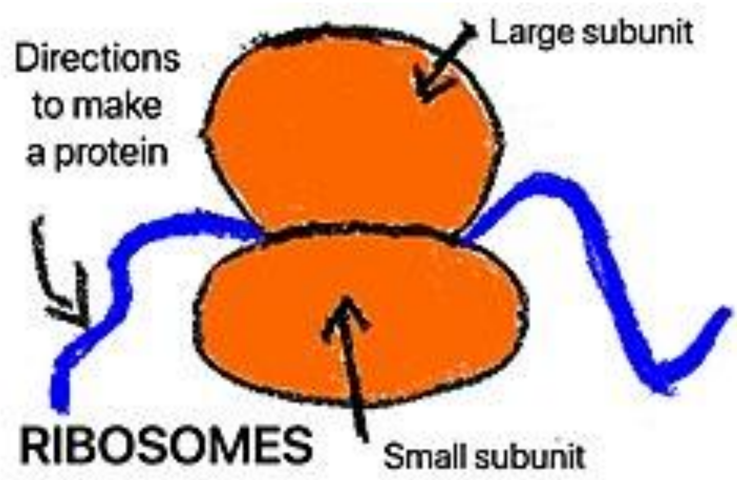

Figure 1.6: Structure of ribosomes

1.2.6 Golgi apparatus

The Golgi apparatus, also known as the Golgi complex or Golgi body, is a membrane-bound organelle found in most eukaryotic cells. It was named after Camillo Golgi, an Italian physician who first described it in 1898. Look at Figure 1.7, for the structure of golgi apparatus consist of a series of flattened, stacked membrane-bound sacs called cisternae. The Golgi apparatus is a stack of flattened, membrane-bound sacs or cisternae, arranged in a series of parallel layers. These cisternae are interconnected and are not physically separated from one another, which gives the Golgi apparatus a distinctive morphology.

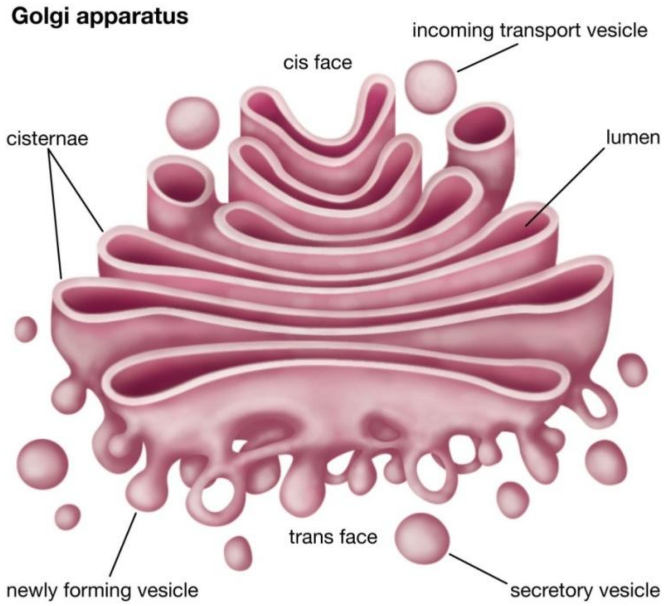

Figure 1.7: Structure of Golgi bodies

The Golgi apparatus has several functions in the cell, including:

1. Protein modification and sorting: One of the primary functions of the Golgi apparatus is to modify and sort proteins that are synthesized in the endoplasmic reticulum (ER). This process involves the addition of various carbohydrate groups to the protein (glycosylation), as well as the trimming of these groups to create a diverse array of protein structures. The Golgi apparatus then sorts these modified proteins into vesicles that are transported to their final destination within the cell, such as the plasma membrane, lysosomes, or secretory vesicles.
2. Lipid synthesis and modification: In addition to protein modification, the Golgi apparatus is also involved in the synthesis and modification of lipids. This includes the addition of carbohydrate groups to lipids to form glycolipids, which are important components of cell membranes.
3. Vesicle formation: The Golgi apparatus is responsible for the formation of transport vesicles that carry proteins and lipids to their final destination within the cell. These vesicles bud off from the Golgi cisternae and are then transported to their destination by motor proteins along microtubules.

4. Calcium storage: The Golgi apparatus has been shown to play a role in calcium storage in some cells. Calcium is an important signaling molecule in many cellular processes, and the Golgi apparatus has been found to act as a reservoir for calcium in some cell types.

1.2.6 Lysosome

Lysosomes are membrane-bound organelles found in most animal cells. They contain digestive enzymes known as hydrolases which break down various complex molecules, including proteins, carbohydrates, lipids, and nucleic acids into simpler forms that can be used by the cell. The enzymes inside lysosomes work best in acidic conditions, which is why lysosomes maintain an acidic pH inside their lumen. Lysosomes are formed by the Golgi apparatus and are involved in various cellular processes, such as the degradation of damaged or obsolete cellular components, the digestion of ingested food particles, and the defense against foreign pathogens. The primary function of lysosomes is intracellular digestion. They fuse with incoming vesicles or organelles through a process called endocytosis, forming endosomes. When a cell is damaged or no longer needed, lysosomes fuse with the damaged organelles and break them down into their component parts, which can then be recycled or eliminated from the cell. Lysosomes also play a critical role in the process of autophagy as shown in figure 1.8. It is a process by which a cell degrades and recycles its own cellular components. During autophagy, a portion of the cytoplasm, including damaged organelles and proteins, is engulfed by a double-membrane structure called an autophagosome. The autophagosome then fuses with a lysosome, which degrades and recycles

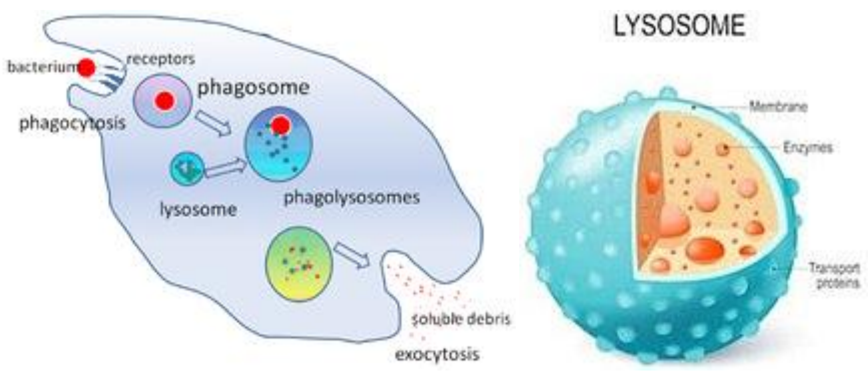

Figure 1.8: Structure Lysosome

1.2.7 Centrosome and Centrioles

The centrosome is a tiny organelle present in most eukaryotic cells, except for a few cell types like red blood cells. As you observed in figure 1.9, it is composed of two centrioles, which are cylindrical structures consisting of microtubules arranged in a specific pattern. The centrosome is responsible for organizing microtubules during cell division and is involved in the formation of the spindle apparatus, which is necessary for proper chromosome segregation during mitosis. In addition, the centrosome plays a role in determining the location of the nucleus within the cell and is also involved in the formation of cilia and flagella, which are used for cell movement and sensory functions.

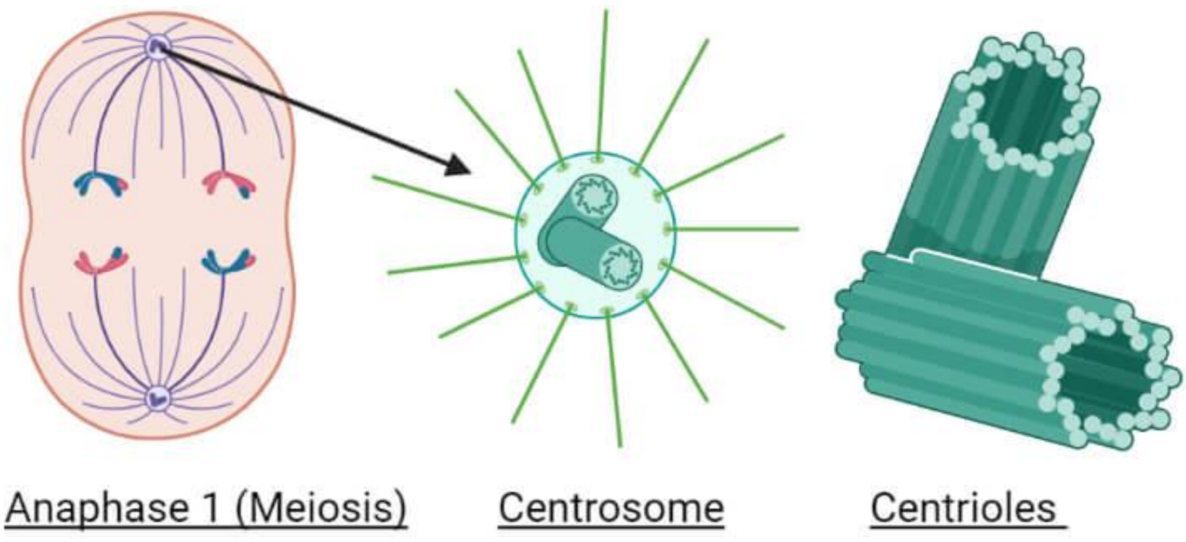

Figure 1.9 : Centrosome and Centrioles (Source: Sagar Aryal and Bikash Dwivedi)

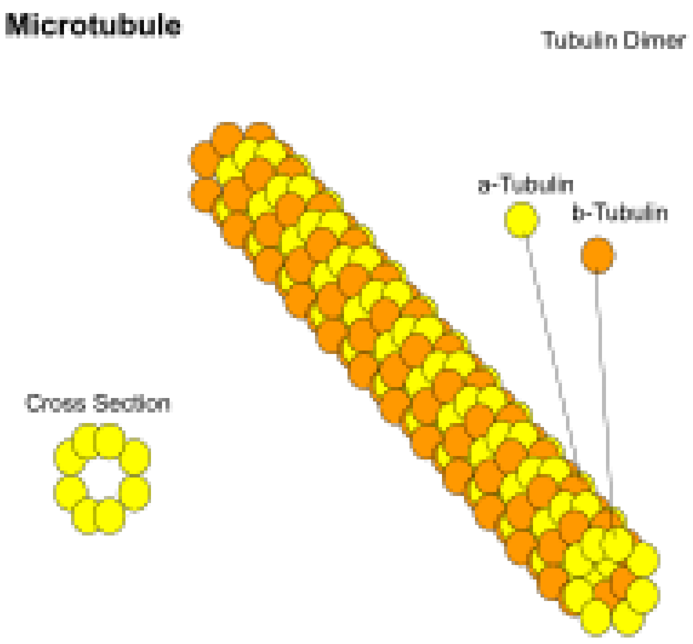

Figure 1.10 : Centrosome and Microtubules

You can see as shown in figure 1.10, Microtubules are long, thin, tube-like structures that are composed of protein subunits called tubulin. They are involved in several cellular processes, including cell division, cell motility, and intracellular transport. During cell division, microtubules form the spindle fibers that are responsible for separating the chromosomes.

Role in Cell division

During cell division, the genetic material is replicated and distributed equally to the two daughter cells as shown in figure 1.11. This process involves the coordinated action of several structures within the cell, including chromosomes, centrioles, and microtubules. Chromosomes are the structures that contain the genetic material of a cell. They are composed of DNA and proteins and are located in the nucleus of eukaryotic cells. Chromosomes are highly condensed during cell division to facilitate their segregation to the daughter cells. During cell division, centrioles are replicated, and the two daughter centrioles move to opposite ends of the cell. The centrioles then serve as organizing centers for the formation of the spindle fibers.The process of cell division can be divided into two main stages: mitosis and cytokinesis. Mitosis is the process by which the replicated chromosomes are distributed equally to the two daughter cells. It can be further divided into several phases, including prophase, metaphase, anaphase, and telophase.

These structures play critical roles in ensuring the fidelity of genetic information and the equal distribution of genetic material to the daughter cells. Defects in centrosome function have been implicated in several human diseases, including cancer, ciliopathies, and neurodegenerative disorders..Understanding the molecular mechanisms of cell division is essential for understanding the fundamental processes of life and for developing new therapies for diseases such as cancer.

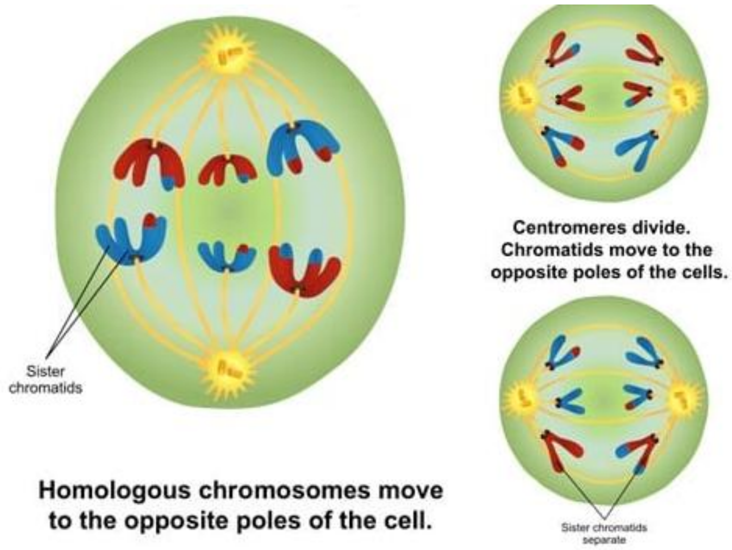

Figure 1.11: Process of Cell division (Source: Wikipedia and Wikipedia (Ali Zifan))

Hope you understand the structure and functions of different components of cell. Let's recapitulate what we learn so far and check your progress

Check your Progress Exercise 1

1. Define cell and enlist the different cell organelle in human cell.

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2. Give the functions of the following cell organelle:

S. no.	Organelle	Functions

a)	Mitochondria	
b)	Golgi Bodies	
c)	Lysosome	
d)	Endoplasmic reticulum	
e)	Centrosome	

Once you have acquired a comprehensive understanding of cells, their organelles, and their functions, Let move to learn about the next level of human organization ie. tissue.

1.3 TISSUE

Learning about tissues and their types is crucial for understanding the structure and function of living organisms. The term tissue is derived from latin word “to weave”. Tissue refers to a group of cells that are similar in structure and arranged together in an organized manner to perform specific functions. The term tissues gave by Nehemiah Grew for plants. Later, Bichat introduced term tissues for animals (1771-1802). Cells of tissues secrete the non living materials between them which facilitate the communication and chemical reactions. The branch of science deals with the study of tissue is known as histology. Marcello Malpighi is referred to as the Father of Histology.

On the basis of origin, structural and functional similarities, human tissue are group together into four categories –

1. Epithelial tissue
2. Muscular tissue
3. Connective tissue
4. Nervous tissue

1.3.1. Epithelial tissues

The term epithelium is derived from Greek word Epi – upon and *thele* – nipple. Epithelial tissues are a continuous sheet of cells that covers the entire body externally and internally. It is made up of layers of tightly packed cells that cover entire body, body cavity, organs and blood vessels. The primary function of epithelial tissue is to provide protection to internal organs and entire body from mechanical injury, entry of germs (infection) and harmful chemicals. They also play important role in absorption, excretion, respiration and sensation..

An epithelial tissue is made up of single or multiple layers of closely packed cells with no or little intercellular material between them. The cells are held together by intercellular junctions such as desmosomes, tight junctions, intercellular bridges and closely fitting folds and depressions. The epithelia rest on a thin non cellular basement membrane or basal lamina. They collect useful materials and give out waste material to the blood flowing in the blood vessels of the connecting tissues across the basement membrane.

Types of Epithelial tissues

Epithelia are classified into different types on the basis of shapes, sizes, and arrangements of cells.

Primarily epithelial tissue classified into two main types depending on the layers of cells- Simple epithelium composed of a single layer of cells

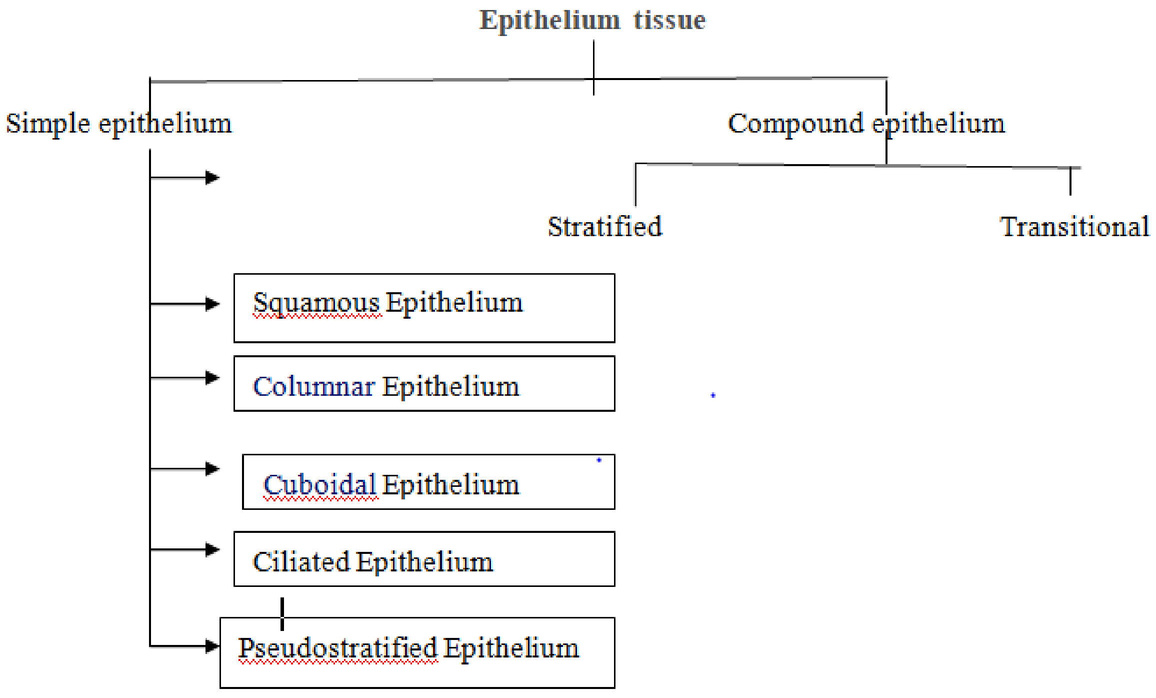

Figure 1.10: Classification of epithelium tissue

A. Simple Epithelia

The simple epithelia consist of a single layer of cells. They are further divided into five types according to the form and structure of their cells which you can see in **f**igure 1.12.

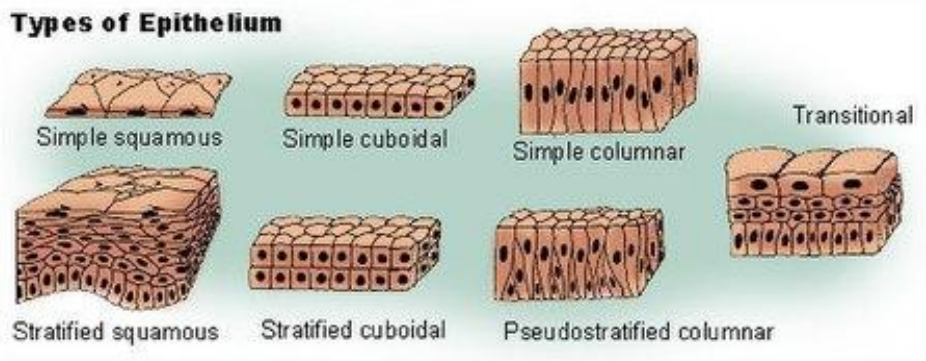

Figure 1.12: Types of Simple Epithelium

The characteristic features and location of different types of simple epithelium is discuss in table 1 as follows:

Table 1.1: Types of Simple Epithelium Tissue

Sno.	Type of Epithelium	Characteristic Feature	Location in body
i.	Squamous Epithelium	• Thin, flat disc like polygonal cells. • Cells closely fitted like titles in a floor. • It is also called pavement epithelium.	Blood vessels, lung alveoli, skin, inner lining of mouth,
ii.	Cuboidal Epithelium	• Cube shaped with a rounded centrally located nucleus	Salivary and pancreatic ducts, proximal parts of urinary tubules, thyroid follicles Ovaries, sperm producing tubules
iii.	Columnar Epithelium	• Column like cells with generally nuclei is towards the base. • It is called as glandular epithelium. • It has secretary and absorptive role.	Lining of stomach, intestine glands, and pancreatic globules.
iv.	Ciliated Epithelium	• Cells that bear fine, vibratile cytoplasmic processes called cilia on the free surface.	Present in urinary tubules of kidney, lines the oviducts, terminal bronchioles.
v.	Pseudostratified epithelium	• This epithelium is simple and one cll thick but appears two layer (stratified),therefore called	Large ducts of certain glands such as parotid

		as pseudostratified.	salivary glands, urethra.lines the tracheae and large bronchi.

B. Compound Epithelia

The compound epithelia are madeup of few to several layers of cells. They provide better protection than simple epithelia because of being multi layered, however; exhibit little secretory and absorptive role. Thecompound epithelia are further divided into two types:

i. **Stratified Epithelium-** It consist of several layers of cells. The cells and nuclei vary in different layers in form of shape and height. The inner layer is only in contact with basement membrane (basal lamina). The cells of these layer undergo mitotic division to form a new cells. The innermost layers has low columnar and cuboidal cells with oval nuclei while outerlayer vary in shape. The stratified epithelium is further sub-divided based on the type of cells in the outer layer. The stratified epithelia are classified into four types: stratified squamous (Keratinized and non keratinized), stratified cuboidal, stratified columnar, stratified ciliated. Commonly present in epithelium of the skin, mucous membranes of gastro intestinal tract, lines larynx, conjunctiva, vagina, part of urethra.

ii. **Transitional Epithelium-** The trasitional epithelium consist of fewer layers of cells having less flattened surface. The cells of trasitional epithelim have remarkable flexibility and lines the organs that required expansion such as urinary bladder, ureters and renal pelvis.

1.3.2 Connective Tissue

The connective tissue is made up of living cells separated by non living extracellular material. The extracellular material generally consists of protein fibres scattered in an amorphous, transparent ground substance called matrix.

Functions-

1. The connective tissue connects one tissue with other tissues and organ of the body and provides structural support.
2. Matrix allows diffusion of food materials, water, gases and wastes to and from the cells. Thus facilitate in transport of materials from one part to another in the body.
3. Certain cells of connective tissues such as macrophages, neutrophiles, monocytes ingest and dispose off bacteria to protect the body from infection.

Types of connective tissue-There are three main types of connective tissues, which is further sub-divided as shown in figure 1.13. The brief review on these types of connective tissue is as follows:

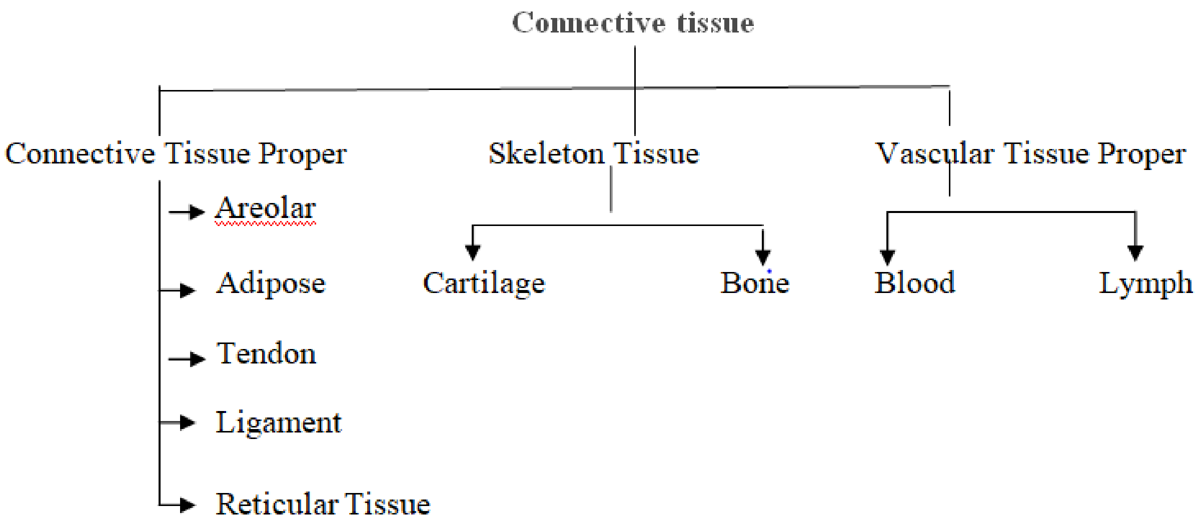

Figure 1.13: Classification of connective tissue

A. Connective Tissues Proper- Connective tissue proper consist of gelatinous matrix, made up of carbohydrates and protein. Its main function is to protect the organs and connect one tissue to other. The connective tissues proper are further divided into following section:

i. **Areolar connective tissue -**Areolar connective tissue is also known as Loose connective tissue . They are rich in cells, fibres and ground substance. There are two types of fibres: white and yellow It contains loosely organized fibers in large volume of jelly like viscous ground substance called matrix. Areolar is derived from latin word, which means "little open space". As named implies fibers are distributed far apart and give large open space. It is most widely distributed connective tissue and primarily presents beneath the dermal layer of skin and lines the external and internal surfaces of the body. Areolar connective tissue holds organs in place and fixes skin with the muscle. It also plays important role in fixing tissue to other tissue and organs. They consists three different types of fibers- Collagen fibers, elastic fibers and reticular fibers.

- **Collagen fibers** Collagen fibers are a type of connective tissue fiber that provides strength and structural support to various tissues in the body. They are composed of a protein called collagen, which is synthesized by specialized cells called fibroblasts.

Collagen fibers are found in a variety of tissues, including the skin, bones, tendons, ligaments, and cartilage. They are the most abundant protein in the human body and provide tensile strength and resistance to deformation. In addition, collagen fibers play an important role in maintaining the structure and function of many organs and tissues.

- **Elastic fibers** Elastic fibers are a type of connective tissue fiber that provides elasticity and resilience to various tissues in the body. They are composed of a protein called elastin, which is synthesized by specialized cells called fibroblasts and smooth muscle cells. Elastic fibers are found in a variety of tissues, including the skin, lungs, blood vessels, and ligaments. They allow these tissues to stretch and recoil in response to mechanical stress and maintain their structural integrity. The unique properties of elastic fibers make them important for the function of many organs and tissues in the body. Elastic fibers are also important for the proper functioning of blood vessels. The elastic fibers in the walls of arteries and veins help to maintain their shape and integrity, allowing for efficient blood flow through the circulatory system. In addition, the elasticity of these fibers helps to absorb the pressure fluctuations that occur during the cardiac cycle, reducing stress on the heart.
- **Reticular fibers** Reticular fibers are a type of connective tissue fibers that provide structural support to various organs and tissues in the body. They are composed of thin, delicate collagen fibers that form a complex meshwork, resembling a net or web-like structure. Reticular fibers are found in a variety of tissues, including the liver, spleen, lymph nodes, bone marrow, and adipose tissue. They provide a supportive framework for these tissues, allowing for the exchange of substances between blood vessels and surrounding cells. In addition, reticular fibers play an important role in the immune

ii. Adipose tissue- It is fat containing loose connecting tissue, found in the subcutaneous tissues, around visceral organs, heart and blood vessel. It is known as fat tissues. The adipose tissue consists of oval fat cells, adipocytes. The primary function of adipose tissue is to store food and energy. In addition, it offers several other important functions include cushing organ, insult body, produce hormones and also blood corpuscles. There are two types of adipose tissue in human on basis of adipocyte morphology- **W**hite adipose tissue- (found commonly in adult) and brown adipose tissue (found commonly newborn).

iii. **Tendons**: It attaches muscle to a bone. It is formed of white fibrous connective tissue. It is tough and flexible. This is a class of dense connective tissue. They are composed of white fibrous (collagen) bands or bundles. Fibroblasts are arranged between these bundles.

iv. **Ligament:** It attaches bone to a bone. It is formed of yellow fibrous connective tissue. It is elastic and flexible. This is a class of dense connective tissue. They are composed of yellow fibres in bundles or networks. The fibres are much thicker as compared to white fibres.

v. **Reticular connective tissue** is produced by modified fibroblasts called reticular cells. These produce reticular fibers arranged in an interlaced network (reticulum), similar to dense irregular connective tissue. It is present in red bone marrow, lymph nodes and the spleen.

B. Skeleton Tissue Skeletal or Supportive Connective Tissue-

The skeleton tissue consists of tough matrix and form a rigid framework. It is of two types-

i. **Cartilage-** It is solid, semi rigid connective tissue present in the ends of the bones. It is composed of closely packed collagenous fibers in a matrix of firm substance called chondrin. It lacks blood vessels and nerves because of this injury to cartilage take long to heal. Chief cartilage cells are known as chondrocytes**,** situated in fluid filled space called cartilage lacuna. The cartiage is surrounded by stiff sheet known as perichondrium. It contains blood vessels which supply food and oxygen to the cells. It is commonly present between the bones of the vertebral column and on tip of the ear, and nose As shown in figure 1.14, there are three types of cartilage in human: elastic, hyaline, and fibrocartilage.

- **Elastic Cartilage:** Elastic cartilage is characterized by the presence of elastic fibers in addition to collagen fibers and proteoglycans. These elastic fibers give the cartilage its elastic properties, allowing it to return to its original shape after being stretched or deformed. Elastic cartilage is found in areas that require both flexibility and support, such as the external ear, epiglottis, and auditory tubes. It provides structural support while allowing for flexibility and movement.

- **Hyaline cartilage-** Hyaline cartilage is the most common type of cartilage in the human body. It has clear homogenous and translucent matrix which gives a glassy appearance. This cartilage is less flexible compared to fibrous cartilage It is commonly found in articular surfaces of long bones, the rib tips, nasal septum, trachea, and bronchial rings, and suprascapula. Hyaline cartilage provides a smooth surface for the articulation of bones, allowing them to glide easily over each other. It also helps absorb shock and distribute forces during movements. Hyaline cartilage contains a matrix composed of collagen fibers and proteoglycans, which provide strength and resilience.
- **Fibrocartilage**- Fibrocartilage is a tough and dense type of cartilage that contains both collagen fibers and proteoglycans. It is found in areas that require additional strength and support, such as the intervertebral discs of the spine, pubic symphysis, and certain tendons. Fibrocartilage acts as a shock absorber and provides stability to joints. It can withstand compression and tension forces, making it ideal for regions where mechanical stress is high.

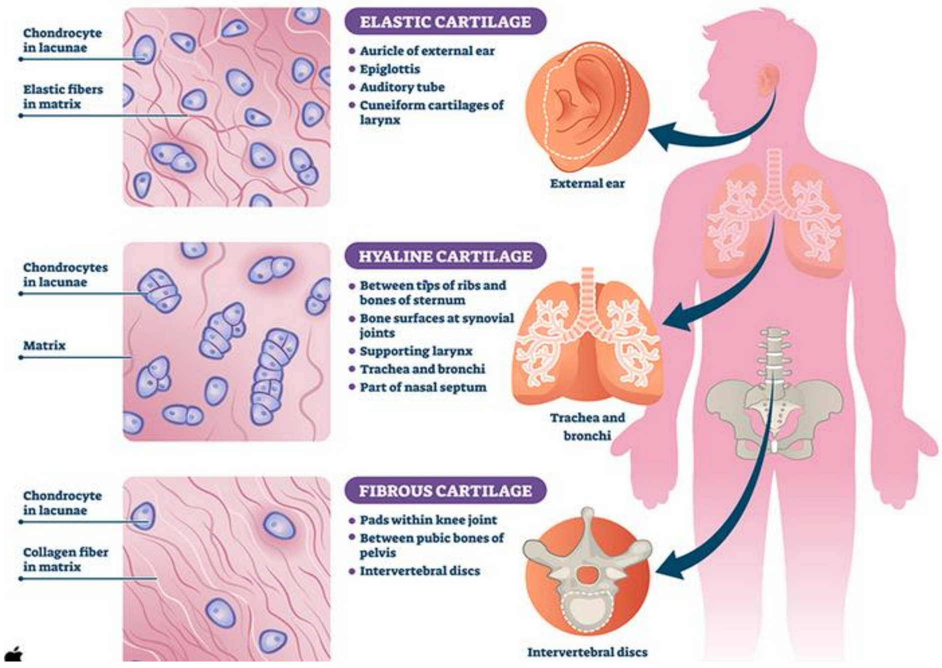

Figure 1.14: Types of cartilage (Source: www.librate.com)

ii. **Bone:** Bone is the solid, rigid and hardest connective tissue. The prominent function of bone is to maintain the shape and posture of the body. In addition it also protects the internal organs. They are rich in collagen fibres and calcium, which give strength. It is externally covered by tough sheath known as periosteum. It contains the special bone forming cells are known as osteoblasts. The matrix of bone is dense and hard, made up of ossein protein. The matrix occurs as layer, the lamellae which are arranged in concentric rings. Each lamella contains a bone cell, known as osteocyte. They are present in fluid filled space, the bone lacunae which give off tiny channels known as canaliculi.

Table 1.2: Difference between bone and cartilage

S.no.	**Bone**	**Cartilage**
1	It is rigid and non flexible connective tissue	It is flexible connective tissue
2.	Matrix is made up of organic and inorganic salts (predominant of calcium salts)	Matrix is made up of organic mainly.
3.	Matrix is arranged in concentric circle	Matrix is not arranged in circle, occur in homogenous mass
4.	Bone cell is known as osteocyte	Cartilage is known as chondrocytes.
5.	Bone is covered with tough sheath, periosteum.	Cartilage is covered with firm sheath, perichondrium.
6.	Rich in blood supply	Lack blood supply

C. **Vascular Tissue or Fluid Connective tissue**

The vascular tissue consists of fluid matrix, free cells with no fibres. Fluid connective tissue is a type of tissue found in the body that is characterized by the presence of cells suspended in a liquid matrix. Fluid connective tissue plays an important role in regulating fluid balance in the body.. These tissues play important roles in the body's immune system, transport of nutrients and waste products, and regulation of fluid balance. The two main types of fluid connective tissue are blood and lymph

i. **Blood:** Blood is a complex fluid connective tissue that circulates throughout the body via a network of blood vessels. It is composed of a liquid matrix called plasma, which is made up of water, electrolytes, hormones, enzymes, and other substances. Blood cells, including erythrocytes (red blood cells), leukocytes (white blood cells), and platelets, are suspended in the plasma. Erythrocytes are the most abundant cells in the blood and circulate in blood vessels primarily to deliver essential chemicals and take off wastes from different sites. The crucial role is to carry oxygen to the body's tissues. They are disc-shaped cells that lack a nucleus and are filled with hemoglobin, a protein that binds oxygen. Leukocytes are less abundant than erythrocytes but play important roles in the immune system. There are several types of leukocytes, including neutrophils, eosinophils, basophils, monocytes, and lymphocytes. Platelets are cell fragments that are involved in blood clotting. It also offers several function includes blood clotting, maintain osmotic pressure etc.

ii. Lymph: Lymph is colorless fluid, circulates in lymph vessels and consist of plasma and white blood corpuscles. Lymph is a fluid connective tissue that circulates through a network of lymphatic vessels and lymph nodes. It is derived from blood plasma and contains a mixture of water, electrolytes, proteins, and lymphocytes. Lymphocytes are the main cell type found in lymph and are involved in the body's immune response. There are two main types of lymphocytes: B lymphocytes, which produce antibodies, and T lymphocytes, which directly attack infected cells.

1.3.3 Muscle tissues

The muscle tissue composed of elongated thin cells called muscle fibres. The muscle fiber surrounded by a membrane, sarcolemma and enclosed the cytoplasm, sarcoplasm. Each muscle fiber is a bundle of thread like protein known as myofibrils. They are rich in mitrochondia, and endoplasmic reticulum is known as sarcosomes and sarcoplasmic reticulum respectively. It can categorize into three types- Skeleton (striated), Smooth (non striated) and Cardiac muscle, which is presented in figure 1.15 and discussed as follows:

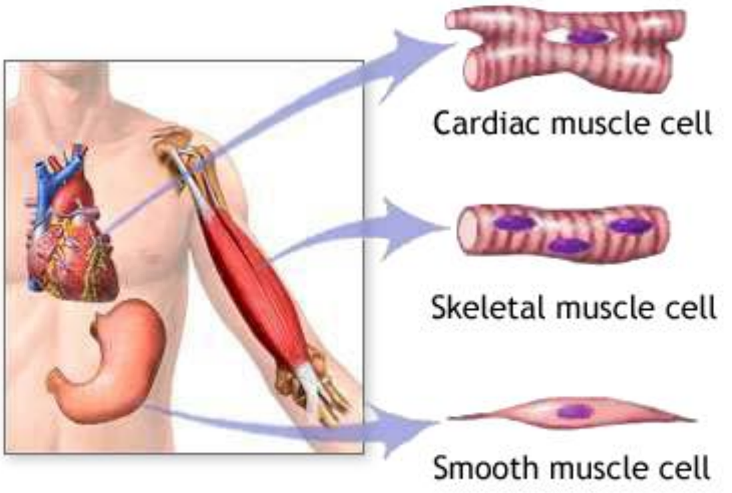

Figure 1.15: Types of muscle tissue (Source: National library of Medicine**)**

A. Skeleton Muscle- Skeletal muscle, also known as striated muscle, is a highly specialized tissue that allows us to move and perform physical activities. Striated muscle fibers are long and cylindrical in shape, and they have a striped or striated appearance under the microscope due to the organization of the proteins within the muscle fibers.

The *structure of striated muscle* is highly organized, consisting of many muscle fibers that are bundled together to form muscle fascicles, which are then bundled together to form whole muscles as shown in figure 1.16. Muscle Fiber is the basic unit of striated muscle is the muscle fiber, also known as a muscle cell. Muscle fibers are long, cylindrical cells that extend the entire length of the muscle. Each muscle fiber is composed of smaller subunits called myofibrils. Myofibrils are thread-like structures that run parallel to the length of the muscle fiber. They are responsible for muscle contraction and are composed of repeating units called sarcomeres.

What is Sarcomere? Sarcomeres are the functional units of striated muscle and are responsible for its characteristic striped appearance. They are arranged end to end along the length of the myofibrils. There are the structures that separate one sarcomere from another, called as Z lines. They serve as anchor points for the thin filaments and provide structural stability to the muscle fiber. Sarcomeres contain two main protein filaments: thick filaments made of myosin and thin filaments made of actin. Myosin is a thick filament protein that is responsible for the contractile force of the muscle. It consists of long, rod-like tails with globular heads. The heads interact with the thin filaments of actin during muscle contraction. Actin is a thin filament protein that, together with myosin, forms the contractile apparatus of the muscle. Actin filaments have binding sites for myosin heads, allowing the sliding of thick and thin filaments during muscle contraction. Tropomyosin and troponin are regulatory proteins associated with the thin filaments of actin. They control the interaction between actin and myosin and regulate muscle contraction. The muscle cells also contain a specialized form of endoplasmic reticulum known as sarcoplasmic reticulum. It plays a crucial role in regulating calcium ions, which are essential for muscle contraction.

Skeleton muscle is responsible for voluntary movement and is attached to bones through tendons. It is also known as voluntary muscle because it is under conscious control. It can be contracted and relaxed at will, allowing us to move our limbs, walk, run, jump, and perform a wide range of other movements.

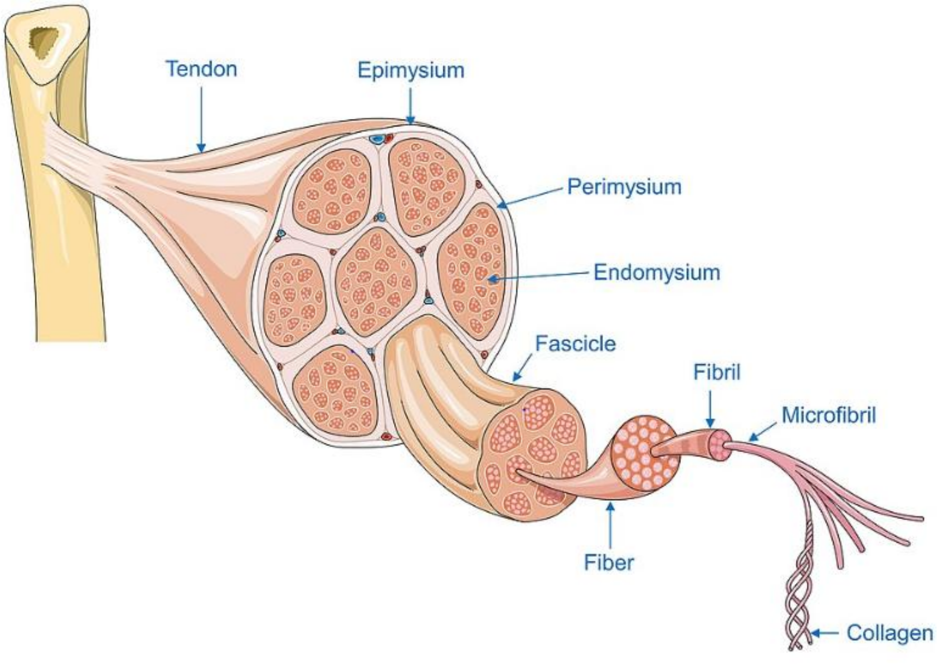

Figure 1.16: Structure of Striated muscle

B. Smooth Muscle- Smooth muscles, also known as Non-striated muscles, are a type of muscle tissue that lacks the characteristic striped appearance of striated muscles. Instead, they have a smooth, uniform appearance under the microscope. As you see in figure 1.15, smooth muscles are composed of long, spindle-shaped cells called smooth muscle cells or myocytes.

Each smooth muscle cell contains a single nucleus and is capable of contraction. Unlike striated muscles, smooth muscle cells do not have a highly organized arrangement of protein filaments. Non-striated muscles are responsible for involuntary movements in the body. They are found in the walls of hollow organs such as the intestines, stomach, bladder, and uterus, where they contract rhythmically to move food, waste, urine, and fetuses through these organs. Smooth muscles also play an important role in regulating blood flow. They are found in the walls of blood vessels, where they help regulate blood pressure and the distribution of blood throughout the body.

C. Cardiac Muscle- Cardiac muscle, also known as myocardium, is a specialized type of muscle tissue that makes up the walls of the heart. It is responsible for the contraction and relaxation of the heart chambers, which is essential for the pumping of blood throughout the body. The structure and function of cardiac muscle are unique and highly specialized, allowing for efficient and coordinated contraction of the heart. The main function of cardiac muscle is to generate the force required for the contraction of the heart chambers. This allows the heart to pump blood throughout the body, providing oxygen and nutrients to the tissues and organs. Unlike skeletal muscle, cardiac muscle is involuntary and contracts spontaneously. The rhythmic contraction and relaxation of the heart is essential for maintaining blood pressure and circulation, and any disruption in this process can lead to serious health problems.

1.3.4. Nervous Tissue

The nervous system is a complex network of cells and organs responsible for transmitting and processing sensory information, controlling movements and behavior, and regulating various bodily functions. The nervous system can be broadly divided into two main parts: the central nervous system (CNS) and the peripheral nervous system (PNS).

The CNS includes the brain and spinal cord, which are responsible for processing and interpreting information received from the PNS and generating appropriate responses. The brain is the control center of the body, responsible for conscious thought, memory, and emotions, while the spinal cord serves as a relay between the brain and the rest of the body, transmitting sensory and motor signals.

The PNS includes all the nerve fibers that lie outside of the CNS, connecting it to the rest of the body. The PNS can be further divided into two branches: the somatic nervous system (SNS) and the autonomic nervous system (ANS).The SNS controls voluntary movements and sensory information, such as muscle contractions and touch, while the ANS regulates involuntary actions, such as heart rate, breathing, and digestion. The ANS is further divided into the sympathetic and parasympathetic nervous systems, which work in opposition to each other to maintain balance and regulate bodily functions.

In addition to the CNS and PNS, the nervous system also includes specialized cells called neurons, which are responsible for transmitting electrical signals throughout and coordinate all activities of body. Neurons are specialized to receive and transmit nerve impulse from one neuron to other neuron with the help of chemicals called neurotransmitter. Nerve cell consists of main cell body called soma or perikaryon and fine protoplasmic processes arising from it. These processes are of two types: axon (long and cylinderical) and dendrites (short and tapering). Neurons are connected by specialized structures called synapses, which allow them to communicate with each other and with other cells in the body. Furthermore, nervous system also includes supporting cells called glial cells or neuroglia, which provides structural support and insulation for neurons, as well as helping to maintain the chemical balance within the brain and spinal cord.

You already learn that tissue forms the building blocks of organs and contribute to the overall functioning of organ systems. By studying different types of tissues, hope you understand the diversity of cell types and their organization within a tissue and their importance for overall functioning of organs. With this we end our discussion on tissue, their types and functions. Next, we will move on the study of next level of organization that is organs and organ systems. Before that, let us review what we have learnt so far.

1.4 ORGANS

Organs are complex structures composed of multiple tissues and cells that work together to carry out specific functions in the body. They are the basic functional units of the organ system and perform a wide range of functions that are essential for life. Some of the most important organs in the human body include the brain, heart, lungs, liver, kidneys, and digestive system. An organ is a group of tissues precisely arranged so as to accomplish specific functions. Examples: the brain is the control center of the body and is responsible for coordinating and regulating all bodily functions. The heart is a muscular organ that pumps blood throughout the body. The lungs are responsible for breathing and gas exchange. The kidneys are responsible for filtering waste products from the blood and regulating the balance of fluids and electrolytes in the body. In addition to these major organs, the body contains many other structures and tissues that work together to maintain health and homeostasis. These include the skin, which protects the body from the external environment, and the endocrine system, which regulates the body's hormonal balance. Together, these organs and tissues form a complex and interconnected system that is essential for life.

1.5 ORGAN SYSTEMS

The human body is composed of several organ systems that work together to perform various functions necessary for survival. As shown in figure 1.17, you can see that each system has specific structures and functions that contribute to overall health and well-being. In this section, we will discuss the major organ systems in the human body and their functions.

1. *The Skeletal System*: The skeletal system consists of bones, cartilage, and ligaments. Its main function is to provide support, protection, and movement. The bones of the skeletal system also serve as a storage site for minerals, such as calcium and phosphorus.
2. *The Muscular System*: The muscular system is composed of skeletal muscles, smooth muscles, and cardiac muscles. Its primary function is to facilitate movement and maintain posture. Skeletal muscles are responsible for voluntary movements such as walking, running, and lifting. Smooth muscles are found in internal organs and help to regulate processes such as digestion and respiration. Cardiac muscles are unique to the heart and are responsible for pumping blood throughout the body.
3. *The Circulatory System*: The circulatory system consists of the heart, blood vessels, and blood. Its primary function is to transport oxygen, nutrients, hormones, and waste products throughout the body. The heart is responsible for pumping blood, while blood vessels serve as conduits for blood flow. Blood contains red blood cells, white blood cells, and platelets, all of which play important roles in maintaining overall health.

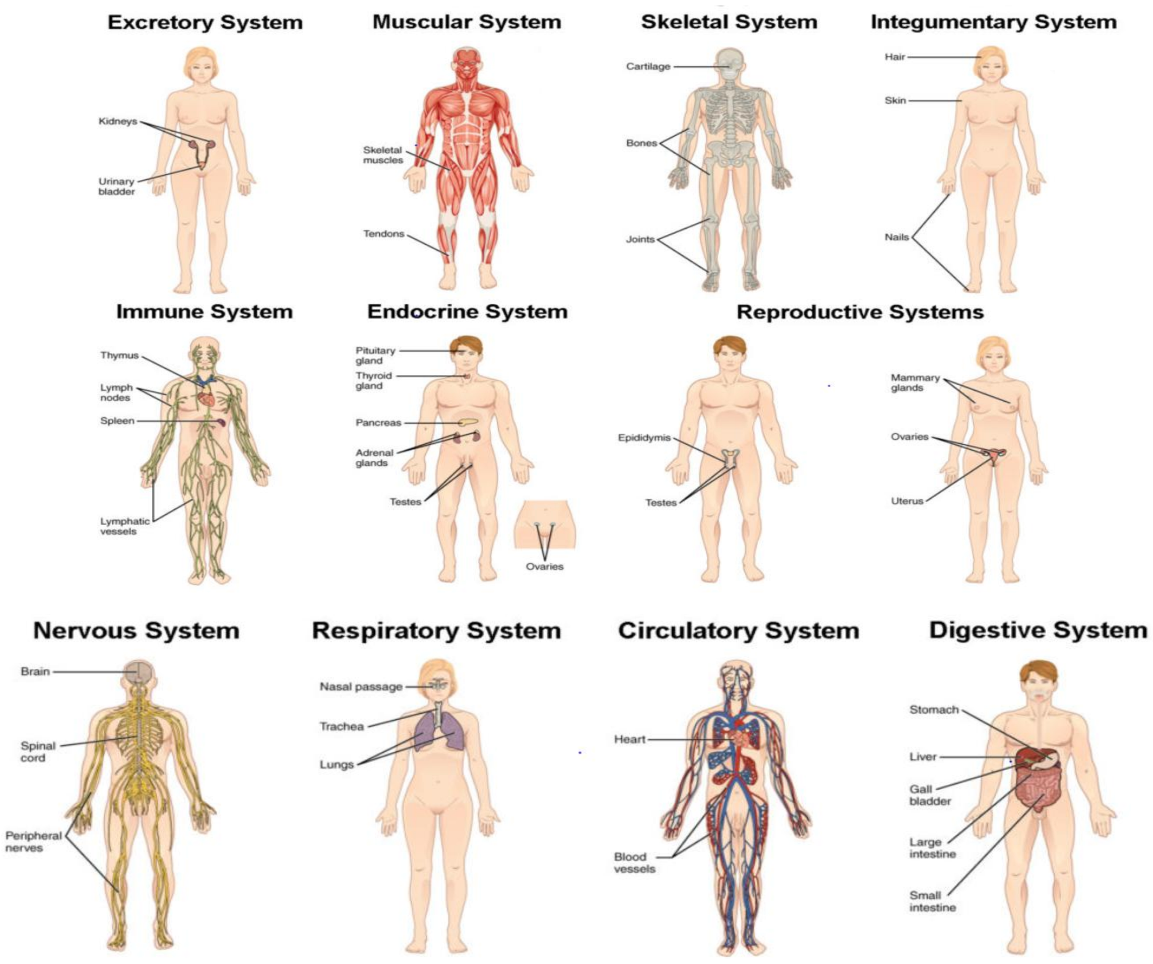

Figure 1.17: Organ system of human body (retrieved from lumenlearning.com)

4. *The Respiratory System*: The respiratory system is responsible for exchanging gases between the body and the environment. It consists of the lungs and airways, which include the trachea, bronchi, and bronchioles. The lungs allow for the exchange of oxygen and carbon dioxide, which is essential for the body to function properly.
5. *The Digestive System*: The digestive system is responsible for breaking down food and absorbing nutrients. It consists of the mouth, esophagus, stomach, small intestine, large intestine, liver, pancreas, and gallbladder. Digestive enzymes and acids aid in the breakdown of food, while nutrients are absorbed into the bloodstream for use by the body.
6. *The Nervous System*: The nervous system is responsible for controlling and coordinating all body functions. It consists of the brain, spinal cord, and nerves. The brain is the command center of the nervous system, while the spinal cord serves as a

pathway for signals to travel between the brain and the body. Nerves carry signals to and from the brain, allowing for movement, sensation, and other bodily functions.

7. *The Endocrine System*: The endocrine system is responsible for regulating hormone production and distribution throughout the body. It consists of several glands, including the pituitary gland, thyroid gland, adrenal glands, and pancreas. Hormones produced by these glands help regulate metabolism, growth, development, and other important bodily functions.
8. *The Immune System*: The immune system is responsible for defending the body against infections and diseases. It consists of white blood cells, lymph nodes, and lymphatic vessels. White blood cells are responsible for recognizing and attacking foreign substances in the body, while lymph nodes and lymphatic vessels help transport white blood cells throughout the body.
9. *The Urinary System*: The urinary system is responsible for filtering waste products from the body and maintaining fluid balance. It consists of the kidneys, ureters, bladder, and urethra. The kidneys filter waste products from the blood, while the ureters, bladder, and urethra help transport and eliminate urine from the body.
10. *The Integumentary System*: The integumentary system is responsible for protecting the body from external damage and regulating body temperature. It consists of the skin, hair, and nails. The skin is the largest organ of the body and serves as a protective barrier against injury

Check your Progress Exercise 2

1. What is tissue? Enlist the various types of simple epithelia

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2. Write the difference between cartilage and bone.

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3. Enlist different types of muscle tissue with one distinct characteristic of each.
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4. Explain different organ system in human body with examples
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1.6 LET'S US SUM UP

In this unit, we have learnt about the single cell and its remarkable ability for carrying out all essential functions such as digestion, respiration, excretion, and reproduction. Cell is the structural and functional unit of life. Human body is made up of billions of cells and each cell is efficient to perform the essential life process. We studied the different types of cell organelle and how they work to perform different life processes. In multicellular organism, specialized cells are grouped together and depended on one another for various functions such as digestion, excretion, reproduction locomotion, respiration etc. Thus in human, cells are specialized, depended on each other, functions in well organized manner to carry out all life processes. Furthermore, they coordinate their activities, exchange their materials and thus improve the performance of life process. In this unit, we also learnt about different types of tissue, muscle, organs and organ system and their functions.

1.7 GLOSSARY

Adipocytes : a oval fat cells in adipose tissue.

Amphiphilic : refers to a molecule or compound that possesses both hydrophilic and hydrophobic properties**.**

Anatomy : is the study of structures that make up the body and how those structures relate with each other.

Autophagy : is a cellular process by which damaged or unnecessary components of a cell are degraded and recycled. It involves the formation of double-membrane vesicles called autophagosomes that engulf cellular material and fuse with lysosomes for degradation.

Chromosome : are thread-like structures composed of DNA and proteins. They carry genetic information in the form of genes

Cisternae : **a** flattened, stacked membrane compartments found in various cellular structures, such as the endoplasmic reticulum (ER) and Golgi apparatus. They serve as sites for storage, modification, and transport of molecules within the cell.

Cristae : inwardly folded structures found in the inner membrane of mitochondria. They provide an increased surface area for various metabolic reactions,

Endocytosis : is a cellular process by which cells internalize substances from the extracellular environment. It involves the formation of a vesicle that engulfs the desired molecules and brings them into the cell.

Microtubules : are hollow cylindrical structures made of tubulin protein subunits.

They play a crucial role in maintaining cell shape and formation of spindle fibers during cell division

RER : is a network of membrane-bound tubules and flattened sacs studded with ribosomes. It is involved in protein synthesis.

SER : a cellular organelle lacks ribosomes on its surface and is primarily responsible for the synthesis of lipids and the detoxification of harmful substances in the cell.

Perikaryon : also known as the cell body or soma, is the main part of a neuron that contains the nucleus and other organelles.

1.8ANSWER TO CHECK YOUR PROGRESS EXERCISES

Check your Progress Exercise 1

1. Cells are the smallest functional and structural units of life. It is capable of independent existence. Within the cytoplasm, the major organelles and cellular structures include: (1) nucleus (2) ribosome (3) endoplasmic reticulum (4) Golgi apparatus (5) mitochondria (6) lysosome (7) centrioles.

2.

a) Primary function of mitochrondria is generating cell's energy in the form of ATP through the process of oxidative phosphorylation.
b) The three primary functions of the Golgi apparatus are the transport, sorting and modification of both protein and lipid.
c) Lysosomes act as a digestive system of cell. It breakdown and digest all macromolecules and foreign substance.
d) Endoplasmic reticulum is an important site of protein synthesis, lipid metabolism, and detoxification.
e) The centrosome is responsible for organizing microtubules during cell division and is involved in the formation of the spindle apparatus, which is necessary for proper chromosome segregation during mitosis.

Check your Progress Exercise 2

1. Tissue refers to a group of cells that are similar in structure and arranged together in an organized manner to perform specific functions. The simple epithelia consist of a single layer of cells. They are further divided into five types according to the form and structure of their cells as follows:

- **a)** Simple squamous,
- **b)** Simple cuboidal,
- **c)** Simple columnar,
- **d)** Simple ciliated and
- **e)** Pseudostratified.

2.

S.no.	**Bone**	**Cartilage**
1	It is rigid and non flexible connective tissue	It is flexible connective tissue
2.	Matrix is made up of organic and inorganic salts (predominant of calcium salts)	Matrix is made up of organic mainly.
3.	Matrix is arranged in concentric circle	Matrix is not arranged in circle, occur in homogenous mass
4.	Bone cell is known as osteocyte	Cartilage is known as chondrocytes.
5.	Bone is covered with tough sheath, periosteum.	Cartilage is covered with firm sheath, perichondrium.
6.	Rich in blood supply	Lack blood supply

3. There are 3 distinct types of muscle tissue: cardiac, smooth, and skeletal.

Cardiac muscle tissue is specifically found within the heart walls, exhibits a striped or striated appearance, and is controlled involuntarily.

Smooth muscle tissue, on the other hand, lines the walls of hollow visceral organs, excluding the heart. It appears spindle-shaped and, like cardiac muscle, is under involuntary control.

Lastly, skeletal muscle tissue is primarily connected to the skeleton, allowing for body movement. It is also striated in appearance but differs in that it is under voluntary control and are under voluntary control (, meaning we can consciously control its contraction and relaxation).

4. The human body is composed of several organ systems that work together to perform various functions necessary for survival. They are:

a) The Skeletal System: bone , cartilage
b) The Muscular System: eg. skeletal muscles, cardiac muscles.
c) The Circulatory System: eg heart, blood vessels
d) The Respiratory System: eg. lungs, trachea
e) The Digestive System: eg. intestine, liver
f) The Nervous System: eg brain, spinal cord
g) The Endocrine System: eg. pituitary gland, thyroid gland
h) The Immune System: eg. lymph nodes, lymphatic vessels
i) The Urinary System: eg. kidney, ureters
j) The Integumentary System: e.g. Skin, hair

UNIT 2 BLOOD AND LYMPHATIC SYSTEM

Structure

2.1 Introduction

2.2 Blood

  2.2.1 Composition of Blood

  2.2.2 Function of Blood

2.3 Plasma

  2.3.1 Composition of Plasma

  2.3.2 Functions of Plasma

2.4 Plasma Protein

2.4.1 Albumin

2.4.2 Globulin

2.4.3 Fibrinogen

2.5 Red Blood Corpuscles (RBC)

2.5.1 Morphology of RBC

2.5.2 Life Cycle of Red Blood Cells:

2.5.3 Functions of RBC

2.5.4 Clinical Significance

2.6 Leukocytes

2.6.1 Types of Leukocytes

2.6.2 Functions of Leukocytes

2.6 Lymphatic System

2.6.1 Structure and Functions

2.6.2 Structure and Functions of Lymphatic Nodes

2.7 Let Us Sum Up

2.8 Glossary

2.9 Answer to Check Your Progress

2.1 INTRODUCTION

The blood and lymphatic systems are essential parts of the human body that work together to maintain homeostasis and protect the body from disease. The blood system is responsible for circulating oxygen, nutrients, hormones, and other essential substances throughout the body, while the lymphatic system is responsible for draining excess fluid and waste products from the tissues and transporting immune cells to fight infections. Both systems are interconnected and play crucial roles in maintaining the body's overall health and function.

Blood is a specialized fluid that circulates through the arteries, veins, and capillaries of the body. It is composed of plasma, a clear yellowish liquid that makes up about 55% of the blood volume, and formed elements, which include red blood cells, white blood cells, and platelets. Red blood cells, or erythrocytes, are the most abundant cells in the blood and are responsible for carrying oxygen from the lungs to the body tissues. White blood cells, or leukocytes, are a diverse group of cells that play important roles in the immune system, defending the body against infection and disease. Platelets, or thrombocytes, are tiny cells that are responsible for blood clotting and preventing excessive bleeding. The lymphatic system, on the other hand, is a network of vessels and organs that help maintain fluid balance in the body and play a critical role in the immune system. The lymphatic vessels carry lymph, a clear fluid that contains white blood cells and waste products, from the tissues back to the bloodstream. Along the way, lymph nodes filter and trap foreign substances, such as bacteria, viruses, and cancer cells, and activate immune cells to destroy them.

Overall, the blood and lymphatic systems work together to ensure the proper function of the body and protect it from harm. A better understanding of these systems is essential for the diagnosis, treatment, and management of various medical conditions, including blood disorders, infections, and cancer. This chapter introduces the component of blood, their structure and its role for proper functioning of human body. Furthermore, in this unit we shall unfold the composition and functioning of lymphatic system.

Expected Outcomes

After studying this unit, you will be able to:

- describes physical composition and role of blood.
- discuss the composition and function of plasma protein.
- explain the structure and role of RBC.
- explain the types of Lymphocytes and its role.
- describe the lymphatic system and its importance in human body

2.2 BLOOD

Blood, as you learn earlier, is a fluid connective tissue that circulates throughout the body. It is a thick, sticky fluid and bright red in colour when oxygenated. The normal temperature of blood in humans is 98.6°F (37°C) and has a slightly alkaline pH ranging from 7.35 to 7.45. The human body contain on an average 5 litre of blood.

Let us get to know more about the composition of blood.

2.2.1 Composition of blood

Blood is a fluid connective tissue that is composed of watery fluids (plasma) and formed cells as shown in figure 2.1.

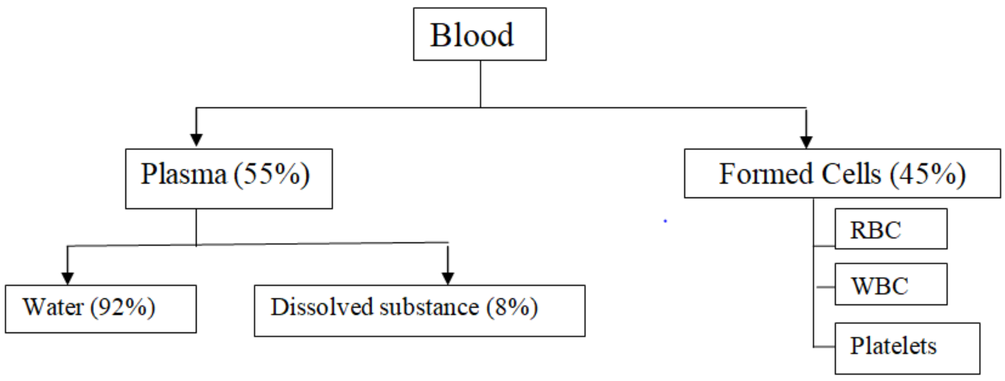
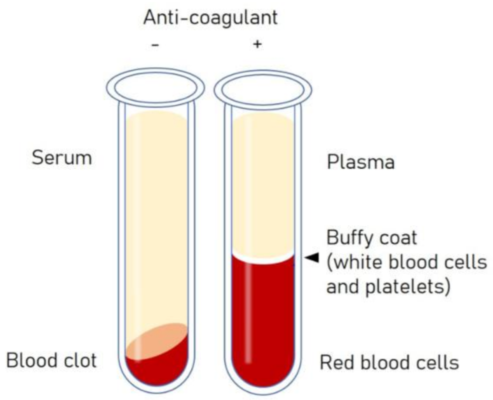


Figure 2.1: Composition of blood

i. **Plasma:** This is the liquid part of blood and contains various proteins, electrolytes, hormones, and nutrients.

ii. **Formed cells:** Formed cells are the floating bodies in plasma which comprises red blood corpuscles, white blood corpuscles and platelets. We can separate the formed elements from fluids by following steps:

- Collect the blood in test tube.
- Prevent the coagulation of blood by adding anticoagulant in the collected human blood.
- Then centrifuge the blood sufficiently.
- The formed cells get collected in lower layer and fluid in upper layer as illustrated in figure 2.2.



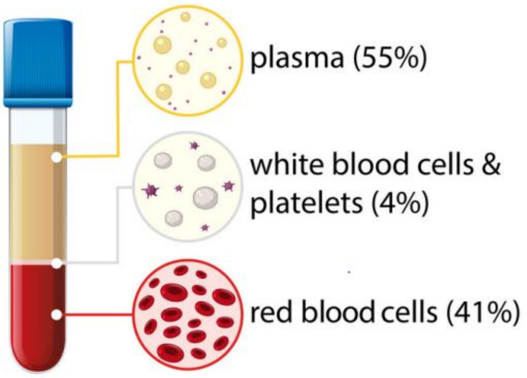
➢ 

Figure 2.2: Separation of plasma and blood cells

a) Red Blood Cells (RBCs) or Erythrocytes: These cells carry oxygen to the body's tissues and organs. They contain haemoglobin, a protein that binds to oxygen.
b) White Blood Cells (WBCs) or Leukocytes: These cells are involved in the body's immune response and help fight infections.
c) Platelets or Thrombocytes: These cell fragments are involved in blood clotting and help to prevent excessive bleeding.

Although, if blood is allow to clot and then centrifuge to separate the clot from the liquid portion. As a result, the liquid portion that separates from the clot is referred to as serum.

2.2.3 Functions of blood

1. Oxygen delivery: RBCs transport oxygen from the lungs to the body's tissues and organs.

2. Carbon dioxide removal: RBCs also help to remove carbon dioxide, a waste product of metabolism, from the body's tissues and transport it to the lungs for exhalation.
3. Immune response: WBCs help to protect the body from infections by identifying and attacking foreign invaders, such as bacteria and viruses.
4. Blood clotting: Platelets are involved in the formation of blood clots, which helps to prevent excessive bleeding.
5. Nutrient and hormone transport: Blood carries nutrients and hormones to the body's cells and tissues.
6. Waste product removal: Blood helps to remove waste products, such as urea, from the body.
7. pH balance: Blood helps to maintain the body's acid-base balance by regulating the pH level.

2.3 PLASMA

After studying the blood, let’s move to learn main component of blood i.e. plasma.

Blood plasma is the liquid component of blood, which makes up about 55% of the total blood volume. It is pale yellow in colour and a complex mixture of water, electrolytes, proteins, hormones, nutrients, and waste products. It is slightly alkaline and plays a vital role in maintaining the body's internal environment and supporting the proper functioning of the body's cells and tissues.

2.3.1 Composition of Plasma

As you know plasma is a mixture of different compounds. Do you know different components of plasma and their significance?

It is a clear, yellowish liquid that is composed mainly of mostly a watery component. It constitute of about 90-92% of water, and 8-10% of solid which comprises 7-8% of proteins, 1% of inorganic salts and 1-2% of water materials, dissolved gases and other regulatory substances. . Let us learn about the functions of plasma proteins in greater detail:

Composition: The various components of blood plasma include:

1. *Water:* Water is the largest component of blood plasma, accounting for about 90% of its volume. It acts as a solvent, dissolving and transporting various solutes throughout the body.
2. *Electrolytes:* Blood plasma contains a variety of ions such as sodium, potassium, chloride, calcium, and magnesium, which help to maintain the body's fluid balance, acid-base balance, and electrical conductivity. These electrolytes are important for various physiological processes such as nerve and muscle function, and regulating blood pressure.
3. *Proteins:* Blood plasma contains a wide range of proteins, which play various roles in the body. The most abundant protein in blood plasma is albumin, which helps to maintain blood pressure and transport various molecules such as hormones and drugs. Other proteins in blood plasma include globulins, which are involved in immune function, and fibrinogen, which plays a key role in blood clotting.
4. *Hormones:* Blood plasma carries a variety of hormones such as insulin, glucagon, and thyroid hormones, which regulate various bodily functions including metabolism, growth, and development.
5. *Nutrients:* Blood plasma carries various nutrients such as glucose, amino acids, and fatty acids, which are delivered to the body's cells and tissues for energy production and other metabolic processes.
6. *Waste products:* Blood plasma also carries waste products such as urea and creatinine, which are removed from the body by the kidneys.

2.3.2 Functions of plasma

Blood plasma is a vital component of the circulatory system, and plays a critical role in maintaining the body's internal environment and supporting the proper functioning of the body's cells and tissues. Its complex composition and diverse functions make it essential for life and health. Let us get to know about these functions:

1. *Maintaining fluid balance:* Blood plasma helps to maintain the body's fluid balance by transporting water and electrolytes throughout the body. Electrolytes in blood plasma help to regulate the amount of fluid in and out of cells, and ensure that the body's cells have the right balance of ions to function properly.
2. *Transporting nutrients and hormones:* Blood plasma carries nutrients and hormones throughout the body, delivering them to the body's cells and tissues where they are

needed. For example, glucose is transported to cells where it is used for energy production, and hormones such as insulin and glucagon are transported to cells where they regulate blood sugar levels.

3. *Immune function*: Blood plasma contains various proteins such as immunoglobulins and complement proteins, which help to protect the body from infection and disease by identifying and neutralizing foreign invaders such as bacteria and viruses.
4. *Blood clotting:* Blood plasma contains fibrinogen, which is converted to fibrin to form blood clots when there is an injury or damage to blood vessels. This process helps to prevent excessive bleeding and promote healing.
5. *pH balance:* Blood plasma helps to maintain the body's acid-base balance by regulating the pH level of the blood. Electrolytes in blood plasma help to regulate the amount of acid and base in the blood, and prevent pH imbalances that can interfere with bodily functions.
6. *Waste removal:* Blood plasma carries waste products such as urea and creatinine, which are removed from the body by the kidneys. This process helps to maintain the body's internal environment and prevent the buildup of harmful substances in the blood.

2.4 PLASMA PROTEIN

Plasma proteins are diverse group of protein found in the blood plasma that plays an important role in maintaining the normal functioning of the human body. Normal concentration of plasma protein is 6-8g/100g of plasma. They play important roles in various physiological processes, including maintaining the osmotic balance of blood, transporting nutrients and hormones, and regulating blood clotting and the immune response. There are many different types of plasma proteins, each with its own unique structure and function.

Let us learn about the different types of proteins and their functions in greater details:

Major types of protein group are:

● Albumin

● Globulin

● Fibrinogen

2.4.1 Blood Albumin

Blood albumin is an important protein that is found in the plasma of the blood. It is produced by the liver and accounts for approximately 60% of the total protein content in the plasma. Albumin is a highly versatile protein and is involved in several critical physiological functions in the human body.

Functions of Blood Albumin:

- **i.** *Maintenance of Osmotic Pressure:* Albumin plays an important role in maintaining the oncotic pressure of the blood. The oncotic pressure is the pressure exerted by proteins in the blood, which helps to maintain the fluid balance between the blood vessels and the surrounding tissues. Albumin is a small and water-soluble protein that can easily pass through the walls of the blood vessels and into the surrounding tissues. It helps to maintain the oncotic pressure by retaining water within the blood vessels and preventing it from leaking out into the surrounding tissues.
- **ii.** *Transport of Substances:* Albumin is involved in the transport of several substances in the blood. It is capable of binding to a wide range of molecules such as hormones, fatty acids, and drugs. It acts as a carrier protein and helps to transport these molecules to their target cells or organs.
- **iii.** *Maintaining pH balance:* Albumin helps maintain the pH balance of the blood by neutrilizing acids and bases. The buffering action of albumin is attributed to histidine residues.

2.4.2 Globulin

Globulin is the second most abundant protein in the plasma, accounting for about 35% of the total protein. Globulin is a type of protein that is found in the blood plasma and other bodily fluids. It is produced by the liver and the immune system and is an important component of the body's defense mechanism against infections and diseases. Globulin is further divided into: alpha-globulin, beta-globulin and gamma globulin. Each type has a unique function in the body.

Functions of Globulin:

i. *Immune Response:* Globulin is an important component of the immune system. It is produced by the immune cells and helps to identify and neutralize foreign substances such as bacteria, viruses, and toxins. The antibodies that are produced by the immune cells are also a type of globulin. These antibodies recognize the foreign substances and bind to them, marking them for destruction by other immune cells.

ii. *Transport of Substances:* Globulin is involved in the transport of various substances in the blood. For example, transferrin, a type of globulin, is involved in the transport of iron in the blood. It binds to iron and transports it to the bone marrow, where it is used to produce new red blood cells.

iii. Blood clotting: Certain types of globulin, such as prothrombin and fibrinogen play a role in blood clotting.

2.4.3 Fibrinogen

Fibrinogen is a large, complex protein that is found in blood plasma. It plays a key role in the process of blood clotting, which is essential for wound healing and preventing excessive bleeding. Fibrinogen is produced in the liver and circulates in the blood in an inactive form until it is needed for clot formation. Fibrinogen levels can be measured through a blood test called a fibrinogen assay. This test is used to evaluate the risk of thrombosis, monitor the progress of certain diseases, and assess the response to treatment. Elevated levels of fibrinogen are associated with an increased risk of cardiovascular disease, stroke, and thrombosis. In contrast, low levels of fibrinogen are associated with bleeding disorders such as hemophilia.

Function:

i. *Blood clotting:* Fibrinogen plays a critical role in the process of blood clotting, which is essential for wound healing and preventing excessive bleeding. When a blood vessel is damaged, a complex series of reactions known as the coagulation cascade is initiated to form a blood clot. Fibrinogen is converted to fibrin by the action of the enzyme thrombin, which is generated during the coagulation cascade. Fibrin molecules then aggregate to form a mesh-like structure that traps platelets and red blood cells to form a stable blood clot.

ii. *Immune response*: Fibrinogen has been shown to interact with various immune cells and contribute to the immune response.

iii. *Other:* Fibrinogen also plays a role in other physiological processes, such as inflammation and wound healing. . In addition, fibrinogen has been shown to promote cell adhesion, migration, and proliferation, which are important for tissue repair and regeneration.

CHECK YOUR PROGRESS EXERCISE 1

1. Explain the composition of blood
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2. Define plasma and serum. How can plasma be separated from whole blood?
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3. What are the different types of plasma proteins and what is their distinct function?

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Next, let us study about the cells found in the blood.

2.5 RED BLOOD CORPUSCLES

Red blood corpuscles, also known as red blood cells (RBCs), or erythrocytes, are one of the major components of blood. They play a critical role in carrying oxygen from the lungs to the body's tissues and removing carbon dioxide from the body. They are the most numerous cells in the human body. The number of red cells in the blood is about 5 million per cubic mm of blood in normal healthy adult. It is about 0.5 million per cubic mm higher in men than women and higher in those living at high altitude than those living at sea level. RBCs occupy about 45% of the blood volume. This figure is referred to as "*Packed Cell Volume"* (PCV) or haematocrit. The unique feature of RBC is the presence of iron containing pigments called haemoglobin which gives it a red colour. Haemoglobin is a protein responsible for binding and carrying oxygen. Haemoglobin is made up of four subunit of polypeptide chains, each of which is bound to a heme group as shown in figure 2.3. Each heme group contains an iron atom, which is responsible for binding to oxygen molecules. The high concentration of haemoglobin in red blood cells allows them to carry large amounts of oxygen. The concentration of haemoglobin in blood is about 15g/100ml of blood. The amount of haemoglobin per unit volume of red cell mass, expressed as a percentage and known as *Mean Corpuscular Haemoglobin Concentration (MCHC).*The average size and volume of RBC in given blood sample is *called "Mean Corpuscular Volume (MCV)"*. It is calculated by dividing the total volume of packed red blood cells (PCV) with the total number of red blood cells present in the sample. The result provides an indication of the average volume of individual red blood cells.

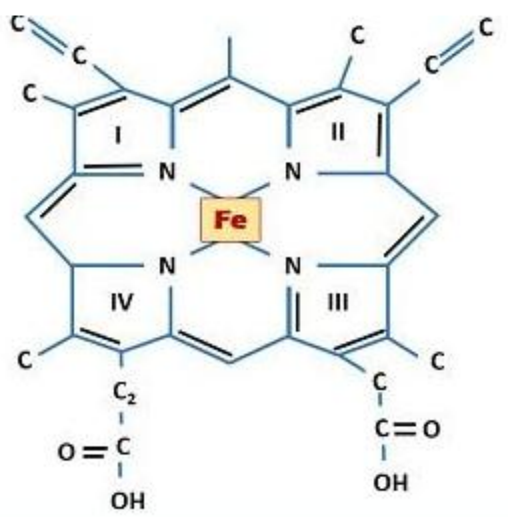

Figure 2.3: Structure of haemoglobin

Let us study about the morphology, life cycle and function of RBC in next section

2.5.1 Morphology of RBC

RBCs are small, biconcave, enucleated discs with a diameter of about 7.5 microns, maximum thickness at the edges is about 2.5 microns and minimum thickness in the center is about 0.8 microns. As you can see in figure 2.4, RBC is biconcave in shape, meaning they are thinner in the middle than at the edges, giving them a distinctive shape. The unique biconcave shape provides flexibility and also facilitate for easy pass through narrow blood vessels and capillaries. Red blood cells are also able to deform and change shape in response to changes in blood flow. In addition, biconcave shape of RBCs allows for a larger surface area-to-volume ratio, which increases the efficiency of oxygen exchange with neighboring cells and tissues. Furthermore, this shape of blood cells is essential for their function, as it allows them to pass through narrow capillaries and maximize their surface area for gas exchange.

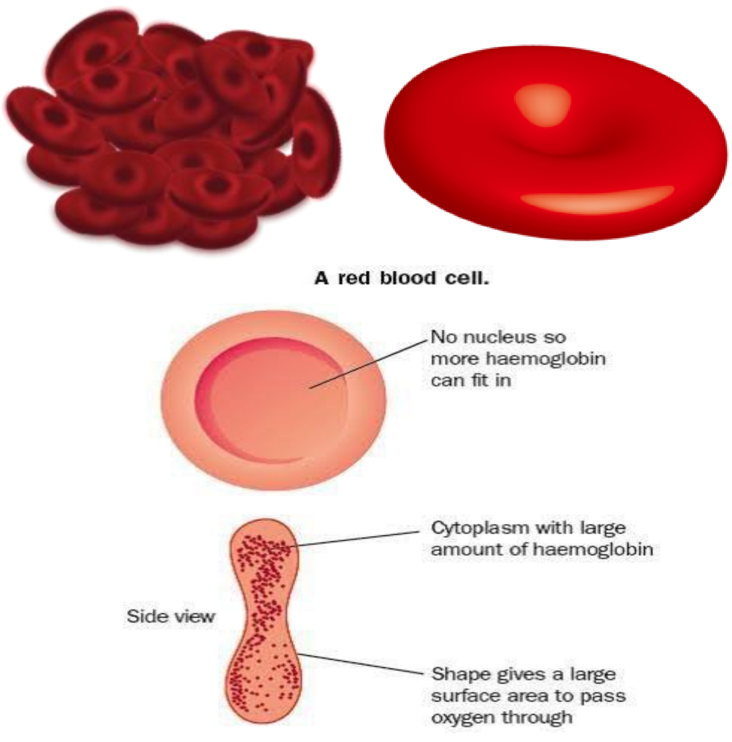

Figure 2.4: Structure of RBC

Let us now further study about the cell structure of RBCs

It contains cytoplasm which loses its nucleus and other cell membrane bounded organelle during development which allows them to have more space for haemoglobin, and the protein responsible for oxygen transport. In addition, it is bounded by an elastic plasma membrane which enables them to squeeze through capillaries. The membrane of red blood cells is composed of a lipid bilayer that contains a variety of proteins, including integral membrane proteins and peripheral membrane proteins. The membrane proteins play an important role in maintaining the shape and flexibility of the cell.

Let us get to know about life cycle of red blood cells.

2.5.2 Life Cycle of Red Blood Cells

What is the life span of erythrocytes? The lifespan of RBC is approximately 120 days during which they undergo constant wear and tear. Old cells are destroyed and replaced by the new ones. To maintain their structural integrity, RBCs contain a protein called spectrin that forms a mesh-like network around the cell membrane. As they age, they become less flexible and more rigid, making them more susceptible to destruction. The spleen and liver are responsible for removing old and damaged red blood cells from circulation. The production of red blood cells is regulated by a hormone called erythropoietin, which is produced by the kidneys in response to low oxygen levels in the blood. Erythropoietin stimulates the bone marrow to produce new red blood cells, a process known as erythropoiesis. You would be curious to know about erythropoiesis and how the erythrocytes or RBC is continuously produced. Firstly, What is erythropoiesis?

Erythropoiesis is the process by which red blood cells, or erythrocytes, are produced in the bone marrow. The life cycle of red blood cells, also known as erythrocytes, involves several stages and a complex process called erythropoiesis. Let's explore the stages and process of erythropoiesis in detail:

i. *Hematopoietic Stem Cell (HSC) Formation*: Erythropoiesis begins with the formation of hematopoietic stem cells (HSCs) in the bone marrow. These pluripotent cells have the ability to differentiate into various blood cell types, including red blood cells.
ii. *Proerythroblast Stage*: HSCs differentiate into proerythroblasts, which are large cells with a round nucleus and basophilic cytoplasm. Proerythroblasts undergo rapid cell division to produce a population of cells committed to becoming red blood cells.

iii. *Basophilic Erythroblast Stage:* Basophilic erythroblasts are the next stage in erythropoiesis. They have a smaller size compared to proerythroblasts and contain more cytoplasm. During this stage, the cells synthesize hemoglobin, the protein responsible for oxygen transport.

iv. *Polychromatic Erythroblast Stage*: Polychromatic erythroblasts are characterized by the presence of both basophilic and acidophilic cytoplasm. The cells continue to synthesize hemoglobin and undergo nuclear condensation.

v. *Orthochromatic Erythroblast Stage*: Orthochromatic erythroblasts have a smaller nucleus and predominantly acidophilic cytoplasm. The nucleus is eventually expelled from the cell, resulting in the formation of a reticulocyte.

vi. *Reticulocyte Stage*: Reticulocytes are immature red blood cells that contain remnants of ribosomal RNA, giving them a reticular or granular appearance under a microscope. Reticulocytes are released into the bloodstream and circulate for about 1-2 days before maturing into fully functional red blood cells.

vii. *Maturation of Red Blood Cells:* During their circulation in the bloodstream, reticulocytes undergo maturation, during which their organelles are further broken down. The final stage of maturation involves the loss of the reticular appearance, resulting in the formation of mature, biconcave-shaped red blood cells.

The entire process of erythropoiesis is tightly regulated by various factors, particularly the hormone erythropoietin (EPO), which is produced by the kidneys in response to low oxygen levels in the blood. EPO stimulates the production and maturation of red blood cells, ensuring the body maintains an adequate supply to carry oxygen to tissues and organs. Overall, erythropoiesis is a highly regulated and dynamic process that ensures the continuous production of red blood cells, allowing for the proper functioning of oxygen transport in the body.

Now, after having a basic understanding about how RBC look like and about its life span, let us move on to study its role in our body in detail.

2.5.3 Functions of RBC

1. *Transportation of oxygen***:** RBCs are responsible for the transportation of oxygen from the lungs to the body tissues. Oxygen is essential for the survival of every cell in the human body as it is required for the process of cellular respiration. RBCs contain

haemoglobin, a protein that binds to oxygen and allows it to be transported in the blood. You would be surprised to learn that one gram of haemoglobin carries 1.34 cc of oxygen. Once the RBCs reach the tissues, the haemoglobin releases the oxygen to be used in cellular respiration. Further, capacity of RBC to carry haemoglobin in the cell fluid is upto about 34g/dl of cells.

2. *Transportation of carbon dioxide:* RBCs are responsible for the transportation of carbon dioxide from the body tissues to the lungs. Carbon dioxide is produced as a waste product of cellular respiration and must be removed from the body to maintain proper pH levels. RBCs contain carbonic anhydrase, an enzyme that converts carbon dioxide into bicarbonate ions. These ions are then transported back to the lungs where they are converted back into carbon dioxide and exhaled.
3. *Maintaining pH balance:* RBCs play a crucial role in maintaining the pH balance of the body. The carbonic anhydrase enzyme in RBCs also helps to regulate the amount of carbonic acid in the blood. Carbonic acid is a weak acid that can lower the pH of the blood if its levels are too high. RBCs help to regulate the levels of carbonic acid by converting it into bicarbonate ions, which are less acidic. This process helps to maintain the pH balance of the blood within a narrow range, which is necessary for proper bodily function.

2.5.4 Clinical Significance

Red blood cells, or erythrocytes, have a significant clinical significance in several ways. Abnormalities in their number, size, shape, and function can provide important diagnostic and prognostic information. Here are some of the clinical significances of red blood cells:

1. *Anemia***:** Anemia is a condition in which there is a decrease in the number of red blood cells or haemoglobin concentration. It can be caused by various factors, including iron deficiency, vitamin B12 or folate deficiency, blood loss, chronic diseases, and hereditary disorders. Anemia can lead to fatigue, weakness, shortness of breath, and other symptoms, and its severity depends on the extent and duration of the reduction in red blood cells.
2. *Polycythemia:* Polycythemia is a condition characterized by an increase in the number of red blood cells. It can be primary, caused by a disorder in the bone marrow, or

secondary, caused by hypoxia, dehydration, or other factors. Polycythemia can lead to an increased risk of thrombosis, hypertension, and other complications.

3. *Hemolytic anemia:* Hemolytic anemia is a type of anemia caused by the destruction of red blood cells. It can be caused by inherited disorders, autoimmune diseases, infections, drugs, or other factors. Hemolytic anemia can lead to jaundice, gallstones, and other complications.
4. *Sickle cell disease*: Sickle cell disease is an inherited disorder that affects the shape of red blood cells. The abnormal haemoglobin causes the cells to form a sickle shape, which can lead to blockages in blood vessels and damage to organs. Sickle cell disease can cause pain, infections, strokes, and other complications.
5. *Haemoglobinopathies:* Haemoglobinopathies are a group of inherited disorders that affect the structure or function of haemoglobin. Examples include sickle cell disease, thalassemia, and haemoglobin C disease. Haemoglobinopathies can cause anemia, jaundice, and other complications.

Let us now move on to the next cell that is Leucocytes or WBC(White Blood Cells).

2.6 WHITE BLOOD CELLS (WBC) or LEUCOCYTES

White blood cells (WBCs), also known as leukocytes, are a crucial component of the immune system, protecting the body against pathogens and foreign substances. White blood cells also known as leukocytes, as they are colorless. Unlike red blood cells, WBCs are larger and have a distinct nucleus. They are produced in the bone marrow and circulate in the blood and lymphatic system, where they help protect the body against infections and diseases. They are the army of the human body. Whenever a germ or infection enters our body, the WBCs snap to attention and destroy the culprit. Their primary function is to produce antibodies (humoral immunity) or kill the invading bacteria directly (cytotoxic immunity). We will learn more about this later in this section.

2.6.1 Composition

White blood cells (WBC) are diverse in their function, morphology, and composition, and they can be classified into several types based on their structure and function. On basis of presence and absence of granules in the ,cytoplasm, WBCs are-divided into two types –

A. Granulocytes and

B. Agranulocytes.

Under the light microscope as shown in figure 2.5, granulocytes are further divided into basophils, eosinophils,neutrophils and agranulocytes are classified into monocytes and lymphocytes on the basis of:

1) Size

2) Granules

3) Nucleus, and

4) Nucleus1 Cytoplasmic ratio

Each type of leukocyte is present in the blood in different proportions:

Basophil : 0.5 - 1 %

Lymphocyte : 20 - 40 '%

Monocyte : 3 - 8%

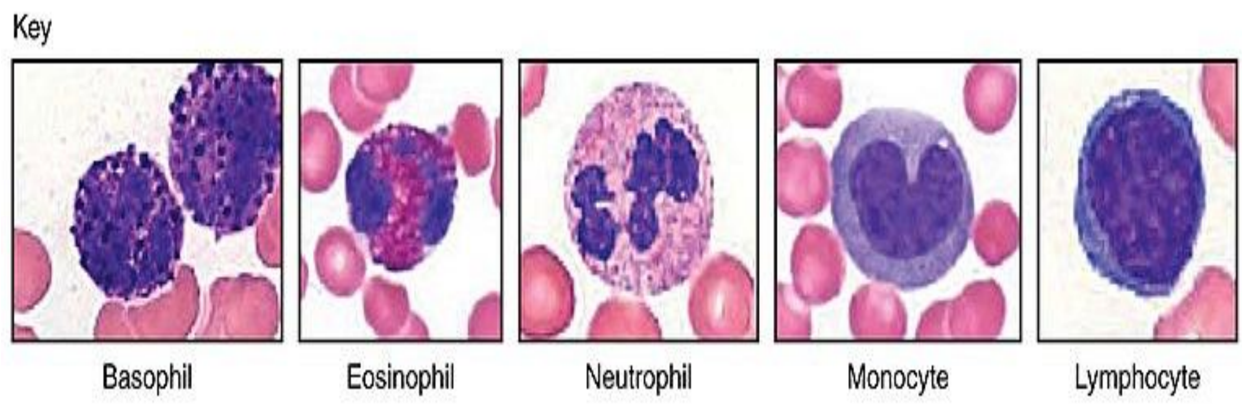

Figure 2.5: Types of WBC/Leucocytes

Here is an overview of the composition of white blood cells in detail:

A. **Agranulocytes:** Agranulocytes are a type of white blood cells (WBCs) that lack visible granules in their cytoplasm.

i. **Monocytes:** Monocytes are the largest type of white blood cells, making up about 6% of the total leukocyte count. They are precursors to macrophages, which are specialized cells that engulf and digest foreign substances and cellular debris. Monocytes are characterized by their kidney-shaped nucleus as can be seen in Figure 2.5.

Monocytes are a type of white blood cell (WBC) that play an important role in the body's immune system. They are produced in the bone marrow and circulate in the blood, but can also migrate into tissues where they differentiate into macrophages or dendritic cells. *Macrophages* are large, phagocytic cells that engulf foreign material (antigens) that enter the body and dead and dying cells of the bodv.

The main function of monocytes is to recognize and engulf foreign particles, such as bacteria or viruses, as well as dead or damaged cells, in a process known as phagocytosis. This allows the monocytes to help clear infections and debris from the body, and initiate the immune response. Monocytes can also play a role in activating and regulating other immune cells. They can release signaling molecules called cytokines, which stimulate the production and activity of other immune cells, including B cells and T cells. Additionally, monocytes can differentiate into macrophages or dendritic cells, which can present antigens to other immune cells and activate the adaptive immune response.

Abnormalities in monocyte levels or function can contribute to a range of medical conditions, including infections, autoimmune disorders, and some types of cancers. For example, deficiencies in monocyte function can result in increased susceptibility to infections, while abnormal proliferation of monocytes can lead to disorders such as chronic inflammation or leukemia.

ii. **Lymphocytes:**

Lymphocytes are the second most abundant type of white blood cells, making up about 30% of the total leukocyte count. They are responsible for coordinating the immune response and are divided into two main types: B cells and T cells.

B cells produce antibodies that recognize and neutralize foreign substances, while T cells play a crucial role in cell-mediated immunity, which involves the destruction of infected or cancerous cells.

Let shall look at the types of lymphocytes in detail:

There are two main types of lymphocytes:

a. B lymphocytes (B cells)

B lymphocytes, also known as B cells, are a type of white blood cell (WBC) that play a crucial role in the body's immune system. They are produced in the bone marrow and mature in the lymphoid tissues, such as the spleen and lymph nodes.

The main function of B cells is to produce antibodies that can bind to and neutralize pathogens such as bacteria and viruses. When a pathogen enters the body, it is recognized by B cells that have receptors on their surface that can bind to specific molecules on the surface of the pathogen, known as antigens. Once activated, the B cells rapidly multiply and differentiate into plasma cells, which produce and secrete large amounts of antibodies specific to the pathogen. Antibodies produced by B cells are highly specific to the pathogen that triggered their production. They can bind to the pathogen and neutralize it in a variety of ways, such as preventing it from entering cells or marking it for destruction by other immune cells. In addition to producing antibodies, B cells also play a role in immune memory. After an infection is cleared, a small population of memory B cells remains in the body, allowing the immune system to mount a faster and more effective response if the same pathogen is encountered again.

Abnormalities in B cell function or levels can contribute to a range of medical conditions, including infections, autoimmune disorders, and some types of cancers. For example, deficiencies in B cell function can result in increased susceptibility to infections, while abnormal proliferation of B cells can lead to disorders such as leukemia or lymphoma.

b. T lymphocytes (T cells).

T lymphocytes, also known as T cells, are a type of white blood cell (WBC) that play a crucial role in the body's immune system. They are produced in the bone marrow, but mature in the thymus gland.

T cells can be divided into several different subtypes, including helper T cells, cytotoxic T cells, regulatory T cells, and memory T cells. Each subtype has a specific role in the immune system.

- *Helper T cells* (also known as CD4+ T cells) play a key role in activating and coordinating the immune response. They recognize and bind to antigens presented by other cells in the body, such as antigen-presenting cells (APCs), and release cytokines that stimulate the production and activity of other immune cells, including B cells and cytotoxic T cells.
- *Cytotoxic T cells* (also known as CD8+ T cells) are responsible for recognizing and destroying cells that have been infected with viruses, as well as abnormal cells, such as cancer cells. They do this by recognizing and binding to antigens presented on the surface of the infected or abnormal cell, and releasing toxic substances that cause the cell to die.

Regulatory T cells play a role in regulating the immune response, helping to prevent excessive or inappropriate immune reactions that can cause damage to the body's own tissues. They do this by suppressing the activity of other immune cells, such as helper T cells and cytotoxic T cells.

- *Memory T cells*, similar to memory B cells, play a role in immune memory. After an infection is cleared, a small population of memory T cells remains in the body, allowing the immune system to mount a faster and more effective response if the same pathogen is encountered again.

Abnormalities in T cell function or levels can contribute to a range of medical conditions, including infections, autoimmune disorders, and some types of cancers. For example, deficiencies in T cell function can result in increased susceptibility to infections, while abnormal proliferation of T cells can lead to disorders such as lymphoma or autoimmune diseases.

B. Granulocytes: Granulocytes are a type of white blood cells (WBCs) that contain visible granules in their cytoplasm. They include neutrophils, eosinophils, and basophils.

i. Eosinophils:

Eosinophils are a type of white blood cell that makes up about 2-4% of the total leukocyte count. Eosinophils are characterized by their bi-lobed nucleus as illustrated in figure 2.5 and the presence of large granules in their cytoplasm, which contain enzymes and other proteins that help them to destroy foreign substances. When activated, eosinophils can release these granules, which can damage or kill parasites and other foreign cells, as well as contribute to inflammation and tissue damage.

Eosinophils are a type of white blood cell (WBC) that play a role in the body's immune system, particularly in response to parasitic infections and allergic reactions. They are produced in the bone marrow and circulate in the blood, but can also migrate into tissues where they become activated.In addition, it also play a role in allergic reactions by releasing substances that cause inflammation and allergic symptoms, such as histamine. This can lead to symptoms such as itching, swelling, and difficulty breathing.

Abnormalities in eosinophil levels or function can contribute to a range of medical conditions, including parasitic infections, allergic reactions, and some types of cancers. For example, increased eosinophil levels are often seen in patients with allergies or parasitic infections, while decreased eosinophil levels can occur in patients with certain immune system disorders.

ii. Basophils:

Basophils are the least abundant type of white blood cells, making up about 0.5-1% of the total leukocyte count. They are involved in the allergic response and the defense against parasitic infections. Basophils are characterized by their multi-lobed nucleus and granules that contain histamine and other inflammatory mediators. Basophils are a type of white blood cell (WBC) that play a role in the body's immune system, particularly in response to allergic reactions and parasitic infections. They are produced in the bone marrow and circulate in the blood, but can also migrate into tissues where they become activated.

Basophils are characterized by the presence of large granules in their cytoplasm, which contain substances such as histamine and heparin. When activated, basophils can release these granules, which can contribute to inflammation and allergic symptoms, such as itching, swelling, and difficulty breathing. Basophils also play a role in the immune response to parasitic infections by releasing substances that help to attract and activate other immune cells to fight the infection.

Abnormalities in basophil levels or function can contribute to a range of medical conditions, including allergies, parasitic infections, and some types of cancers. For example, increased basophil levels are often seen in patients with allergies, while decreased basophil levels can occur in patients with certain immune system disorders.

iii. Neutrophils

are the most abundant type of white blood cells, making up about 60% of the total leukocyte count. They are the first cells to arrive at the site of infection and play a crucial role in fighting bacterial and fungal infections. Neutrophils are characterized by their multi-lobed nucleus and granules that contain enzymes and proteins that are toxic to microorganisms.

Neutrophils are produced in the bone marrow and are released into the bloodstream where they circulate for a short period of time before migrating to the site of infection or inflammation. They are attracted to the site of infection by chemical signals, such as cytokines and chemokines, that are produced by damaged tissues and immune cells. Once they reach the site of infection, neutrophils can recognize and engulf foreign substances, such as bacteria and fungi, through a process called phagocytosis. Neutrophils can also release granules that contain antimicrobial proteins, such as defensins and lysozyme, which can directly kill microorganisms.

Neutrophils also play an important role in the inflammatory response. They can release cytokines and chemokines that recruit other immune cells to the site of infection and can cause vasodilation and increased permeability of blood vessels, which allows other immune cells and antibodies to enter the infected tissues.

Abnormalities in neutrophil counts or function can have significant clinical implications. An increase in neutrophil count, known as neutrophilia, may indicate bacterial or fungal infections, inflammation, or tissue damage. Conversely, a decrease in neutrophil count, known as neutropenia, may indicate viral infections, autoimmune disorders, or chemotherapy-induced suppression of the bone marrow. In some cases, abnormalities in neutrophil function, such as defects in phagocytosis or granule release, can lead to recurrent or severe infections.

In addition to these five types of white blood cells, there are other types of cells that are involved in the immune response, including natural killer cells, dendritic cells, and mast cells. Each type of white blood cell has a unique structure, function, and composition that allows it to play a specific role in the immune system.

Next, we shall look at the platelets.

2.8 PLATELETS

Platelets, also known as thrombocytes. Blood platelets, the third blood cells are the smallest irregularly shaped cell fragments as illustrated in figure 2.6. It play a crucial role in the process of blood clotting or hemostasis. Despite not being complete cells, they are essential for maintaining the integrity of the blood vessel walls and preventing excessive bleeding.

It is formed by the pinching of a very large bone marrow cell called megakaryocyte. Platelets literally mean a small plate. The platelets form a plug to stop bleeding when an injury disrupts the lining of the blood vessel. Their diameter is about 2-3 pm, hence they are much smaller than erythrocytes. Their density in the blood is 2,00,000-3,00,000 /mm3.

Functions of platelets: The main function of platelets, or thrombocytes, is to stop the loss of blood from wounds, i.e. haemostasis. Let us learn about the function of platelets in detail:

1. *Hemostasis:* Platelets are the primary players in the initial stages of blood clotting. When a blood vessel is damaged, platelets adhere to the site of injury, forming a temporary plug to stop bleeding. They release substances that promote vasoconstriction, reducing blood flow, and initiate the activation of other components involved in clot formation.
2. *Formation of blood clots:* Through a complex series of interactions with proteins and other platelets, platelets aggregate and form a stable blood clot. They release clotting

factors that activate a cascade of reactions, leading to the formation of fibrin, a protein that forms a mesh-like structure to strengthen and stabilize the clot.

3. *Wound healing:* Platelets release growth factors and cytokines that play a role in tissue repair and regeneration. These substances promote the proliferation of cells involved in the healing process, such as fibroblasts and endothelial cells, and stimulate the formation of new blood vessels.
4. *Immune response:* Platelets have immune-modulatory functions and can interact with immune cells. They can secrete and present immune-related molecules, contributing to the body's defense against pathogens.
5. *Maintenance of vascular integrity*: Platelets release substances that help maintain the integrity of blood vessel walls, such as platelet-derived growth factor (PDGF) and vascular endothelial growth factor (VEGF). These factors promote the growth and repair of blood vessels, ensuring their proper functioning.

Disorders related to platelets include thrombocytopenia (low platelet count), thrombocytosis (high platelet count), and platelet function disorders. These conditions can affect the ability of platelets to form clots or lead to abnormal clotting, increasing the risk of bleeding or clotting disorders.

It's important to note that platelets are not cells in the traditional sense but rather fragments of larger cells called megakaryocytes that are present in the bone marrow. Nonetheless, their role in hemostasis and wound healing is vital for maintaining the normal functioning of the circulatory system.

Process of blood clotting: The process of blood clotting, also known as coagulation, is a complex series of events that helps to stop bleeding and maintain the integrity of blood vessels. It involves the interaction of various components, including platelets, clotting factors, and the protein fibrin. The process can be divided into three main stages: vascular constriction, platelet plug formation, and coagulation cascade.

- *Vascular Constriction:* When a blood vessel is damaged, smooth muscle in the vessel wall contracts, causing vasoconstriction. This narrowing of the blood vessel reduces blood flow to the site of injury, helping to minimize blood loss.
- *Platelet Plug Formation:* Platelets play a crucial role in the initial formation of a clot. Upon exposure to the damaged vessel wall, platelets adhere to the site and become

activated. This activation causes them to change shape, release chemical signals, and aggregate together to form a platelet plug. The plug acts as a temporary seal to stop bleeding.

- *Coagulation Cascade:* The coagulation cascade is a series of complex reactions involving clotting factors, which are proteins in the blood. These factors interact with each other in a sequential manner to form a fibrin clot. The clotting factors are designated by Roman numerals, such as Factor I, Factor II, etc. The cascade can be activated through two pathways: the intrinsic pathway (contact activation) and the extrinsic pathway (tissue factor pathway). Both pathways eventually converge to a common pathway leading to the formation of fibrin.

In the clotting cascade, the activated clotting factors interact to convert a soluble protein called fibrinogen into insoluble fibrin threads. Fibrin strands form a mesh-like structure that traps blood cells, platelets, and plasma, creating a stable blood clot. The clot reinforces the platelet plug, further sealing the damaged vessel.

As the damaged blood vessel heals, the clot is gradually broken down and dissolved by enzymes called plasmin, allowing for tissue repair and restoration of normal blood flow.

It's important to note that blood clotting is a tightly regulated process to prevent excessive clotting (thrombosis) or inadequate clotting (hemorrhage). Any disruption or imbalance in the clotting process can lead to bleeding disorders or an increased risk of abnormal clot formation, such as deep vein thrombosis or pulmonary embolism.

Overall, the process of blood clotting is a remarkable and intricate system that helps to maintain the balance between preventing excessive bleeding and ensuring proper wound healing.

2.8 LYMPHATIC SYSTEM

The lymphatic system is a network of vessels, organs, and tissues that play a critical role in the body's immune system. It is responsible for maintaining the fluid balance in the body, filtering out harmful substances, and fighting off infections. The lymphatic system begins with lymphatic capillaries, which are small, thin-walled vessels located in most tissues of the body. These capillaries collect excess fluid and waste products from the tissues and transport them into larger lymphatic vessels. Lymphatic vessels are similar in structure to blood vessels, but they have thinner walls and larger gaps between their cells, allowing them to collect larger molecules and cells that cannot pass through blood vessel walls. These vessels eventually converge into larger lymphatic trunks, which drain into the thoracic duct or right lymphatic duct. These ducts empty into the bloodstream, where the filtered lymph is returned to the circulatory system.The lymphatic system also includes various lymphoid organs and tissues that play important roles in the immune system. These include the lymph nodes, which are small, bean-shaped structures located throughout the body that filter out foreign substances and produce immune cells to fight off infections. Other lymphoid organs include the spleen, which filters the blood and removes old or damaged blood cells, and the thymus, which produces T cells. The lymphatic system is crucial in defending the body against infections and disease. Lymphatic vessels and lymphoid tissues are involved in the production and circulation of lymphocytes, a type of white blood cell that is important in fighting infections. The lymphatic system also plays a role in removing waste products and excess fluid from the body.

2.81 Component of Lymphatic System

The lymphatic system is composed of a variety of components, including lymphatic vessels, lymphoid organs, and lymphatic tissues. Here are some of the main components of the lymphatic system:

Lymph: Lymph is a clear fluid that is part of the body's immune system and circulates through the lymphatic system. It is derived from blood plasma and contains a variety of components, including immune cells, proteins, and waste products. Lymph is formed from fluid that leaks out of the capillaries in tissues and organs. This fluid, called interstitial fluid, contains nutrients, oxygen, and other substances that are needed by cells. Unlike blood, it is a colourless fluid tissues as it lacks red blood cells and haemoglobin. Although, it contains fewer blood protein, and calcium.

Lymphatic capillaries: Lymphatic capillaries are the smallest vessels in the lymphatic system and are responsible for collecting lymphatic fluid from tissues and returning it to the bloodstream. They are located in the spaces between cells and are similar in structure to blood capillaries, but with some important differences.The walls of lymphatic capillaries are permeable, meaning that they allow larger particles, such as cells and proteins, to enter into the lymphatic system. This is important because lymphatic fluid contains immune cells, such as lymphocytes and macrophages, that can recognize and destroy pathogens, as well as cancer cells and other foreign substances. Lymphatic capillaries are found throughout the body, but are most abundant in tissues that are rich in blood vessels, such as the skin, lungs, and digestive tract. They are also present in lymph nodes, where they play a critical role in filtering and purifying lymphatic fluid.

Abnormalities in lymphatic capillaries can lead to a range of medical conditions, including lymphedema, which is a swelling of the limbs caused by an accumulation of lymphatic fluid. Understanding the structure and function of lymphatic capillaries is therefore important for maintaining overall health and immune function.

Lymphatic vessels: These vessels are thin-walled tubes that run throughout the body and collect lymph, a clear fluid that contains immune cells, waste products, and excess fluid from tissues. The lymphatic vessels transport lymph from the tissues and return it to the bloodstream. Lymphatic vessels are a network of tubes that transport lymphatic fluid from the tissues to the lymph nodes and eventually back to the bloodstream. These vessels are an essential part of the lymphatic system, which is responsible for maintaining fluid balance in the body and supporting the immune system.

Lymphatic vessels are similar in structure to blood vessels, but with some important differences. They are composed of three layers: an inner layer of endothelial cells, a middle layer of smooth muscle, and an outer layer of connective tissue. The endothelial cells are responsible for regulating the flow of lymphatic fluid into and out of the vessels.

Lymphatic vessels are located throughout the body, but are most concentrated in the lymph nodes, where they play a critical role in filtering and purifying lymphatic fluid. The vessels carry lymphatic fluid away from the tissues and towards the lymph nodes, where it is filtered and purified by immune cells such as lymphocytes and macrophages. The purified lymphatic fluid is then returned to the bloodstream through the thoracic duct or the right lymphatic duct, which empty into veins near the heart.

Lymph nodes: These small, bean-shaped organs are located throughout the body and act as filters for the lymphatic fluid. Lymph nodes contain immune cells that can recognize and destroy pathogens, such as viruses and bacteria, as well as cancer cells. Lymph nodes are small, bean-shaped organs that are distributed throughout the body along the lymphatic vessels. They are an important part of the lymphatic system and play a crucial role in the immune response by filtering and purifying lymphatic fluid.

Lymph nodes act as filters for lymphatic fluid, trapping and destroying foreign particles that have been recognized by the immune cells. The lymphatic fluid flows through the lymph nodes, where it is exposed to lymphocytes and macrophages. If these cells recognize a foreign substance, they will mount an immune response to destroy it.. Lymph nodes can become swollen or enlarged in response to infection or disease. This is because the immune system is working to fight off the foreign particles and the lymph nodes are producing more immune cells to help in the fight. In some cases, swollen lymph nodes can be a sign of a more serious medical condition, such as cancer.

Spleen: The spleen is largest lymphatic organ / important organ located in the upper left side of the abdomen, just behind the stomach. It is part of the lymphatic system and plays several vital roles in the body, including filtering the blood, removing old or damaged red blood cells, and producing immune cells.

The spleen is a soft, spongy organ that is typically about the size of a fist in adults. It is composed of two main regions: the white pulp and the red pulp. The white pulp contains immune cells called lymphocytes, which are responsible for recognizing and attacking foreign substances such as bacteria, viruses, and cancer cells. The red pulp is responsible for filtering the blood and removing old or damaged red blood cells.

The spleen acts as a blood filter, removing damaged or abnormal red blood cells, bacteria, and other foreign particles from the bloodstream. This helps to maintain the quality of the blood and prevent infections and other diseases. The spleen also serves as a reservoir for red blood cells, which can be released into the bloodstream in times of need, such as during periods of heavy bleeding.

In addition to its blood-filtering function, the spleen is also an important organ for the immune system. It produces immune cells called B cells, which are responsible for producing antibodies that help to fight off infections and other foreign invaders.

The spleen can become enlarged or damaged in response to various medical conditions, including infections, cancer, and autoimmune disorders. In some cases, the spleen may need to be removed through a surgical procedure known as a splenectomy. However, this can increase the risk of infections and other health complications, so it is typically only recommended in cases where the spleen is severely damaged or causing significant health problems.

Thymus: The thymus is a gland located in the upper chest that plays a key role in the development and maturation of T lymphocytes, a type of white blood cell that is important in fighting infections.

Bone marrow: The bone marrow is a spongy tissue found inside bones that produces red blood cells, platelets, and some types of white blood cells, including lymphocytes.

Mucosa-associated lymphoid tissue (MALT): MALT is a type of lymphoid tissue found in mucous membranes, such as those lining the respiratory and digestive tracts. It contains immune cells that can respond to pathogens and other foreign substances.

2.8.2 Lymph Movement

The lymphatic system relies on movement and muscular contractions to move lymph fluid throughout the body. Unlike the circulatory system, which has the heart to pump blood, the lymphatic system does not have a central pump. Instead, lymphatic movement is achieved through a combination of muscular contractions, respiratory movements, and the rhythmic movement of surrounding tissues.

Muscular contractions: Lymphatic vessels are surrounded by smooth muscle cells that contract and relax to propel lymph fluid forward. These muscular contractions are similar to the contractions that move food through the digestive system. Exercise, particularly aerobic exercise, can stimulate these muscular contractions and increase lymphatic flow.

Respiratory movements: The lymphatic vessels in the thoracic region are influenced by respiratory movements. When we breathe in, the pressure in the thoracic cavity decreases, causing the lymphatic vessels to expand and pull in lymph fluid. When we exhale, the pressure in the thoracic cavity increases, causing the lymphatic vessels to contract and push lymph fluid forward.

Surrounding tissue movement: Lymphatic vessels are surrounded by tissues that constantly move, such as muscles and joints. As these tissues move, they compress the lymphatic vessels and propel lymph fluid forward. This is particularly true for lymphatic vessels in the arms and legs.

The movement of lymph fluid is also influenced by external factors such as gravity, body position, and massage. For example, lymphatic flow is typically slower when we are standing or sitting, as gravity can hinder the movement of lymph fluid from the legs to the upper body. Lymphatic drainage massage is a technique that uses gentle pressure and rhythmic movements to stimulate lymphatic flow and reduce swelling and inflammation.

Overall, lymphatic movement is a complex process that relies on a combination of muscular contractions, respiratory movements, and the movement of surrounding tissues. By understanding how lymphatic fluid moves throughout the body, we can take steps to support lymphatic function and promote overall health and well-being.

2.8.3 Functions of Lymph or Lymphatic system

Its main function is to transport immune cells and other substances, such as proteins and excess fluid, from the tissues back to the bloodstream. Here are some of the main functions of lymph:

1. Immune defense: The lymph contains a variety of immune cells, including lymphocytes and macrophages, that help to defend the body against infections and other foreign invaders. These immune cells can recognize and attack pathogens such as viruses, bacteria, and fungi.
2. Fluid balance: The lymphatic system plays an important role in maintaining fluid balance in the body. When excess fluid accumulates in the tissues, the lymphatic

vessels absorb it and transport it back to the bloodstream. This helps to prevent swelling and edema.

3. Absorption of fats: The lymphatic system also plays a key role in the absorption of dietary fats and fat-soluble vitamins from the small intestine. Fats and fat-soluble vitamins are absorbed into the lymphatic vessels called lacteals, which transport them to the bloodstream.
4. Removal of waste: The lymphatic system helps to remove waste products from the body, such as cellular debris and metabolic waste. This is particularly important in the lymph nodes, which filter the lymph and remove harmful substances.
5. Transport of hormones: The lymphatic system also helps to transport hormones and other signaling molecules throughout the body. For example, lymphatic vessels in the gut transport hormones that regulate appetite and digestion.

Overall, the lymph plays a critical role in maintaining the health and function of the immune system, regulating fluid balance, absorbing dietary fats, removing waste products, and transporting hormones and other signaling molecules.

CHECK YOUR PROGRESS EXERCISE 2

1. Discuss the advantage of biconcave shape of RBC.

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2. What is Erythropoiesis? Name the hormones responsible for erythrocytes production.

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3. Enlist the different types of leucocytes

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2.9 GLOSSARY

Erythropoiesis : is the process by which red blood cells, or erythrocytes, are produced in the bone marrow.

Haemoglobin : is a protein responsible for binding and carrying oxygen

Hemolytic anemia *:* Hemolytic anemia is a type of anemia caused by the destruction of red blood cells.

Mean Corpuscular Volume: (MCV) is a measurement used to determine the average size of red blood cells (RBCs) in a given blood sample. It is typically reported in femtoliters (fL).

Packed Cell Volume (PCV) : also known as hematocrit, is a measurement used to determine the proportion of red blood cells (RBCs) in a given volume of whole blood. It is expressed as a percentage.

Polycythemia : is a condition characterized by an increase in the number of red blood cells.

Sickle cell anemia **:** is a genetic disorder characterized by abnormal hemoglobin molecules that cause red blood cells to become rigid and sickle-shaped.

2.10 LET US SUM

Understanding the function and importance of RBCs is essential for maintaining good health and preventing disease.In this unit we learnt about composition of blood and their function. Now, you gain the understanding that blood is composed of plasma and various types of cells, including red blood cells (erythrocytes), white blood cells (leukocytes), and platelets (thrombocytes). Plasma contains water, proteins, hormones, electrolytes, nutrients, and waste products. Red blood cells carry oxygen to tissues and remove carbon dioxide. White blood cells play a role in the immune response, and platelets are involved in blood clotting.

2.11 ANSWER TO CHECK YOUR PROGRESS EXERCISES

CHECK YOUR PROGRESS EXERCISE 1

1. Blood is a fluid connective tissue that is composed of –

   i. **Plasma:** This is the liquid part of blood and contains various proteins, electrolytes, hormones, and nutrients.
   ii. **Formed cells:** Formed cells are the floating bodies in plasma which comprises red blood corpuscles, white blood corpuscles and platelets.

2. Plasma is yellowish fluid portion of blood that constitutes about 55% of the total blood volume. On other hand, serum is the fluid that remains after blood has clotted and the clot has been removed. Unlike plasma, serum does not contain fibrinogen, the protein responsible for blood clotting.

To separate plasma from whole blood, the blood sample is typically collected in a tube containing an anticoagulant to prevent clotting. The tube is then centrifuged at a specific speed and duration to separate the heavier blood cells from the lighter plasma which is collected in upper layer.

3. Here are the various types of plasma proteins along with their specific functions:

i. **Albumin:** This protein is responsible for maintaining the osmotic pressure of the blood, which helps regulate the distribution of fluids between blood vessels and body tissues.
ii. **Globulins:** These proteins are involved in the transport of substances such as hormones, lipids, and metal ions. Forms immunoglobulins or antibodies that are crucial for the immune system's defense against infections and diseases.
iii. **Fibrinogen**: Fibrinogen is a key protein involved in blood clotting.

CHECK YOUR PROGRESS EXERCISE 2

1. The unique biconcave shape provides flexibility and also facilitate for easy pass through narrow blood vessels and capillaries. In addition, biconcave shape increases the efficiency of oxygen exchange with neighboring cells and tissues.
2. Erythropoiesis is the process by which red blood cells, or erythrocytes, are produced in the bone marrow. Erythropoitein is a hormones responsible for erythrocytes production.
3. There are two types of leucocyte granulocyte and agranulocyte.

   Granulocytes are further divided into basophils, eosinophils,neutrophils and agranulocytes are classified into monocytes and lymphocytes

UNIT 3 CIRCULATORY SYSTEM

Structure

3.1 Introduction
3.2 Anatomy of Heart
3.2.1 Chambers of the Heart
3.2.2 Valves of the Heart
3.2.3 Pericardium
3.3 Anatomy of Blood Vessels
3.3.1 Arteries
3.3.2 Veins
3.3.3Capillaries
3.4 Arterial and Venous systems
3.4.1 Arterial System
3.4.2 Venous System
3.5 Cardiac Muscle
3.6 Innervations of heart
3.6.1 Electrical Conduction System
3.6.2 Nerve Conduction System
3.7 Cardiac Cycle
37.1 Cardiac Cycle
3.7.2 Factors Affecting Cardiac Cycle
3.8 Circulation in Human
3.8.1 Pulmonary Circulation
3.8.2 Systematic Circulation

3.8.3 Feedback Mechanism of Circulation
3.9 Portal Circulation
3.9.1 Hepatic Portal Circulation
3.9.2 Hypophysal Portal Circulation
3.10 Heart Beat and Rate
3.10.1 Heart beat
3.10.2 Heart rate
3. 11 Cardiac Output
3.12 Blood pressure.
3.13Electrocardiogram
3.14 Let Us Sum Up
3.15 Glossary
3.16 Answer to Check Your Progress

3.1 INTRODUCTION

The cardiovascular system is responsible for delivering oxygen, nutrients, hormones, and other essential substances to every cell in the body. It consists of the heart, blood vessels, and blood, all of which work together to ensure the proper functioning of vital organs such as the brain, lungs, liver, and kidneys. The collective network of the different blood vessels is called the vascular or circulatory system that carries blood throughout the body. In humans, closed circulatory system is found. In this system, the blood is contained within a network of blood vessels and does not come into direct contact with the tissues or organs. The system consists of a central pump, usually the heart, which propels the blood through arteries, capillaries, and veins. The heart is the chief organ that generates efficient force to pump blood throughout the body. The blood carries oxygen, nutrients, hormones, and waste products throughout the body. The closed circulatory system allows for more efficient and controlled transport of substances and enables the regulation of blood flow to different tissues and organs.The blood flow distributes oxygen to all the body cells and in return, removes metabolic waste products. Understanding the cardiovascular system helps us grasp the intricate mechanisms that support organ function and overall health. The study of physiology of the cardiovascular system gives you the knowledge of how the heart, blood vessels, and blood work together to maintain circulation and provide oxygen, nutrients, and waste removal throughout the body. In this unit, we shall learn about structure and functions of heart, cardiac cycle, blood vessels, blood pressure, and blood circulation.

We shall learn about how blood vessels transport blood throughout the body. In this unit, you will learn the detailed structure and function of arterial (i.e. arteries, arterioles, capillaries) and venous system (i.e. veins). The regulation of arterial pressure is also described

Objectives

After studying this unit, you will be able to:

- explain the structure of the heart and blood vessels,
- understand cardiac cycle and factor affecting
- discuss systematic and portal circulation
- understand arterial pressure and its regulation; and
- Know about the ECG

3.2 ANATOMY OF HEART

The human heart is a remarkable organ that plays a vital role in the circulatory system. Its anatomy and working is complex, involving various structures, chambers, valves, and electrical conduction pathways. Let us begin our study of the cardiovascular system with the anatomy of heart.

3.2.1 Chambers of the Heart

The heart is a muscular organ, located in the thoracic cavity, between the lungs, slightly tilted towards the left side of the body. The heart and its components are shown in the figure 3.1. As you can see, heart divided into four chambers: two atria and two ventricles. The atria are the upper chambers, while the ventricles are the lower chambers.

Now how does the blood circulate in our body? This is explained as follows:

*The Right Atrium***:** The right atrium receives deoxygenated blood from the body through two large veins called the superior vena cava (which brings blood from the upper body) and the inferior vena cava (which brings blood from the lower body). The blood enters the right atrium and then flows into the right ventricle.

The Right Ventricle: From the right atrium, the blood is pumped into the right ventricle. The right ventricle is responsible for pumping deoxygenated blood to the lungs for oxygenation. When the right ventricle contracts, the tricuspid valve, located between the right atrium and the right ventricle, closes to prevent the backflow of blood into the atrium. Simultaneously, the pulmonary valve opens, allowing the blood to flow into the pulmonary artery, which carries it to the lungs.

The Left Atrium: Oxygenated blood from the lungs is returned to the heart through the pulmonary veins, which enter the left atrium. The left atrium receives the oxygenated blood and then passes it into the left ventricle.

The Left Ventricle: The left ventricle is responsible for pumping oxygenated blood to the rest of the body. It has thicker walls compared to the other chambers because it needs to generate enough force to propel the blood through the systemic circulation. When the left ventricle contracts, the mitral valve, located between the left atrium and the left ventricle, closes to prevent the backflow of blood into the atrium. At the same time, the aortic valve opens, allowing the blood to flow into the aorta, the largest artery in the body.

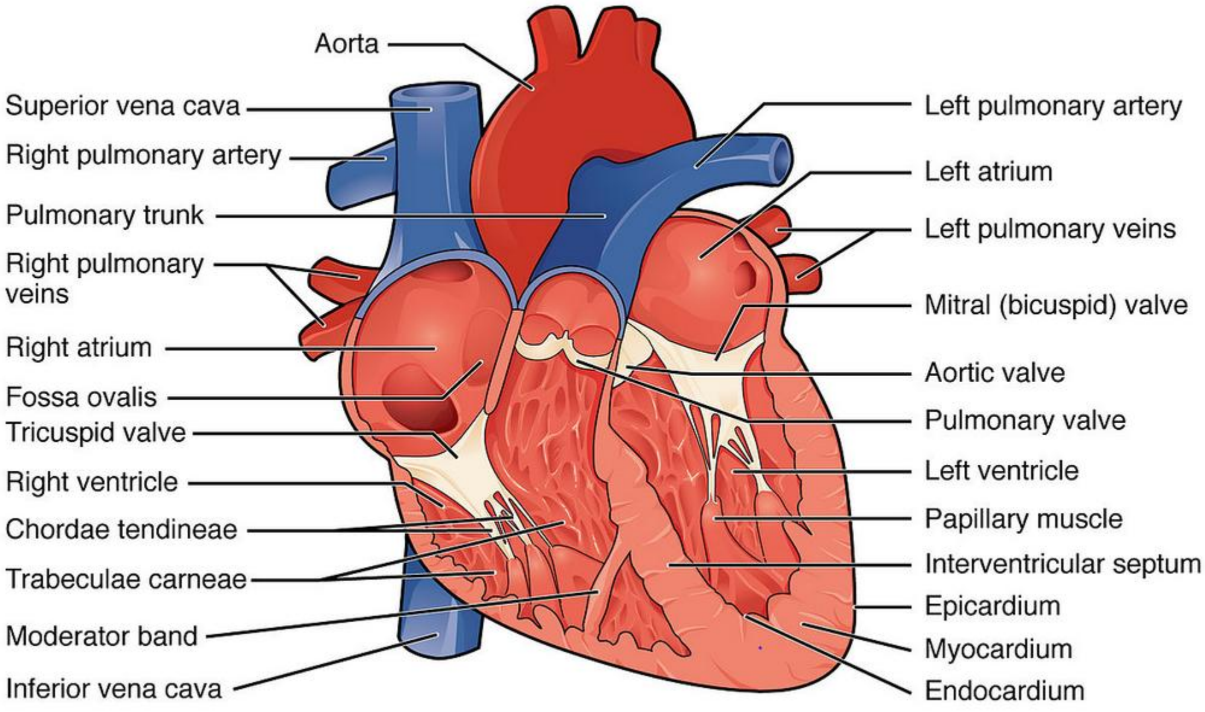

Figure 3.1: Anatomy of Heart

3.2.2 Valves of the Heart

The heart is equipped with valves that ensure one-way blood flow through its chambers. These valves prevent the backward flow of blood and maintain the direction of blood flow.

1. *Tricuspid Valve*: Located between the right atrium and the right ventricle, the tricuspid valve consists of three flaps or cusps, as you can see in figure 3.2. It prevents the backflow of blood from the right ventricle to the right atrium during ventricular contraction.
2. *Pulmonary Valve:* Situated between the right ventricle and the pulmonary artery, the pulmonary valve consists of three semilunar cusps. It prevents the backflow of blood from the pulmonary artery to the right ventricle when the ventricle relaxes.
3. *Mitral Valve (Bicuspid Valve):* Found between the left atrium and the left ventricle, the mitral valve consists of two flaps or cusps. It prevents the backflow of blood from the left ventricle to the left atrium during ventricular contraction.
4. *Aortic Valve*: Located between the left ventricle and the aorta, the aortic valve also consists of three semilunar cusps. It prevents the backflow of blood from the aorta to the left ventricle when the ventricle relaxes.

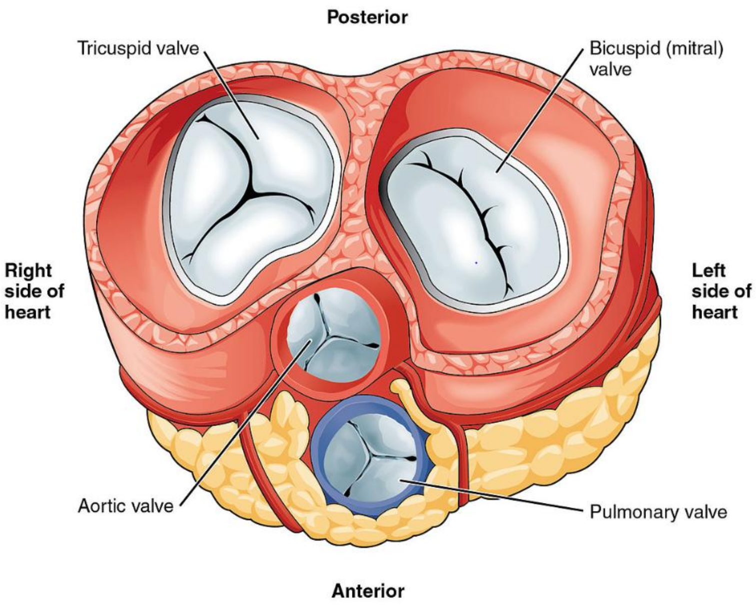

Figure 3.2: Valves of heart

3.2.3 Pericardium:

The heart is surrounded by a protective sac called the pericardium. It consists of two layers: the outer fibrous pericardium and the inner serous pericardium. The serous pericardium is further divided into the parietal pericardium (lining the outer surface of the fibrous pericardium) and the visceral pericardium (also known as the epicardium, which covers the heart muscle).

3.3 ANATOMY OF BLOOD VESSEL

The circulatory system consists of a vast network of blood vessels that transport blood throughout the body. The blood vessels which supply blood to an organ are termed as *afferent blood vessels* and those drains an organ are known as *efferent blood vessels*. *Aorta* is the major artery carries oxygen-rich blood to all the organs and tissues through systemic circulation. The pulmonary artery is an exception which carries deoxygenated blood to the lungs via pulmonary circulation. Heart has own blood vessel called *coronary artery* that supply blood to the muscles cells of the heart.

Blood vessels are tubes of varied diameter and can be classified into three main types: arteries, veins, and capillaries. Each type has distinct anatomical features and functions as youcan see in figure 3.3. Each type of blood vessel has a unique structure that reflects its function in the circulatory system. In this section, we will discuss the anatomy of blood vessels, including their structure and function.

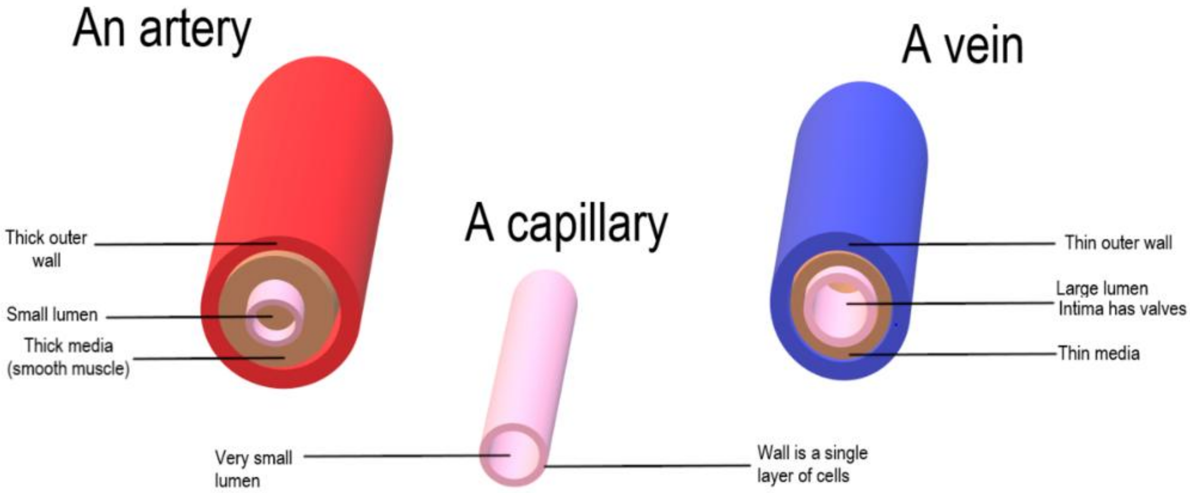

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Figure 3.3: Types of blood vessels

3.3.1 Arteries

Arteries are blood vessels that carry oxygenated blood away from the heart to the rest of the body. As you see in figure, artery wall is made up of three layers:

- tunica adventitia,
- tunica media and
- tunica intima.

Let us discuss the artery wall in detail

- *Tunica Adventitia* (Outer Layer): Tunica adventitia has a thick and elastic outer layer, which is composed of connective tissue and provides support and protection.
- *Tunica Media* (Middle Layer): The tunica media is the thickest layer of arterial walls. It consists of smooth muscle cells and has elastic fibers. It regulates the diameter of the artery and plays a crucial role in maintaining blood pressure and blood flow by contracting or relaxing..
- *Tunica Intima* (Inner Layer): The tunica intima is a thin layer composed of endothelial cells that form a smooth lining to promote smooth blood flow and prevent clotting. It also releases substances that regulate vessel dilation and contraction.

Mostly arteries are named after the body parts they supply blood; such as the coronary (heart), brachial (arm), celiac (different part of GI tract) or the metacarpal (wrist) artery. Some arteries are named based on the organ they supply blood: as the hepatic artery (liver), uterine or the ovarian artery. Each artery divides into smaller blood vessels i.e. arterioles and capillaries to deliver nutrient rich blood to each cell of the body. The blood in arteries flow under high pressure. They can expand and constrict with each heart beat in a rhythmic movement that may be felt as the pulse.

3.3.2 Veins: Veins are blood vessels that carry deoxygenated blood back to the heart from various organs and tissues (except for pulmonary vein which carries oxygenated blood). They have thinner walls compared to arteries and a larger diameter. The three layers of venous walls are similar to those of arteries but with less muscle and elastic tissue. Veins have valves located throughout their length, especially in the limbs. These valves prevent backward flow of blood and assist in propelling blood towards the heart, overcoming the low pressure in the venous system. Valves are particularly important in counteracting the effects of gravity. Veins merge to form larger vessels, eventually leading to the two main veins that return blood to the heart: the superior vena cava (from the upper body) and the inferior vena cava (from the lower body).

3.3.3 Capillaries

Capillaries are the smallest and thinnest blood vessels with 1 μm thickness and 5-10μm diameter, connecting arterioles to venules. Their thin walls consist of a single layer of endothelial cells, allowing for the exchange of gases, nutrients, and waste products between the blood and surrounding tissues. Capillaries are the site of vital processes such as oxygen and nutrient delivery to cells and the removal of carbon dioxide and metabolic waste products. They supply nutrition and oxygen-rich blood directly to the tissues. This process is called as perfusion. Capillaries are found in large numbers in tissues that require a high supply of oxygen and nutrients, such as the lungs, liver, and muscles. They connect arterioles and venules to form a network of blood vessels throughout the body. Capillaries have about 7% total volume of blood. The flow of blood through these minute capillaries is often described as microcirculation. These capillaries organize into a 'capillary bed' that may consist of a network of 10–100 capillaries. These capillaries bed form extensive networks within tissues, with their vast surface area ensuring efficient exchange. Capillary beds can be opened or closed to regulate blood flow based on the metabolic demands of the tissues.

3.4 ARTERIAL AND VENOUS SYSTEMS

3.4.1 Arterial System

The arterial system is a vital component of the circulatory system responsible for delivering oxygenated blood from the heart to various tissues and organs throughout the body. Arteries play a crucial role in maintaining proper blood flow, supplying essential nutrients and oxygen to cells, and facilitating waste removal. Arteries have a distinct structure that enables them to withstand high pressure and efficiently transport blood. They consist of three main layers: the tunica intima, tunica media, and tunica adventitia, as we discussed in earlier section. Arteries are thicker and more muscular than veins to withstand the higher pressure of blood flow. Arteries branch into smaller vessels known as arterioles, which further divide into capillaries as shown in figure 3.4.

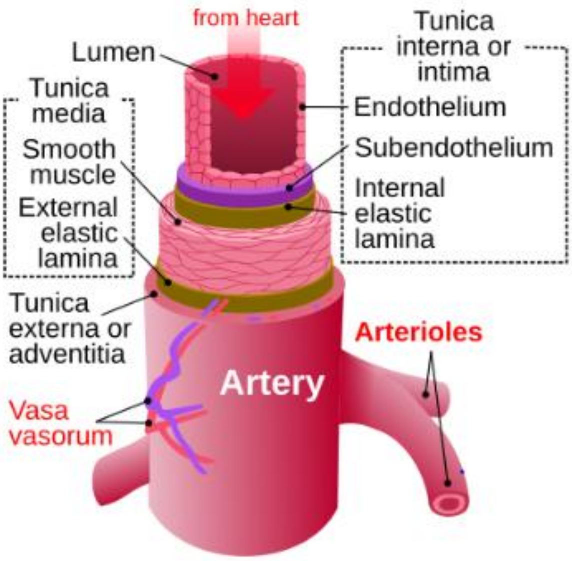

Figure 3.4: Wall of artery

Arterioles: Arterioles are smaller branches of arteries that further divide into capillaries. Like arteries, the walls of arterioles also consist of three layers comprising endothelium, smooth muscle, and connective tissue but the thickness of each layer diminishes remarkably in arterioles. Arterioles have much smaller diameter; 100 to 300 µm. They have a thinner tunica media and play a crucial role in regulating blood flow to capillary beds. By constricting (Vasoconstriction) or dilating (vasodilatation), arterioles control the amount of blood reaching specific tissues and organs, thus regulating blood pressure and directing blood flow. Vasoconstriction and vasodilatation in the arterioles are the primary mechanisms for regulation of blood flow. These are primary site of vascular resistance causing substantial drop in blood pressure and are thus referred to as 'resistance' vessels. Arterioles play a crucial role in regulating blood flow and blood pressure. They have a high degree of smooth muscle and can constrict or dilate, controlling the distribution of blood to different organs and tissues.

Capillaries: As this you have already learnt in section 3.3.2.

3.4.2 Venous Systems

Unlike arterial system, the venous system is a network of veins and venules that carry deoxygenated blood from tissues to the heart. The only exception is pulmonary vein which carries oxygenated blood from lungs to the heart. Many small branches of venules form the veins. They structurally and functionally differ from the arterial system.

*Venules:*Venules are small blood vessels that connect capillaries to larger veins in the circulatory system. They play a crucial role in the microcirculation, acting as a bridge between the capillary network and the larger venous system as illustrated in figure 3.5. Venules have a similar anatomical structure to veins but are smaller in diameter. A venule is about 8-100μm in diameter and delivers deoxygenated blood from capillaries to the veins. A venule also consists of three layers:

1. An outer layer of fibrous connective tissue. (tunica intima).

2. A middle layer of muscle and elastic tissue (tunica media).

3. An inner of squamous endothelium cells (tunica adventitia).

Unlike arterioles, the middle layer is poorly developed; because of which venules have thinner walls. Venules have extremely porous wall which facilitates exchange of fluid and white blood cells between body cells and blood stream.

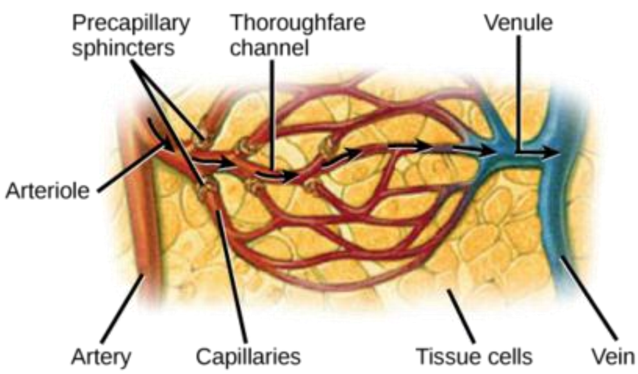

Figure 3.5: Capillary bed, Venules and Vein

There are two primary types of venules: postcapillary venules and muscular venules.

1. *Postcapillary Venules:* Postcapillary venules are the smallest venules and directly connect capillaries to the larger venous system. They are characterized by a thin or absent tunica media and a high proportion of endothelial cells. Postcapillary venules play a crucial role in the exchange of nutrients, gases, and waste products between the

bloodstream and the surrounding tissues. They also contribute to the migration of immune cells from the bloodstream into tissues during inflammation.

2. *Muscular Venules:* Muscular venules are larger than postcapillary venules and possess a more developed tunica media containing smooth muscle fibers. They receive blood from postcapillary venules and continue to transport it towards larger veins. Muscular venules regulate blood flow by constricting or dilating their smooth muscle layer, helping to maintain proper circulation throughout the body.

Venules play several important roles in the circulatory system:

- *Blood Drainage:* Venules collect deoxygenated blood, waste products, and carbon dioxide from the capillaries, serving as conduits for blood drainage from the tissues. They gradually merge and merge with each other, forming larger veins that eventually return blood to the heart.
- *Regulation of Blood Pressure:* Venules, especially the muscular venules, contribute to the regulation of blood pressure. The contraction and relaxation of the smooth muscle in their walls help control blood flow and maintain proper venous return to the heart. By adjusting their diameter, venules can influence the resistance to blood flow and ensure adequate circulation throughout the body.
- *Immune Response:* Postcapillary venules play a crucial role in the immune response. During inflammation, these venules become more permeable, allowing immune cells, such as white blood cells, to exit the bloodstream and migrate into the affected tissues. This facilitates immune surveillance, tissue repair, and the clearance of pathogens or foreign substances.
- *Capillary Bed Regulation:* Venules help regulate blood flow and pressure within the capillary beds. By constricting or dilating their smooth muscle layer, venules can alter the resistance to blood flow and control the distribution of blood to different tissues and organs.

Veins: As you know, veins are blood vessels that carry deoxygenated blood from various parts of the body back to the heart (except for pulmonary vein which carries oxygenated blood). Here is a comprehensive explanation of the structure, function, and significance of veins.

- Veins are less muscular than arteries.

- The inner layer folds into the flap like cusps called valves that direct blood flow towards the heart and prevent backflow of blood even at low pressure.
- Like arteries, the wall of veins also consists of three layers; the outer layer -Tunica externa, the thin middle layer - Tunica mediaand the single-celled thick inner layer - Tunica intima.
- Veins are closer to the skin as compared to the deep-seated arteries.
- Because of thin walls, veins can expand their diameter easily to hold large volume of blood even at low pressure. They are, thus considered as blood reservoirs or capacitance vessels because they contain almost 60-64% volume of total blood.

But before we move to the section, let us recapitulate what we have learnt so far.

Check Your Progress Exercise 1

1. Explain the role of the atria and ventricles in the pumping of blood through the heart.
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2. Discuss the general structure and functions of the arterial walls.
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3. Explain the significance of thicker ventricle wall.
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4. Match the following

	A	B
a)	Bicuspid Valve	i. Located between the right atrium and the right ventricle
b)	Tricuspid Valve	ii. Located between the left ventricle and the aorta
c)	*Pulmonary Valve*	iii. between the left atrium and the left ventricle
d)	Aortic Valve	iv. Situated between right ventricle and pulmonary artery

Let us move to learn about cardiac muscle and its structure and role in heart functioning

3.5 CARDIAC MUSCLE

Cardiac muscle, also known as myocardium, forms the middle layer of the heart wall. It is a unique type of muscle tissue found exclusively in the heart. It possesses distinct properties that enable the heart to perform its vital function of pumping blood throughout the body. Let's explore the structure and function of the cardiac muscle and its layers in more detail.

The *myocardium*, as mentioned earlier, is the middle layer of the heart wall. It is composed of cardiac muscle fibers, connective tissue, blood vessels, and nerves. The myocardium is responsible for the forceful contractions of the heart that pump blood throughout the circulatory system. It is significantly thicker in the left ventricle, which pumps oxygenated blood to the rest of the body, compared to the other chambers of the heart. The myocardium receives oxygenated blood supply through the coronary arteries, which branch off from the aorta. These arteries penetrate into the myocardium, forming a network of smaller blood vessels called coronary capillaries. The capillaries supply oxygen and nutrients to the cardiac muscle cells and remove waste products. The deoxygenated blood is then collected by coronary veins and eventually drains into the right atrium.

The myocardium is surrounded by other layers that provide support and protection to the heart. The innermost layer is the *endocardium,* which lines the chambers of the heart and covers the heart valves. It consists of a thin layer of endothelial cells, which provide a smooth surface to facilitate the flow of blood and prevent clotting. The endocardium also contains some connective tissue and purkinje fibers, which are specialized conducting cells involved in electrical signaling within the heart.

The outermost layer of the heart is the *epicardium,* also known as the visceral layer of the serous pericardium. It is a thin, protective layer consisting of connective tissue covered by a layer of mesothelial cells. The epicardium also contains blood vessels, nerves, and adipose tissue. It provides lubrication to the heart, reducing friction as it beats within the pericardial sac.

Let us discuss some key features of cardiac muscle:

- The cardiac muscle is a specialized type of muscle tissue that exhibits striations, similar to skeletal muscle, but with some distinct differences. It is involuntary muscle, meaning it contracts without conscious control. The cardiac muscle cells, called cardiomyocytes, are interconnected and form a complex network that allows for coordinated contractions.
- The cardiac muscle cells have unique structural features that contribute to their specialized function. They are branched cells with intercalated discs, which are specialized cell-to-cell junctions. Intercalated discs contain *desmosomes,* which provide mechanical strength and prevent the cells from separating during contractions, and gap junctions, which allow for rapid electrical signaling between cells. This arrangement enables coordinated and synchronized contractions of the myocardium.
- Cardiac muscle cells have a high density of mitochondria, which are responsible for generating energy in the form of adenosine triphosphate (ATP). ATP is essential for the continuous contraction and relaxation of the heart muscle. The high demand for ATP is met by the abundance of mitochondria in cardiac muscle cells, ensuring the heart's continuous pumping action.
- Cardiac muscle contractions last longer than skeletal muscle contractions. This property allows the heart to expel blood effectively and efficiently throughout the

body. The prolonged contractions of cardiac muscle cells ensure a complete ejection of blood from the heart chambers, optimizing cardiac output.

- Cardiac muscle is highly resistant to fatigue due to its continuous and rhythmic contractions. The heart must contract tirelessly throughout an individual's lifetime without rest. This ability of cardiac muscle to endure and resist fatigue is crucial for its sustained function in pumping blood.
- Unlike skeletal muscle, cardiac muscle has limited regenerative capacity. Cardiac muscle cells do not readily undergo cell division, making it challenging for the heart to repair itself after injury or damage. This limited regenerative capacity is one of the reasons why heart conditions and injuries can have severe consequences.

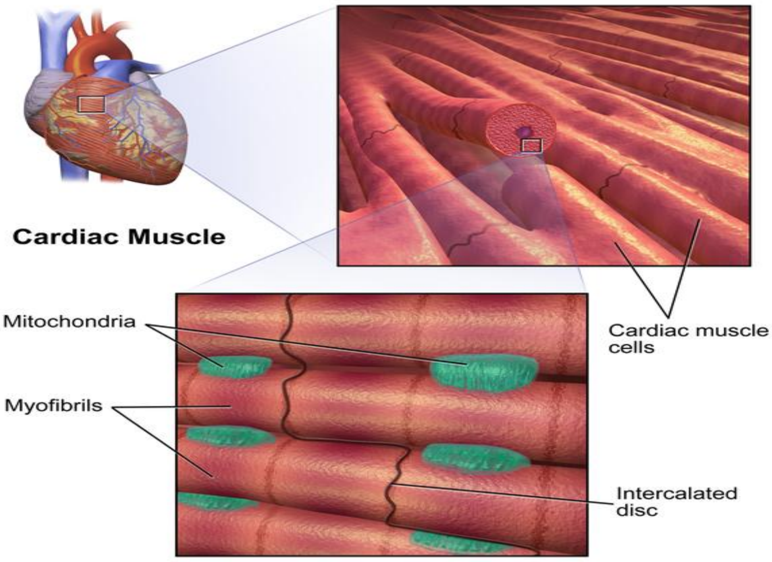

Figure 3.6: Structure of Cardiac Muscle

3.6 INNERVATIONS OF THE HEART

The innervations of the heart refer to the network of nerves that control the cardiac muscle and regulate the heart's function. The main components of the cardiac innervation system include the autonomic nervous system and specialized cardiac conduction tissues.

3.6.1 Electrical Conduction System of the Heart

The innervation of the heart involves specialized cardiac conduction tissues that coordinate and regulate the electrical impulses responsible for the contraction of the heart. The electrical impulses originate from the sinoatrial (SA) node, also known as the natural pacemaker of the heart, located in the right atrium. From there, the impulses travel through specialized pathways known as the atrioventricular (AV) node, the bundle of His, and the Purkinje fibers, resulting in contraction of the heart muscle. This system ensures that the chambers of the heart contract in a synchronized manner, allowing for effective pumping of blood. The main components of the electrical conduction system include the sinoatrial (SA) node, atrioventricular (AV) node, bundle of His, Purkinje fibers, and the myocardium as illustrated in figure 3.7. Pacemaker and conduction tissues are made up of modified cardiac muscles, which are not well striated. They conduct electrical impulse to the cardiac muscle. Let us get to know them.

1. *Sinoatrial (SA) Node:* The SA node is often referred to as the "natural pacemaker" of the heart. It is a small cluster of specialized cells located in the right atrium near the opening of the superior vena cava as can see in figure 3.7. The SA node initiates the electrical impulses that regulate the heart's rhythm. It generates electrical signals at regular intervals, causing the atria to contract and pump blood into the ventricles.
2. *Atrioventricular (AV) Node:* The AV node is located in the lower part of the right atrium near the septum, between the atria and ventricles as illustrated in figure 3.7. It acts as a gateway for the electrical signals from the atria to pass into the ventricles. One of the most important functions of the AV node is to introduce a slight delay in the transmission of electrical impulses. This delay allows for the atria to fully contract and pump blood into the ventricles before the ventricles contract. The delay ensures efficient filling of the ventricles and helps optimize the coordination of atrial and ventricular contractions.
3. *Bundle of His (Atrioventricular Bundle):* AV node is bulbous in appearance and giverise to a bundleof conduction tissues called as *Bundle of His*. After passing through the AV node, the electrical signals travel down the bundle of His. The bundle of His is a specialized group of fibers that divides into two branches, the left bundle branch and the right bundle branch. These branches extend along the septum of the heart, transmitting the electrical signals to the ventricles.
4. *Purkinje Fibers:* The bundle of His further divides into smaller fibers known as Purkinje fibers. These fibers spread throughout the ventricles, delivering the electrical impulses to the ventricular muscle cells. The Purkinje fibers ensure that the ventricles

contract in a coordinated and synchronized manner, from the apex of the heart upward, pushing blood out of the ventricles and into the arteries.

The myocardium, the muscular layer of the heart, receives the electrical impulses transmitted by the Purkinje fibers. The electrical impulses trigger the contraction of the myocardium, resulting in the pumping action of the heart. The coordinated contraction of the atria and ventricles is essential for efficient blood flow through the heart and the rest of the body.

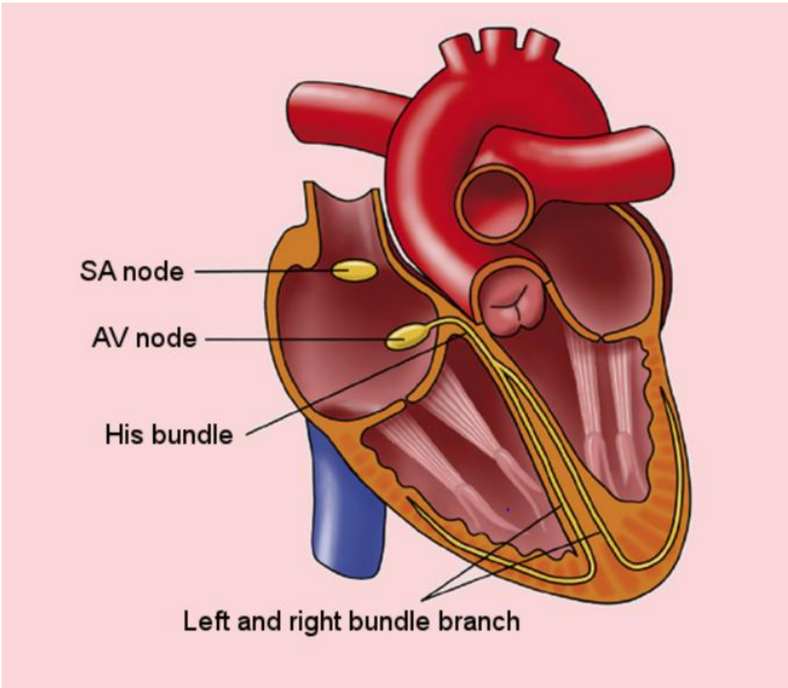

Figure 3.7: Electrical component of heart

Overall, the electrical conduction system of the heart ensures coordinated and rhythmic contractions of the atria and ventricles, enabling the heart to pump blood effectively and maintain proper circulation throughout the body. The electrical conduction system of the heart is regulated by both the autonomic nervous system and intrinsic factors which we will discuss next .

3.6.2 Nerve Conduction system: The autonomic nervous system (ANS) plays a crucial role in regulating the heart's activity and maintaining its balance. It consists of two main divisions: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS).

- *Sympathetic Nervous System* (SNS): The SNS is responsible for increasing the heart rate and enhancing cardiac contractility. The sympathetic nerves originate from the thoracic spinal cord and release the neurotransmitter norepinephrine. When activated, the SNS increases the heart's responsiveness to external stimuli, preparing the body for "fight-or-flight" responses.
- *Parasympathetic Nervous System* (PNS): The PNS, also known as the vagus nerve, has the opposite effect of the SNS. It slows down the heart rate and decreases cardiac contractility. The vagus nerve originates from the medulla oblongata in the brainstem and releases the neurotransmitter acetylcholine. Activation of the PNS promotes a state of relaxation and helps conserve energy.

The balance between the sympathetic and parasympathetic innervations determines the heart's overall rate and strength of contraction. This balance is regulated by the cardiac centers located in the medulla oblongata, which receive input from various sensory receptors and send signals to the heart via the autonomic nerves.

3.7 CARDIAC CYCLE

The heart is a muscular organ located in the chest, slightly tilted to the left. The heart is a vital organ that pumps blood throughout the body, supplying oxygen, nutrients, and removing waste products. As you know, heart is divided into four chambers: the right atrium, right ventricle, left atrium, and left ventricle. The right side of the heart is responsible for pumping deoxygenated blood from the body to the lungs for oxygenation, while the left side of the heart pumps oxygenated blood from the lungs to the rest of the body. The heart's pumping action is controlled by an electrical conduction system that ensures rhythmic contraction and relaxation of its chambers. The working of the heart begins with the blood flowing through the chambers in a coordinated sequence, known as the cardiac cycle. You can see the path of blood flow in heart in figure 3.8.

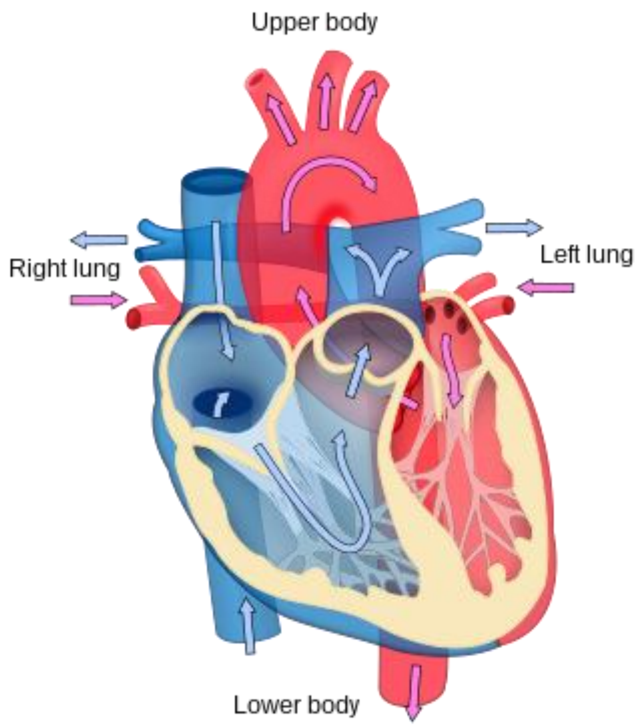

Figure 3.8: Blood flow in heart

In this unit, we will delve into the detailed working of the heart, describing each stage of cardiac cycle and the mechanisms involved.

3.7.1 Cardiac Cycle: The cardiac cycle refers to the complete sequence of events that occur during one heartbeat. It consists of two phases: the diastolic phase and the systolic phase. During the diastolic phase, the heart muscle relaxes, allowing blood to fill the chambers. During the systolic phase, the heart muscle contracts, forcing blood out of the chambers and into the blood vessels.

The following is a detailed description of the working of the heart:

i. *Diastole:* The cardiac cycle begins with the diastole phase, during which the heart muscle relaxes and the chambers fill with blood. The atria and ventricles are both in diastole, and the heart's pressure is at its lowest. The blood flows from the superior and inferior vena cava into the right atrium and then to the right ventricle through the tricuspid valve. At the same time, oxygenated blood from the lungs flows into the left atrium through the pulmonary veins and then to the left ventricle through the mitral valve. The chambers of the heart undergo the following actions:

- *Atrial Diastole:* Both atria are relaxed, and blood from the body (via the superior and inferior vena cava) enters the right atrium, while oxygenated blood from the lungs enters the left atrium through the pulmonary veins.
- *Ventricular Diastole*: The ventricles are also relaxed, and the atria contract slightly, pushing the remaining blood into the ventricles. This phase is known as atrial systole. The tricuspid valve (between the right atrium and right ventricle) and the mitral valve (between the left atrium and left ventricle) are open, allowing blood to flow into the ventricles.

ii. *Atrial Systole:* The atrial systole is a brief period during which the atria contract, forcing the remaining blood into the ventricles. This phase contributes to the ventricles being filled with blood to about 70%.

iii. *Isovolumic Contraction:* Following the atrial systole, the ventricles start to contract, and the pressure in the chambers rises. This leads to the closing of the tricuspid and mitral valves, preventing backflow of blood into the atria. However, since the pressure is not high enough to open the semilunar valves, the ventricles are said to be in isovolumic contraction.

iv. *Ventricular Ejection:* Once the pressure in the ventricles rises to a certain level, the semilunar valves open, allowing blood to flow out of the heart. The right ventricle pumps deoxygenated blood to the lungs through the pulmonary artery, while the left ventricle pumps oxygenated blood to the rest of the body through the aorta.

v. *Isovolumic Relaxation:* Following the ventricular ejection, the pressure in the ventricles drops, causing the semilunar valves to close. The ventricles then start to relax, but since the pressure is still higher than that in the atria, the tricuspid and mitral valves remain closed, and the ventricles are said to be in isovolumic relaxation.

vi. *Diastole:* Finally, the ventricles are fully relaxed, and the pressure in the heart is at its lowest. The tricuspid and mitral valves open again, allowing blood to flow from the atria into the ventricles, and the cardiac cycle begins again.

3.7.2 Factors affecting Cardiac Cycle

The cardiac cycle, which refers to the sequence of events that occur during one complete heartbeat, is influenced by various factors. These factors can affect the duration and intensity of each phase of the cardiac cycle and ultimately impact the overall function of the heart. Some of the key factors that affect the cardiac cycle include:

1. *Autonomic Nervous System*: The autonomic nervous system, consisting of the sympathetic and parasympathetic divisions, plays a significant role in regulating the cardiac cycle. The sympathetic nervous system, activated during times of stress or increased demand, releases norepinephrine, which increases heart rate, contractility, and conduction velocity. Conversely, the parasympathetic nervous system, mediated by the vagus nerve, releases acetylcholine, which slows heart rate and decreases contractility.
2. *Hormones:* Hormones, such as epinephrine and norepinephrine (released by the adrenal glands), influence the cardiac cycle. These hormones bind to specific receptors in cardiac muscle cells, increasing heart rate, contractility, and conduction velocity. Other hormones, such as thyroid hormones, can also affect heart rate and contractility.
3. *Preload:* Preload refers to the amount of blood in the ventricles at the end of diastole, just before contraction. It is influenced by factors such as venous return, blood volume, and venous tone. An increase in preload stretches the myocardial fibers, leading to a more forceful contraction during systole.
4. *Afterload:* Afterload is the resistance that the ventricles must overcome to eject blood into the arterial system during systole. It is influenced by factors such as peripheral vascular resistance and arterial blood pressure. An increase in afterload can impede ventricular ejection and affect the duration and intensity of the cardiac cycle.
5. *Heart Rate:* Heart rate, controlled by the sinoatrial (SA) node, is a critical factor affecting the duration and timing of the cardiac cycle. Various factors, such as neural input, hormonal influence, body temperature, and physical activity, can modulate heart rate. An increase in heart rate shortens the duration of the cardiac cycle, while a decrease in heart rate prolongs it.
6. *Contractility:* Contractility refers to the force of contraction generated by the cardiac muscle fibers. It is influenced by factors such as sympathetic stimulation, circulating catecholamines, and calcium availability. An increase in contractility leads to a more forceful contraction and affects the stroke volume and cardiac output.
7. *Electrolyte Balance:* Proper electrolyte balance, particularly levels of calcium, potassium, and sodium, is essential for the normal function of cardiac muscle cells. Disturbances in electrolyte concentrations can alter the action potential and contractile properties of the heart, affecting the cardiac cycle.

8. *Body Temperature:* Changes in body temperature can influence heart rate. An increase in body temperature, such as during fever or exercise, tends to raise heart rate, while a decrease in body temperature can lower heart rate.
9. *Age and Fitness Level:* Age and fitness level can impact the cardiac cycle. Generally, younger individuals and those with a higher level of fitness have lower resting heart rates, more efficient cardiac function, and shorter cardiac cycles compared to older individuals or those with lower fitness levels.

These factors interact and work together to regulate the cardiac cycle, ensuring that the heart functions optimally to meet the body's demands for oxygen and nutrients. Any disturbances in these factors can lead to alterations in heart rate, contractility, and overall cardiac performance.

3.8 CIRCULATION IN HUMAN

The circulatory system consists of two major components: the pulmonary circulation and the systemic circulation. These two circulations work together to transport blood throughout the body, ensuring the delivery of oxygen and nutrients to tissues and the removal of waste products as shown in figure 3.9.

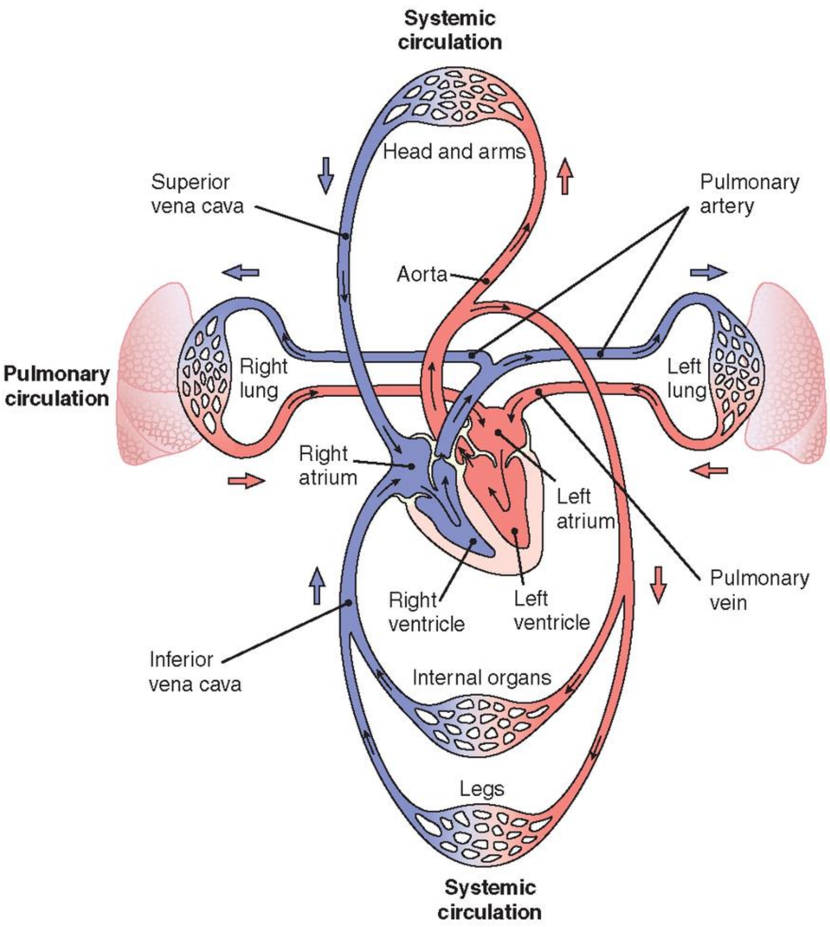

Figure 3.9: Blood flow to Systematic and Pulmonary Circulation (newhealthadvisor.org)

Next, we will discuss the pulmonary and systemic circulations, and their functions in detail.

3.8.1 Pulmonary Circulation

The pulmonary circulation is responsible for carrying deoxygenated blood from the heart to the lungs and returning oxygenated blood back to the heart. It involves the blood vessels that supply the lungs, including the pulmonary arteries, pulmonary capillaries, and pulmonary veins.

1. *Pulmonary Arteries:* The pulmonary arteries carry deoxygenated blood from the right ventricle of the heart to the lungs as shown in figure 3.10. They are the only arteries in the body that carry deoxygenated blood. The pulmonary trunk, a large artery, branches into the right and left pulmonary arteries, which further divide into smaller arterioles and eventually form the pulmonary capillaries.

2. *Pulmonary Capillaries:* The pulmonary capillaries are tiny blood vessels that surround the alveoli in the lungs. These capillaries are the site of gas exchange. Deoxygenated blood from the pulmonary arteries flows through the capillaries, and oxygen diffuses from the alveoli into the blood while carbon dioxide diffuses from the blood into the alveoli. This exchange of gases allows for the oxygenation of blood and the removal of carbon dioxide.
3. *Pulmonary Veins:* Oxygenated blood from the pulmonary capillaries is collected by pulmonary venules, which merge to form the pulmonary veins, as you can see in figure 3.10. The pulmonary veins carry oxygenated blood from the lungs back to the left atrium of the heart. Unlike other veins in the body, the pulmonary veins carry oxygenated blood.

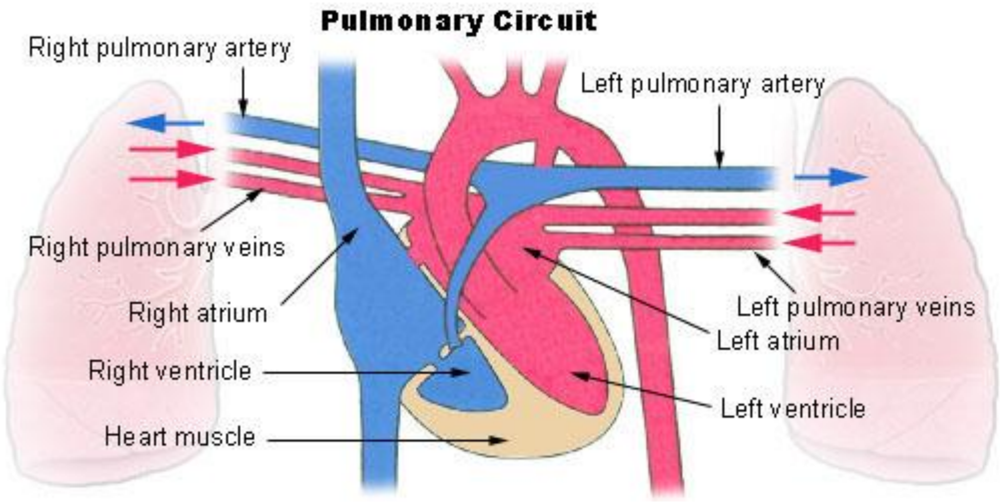

Figure 3.10: Pulmonary Circulation

The pulmonary circulation has a relatively low resistance compared to the systemic circulation. This is because the blood vessels in the lungs have a larger cross-sectional area, allowing for slower blood flow and facilitating gas exchange. The low resistance ensures that blood flow through the lungs is optimized for efficient oxygenation.

3.8.2 Systemic Circulation

The systemic circulation is responsible for delivering oxygenated blood from the heart to all the tissues and organs of the body, except for the lungs as shown in figure 3.9.The systemic circulation has a higher resistance compared to the pulmonary circulation due to the larger number of blood vessels and the greater distance that the blood must travel. In the systemic circulation, the oxygen-rich blood is pumped out of the left ventricle of the heart through the aorta, the largest artery in the body. The aorta branches out into smaller arteries that supply the various organs and tissues of the body. These arteries branch out even further into arterioles and then into capillaries, which are the smallest blood vessels in the body. It is through the capillaries that the exchange of oxygen, nutrients, and waste products occurs between the blood and the cells of the body. The oxygen-depleted blood then travels back to the heart through venules and veins, eventually returning to the right atrium of the heart to begin the pulmonary circulation again.

3.8.3 Feedback Mechanism of Circulation

The circulation of blood throughout the body is regulated by a complex system of feedback mechanisms that maintain homeostasis, or balance, in the body. These feedback mechanisms ensure that blood flow, blood pressure, and other cardiovascular parameters remain within a narrow range. Here are some of the key feedback mechanisms involved in the regulation of circulation:

1. *Baroreceptor Reflex:* Baroreceptors are specialized sensory receptors located in the walls of certain blood vessels, particularly the carotid sinus and aortic arch. They detect changes in blood pressure. When blood pressure increases, baroreceptors are stimulated, sending signals to the cardiovascular control center in the brain (specifically the medulla oblongata). The control center then initiates a response to decrease blood pressure, such as vasodilation of blood vessels and a decrease in heart rate. Conversely, when blood pressure decreases, the control center triggers a response to increase blood pressure, including vasoconstriction and an increase in heart rate.
2. *Chemoreceptor Reflex:* Chemoreceptors are sensory receptors located in the carotid bodies and aortic bodies. They monitor the levels of oxygen, carbon dioxide, and pH in the blood. If oxygen levels decrease or carbon dioxide and pH levels increase (indicating a decrease in oxygen supply or an increase in metabolic activity), chemoreceptors stimulate the control center in the brain to increase heart rate and respiratory rate. This response helps increase oxygen delivery and remove carbon dioxide from the body.

3. *Bainbridge Reflex:* The Bainbridge reflex, also known as the atrial reflex, is a feedback mechanism involving the stretch receptors located in the atria of the heart. When the atria are stretched due to an increased volume of blood returning to the heart (increased venous return), the stretch receptors signal the cardiovascular control center to increase heart rate. This response helps the heart pump out the increased blood volume more efficiently.
4. *Renin-Angiotensin-Aldosterone System* (RAAS): The RAAS is an intricate hormonal feedback mechanism that regulates blood pressure and fluid balance. When blood pressure decreases or blood volume decreases, special cells in the kidneys release the enzyme renin. Renin converts angiotensinogen (a protein produced by the liver) into angiotensin I. Angiotensin I is then converted into angiotensin II by the enzyme angiotensin-converting enzyme (ACE), primarily located in the lungs. Angiotensin II is a potent vasoconstrictor that causes blood vessels to narrow, thereby increasing blood pressure. It also stimulates the release of aldosterone from the adrenal glands, which promotes the reabsorption of sodium and water by the kidneys, leading to an increase in blood volume. The increase in blood pressure and volume helps restore normal cardiovascular parameters.
5. *Central Nervous System Regulation:* The central nervous system, particularly the medulla oblongata, plays a crucial role in regulating cardiovascular function. It receives input from various receptors, including baroreceptors, chemoreceptors, and stretch receptors, and sends signals to regulate heart rate, contractility, and vascular tone. The sympathetic nervous system activation increases heart rate and vasoconstriction, while the parasympathetic nervous system activation decreases heart rate and promotes vasodilation.

These feedback mechanisms work in coordination to maintain the stability of cardiovascular parameters. They respond to changes in blood pressure, blood volume, oxygen levels, and other factors, ensuring that blood flow and organ perfusion remain within appropriate ranges. The continuous adjustments made by these mechanisms help maintain the equilibrium necessary for proper cardiovascular function.

3.9 PORTAL CIRCULATION

Portal circulation refers to a specialized circulation system in the body that involves the passage of blood from one set of blood vessels to another set of blood vessels through a portal vein. Unlike the typical pattern of blood flow, where oxygenated blood travels from the heart to the organs and deoxygenated blood returns to the heart, portal circulation diverts blood from one organ to another before returning it to the heart.

Portal circulation plays a crucial role in directing blood flow from one set of organs to another, allowing for specialized processing and regulation of substances before they enter the systemic circulation. The hepatic portal circulation and hypophyseal portal circulation are key examples of this specialized circulation system, serving important functions in nutrient metabolism, detoxification, and hormone regulation.

Let us learn about two main examples of portal circulation in the human body that are: the hepatic portal circulation and the hypophyseal portal circulation.

3.9.1 Hepatic Portal Circulation

The hepatic portal circulation involves the transport of blood from the gastrointestinal tract, pancreas, and spleen to the liver through the hepatic portal vein before it reaches the heart as shown in figure 3.11. In the case of hepatic portal circulation, it allows the liver to process and metabolize nutrients, drugs, and toxins absorbed from the gastrointestinal tract before they enter the systemic circulation. The liver acts as a filter, removing harmful substances and maintaining a proper balance of nutrients and waste products in the blood. Additionally, the hepatic portal circulation allows for the storage and release of glucose and other nutrients as needed by the body.

This unique circulatory pathway is vital for nutrient processing, detoxification, storage and release of nutrients, metabolism of drugs and hormones, immune function, regulation of blood volume and pressure, and the metabolism of bilirubin. It ensures proper functioning of the liver, which is a central organ involved in numerous metabolic, synthetic, and detoxification processes necessary for overall health and well-being.

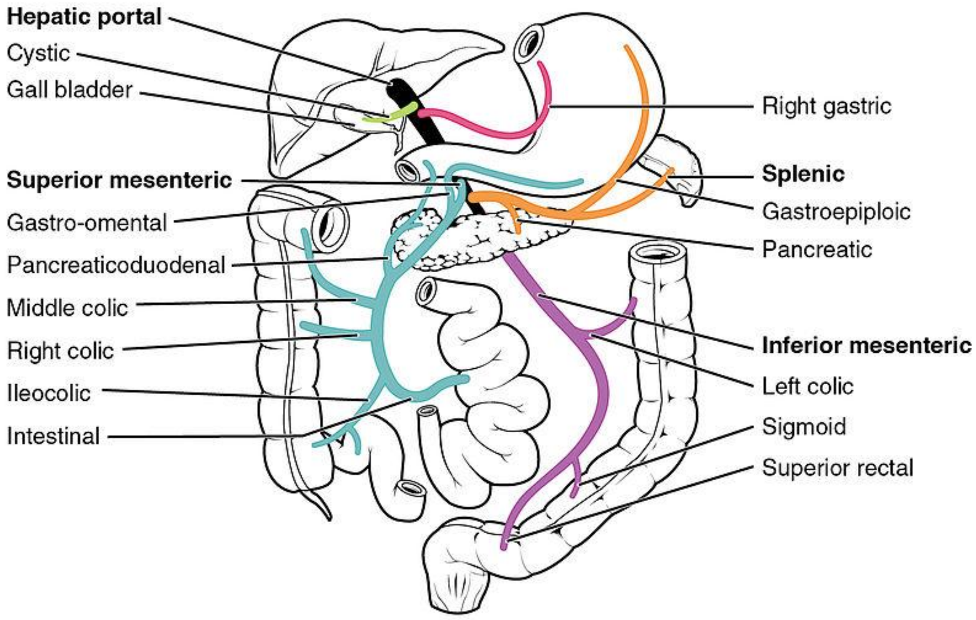

Figure 3.11: Hepatic Portal Circulation

3.9.2 Hypophyseal Portal Circulation

The hypophyseal portal circulation is a unique blood supply system that connects the hypothalamus (a region of the brain) to the anterior pituitary gland as illustrated in figure 3.12. The hypophyseal portal circulation is vital for the regulation of hormone secretion from the anterior pituitary gland. The releasing and inhibiting hormones from the hypothalamus control the production and release of specific hormones, such as growth hormone, thyroid-stimulating hormone, and gonadotropins, which are essential for the regulation of growth, metabolism, reproduction, and other physiological processes. These hormones travel through a portal vein called the hypothalamic-hypophyseal portal vein and reach the anterior pituitary gland. Therefore the main significance of hypophysial portal system is to enables the hormones from hypothalamus to reach the anterior pituitary lobe.

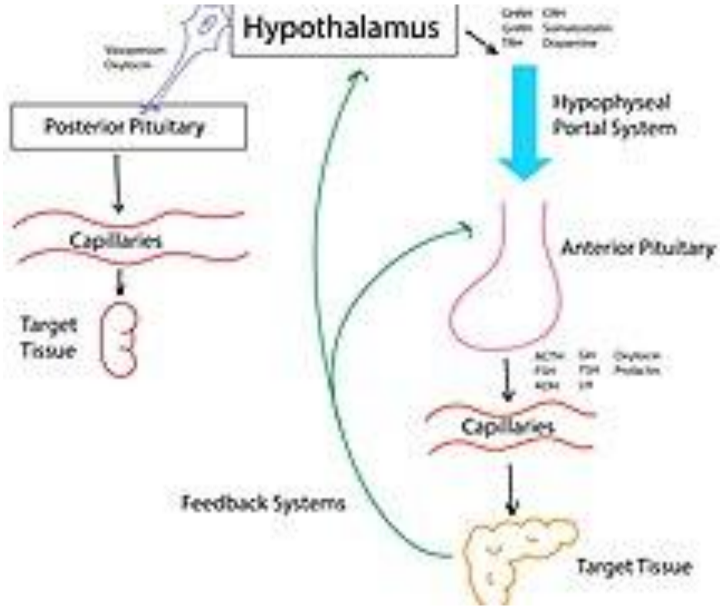

Figure 3.12: Hypophyseal Portal Circulation

3.10 HEART BEAT AND HEART RATE

3.10.1 Heart Beat

Heartbeat refers to the rhythmic contraction and relaxation of the heart muscle, resulting in the pumping of blood throughout the body. It is a vital physiological process that ensures the continuous circulation of oxygen, nutrients, and waste products to and from the body's tissues.

The heartbeat produces specific sounds, known as heart sounds, which can be heard with a stethoscope. The two main heart sounds are "lub-dub."

- S1 ("Lub"): The first heart sound (S1) occurs during ventricular systole and is caused by the closure of the mitral and tricuspid valves. It marks the beginning of ventricular contraction.
- S2 ("Dub"): The second heart sound (S2) occurs during ventricular diastole and is caused by the closure of the aortic and pulmonary valves. It marks the beginning of ventricular relaxation.

Next, learn here some key points about the heartbeat:

- The heartbeat is a result of the cardiac cycle, which is the sequence of events that occur during one complete heartbeat. The cardiac cycle consists of two main phases: diastole and systole.
- Electrical Conduction System: The heartbeat is regulated by the heart's electrical conduction system, which coordinates the timing and sequence of cardiac muscle contractions. The system includes specialized cells that generate and conduct electrical impulses throughout the heart, ensuring synchronized contractions.

Control of heart beat: The rate of heartbeats is primarily controlled by the autonomic nervous system, specifically through the actions of the sympathetic and parasympathetic divisions. These divisions work in opposition to regulate the heart rate and maintain a balance in response to various physiological and environmental conditions. The intricate control of heart rate by the autonomic nervous system ensures that the heart responds appropriately to the body's demands. The balance between sympathetic and parasympathetic influences allows for precise regulation of heart rate under different physiological conditions, ensuring efficient blood circulation and maintaining overall cardiovascular health.

Here's a closer look at how the rate of heartbeats is controlled:

1. **Sympathetic Nervous System:** The sympathetic division of the autonomic nervous system is responsible for increasing the heart rate. When the body requires increased blood flow, such as during physical activity or times of stress or excitement, the sympathetic nerves release norepinephrine, which binds to beta-adrenergic receptors in the heart. This binding stimulates the following effects:

   - *Increased Heart Rate:* The sympathetic stimulation enhances the generation of electrical impulses in the sinoatrial (SA) node, the heart's natural pacemaker. This increases the firing rate of the SA node, leading to an increased heart rate.

If the S.A. node become defective, then it fails to generate cardiac impulse at the normal rate and resulting the slow and irregular heart beat. This can be corrected by implanting artificial pacemaker in patient’s chest, which stimulates the electric impulse in heart at regular intervals to beat at normal rate.

- *Increased Conduction Speed:* Sympathetic stimulation also increases the conduction speed of electrical impulses through the atrioventricular (AV) node and the conducting fibers in the ventricles. This allows for faster transmission of electrical signals and more efficient contraction of the heart muscle.
- *Increased Contractility:* The sympathetic system enhances the force of contraction in the heart muscle, increasing the volume of blood pumped with each heartbeat. This is achieved by increasing the availability of calcium ions, which are necessary for muscle contraction.

2. **Parasympathetic Nervous System:** The parasympathetic division of the autonomic nervous system, specifically the vagus nerve (cranial nerve X), is responsible for decreasing the heart rate. It is the primary controller of the heart's resting rate. When the body is at rest or during periods of relaxation, the parasympathetic system predominates. The release of acetylcholine from the vagus nerve binds to muscarinic receptors in the heart, leading to the following effects:

   - *Decreased Heart Rate*: Parasympathetic stimulation reduces the firing rate of the SA node, slowing down the heart rate and promoting a state of relaxation.
   - *Decreased Conduction Speed:* Parasympathetic stimulation also slows down the conduction of electrical impulses through the AV node, resulting in a longer delay between atrial and ventricular contractions. This allows for more efficient filling of the ventricles before each contraction.

3. **Hormonal Regulation:** Hormones can also influence heart rate. For example, adrenaline (epinephrine) and noradrenaline (norepinephrine) released by the adrenal glands during the "fight-or-flight" response have a stimulating effect on the heart, similar to the sympathetic nervous system.
4. **Baroreceptor Reflex:** Specialized pressure receptors called baroreceptors are located in the walls of certain blood vessels, such as the carotid arteries and aortic arch. These receptors detect changes in blood pressure. When blood pressure increases, the baroreceptors send signals to the cardiovascular control centers in the brainstem, which in turn can modulate heart rate to maintain homeostasis.
5. **Other Factors:** Various other factors can affect heart rate, including body temperature, emotions, medications, exercise, and certain medical conditions. Fever, anxiety, certain

drugs, and stimulants can increase heart rate, while relaxation, deep breathing exercises, and certain medications (e.g., beta-blockers) can decrease heart rate.

3.10.2 Heart Rate

Heart rate refers to the number of times the heart beats per minute (bpm). It is an essential physiological parameter that provides valuable information about cardiovascular health and function. The heart rate is regulated by a complex interplay of various factors and can be influenced by both internal and external stimuli.

Here are some key points about heart rate:

1. *Normal Resting Heart Rate:* The average resting heart rate for adults is typically between 60 and 100 bpm. However, well-conditioned athletes may have resting heart rates below 60 bpm, which is a reflection of their cardiovascular fitness.
2. *Measurement:* Heart rate can be measured using various methods, including manually checking the pulse at certain points on the body (such as the wrist or neck) or by using electronic devices like heart rate monitors or electrocardiogram (ECG) machines.
3. *Factors Influencing Heart Rate:* Heart rate is influenced by several factors, including:
    - *Age:* Heart rate tends to decrease with age. Newborns have a higher resting heart rate compared to adults, and it gradually decreases throughout childhood and into adulthood.
    - *Physical Activity:* Heart rate increases during physical activity or exercise to meet the increased demand for oxygen and nutrients in the body's tissues. This response is mediated by the sympathetic nervous system.
    - Emotional and Psychological Factors: Heart rate can be influenced by emotions, stress, anxiety, and other psychological factors. For example, a heightened state of arousal or anxiety can increase heart rate.
    - *Body Temperature:* Heart rate may increase with an increase in body temperature. This is why heart rate is commonly measured as part of a routine clinical examination, particularly during fever or heat-related conditions.

Medications and Drugs: Certain medications, such as beta-blockers or stimulants, can

a) ts passage through the GI tract.

b) **Immune defence:** The GI tract plays a vital role in the body's immune system as it encounters numerous foreign substances, including bacteria and viruses. The lining of the GI tract contains numerous immune cells that protect the body from harmful pathogens.

c) **Hormone production:** Cells lining the GI tract produce various hormones that have important roles in digestion and metabolism. For instance, gastrin stimulates the production of gastric acid, while insulin regulates glucose metabolism.

In summary, you have learnt that,the GI tract serves essential functions in digestion, absorption, secretion, motility, immune defence, and hormone production.

	Stimulus of Release	Primary Target	Primary Effect	Other Information
Stomach				
Gastrin (G Cells)	Peptides and amino acids; neural reflexes	ECL cells and parietal cells	Stimulates gastric acid secretion and mucosal growth	Somatostatin inhibits release
Intestine				
Cholecystokinin (CCK)	Fatty acids and some amino acids	Gallbladder, pancreas, stomach	Stimulates gallbladder contraction and pancreatic enzyme secretion Inhibits gastric emptying and acid secretion	Promotes satiety Some effects may be due to CCK as a neurotransmitter
Secretin	Acid in small intestine	Pancreas, stomach	Stimulates HCO3- secretion Inhibits gastric emptying and acid secretion	
Motilin	Fasting: periodic release every 1.5–2 hours	Gastric and intestinal smooth muscle	Stimulates migrating motor complex	Inhibited by eating a meal
Gastric Inhibitory Peptide (GIP)	Glucose, fatty acids, and amino acids in small intestine	Beta cells of pancreas	Stimulates insulin release (feedforward mechanism) Inhibits gastric emptying and	

			acid secretion	
Glucagon-Like Peptide-1 (GLP-1)	Mixed meal that includes carbohydrates or fats in the lumen	Endocrine pancreas	Stimulates insulin release Inhibits glucagon release and gastric function	Promotes satiety

Table 4.2 The Gastrointestinal Hormones

Check Your Progress- Exercise II

1.) How does the process of digestion start in the mouth?

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2.) How are nutrients absorbed in the small intestine?

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3.) What is the primary function of digestion in the human body?

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Source: Retrieved from The Digestive System 'Pearson'

4.6 STOMACH

Let's discuss, the stomach, situated in the upper left side of the abdomen, is a muscular sac-shaped organ that plays a crucial role in the mechanical and chemical digestion of food as part of the digestive system. After receiving food from the esophagus, it mixes it with gastric juice to break it down into smaller particles and controls the release of food into the small intestine at a regulated rate. Due to its specialized muscles and cells, the stomach has a distinctive structure that enables it to perform its digestive functions effectively.

4.6.1 Structure of Stomach

Here is an overview of the structure of the stomach:

a) **Cardiac sphincter**: The cardiac sphincter, also known as the lower esophageal sphincter, positioned at the junction of the esophagus and stomach, the cardiac sphincter, also known as the lower esophageal sphincter, is a muscular valve. Its primary role is to prevent the backward flow of stomach contents into the esophagus. This function is essential because the acidic nature of the stomach can cause harm to the delicate lining of the esophagus and give rise to conditions like gastroesophageal reflux disease (GERD). When food is swallowed, it travels through the esophagus and reaches the cardiac sphincter. At this point, the sphincter opens to allow the food to enter the stomach. Once the food has entered the stomach, the sphincter closes to prevent the acidic contents of the stomach from flowing back up into the esophagus. Occasionally, the cardiac sphincter may malfunction, resulting in conditions such as GERD or hiatal hernia. Symptoms of these conditions may include heartburn, chest pain, and swallowing difficulties. Treatment options may involve lifestyle adjustments, medications to reduce acid production, or surgical intervention to repair the sphincter.

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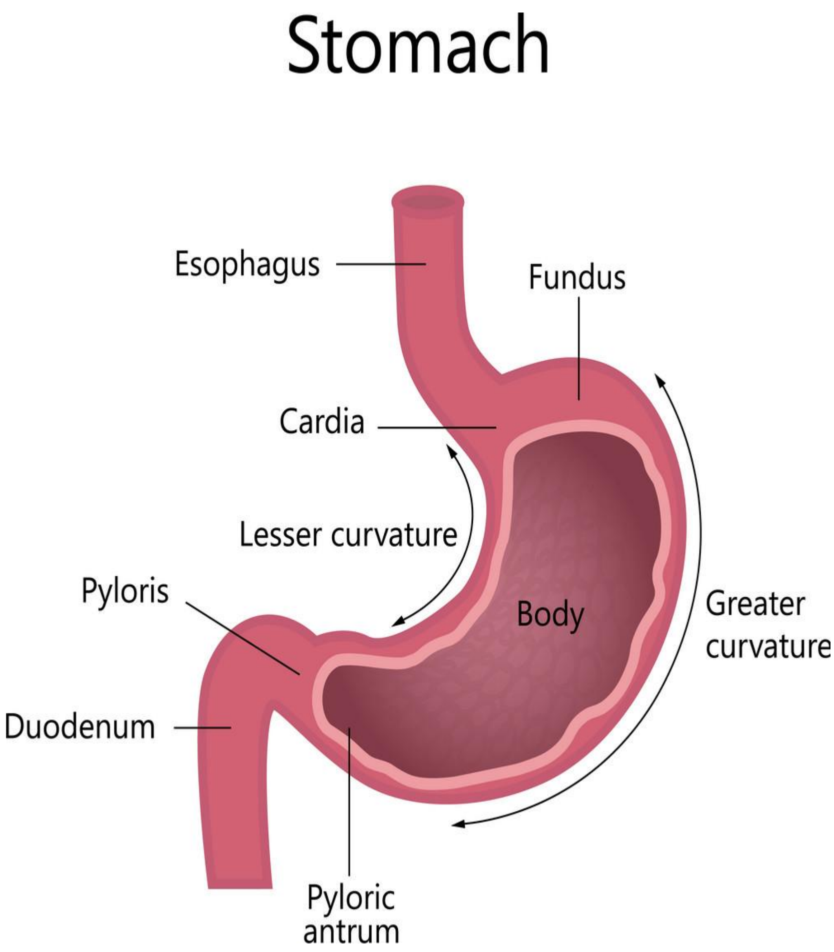

Figure 4.4 The Stomach Structure

b) **Fundus:**The fundus is located above the cardiac sphincter and serves as the uppermost part of the stomach. Its shape is rounded and dome-like, and it can expand as it fills with food. The fundus acts as a temporary storage site for newly ingested food. Due to its size and elasticity, it can hold up to 1.5 liters of food and liquid. It also helps regulate the speed at which food enters the rest of the stomach by controlling pressure. As food enters the stomach, the lower esophageal sphincter relaxes, enabling food to pass through. Then, the fundus contracts to accommodate the incoming food, while the pyloric sphincter remains closed to prevent food from leaving the stomach too quickly. This ensures that the food is thoroughly mixed and broken down before passing into the small intestine. The fundus also plays a vital role in protein digestion by secreting gastrin, a hormone that stimulates the release of gastric juice and the contraction of stomach muscles, both of which aid in mechanical and chemical digestion. Moreover, the fundus contains parietal cells, which secrete hydrochloric acid and intrinsic factor. Natural Component is necessary for the absorption of vitamin B12.

c) **Body:**The body of the stomach is where the bulk of the digestive process takes place. Gastric glands lining the stomach walls produce gastric juice, which comprises hydrochloric acid, mucus, and digestive enzymes, including pepsin and rennin. The gastric juice aids in the breakdown of food into a semi-liquid substance known as chyme, which is gradually released through the pyloric sphincter into the small intestine for further digestion and absorption. Coordinated contractions and relaxation of the stomach muscles enable the mixing of food with gastric juice and movement towards the pyloric sphincter. The frequency and rate of stomach contractions are controlled by the nervous system and hormones like gastrin. Stretch receptors in the stomach wall are activated by the entry of food, resulting in signals sent to the brain to stimulate gastrin release. Gastrin, in turn, increases gastric juice secretion and the rate of stomach contractions. The stomach's body can expand and contract to accommodate varying amounts of food. The stomach lining folds, called rugae, enable it to stretch and increase in volume to accommodate larger meals. This temporary storage capability facilitates more effective nutrient digestion and absorption in the small intestine.

d) **Pylorus:**The narrowest part of the stomach is known as the pylorus, located at the bottom near the small intestine where it connects the stomach to the first section of the small intestine called the duodenum. It contains the pyloric sphincter, a thick ring of smooth muscle, which controls the flow of partially digested food from the stomach into the small intestine. By detecting the consistency of the partially digested food, the pylorus adjusts the opening of the pyloric sphincter to regulate the rate at which the stomach empties its contents into the small intestine. This allows the small intestine to receive a manageable amount of food at a time, optimizing digestion and absorption. Additionally, the pylorus prevents undigested food particles and large molecules from passing into the small intestine by creating a barrier with the contracting pyloric sphincter. Instead, the food is further broken down in the stomach until it is in a form that can be easily absorbed by the small intestine.

e) **Pyloric sphincter:**The pyloric sphincter is a muscular valve situated at the end of the narrow lower part of the stomach called the pylorus. Its primary function is to control the flow of partially digested food from the stomach to the small intestine. This opening and closing mechanism of the pyloric sphincter is regulated by both neural and hormonal signals. The opening of the pyloric sphincter occurs when the stomach is full and the food is partially digested, allowing small amounts of chyme to pass through to the duodenum for further digestion and absorption. The rate of opening and closing of the pyloric sphincter depends on several factors such as the consistency and volume of the chyme, the pH level, and the presence of digestive hormones like gastrin. When the pyloric sphincter opens too slowly or fails to open, food may remain in the stomach longer than usual, leading to discomfort and nausea. On the other hand, if it opens too quickly or fails to close properly, the chyme may flow back into the stomach, causing acid reflux and other digestive issues.

f) **Rugae:**The rugae are folds or wrinkles found in the inner lining of the stomach. They have the ability to expand or contract depending on the amount of food being digested. The presence of rugae increases the surface area of the stomach, allowing it to accommodate more food when needed. When the stomach is empty, the rugae flatten out, resulting in a smoother appearance of the stomach lining. The rugae also play a crucial role in the mixing and grinding of food. By increasing the surface area in contact with the food, they facilitate more effective mechanical digestion. This process breaks down the food into smaller pieces that are easier to digest. Apart from their mechanical function, the rugae contribute to the secretion of gastric juice. These folds create pockets where gastric glands are located, and these glands secrete gastric juice containing enzymes and acid necessary for the chemical digestion of proteins, fats, and carbohydrates.

g) Gastric glands: The lining of the stomach contains gastric glands that are specialized cells responsible for secreting gastric juice, which is a mixture of mucus, enzymes, and hydrochloric acid. The gastric juice is critical for the digestive process, as it helps to break down complex molecules like proteins into smaller units. The chief cells within the gastric glands secrete pepsinogen, an inactive form of pepsin that is responsible for the digestion of proteins into smaller peptides. The secretion of pepsinogen is stimulated by the hormone gastrin, which is released in response to the presence of food in the stomach. Additionally, parietal cells in the gastric glands secrete hydrochloric acid, which helps to create an acidic environment optimal for pepsin activity. Hydrochloric acid also helps to destroy harmful bacteria in the food. The gastric glands also secrete intrinsic factor, a hormone required for the absorption of vitamin B12 in the small intestine. The mucus-secreting cells in the gastric glands produce mucus that helps to protect the stomach lining from the corrosive effects of gastric juice. The gastric glands are crucial in the digestive process, and their secretions play vital roles in the breakdown and absorption of nutrients from food.

You have learnt about the structure of stomach. Let's understand its function also.

4.6.2 Functions of Stomach

The stomach serves multiple vital functions in the process of digestion. Here are some key roles of the stomach:

a) **Storage:** The stomach acts as a temporary reservoir, holding ingested food until it is ready to proceed to the small intestine for further digestion.
b) **Mechanical digestion:** Through the contraction of its muscular walls, the stomach effectively mixes and grinds food, transforming it into a liquid form called chyme. This process breaks down the food into smaller particles, increasing the available surface area for subsequent chemical digestion.
c) **Chemical digestion:** Specialized gastric glands within the stomach produce gastric juice, comprising hydrochloric acid and digestive enzymes like pepsin and rennin. These enzymes play a vital role in breaking down proteins and other food components, facilitating their absorption into the body.
d) **Protection:** The stomach lining secretes a protective layer of mucus, safeguarding the stomach wall from the harsh effects of gastric acid. This protective mechanism prevents damage to the stomach tissues, ensuring the smooth continuation of the digestive process.
e) **Hormone production:** The stomach also synthesizes various hormones, including ghrelin and gastrin. Ghrelin regulates appetite, while gastrin stimulates the production and release of gastric juice, and controls the movement of food through the digestive system.

Overall, the stomach's unique functions enable it to contribute significantly to the digestion and processing of ingested food.

4.7 LIVER

In this section, you are going to learn very important organ i.e., Liver. The liver is an essential organ positioned in the upper right side of the abdomen and situated beneath the diaphragm. Its numerous physiological processes include digestion, metabolism, and detoxification. Blood from the digestive system is received by the liver, which filters and processes it before circulating it back to the body. Moreover, the liver produces bile, a fluid that helps in the digestion of fats within the small intestine. The liver is also involved in the metabolism of carbohydrates, fats, and proteins, as well as in the synthesis of significant molecules such as cholesterol and blood-clotting factors.

The liver has a reddish-brown appearance and is relatively large, being divided into two primary lobes known as the right and left lobes. Each of these lobes consists of smaller lobules, which serve as functional units of the liver. Within each lobule, numerous hepatocytes, or hepatic cells, carry out essential functions.

4.7.1 Structure of Liver

The liver is composed of several structures, including:

a) **Hepatic artery:**The hepatic artery is a crucial blood vessel responsible for supplying oxygen-rich blood to the liver from the heart. Originating from the celiac trunk, a major artery that emerges from the abdominal aorta, it contributes about a quarter of the liver's blood supply. This oxygenated blood plays a vital role in facilitating the liver's metabolic activities by providing the necessary oxygen to support liver cells. Furthermore, the hepatic artery transports essential nutrients such as glucose and amino acids, which are required for the liver's metabolic processes. Additionally, the hepatic artery is responsible for removing waste products from the liver by carrying away depleted blood containingwaste and nutrients back to the heart for oxygenation.

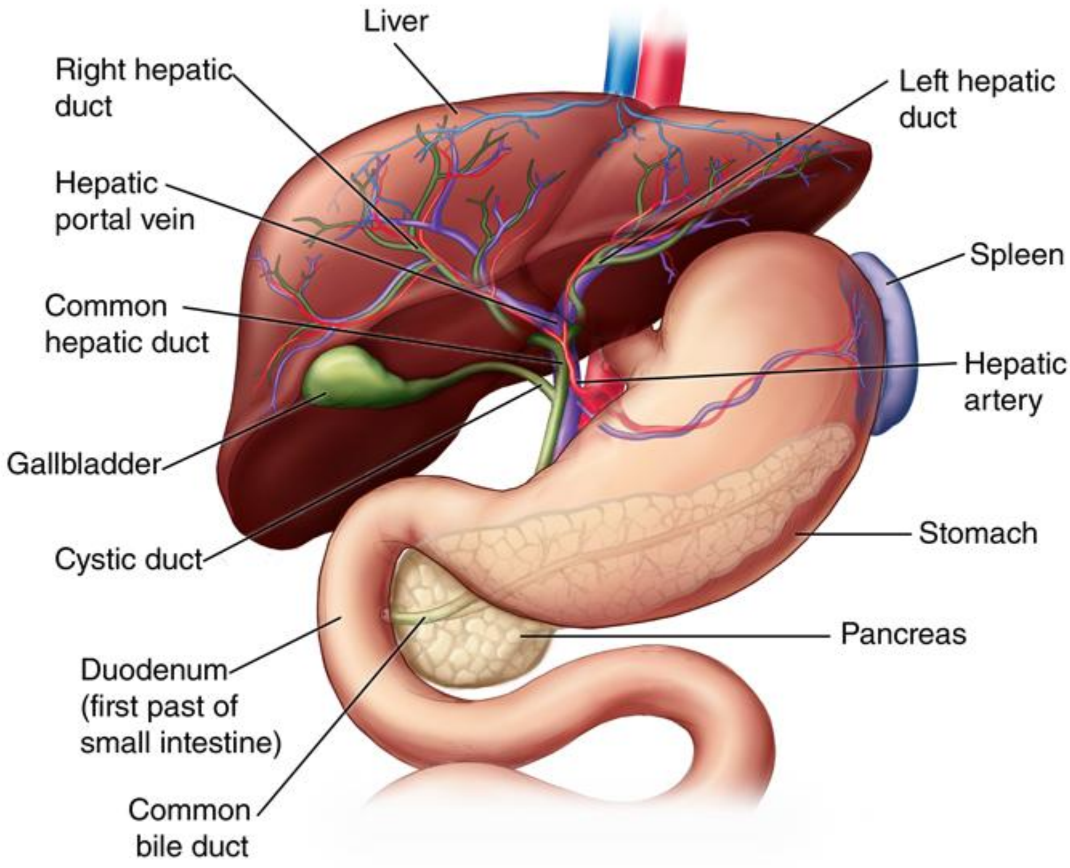

Figure 4.5 The Liver Structure

b) **Portal vein:**The portal vein is a significant blood vessel responsible for carrying blood rich in nutrients and substances absorbed from the digestive tract to the liver. It originates from the convergence of the superior mesenteric vein and the splenic vein behind the pancreas, and then branches into smaller vessels as it enters the liver. Upon reaching the liver, the blood undergoes filtration and processing by hepatocytes. The liver's detoxification process eliminates harmful toxins, while the breakdown of nutrients allows the liver to store or release glucose according to the body's needs. Additionally, the portal vein aids in regulating blood glucose levels and maintaining a healthy nutrient balance in the body.

c) **Bile ducts:**Bile ducts are a network of thin tubes that carry bile from the liver to the small intestine for the digestion of fats and fat-soluble vitamins. The bile ducts start as small channels called canaliculi in the liver, which merge to form larger ducts that join to form the right and left hepatic ducts. The hepatic ducts exit the liver and merge to form the common hepatic duct, which joins with the cystic duct from the gallbladder to form the common bile duct. The flow of bile through the bile ducts is regulated by a ring of muscle called the sphincter of Oddi, which opens and closes to allow bile to flow into the small intestine when needed. When food containing fats enters the small intestine, the sphincter of Oddi relaxes, allowing bile to aid in digestion. Obstruction or blockage of the bile ducts can cause a buildup of bile in the liver, leading to jaundice, itching, and other symptoms. Medical interventions like surgery or endoscopic procedures may be necessary to remove the obstruction and restore normal bile flow.

d) **Gallbladder:** This is a small, pear-shaped organ located beneath the liver that stores bile. We will discuss it in upcoming section.

e) **Sinusoids:**Sinusoids are specialized capillaries found only in the liver's functional units called lobules. These capillaries are lined with endothelial cells, which are separated from the hepatocytes by the space of Disse. The sinusoids play a crucial role in filtering and processing blood as it flows through the liver. Their unique structure enables them to remove foreign particles such as bacteria, viruses, and toxins from the bloodstream. The sinusoids also contain Kupffer cells, which are phagocytic cells that can engulf and remove these foreign particles. In addition to filtering the blood, the sinusoids facilitate the exchange of nutrients and waste products between the blood and hepatocytes. The space of Disse between the endothelial cells and hepatocytes allows for the exchange of molecules such as oxygen, glucose, and amino acids. Overall, sinusoids are essential for the liver's function in maintaining homeostasis by filtering the blood and enabling the exchange of molecules between the blood and hepatocytes.

f) **Kupffer cells:**Kupffer cells are a type of specialized immune cell that resides in the liver sinusoids. These cells are a type of macrophage, which means their primary function is to engulf and degrade foreign substances and cellular debris present in the liver. By performing this function, Kupffer cells play a vital role in protecting the liver from inflammation and infection caused by the buildup of toxins, pathogens, and waste products in the bloodstream. These cells can recognize and bind to a wide variety of substances, including damaged cells, bacteria, viruses, and other foreign particles. Furthermore, Kupffer cells produce cytokines and other signaling molecules that activate other immune cells such as T and B cells to initiate a more robust immune response. Finally, Kupffer cells also play a role in regulating liver inflammation and repairing damaged liver tissue.

You have learnt about the structure of liver. Let's understand its function also.

4.7.2 Functions of liver

The liver is a vital organ that performs a wide array of functions crucial for maintaining overall health and well-being. Here are some of the key roles of the liver:

a) **Detoxification:** The liver plays a critical role in detoxifying the body by metabolizing and eliminating harmful substances, including alcohol, drugs, and toxins. It transforms these substances into less harmful forms that can be excreted from the body.

b) **Bile production:** The liver produces bile, a greenish-yellow fluid that aids in the digestion and absorption of fats and fat-soluble vitamins in the small intestine. Bile also helps eliminate waste products, such as bilirubin, derived from the breakdown of red blood cells.

c) **Metabolism:** The liver regulates metabolism by processing and converting nutrients from food into usable forms. It is involved in carbohydrate, protein, and fat metabolism and stores essential vitamins and minerals. The liver maintains stable blood sugar levels by producing and storing glucose, which can be released into the bloodstream as needed.

d) **Blood filtration:** The liver filters the blood by removing old or damaged red blood cells and breaking down and eliminating excess hormones, drugs, and toxins. Additionally, it produces bile, facilitating the excretion of waste products and excess cholesterol.

e) **Storage:** The liver stores nutrients such as glucose, which can be released into the bloodstream to maintain proper blood sugar levels. It also stores essential vitamins and minerals, including iron, necessary for haemoglobin production.

f) **Immune system support:** The liver supports the immune system by producing proteins like complement and acute-phase proteins that assist in combating infections and foreign substances. It also filters out bacteria, viruses, and other pathogens from the bloodstream.

g) **Hormone regulation:** The liver contributes to hormone regulation by metabolizing and removing excess hormones from the bloodstream. It also produces hormones like insulin-like growth factor 1 (IGF-1), vital for tissue and organ growth and development.

h) **Blood clotting:** The liver synthesizes clotting factors, including fibrinogen and prothrombin, essential for proper blood clotting and preventing excessive bleeding.

So you have enhances your knowledge about the liver. Concluding that the liver is crucial for maintaining the body's metabolic balance, biochemical processes, immune function, hormone regulation, and blood clotting. Any impairment or dysfunction of the liver can lead to significant health issues.

Check Your Progress- Exercise III

1.) What is the role of gastric juices in the stomach?

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2.) How does the liver contribute to detoxification?

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3.) What is bile?

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4.8 GALL BLADDER

Let’s discuss gall bladder. The gallbladder, a small pear-shaped organ situated beneath the liver, stores bile, a fluid produced by the liver that assists in the digestion and absorption of fats in the small intestine. It measures around 3-4 inches in length and 1 inch in diameter. Whenever required, the gallbladder releases the stored bile into the small intestine via a network of ducts that connect it to the liver and small intestine.

4.8.1 Structure of Gall Bladder

The gallbladder consists of three primary sections: the fundus, body, and neck. The fundus refers to the rounded and bulbous part of the gallbladder located above the body. The body represents the largest portion of the gallbladder and connects to the neck, a narrow channel that leads to the bile duct. Comprising various layers of tissue, including an outer serous membrane, a muscular layer, and an inner mucous membrane, the gallbladder possesses distinct features for its functionality.

The mucous membrane within the gallbladder contains folds called rugae, enabling the organ to expand and contract as it stores and releases bile. Surrounding the gallbladder, there exists a network of blood vessels, nerves, and lymphatic vessels, which provide essential nutrients, oxygen, and facilitate communication with other parts of the body. Additionally, the gallbladder possesses a muscular layer that contracts and releases bile into the bile duct upon receiving signals from the digestive system, particularly after a meal rich in fats. The bile is subsequently transported to the small intestine, aiding in the digestion of fats and the absorption of fat-soluble vitamins.

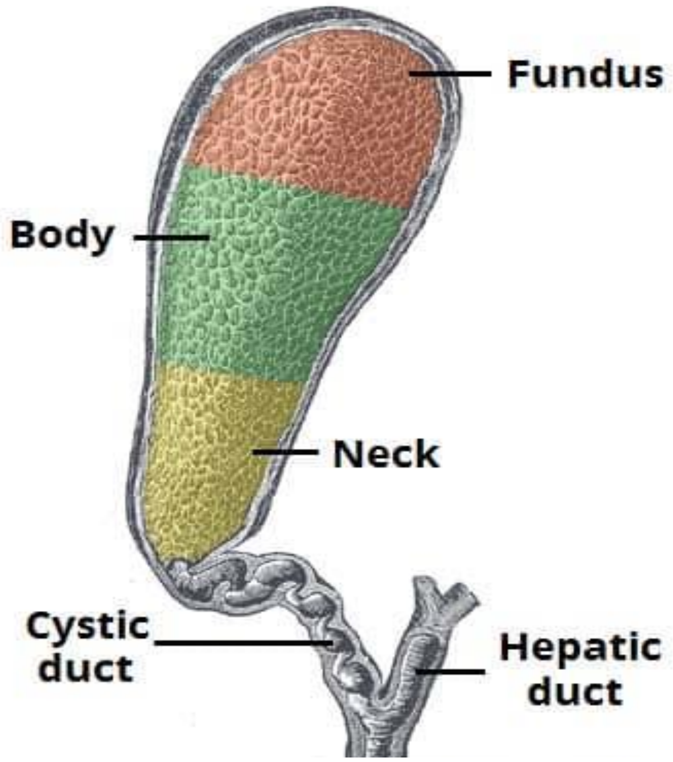

Figure 4.6 The Gall Bladder Structure

You have learnt about the structure of gall bladder. Let’s understand its function also.

4.8.2 Functions of Gall Bladder

Some functions of gall bladder are listed below:

a) **Bile Storage:** The gallbladder's primary role is to store and concentrate bile, produced by the liver, which aids in the digestion and absorption of fats in the small intestine.
b) **Bile Secretion:** Upon the arrival of fat-containing foods in the small intestine, the gallbladder contracts and releases bile through the bile ducts to facilitate digestion.
c) **Bile Modification:** The gallbladder can modify bile composition by extracting water and electrolytes, enhancing its potency and effectiveness in breaking down fats.
d) **Waste Elimination:** The gallbladder contributes to waste elimination by expelling waste products such as bilirubin, a byproduct of red blood cell breakdown, through the bile.
e) **Hormonal Control:** Hormones, like cholecystokinin (CCK), regulate the gallbladder's functions. CCK is released in response to the presence of fat in the small intestine, stimulating gallbladder contraction and bile release.
f) **Digestive Role:** The gallbladder plays a critical part in digestion by aiding in the absorption of dietary fats and fat-soluble vitamins, including vitamins A, D, E, and K.
g) **Protection against Infections:** Bile contains antimicrobial agents that help defend against infections caused by harmful intestinal bacteria, preventing bacterial overgrowth and promoting a healthy gut microbiome.

In summary, the gallbladder is vital for fat digestion and absorption, waste elimination, and protection against infections.

4.9 PANCREAS

In this section you will understand about the pancreas. The pancreas is a glandular organ located in the abdominal cavity, behind the stomach. It has both endocrine and exocrine functions and plays a crucial role in digestion and metabolism.The pancreas is a long, flattened gland located behind the stomach in the upper abdomen. It is about 6-8 inches long and is composed of two main types of tissue: exocrine tissue and endocrine tissue.

Exocrine tissue: The exocrine tissue of the pancreas is composed of small, grape-like clusters of cells called acini. These cells produce and secrete digestive enzymes into a network of ducts that ultimately lead to the small intestine. The enzymes produced by the pancreas help break down proteins, fats, and carbohydrates in the small intestine, allowing the body to absorb nutrients from food.

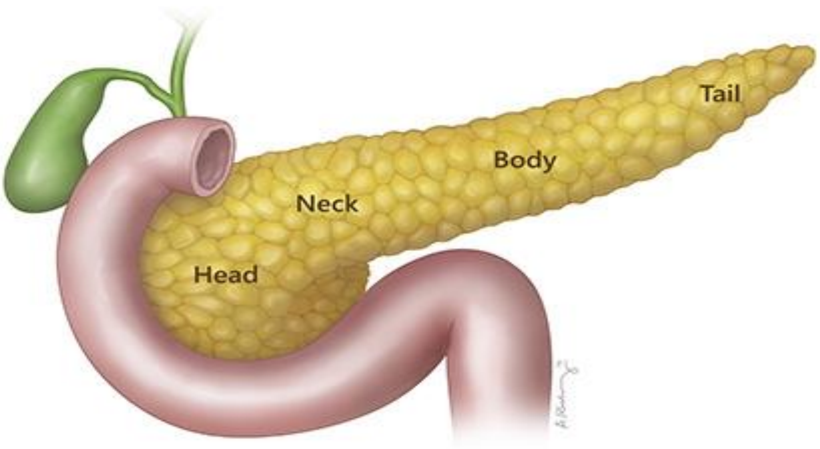

Figure 4.7 The structure of Pancreas

Endocrine tissue: The endocrine tissue of the pancreas is composed of specialized cells called islets of Langerhans. These cells produce and secrete hormones, such as insulin and glucagon, directly into the bloodstream. Insulin helps regulate blood sugar levels by promoting the uptake of glucose from the blood into cells for energy, while glucagon stimulates the liver to release stored glucose into the bloodstream when blood sugar levels are low.

4.9.1 Structure of Pancreas

The pancreas can be divided into three main regions: the head, the body, and the tail.

1. **Head:** The head of the pancreas is the widest part and is located on the right side of the abdomen. It is connected to the first part of the small intestine, called the duodenum, through a small duct called the pancreatic duct. The head of the pancreas also surrounds the first part of the small intestine and the common bile duct, which carries bile from the liver and gallbladder to the small intestine.

2. **Neck:** The neck of the pancreas is a narrow, elongated region that connects the head and body of the pancreas. It is located between the superior mesenteric artery and vein, which are important blood vessels that supply the intestines and other abdominal organs. The neck of the pancreas is also adjacent to the portal vein, which is the large vein that carries nutrient-rich blood from the intestines to the liver. The pancreatic duct, which carries digestive enzymes produced by the pancreas, runs through the neck of the pancreas before entering the duodenum, the first part of the small intestine.
3. **Body:** The body of the pancreas extends from the head towards the left side of the abdomen. It is located behind the stomach and in front of the spine. The body of the pancreas is slightly narrower than the head and has a slightly curved shape.
4. **Tail:** The tail of the pancreas is the narrowest part and extends to the left side of the abdomen, ending near the spleen. The tail is also located behind the stomach and in front of the left kidney.

Overall, the pancreas has a unique structure that allows it to perform its many functions. The different regions of the pancreas have varying roles in producing and secreting digestive enzymes and hormones, such as insulin and glucagon, into the bloodstream. You have learnt about the structure of pancreas. Let’s understand its function also.

4.9.2 Function of Pancreas

The pancreas has both exocrine and endocrine functions.

A. Exocrine functions:

1. **Digestive enzyme production:** The exocrine cells of the pancreas produce and secrete enzymes, such as amylase, lipase, and proteases, that help break down carbohydrates, fats, and proteins in the small intestine.
2. **Bicarbonate production:** The exocrine cells also produce and secrete bicarbonate, which helps neutralize stomach acid as it enters the small intestine.

B. Endocrine functions:

1. **Insulin production:** The endocrine cells of the pancreas, specifically the beta cells in the islets of Langerhans, produce and secrete the hormone insulin, which regulates blood glucose levels by promoting the uptake of glucose into cells.

2. **Glucagon production:** The alpha cells in the islets of Langerhans produce and secrete the hormone glucagon, which stimulates the liver to release glucose into the bloodstream when blood glucose levels are low.
3. **Somatostatin production:** The delta cells in the islets of Langerhans produce and secrete the hormone somatostatin, which helps regulate the release of insulin and glucagon and slows down the digestive process.

4.10 GLOSSARY

Colon: The large intestine is responsible for absorbing water, electrolytes, and vitamins from undigested food and forming and eliminating feces.

Anus: The anus is the opening at the end of the digestive tract through which feces are expelled from the body.

Enzymes: Enzymes are proteins that speed up chemical reactions in the body. In the digestive system, enzymes break down complex molecules (carbohydrates, proteins, and fats) into simpler forms for absorption.

Peristalsis: Peristalsis is the muscular contractions that propel food through the digestive system, from the esophagus to the anus.

Feces: Feces are the solid waste materials, including undigested food, bacteria, and waste products, that are eliminated from the body through the rectum and anus.

Microbiota: Microbiota refers to the community of microorganisms (bacteria, fungi, and viruses) that reside in the digestive system. They play a crucial role in digestion, nutrient absorption, and overall gut health.

Mucus: Mucus is a slimy substance produced by the cells lining the digestive tract. It lubricates and protects the lining of the digestive organs, allowing for smooth movement of food and protecting against digestive enzymes.

4.11LET US SUM UP

In conclusion, the digestive system is a complex and essential system in the human body, responsible for breaking down food into nutrients that the body can use for energy and other functions. The gastrointestinal tract, stomach, liver, gallbladder, and pancreas are all involved in this process, working together to ensure proper digestion and absorption of nutrients. Understanding the functions and structures of these organs is crucial to maintaining good health and preventing digestive disorders.

4.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISE

Check Your Progress I

1. The gastrointestinal tract is responsible for the digestion and absorption of food, as well as the elimination of waste products from the body.
2. The salivary glands produce amylase, which breaks down carbohydrates, and the pancreas produces enzymes such as lipase (for fat digestion), proteases (for protein digestion), and amylase (for carbohydrate digestion).
3. Lipase is an enzyme that breaks down fats into smaller molecules called fatty acids and glycerol. Villi are finger-like projections in the small intestine that increase the surface area for absorption of nutrients into the bloodstream.

Check Your Progress II

1. The process of digestion starts in the mouth with the mechanical and chemical breakdown of food. Chewing breaks food into smaller pieces, while saliva, containing the enzyme amylase, begins the digestion of carbohydrates.
2. Nutrients are absorbed in the small intestine through the lining of its walls. The small intestine is lined with villi, which have tiny blood vessels called capillaries and lymphatic vessels called lacteals. Nutrients are absorbed into these vessels and transported to the bloodstream for distribution throughout the body.
3. The primary function of digestion in the human body is to break down food into smaller, absorbable molecules. This allows the body to extract and utilize nutrients for energy, growth, repair, and various metabolic processes.

Check Your Progress III

1. The role of gastric juices in the stomach is to aid in the digestion of food. Gastric juices, including hydrochloric acid and enzymes like pepsin, help break down proteins and kill bacteria present in the food.
2. The liver contributes to detoxification by filtering and metabolizing harmful substances in the body. It detoxifies various toxins, drugs, and metabolic waste products, converting them into less harmful forms that can be eliminated from the body.
3. Bile is a substance produced by the liver and stored in the gallbladder. It plays a crucial role in the digestion and absorption of fats. Bile emulsifies fats, breaking them down into smaller droplets, which enhances their digestion by enzymes and facilitates their absorption in the small intestine.

UNIT 5 RESPIRATORY SYSTEM

STRUCTURE

5.1 Introduction

5.1.1 Objectives

5.2 Structure of Respiratory System

5.3 Mechanism of Breathing

5.3.1 Inhalation

5.3.2 Exhalation

5.3.3 Respiratory Volumes and Capacity

5.4 Exchange of gases

5.5 Transport of Gases

5.5.1 Oxygen Transport

5.5.2 Carbon dioxide Transport

5.6 Regulation of Respiration

5.7 Glossary

5.8 Let Us Sum Up

5.9 Answers to Check your Progress

5.1 INTRODUCTION

In this unit, we will learn about the respiratory system. The respiratory system comprises various organs and structures in the body that enable breathing and facilitate the exchange of gases. Its primary purpose is to deliver oxygen to the body while eliminating carbon dioxide, a by-product of cellular respiration. The respiratory system also helps regulate the body's pH balance by controlling carbon dioxide levels in the blood. It consists of the upper respiratory tract, which includes the nose, nasal cavity, sinuses, pharynx, and larynx, as well as the lower respiratory tract, which encompasses the trachea, bronchi, bronchioles, and lungs. The upper respiratory tract filters and warms incoming air, whereas the lower respiratory tract facilitates gas exchange within the lungs.The lungs serve as the central organs of the respiratory system, comprising numerous tiny air sacs called alveoli. Oxygen from the inhaled air diffuses through the alveolar walls into the bloodstream, while carbon dioxide from the blood moves into the alveoli to be expelled from the body.

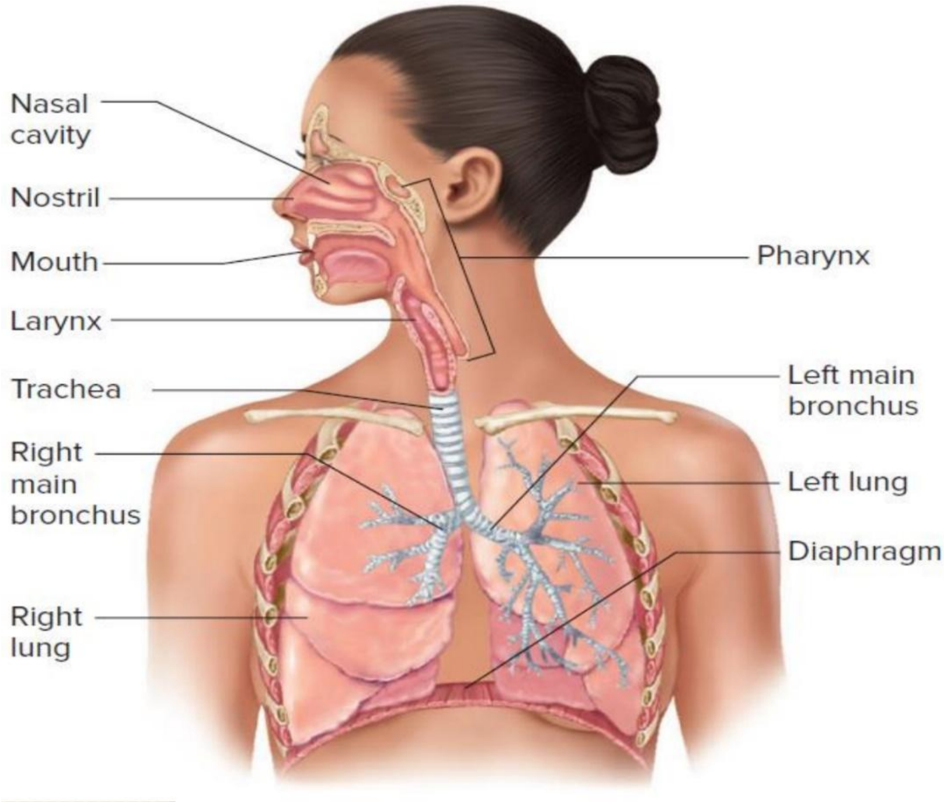

Figure 5.1 Respiratory System

Source: Retrieved from Vander’s Human Physiology 15th ed.,

Breathing is facilitated by the diaphragm, a dome-shaped muscle situated between the chest and abdominal cavities. During inhalation, the diaphragm contracts and moves descending, expanding the chest cavity to accommodate the expanding lungs. Exhalation occurs when the diaphragm relaxes and moves upward, reducing the chest cavity's size and enabling the lungs to expel air.

In addition to its respiratory functions, the respiratory system plays a role in immune defense, as immune cells line the respiratory tract and help combat infections and diseases. Furthermore, the respiratory system aids in regulating the body's temperature by releasing heat and water vapor during exhalation.

To sum up, the respiratory system is a complex and vital system that supplies oxygen, eliminates carbon dioxide, and maintains the body's pH balance. Its proper functioning is crucial for overall health and well-being. In this unit we will learn below objectives.

5.1.1 OBJECTIVES

- Understand the structure and functions of the respiratory system.
- Explore the mechanisms of breathing and the role of respiratory muscles.
- Learn about the exchange of gases in the lungs and tissues.
- Understand the transport of oxygen and carbon dioxide in the bloodstream.
- Explore the regulation of respiration and the factors that influence breathing.

5.2 STRUCTURE OF RESPIRATORY SYSTEM

Let’s discuss the structure of respiratory system anatomy includes the structures and organs that are involved in breathing and gas exchange in the body. These include:

a) **Nose and nasal cavity:** The nose and nasal cavity are the primary entrance for air into the respiratory system. The nose is composed of bone, cartilage, and soft tissue and is the visible part of the respiratory system. It is designed to capture airborne particles and filter them out of the air we breathe. The external part of the nose is made up of two nostrils (also called nares) that lead into the nasal cavity. The nasal cavity is lined with tiny hairs called cilia and mucus-producing cells known as goblet cells. These structures work together to filter, humidify, and warm the air as it passes through the nasal cavity. The cilia act like tiny brooms, trapping foreign particles, such as dust and pollen, and moving them towards the throat, where they can be swallowed or coughed out. The mucus also helps to trap these particles and moistens the air, making it easier to breathe. The nasal cavity also contains three bony structures called turbinates or nasal conchae. These structures help to increase the surface area of the nasal cavity, providing more space for air to come into contact with the nasal lining. This increases the time that the air spends in the nasal cavity, allowing for more efficient filtering and humidification. The nasal cavity is also richly supplied with blood vessels, which help to warm the air as it passes through the nose. This is important because cold air can cause the airways to constrict, making it more difficult to breathe.

b) **Pharynx:** The pharynx is a muscular tube that is part of both the respiratory and digestive systems. It extends from the back of the nasal cavity and mouth down to the larynx and esophagus. The pharynx is a passageway for air and food, but these two functions are separated by a flap of tissue called the epiglottis, which prevents food from entering the airway. The pharynx is divided into three parts: the nasopharynx, oropharynx, and laryngopharynx. The nasopharynx is the uppermost part of the pharynx and is located behind the nasal cavity. It serves as a passageway for air from the nose to the rest of the respiratory system. The oropharynx is the middle part of the pharynx and is located behind the mouth. It serves as a passageway for both air and food. The laryngopharynx is the lowermost part of the pharynx and is located between the hyoid bone and the esophagus. It serves as a passageway for both air and food, but these two functions are separated by the epiglottis. The pharynx is lined with mucous membrane, which helps to moisten and lubricate the air as it passes through. The walls of the pharynx are made up of muscles that help to propel food and liquid down the esophagus during swallowing. The pharynx also contains tonsils, which are part of the immune system and help to defend against infections.

c) **Larynx:**The larynx, commonly referred to as the voice box, is a vital structure located in the throat region. It plays a crucial role in the production of sound and acts as a passageway for air to enter the trachea, which leads to the lungs.One of the primary functions of the larynx is to house the vocal cords. These are elastic bands of tissue stretched across the interior of the larynx. When we speak or produce sounds, the air passing through the larynx causes the vocal cords to vibrate. The vibration, in turn, produces sound waves that can be shaped by the movement of the tongue, lips, and other articulatory organs to create different speech sounds and vocalizations.Beyond its role in sound production, the larynx also serves as a protective mechanism for the respiratory system. It contains the epiglottis, a flap-like structure that prevents food and liquids from entering the airway during swallowing. The epiglottis closes off the larynx, directing swallowed substances into the esophagus instead of the trachea.Moreover, the larynx plays a role in controlling airflow during breathing. The muscles surrounding the larynx can adjust the size of the opening, called the glottis, to regulate the flow of air into the trachea. This mechanism helps to protect the lungs from foreign particles or substances that may be present in the inhaled air.

d) **Trachea:**The trachea, commonly referred to as the windpipe, is a tubular structure that plays a vital role in the respiratory system. It serves as a passageway for air, allowing it to travel from the larynx, or voice box, to the lungs. The trachea is composed of a series of C-shaped cartilage rings stacked on top of each other. These rings provide structural support and help to keep the trachea open, ensuring unobstructed airflow. The cartilage rings are connected by smooth muscles and elastic tissues, allowing flexibility and movement. Located in the front of the neck, the trachea extends downward and splits into two branches called the bronchi, which lead to the left and right lungs. These branches further divide into smaller tubes known as bronchioles, which eventually lead to the alveoli, the tiny air sacs where gas exchange occurs. The inner lining of the trachea is composed of ciliated epithelial cells. These cells are equipped with small hair-like projections called cilia. The cilia constantly beat in a coordinated manner, sweeping mucus and trapped particles upward and out of the trachea. This mechanism helps to protect the respiratory system by clearing the airway of dust, debris, and potentially harmful substances. The trachea also contains numerous mucous glands that produce mucus. This sticky substance helps to humidify and moisturize the air as it passes through the trachea, preventing the delicate tissues of the respiratory system from drying out.

e) **Bronchi:**The bronchi are the two primary branches that arise from the division of the trachea and serve as the main passageways for air to enter the lungs. They are part of the lower respiratory tract and play a critical role in facilitating the exchange of gases between the lungs and the external environment. As the trachea reaches the chest region, it divides into the right and left bronchi, with each bronchus leading to its respective lung. These bronchi are composed of cartilage rings similar to those found in the trachea, which provide structural support and prevent collapse of the airways during breathing. The bronchi further divide into smaller branches called bronchioles. This branching pattern continues multiple times, resulting in a network of progressively smaller bronchioles within the lungs. The bronchioles eventually lead to tiny air sacs called alveoli, where gas exchange takes place. The bronchi, along with the bronchioles, are lined with ciliated epithelial cells. These cells are equipped with small hair-like projections called cilia. The cilia constantly move in coordinated motions, propelling mucus and trapped particles upward towards the throat, where they can be expelled through coughing or swallowing. This mechanism helps to protect the lungs by clearing the airways of debris and potentially harmful substances. The bronchi also contain smooth muscle tissue, allowing them to constrict or dilate in response to various factors. This muscle control plays a role in regulating the airflow and distribution of air within the lungs, helping to optimize gas exchange.

f) **Lungs:**The lungs are the essential organs of the respiratory system, responsible for the exchange of gases between the air and the bloodstream. They are located within the thoracic cavity, on either side of the heart, and protected by the rib cage. The lungs are composed of a complex network of bronchioles, alveoli, and capillaries. The bronchioles are small branches that originate from the bronchi, and they continue to divide into even smaller airways throughout the lungs. These bronchioles serve to distribute air to different regions of the lungs. At the end of the bronchioles, there are millions of tiny air sacs called alveoli. The alveoli are surrounded by a network of capillaries, which are tiny blood vessels. This close proximity of the alveoli and capillaries allows for efficient gas exchange to occur. During inhalation, oxygen-rich air enters the alveoli and diffuses across their thin walls into the adjacent capillaries. At the same time, carbon dioxide, a waste product of cellular respiration, moves from the capillaries into the alveoli. This process of gas exchange is driven by differences in oxygen and carbon dioxide concentrations between the air in the alveoli and the blood in the capillaries. The alveoli have a unique structure that optimizes gas exchange. They are lined with a thin layer of moist epithelial cells and surrounded by a dense network of capillaries. This thin barrier between the air and blood allows for rapid diffusion of gases. The lungs also have elastic properties that aid in breathing. They are composed of elastic tissues, including connective tissue and smooth muscle fibers. These elastic properties allow the lungs to expand and contract during inhalation and exhalation. The expansion of the lungs during inhalation creates negative pressure within the thoracic cavity, drawing air into the lungs. Conversely, relaxation of the lungs during exhalation helps expel air from the lungs.

g) **Bronchioles:** The bronchioles are a network of small airways that form part of the lower respiratory tract. They branch out from the bronchi, which are the main air passages that connect the trachea to the lungs, and play a crucial role in delivering air to the alveoli, where gas exchange occurs.As the bronchi continue to divide within the lungs, they give rise to smaller and narrower airways known as bronchioles. These bronchioles further divide into even smaller branches, creating an intricate network throughout the lung tissue. The branching pattern of the bronchioles allows for the distribution of air to different regions of the lungs. The walls of the bronchioles are composed of smooth muscle and elastic fibers, which give them flexibility and the ability to constrict or dilate. This muscular control helps regulate the flow of air through the bronchioles, allowing for adjustments in response to various factors such as exercise, allergens, or irritants. Constriction of the bronchioles can occur in conditions like asthma, leading to narrowing of the airways and difficulty in breathing.The bronchioles play a crucial role in preparing the inhaled air for gas exchange in the alveoli. They are lined with a layer of ciliated epithelial cells, similar to the larger airways, and these cells have small hair-like projections called cilia. The cilia beat in a coordinated manner, constantly moving and sweeping mucus along with trapped particles upward towards the throat. This mechanism helps to clear the airways of debris, dust, and potential pathogens, reducing the risk of infection.As the bronchioles continue to branch and become narrower, they eventually lead to the alveoli. The alveoli are the tiny air sacs where the actual exchange of oxygen and carbon dioxide occurs with the surrounding capillaries. The extensive network of bronchioles ensures that each alveolus receives a fresh supply of air, allowing for efficient gas exchange.

h) **Alveoli:** The alveoli are tiny, sac-like structures located at the end of the bronchioles within the lungs. These small, balloon-like structures are the sites where essential gas exchange takes place between the air we breathe in and the bloodstream. The walls of the alveoli are incredibly thin and composed of a single layer of cells called the alveolar epithelium. This thin barrier is designed to facilitate efficient diffusion of gases. It is through these thin walls that oxygen from the inhaled air moves into the bloodstream, while carbon dioxide, a waste product of cellular metabolism, moves out of the bloodstream and into the alveoli to be exhaled. Surrounding the alveoli are numerous capillaries, which are the tiniest blood vessels in the body. The close proximity of the alveoli and capillaries allows for rapid exchange of gases due to the short distance that oxygen and carbon dioxide need to travel. The capillaries have thin walls, allowing for easy diffusion of gases between the air in the alveoli and the blood in the capillaries. During inhalation, fresh air rich in oxygen enters the alveoli. The oxygen molecules then pass through the thin alveolar walls and diffuse into the surrounding capillaries, binding to red blood cells and being transported throughout the body. At the same time, carbon dioxide, which has been produced as a waste product by cells in the body, diffuses from the capillaries into the alveoli. This carbon dioxide is then expelled from the lungs during exhalation. The large surface area of the alveoli, combined with their thin walls and proximity to the capillaries, ensures efficient gas exchange. It allows for a significant amount of oxygen to be absorbed into the bloodstream while facilitating the removal of carbon dioxide.

i) **Diaphragm:** The diaphragm is a vital muscle located at the base of the chest cavity, separating it from the abdominal cavity. It has a dome-like shape and plays a central role in the process of breathing, aiding in inhalation and exhalation. When you inhale, the diaphragm contracts and moves downward. This contraction expands the volume of the chest cavity, creating a vacuum-like effect. As a result, air is drawn into the lungs through the nose or mouth. The diaphragm's downward movement increases the space available for the lungs to expand and fill with air. Conversely, during exhalation, the diaphragm relaxes and moves upward. This relaxation reduces the volume of the chest cavity, causing the air in the lungs to be expelled. The diaphragm's upward movement compresses the lungs, helping to push out the air rich in carbon dioxide. The diaphragm's movement is controlled by the phrenic nerve, which sends signals from the brain and spinal cord to stimulate its contraction and relaxation. The coordination of the diaphragm's action with other muscles involved in breathing, such as the intercostal muscles between the ribs, allows for efficient and rhythmic breathing. In addition to its role in respiration, the diaphragm also plays a part in other bodily functions. It assists in the regulation of intra-abdominal pressure, helping with processes like coughing, sneezing, and defecation. Furthermore, the diaphragm contributes to core stability and posture, as it interacts with other muscles in the abdominal and back regions.

Together, these structures and organs make up the complex respiratory system anatomy that allows for efficient gas exchange and oxygenation of the body.

5.3 MECHANISM OF BREATHING

Now we are going to learn about breathing. Breathing also known as respiration, is the process by which air is taken into the body and then expelled. It involves a series of coordinated actions by the respiratory system to ensure the exchange of gases, specifically oxygen and carbon dioxide, between the body and the environment. The mechanism of breathing can be divided into two phases: inhalation (inspiration) and exhalation (expiration).

5.3.1 INHALATION (Inspiration):

During the process of inhalation, the diaphragm and intercostal muscles work in harmony to facilitate the expansion of the thoracic cavity, leading to an increase in its volume. This expansion plays a crucial role in creating a negative pressure within the lungs, which allows air to be drawn into the respiratory system.

- The diaphragm, a large, dome-shaped muscle situated at the base of the chest cavity, contracts and moves downward. This contraction causes the diaphragm to flatten and descend towards the abdominal cavity. As a result, the vertical dimension of the thoracic cavity increases. The contraction of the diaphragm is the primary muscle movement responsible for inhalation.

- Simultaneously, the intercostal muscles, which are located between the ribs, contract as well. This contraction leads to the elevation and expansion of the ribcage, thereby increasing the lateral dimension of the thoracic cavity. The intercostal muscles can be further categorized into two types: the external intercostal muscles and the internal intercostal muscles. The external intercostal muscles primarily assist in the elevation of the ribcage during normal inhalation, while the internal intercostal muscles aid in forced inhalation by elevating the ribcage even more.
- As the thoracic cavity expands both vertically and laterally, the volume of the lungs increases. This increase in volume causes the air pressure within the lungs to decrease, creating a pressure gradient between the lungs and the atmosphere. Due to the principle of gas diffusion, air moves from an area of higher pressure (the atmosphere) to an area of lower pressure (the lungs). Consequently, atmospheric air rushes in through the airways, which can be accessed through either the nose or mouth.
- The inhaled air travels through the nasal cavity or oral cavity, passing down the pharynx, a common passage for both air and food. From there, it continues through the larynx, which houses the vocal cords and helps produce sound when air passes over them. The air then enters the trachea, a tube-like structure commonly referred to as the windpipe, which leads to the branching network of bronchi and bronchioles within the lungs.

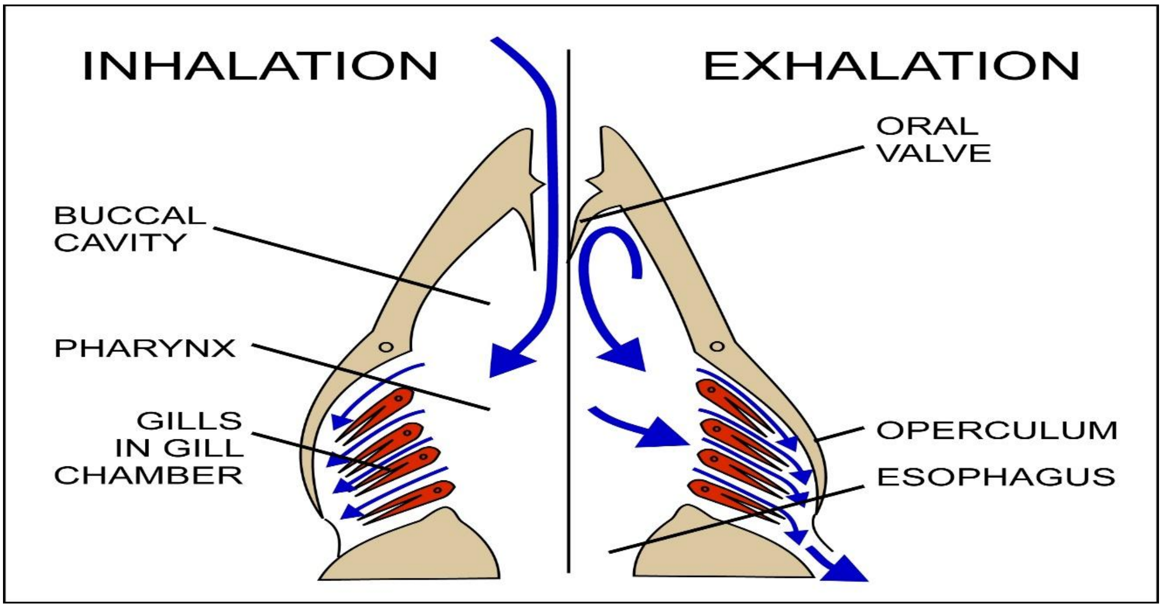

Figure 5.2 Mechanism of Breathing

5.3.2 EXHALATION (Expiration):

Exhalation, or expiration, is a passive process that primarily relies on the elastic recoil of the lungs and the relaxation of the respiratory muscles. Its main purpose is to reduce the volume of the thoracic cavity and expel carbon dioxide, a waste product, from the body.

- When exhalation begins, the diaphragm, which had contracted and moved downward during inhalation, relaxes and moves back into its relaxed dome shape. This relaxation causes the diaphragm to ascend, decreasing the vertical dimension of the thoracic cavity. Simultaneously, the intercostal muscles between the ribs also relax, causing the ribcage to lower and move inward. This reduces the lateral dimension of the thoracic cavity.
- As the thoracic cavity decreases in volume, the elastic lungs recoil passively due to their inherent elasticity. The recoil generates an increase in air pressure within the lungs. The higher pressure in the lungs now exceeds the pressure in the atmosphere, creating a pressure gradient. Consequently, air flows from the lungs, where the pressure is higher, to the atmosphere, where the pressure is lower.
- The exhaled air travels back through the airways, beginning with the trachea. It passes through the larynx, which houses the vocal cords, and then exits through either the nose or mouth.

- Throughout the process of exhalation, the relaxation of the diaphragm and intercostal muscles, combined with the elastic recoil of the lungs, work in harmony to decrease the volume of the thoracic cavity. This decrease in volume leads to an increase in air pressure within the lungs, facilitating the movement of air out of the respiratory system and back into the atmosphere.

It is important to note that while exhalation is primarily a passive process, certain circumstances, or activities, such as forceful exhalation during exercise or singing, may involve the active contraction of specific respiratory muscles, such as the internal intercostal muscles. However, in normal resting conditions, exhalation is predominantly a passive process driven by the elastic recoil of the lungs. The process of breathing is not solely controlled by the respiratory muscles. The regulation of breathing is primarily governed by the respiratory control centers in the brainstem, which monitor the levels of oxygen and carbon dioxide in the blood. These control centers adjust the rate and depth of breathing to ensure an adequate supply of oxygen and the removal of carbon dioxide in response to the body's metabolic demands.

In summary, the mechanism of breathing involves the coordinated action of the diaphragm, intercostal muscles, and the respiratory control centers in the brainstem. Inhalation occurs when these muscles contract, expanding the thoracic cavity and creating a negative pressure that draws air into the lungs. Exhalation, on the other hand, is a passive process facilitated by the relaxation of the respiratory muscles and the elastic recoil of the lungs, resulting in the expulsion of air and carbon dioxide from the body.

5.3.3 RESPIRATORY VOLUMES AND CAPACITY

Respiratory volumes and capacities are measurements used to assess various aspects of lung function and respiratory efficiency. These measurements provide valuable information about the amount of air involved in different phases of respiration. Here, we will elaborate on these respiratory volumes and capacities:

a) **Tidal Volume (TV):** Tidal volume refers to the volume of air inspired or expired during normal, quiet breathing. It represents the amount of air that moves in and out of the lungs with each breath, typically around 500 milliliters (ml) in healthy adults.
b) **Inspiratory Reserve Volume (IRV):** The inspiratory reserve volume represents the maximum amount of air that can be forcibly inhaled beyond the tidal volume. It represents the additional air that can be inspired when taking a deep breath.
c) **Expiratory Reserve Volume (ERV):** The expiratory reserve volume is the maximum amount of air that can be forcibly exhaled beyond the tidal volume. It represents the additional air that can be expired forcefully after a normal exhalation.
d) **Residual Volume (RV):** The residual volume is the volume of air that remains in the lungs even after a maximal exhalation. It is the air that cannot be voluntarily expelled from the lungs and helps maintain lung inflation and prevent lung collapse.
e) **Inspiratory Capacity (IC):** The inspiratory capacity is the sum of the tidal volume and the inspiratory reserve volume. It represents the maximum amount of air that can be inhaled after a normal exhalation.
f) **Functional Residual Capacity (FRC):** The functional residual capacity is the sum of the expiratory reserve volume and the residual volume. It represents the volume of air that remains in the lungs at the end of a normal exhalation.
g) **Vital Capacity (VC):** The vital capacity is the total volume of air that can be exhaled forcefully after a maximal inhalation. It is the sum of the tidal volume, inspiratory reserve volume, and expiratory reserve volume. The vital capacity represents the maximum amount of air a person can move in and out of their lungs.
h) **Total Lung Capacity (TLC):** The total lung capacity is the sum of all the lung volumes, including the tidal volume, inspiratory reserve volume, expiratory reserve volume, and residual volume. It represents the maximum volume of air that the lungs can hold.

These respiratory volumes and capacities can be measured using various techniques, such as spirometry, which involves breathing into a device called a spirometer. These measurements provide valuable information in diagnosing and monitoring respiratory conditions, assessing lung function, and evaluating the efficiency of gas exchange in the lungs.

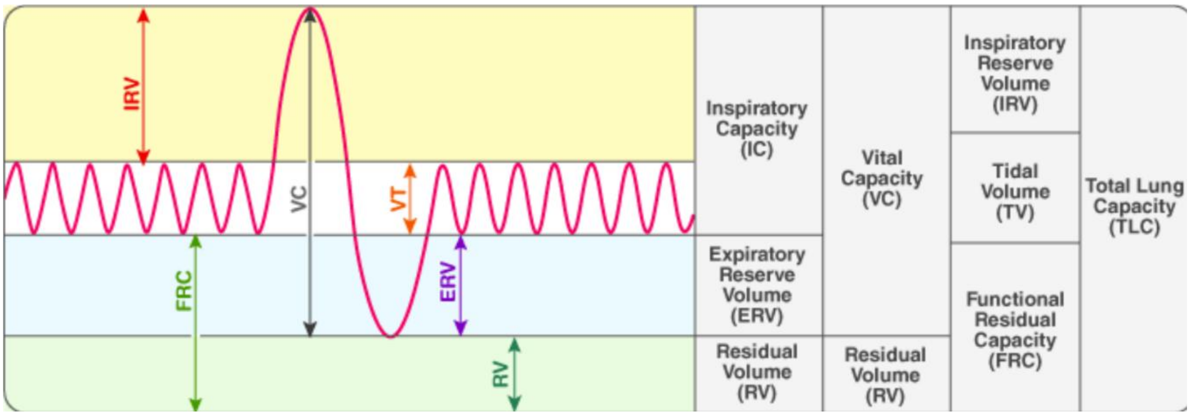

Figure 5.3 Lungs Volume and Capacities

Check your Progress I

1. What is the primary function of the respiratory system?

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2. What is the role of the diaphragm in breathing?

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3. What is the process of inhalation?

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5.4 EXCHANGE OF GASES

Here we are going to discuss, the exchange of gases refers to the process by which oxygen (O2) from inhaled air is taken up by the bloodstream, while carbon dioxide (CO2) is released from the bloodstream into the air for exhalation. This gas exchange occurs in the lungs within tiny, thin-walled structures called alveoli.When we inhale, fresh air enters the alveoli, which are surrounded by a network of capillaries. The alveoli provide a large surface area and are lined with a thin layer of moisture. Oxygen molecules in the inhaled air easily diffuse across the moist alveolar walls and into the bloodstream. This process is driven by the partial pressure gradient of oxygen, with higher partial pressure in the alveoli compared to the capillaries.Once oxygen enters the bloodstream, it binds to haemoglobin, a protein within red blood cells. The oxygenated haemoglobin then travels through the circulatory system, delivering oxygen to the body's cells where it is needed for cellular respiration, the process that produces energy.Meanwhile, within the cells, metabolic processes produce carbon dioxide as a waste product. Carbon dioxide diffuses out of the cells into the bloodstream, where it binds with water to form bicarbonate ions (HCO3-) or combines directly with haemoglobin to form carbaminohaemoglobin. These forms of carbon dioxide are carried in the bloodstream back to the lungs.

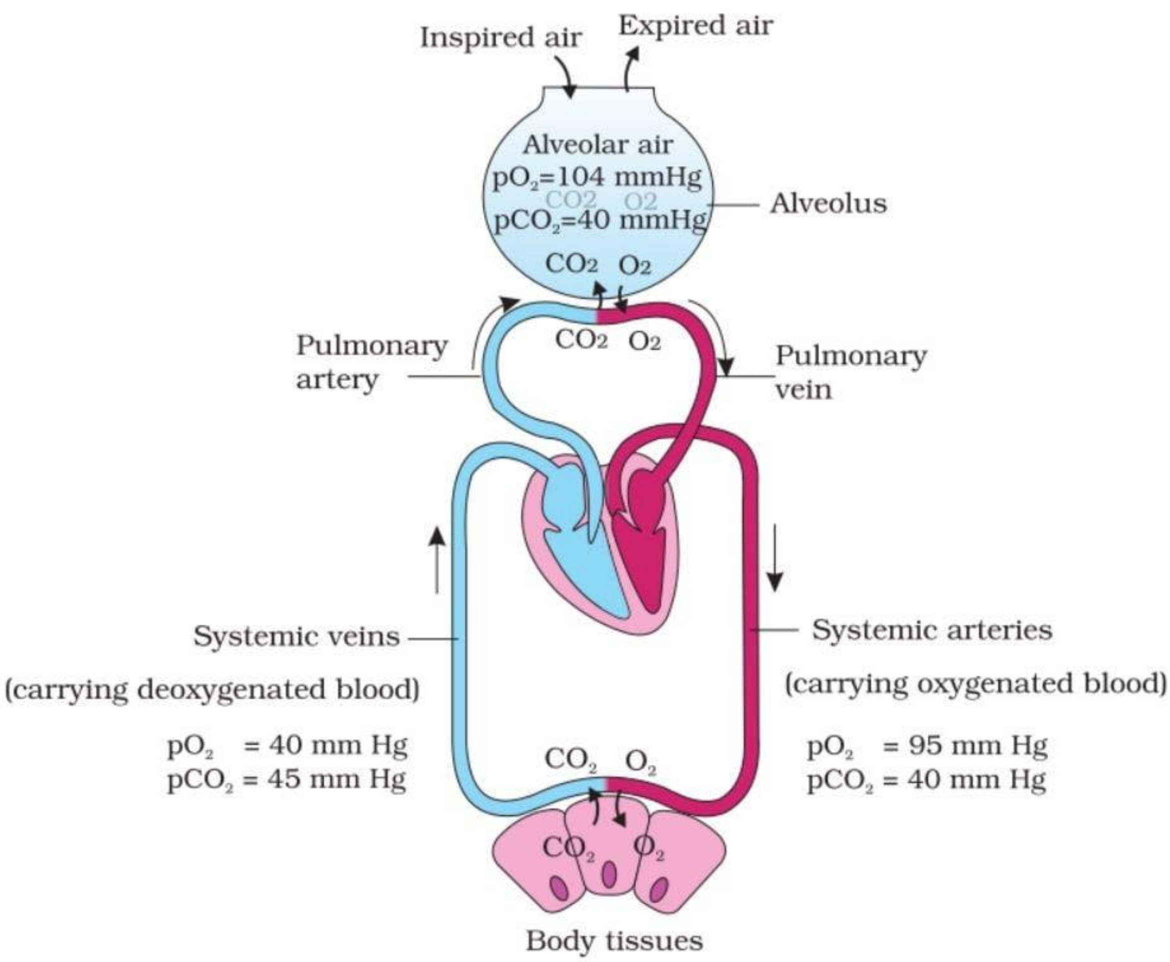

Figure 5.4 Diagrammatic representation of exchange of gases at the alveolus and

the body tissues with blood and transport of oxygen and carbon dioxide

Source: Retrieved from NCERT

In the lungs, the bicarbonate ions can be converted back to carbon dioxide, which can then diffuse across the alveolar walls into the alveoli. Similarly, carbaminohemoglobin releases carbon dioxide, which also diffuses into the alveoli. The concentration of carbon dioxide is higher in the bloodstream compared to the alveoli, establishing a partial pressure gradient that drives the movement of carbon dioxide out of the body during exhalation.During exhalation, the carbon dioxide-rich air is expelled from the lungs into the atmosphere. This clears the way for the next inhalation, ensuring a continuous supply of oxygen for cellular respiration and the removal of carbon dioxide waste.The exchange of gases in the lungs is facilitated by several factors, including the large surface area of the alveoli, the thinness of the alveolar walls, the presence of a moisture layer, and the partial pressure gradients of oxygen and carbon dioxide. These factors optimize the diffusion of gases, allowing for efficient gas exchange between the respiratory system and the circulatory system.

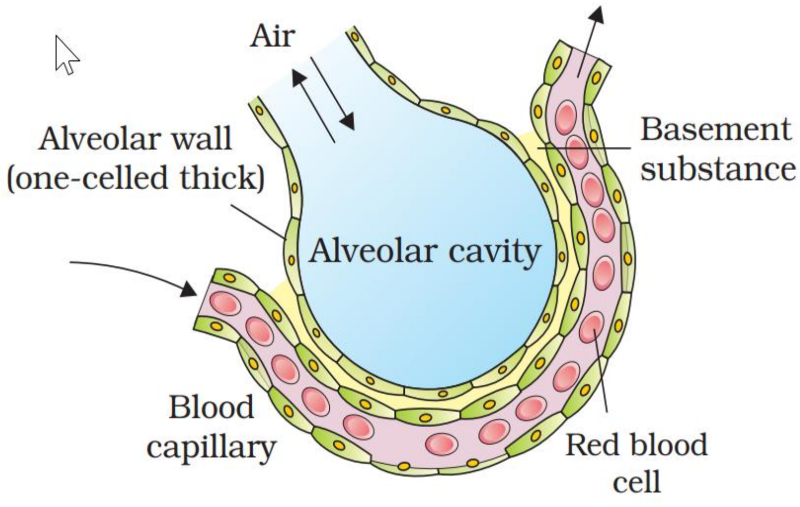

Figure 5.5 A Diagram of a section of analveolus with a pulmonarycapillary.

Source: Retrieved from NCERT

In summary, the exchange of gases occurs in the lungs, where oxygen from inhaled air diffuses into the bloodstream and binds to hemoglobin for transport to the body's cells. At the same time, carbon dioxide, a waste product produced by cells, is released into the bloodstream and transported back to the lungs. In the lungs, carbon dioxide is expelled during exhalation, ensuring the removal of waste and the replenishment of oxygen for vital cellular functions.

Respiratory gas	Atmospheric pressure	Alveoli	Blood (deoxygenated)	Blood (oxygenated)	Tissues
O2	159	104	40	95	40
Co2	0.3	40	45	40	45

Table 5.1 Partial Pressures (in mm Hg) of Oxygen and Carbon dioxide at DifferentParts Involved in Diffusion in Comparison to those in Atmosphere

5.5 TRANSPORT OF GASES

The transport of gases in the human body involves the movement of oxygen (O2) from the lungs to the body's tissues and the transportation of carbon dioxide (CO2) from the tissues back to the lungs for elimination. This vital process is facilitated by the circulatory system, specifically through the coordination of the respiratory and cardiovascular systems.

5.5.1 Oxygen Transport:

When we inhale, oxygen-rich air enters the lungs and diffuses across the thin walls of the alveoli into the pulmonary capillaries, which surround the alveoli. This process occurs due to the difference in partial pressure of oxygen between the alveoli and the capillaries. Oxygen molecules then bind to haemoglobin, a protein found in red blood cells, forming oxyhaemoglobin.The oxygenated blood is carried away from the lungs by the pulmonary veins and enters the left side of the heart, specifically the left atrium and left ventricle. From there, it is pumped into the systemic circulation through the aorta, the largest artery in the body. The oxygen-rich blood is then distributed to the body's tissues and organs through a vast network of arteries, arterioles, and capillaries.At the capillary level, oxyhaemoglobin releases oxygen molecules due to the lower partial pressure of oxygen in the tissues. The oxygen diffuses out of the capillaries and enters the cells, where it is utilized in cellular respiration to produce energy. This exchange of oxygen from the bloodstream to the tissues is facilitated by the partial pressure gradient of oxygen.

5.5.2 Carbon Dioxide Transport:

As cells carry out metabolic activities, they produce carbon dioxide as a waste product. Carbon dioxide diffuses out of the cells and enters the surrounding capillaries, where it is transported in three primary ways:

- **Dissolved in plasma:** A small portion of carbon dioxide dissolves directly in the plasma of the blood.
- **Bicarbonate ions (HCO_3^-):** Most of the carbon dioxide combines with water in the red blood cells, forming carbonic acid (H_2CO_3), which quickly dissociates into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+). The enzyme carbonic anhydrase aids in this reaction. Bicarbonate ions are highly soluble and can be transported in the plasma.
- **Bound to haemoglobin:** A small fraction of carbon dioxide binds to the amino groups of haemoglobin within red blood cells, forming carbaminohaemoglobin.

The carbon dioxide-rich blood is then transported through veins back to the heart's right side, specifically the right atrium and right ventricle. It is then pumped into the pulmonary circulation through the pulmonary artery. The deoxygenated blood reaches the pulmonary capillaries surrounding the alveoli in the lungs, where gas exchange occurs.In the lungs, the partial pressure of carbon dioxide is higher in the capillaries than in the alveoli, creating a pressure gradient that drives the diffusion of carbon dioxide. Carbon dioxide diffuses across the alveolar walls and is eliminated from the body when we exhale.The cycle of gas exchange and transport continues as oxygenated blood is pumped from the heart to the tissues, delivering oxygen for cellular respiration, while deoxygenated blood returns to the lungs, eliminating carbon dioxide.

$$CO_2 + Hb \longleftrightarrow HbCO_2 + H^+$$

In summary, the transport of gases involves the movement of oxygen from the lungs to the tissues and the transportation of carbon dioxide from the tissues back to the lungs. Oxygen is carried by haemoglobin in red blood cells and delivered to the tissues through systemic circulation. Carbon dioxide is transported in the form of dissolved gas, bicarbonate ions, and bound to haemoglobin. The circulatory system facilitates the exchange and transport of gases, ensuring the supply of oxygen and removal of carbon dioxide to maintain proper cellular function and homeostasis within the body.

5.6 REGULATION OF RESPIRATION

The regulation of respiration is a complex process that ensures the proper balance of oxygen (O_2) and carbon dioxide (CO_2) levels in the body. It involves the coordination of various structures and feedback mechanisms to maintain respiratory function and meet the body's metabolic demands. Here is an elaboration on the regulation of respiration:

Check your Progress II

1. How does gas exchange occur in the lungs?

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2. What are respiratory volumes and capacities used for?

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3. What role do the bronchi play in the respiratory system?

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4. What is the purpose of the respiratory system's regulation of respiration?

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i. **Central Respiratory Centers:**Respiration is primarily controlled by two regions in the brainstem known as the central respiratory centers: the medullary respiratory center and the pontine respiratory center. The medullary respiratory center consists of the ventral respiratory group (VRG) and the dorsal respiratory group (DRG). The VRG generates the basic rhythm of breathing, while the DRG integrates sensory input and modulates the breathing pattern.

ii. **Neural Control:**The central respiratory centers receive input from various sources, including chemoreceptors, mechanoreceptors, and other sensory receptors. These receptors monitor the levels of oxygen, carbon dioxide, and pH in the blood and provide feedback to the respiratory centers to adjust ventilation.

iii. **Chemoreceptors:** The central and peripheral chemoreceptors are sensitive to changes in blood gases and pH. The central chemoreceptors, located in the medulla, respond primarily to changes in CO_2 and pH levels in the cerebrospinal fluid. The peripheral chemoreceptors, located in the carotid bodies and aortic bodies, respond primarily to changes in arterial oxygen and carbon dioxide levels.

iv. **Mechanoreceptors:** Mechanoreceptors located in the lungs, airways, and chest wall detect changes in lung volume, stretch, and respiratory muscle activity. They provide feedback to the respiratory centers to adjust the rate and depth of breathing based on the body's respiratory needs.

v. **Respiratory Muscles:**The respiratory centers in the brainstem send neural signals to the respiratory muscles to control the process of inhalation and exhalation.

vi. **Diaphragm:** The diaphragm, the primary muscle of respiration, contracts and moves downward during inhalation, increasing the volume of the thoracic cavity and causing air to enter the lungs. Relaxation of the diaphragm allows for passive exhalation.

vii. **Intercostal Muscles:** The intercostal muscles between the ribs also play a role in respiration. Contraction of the external intercostal muscles helps elevate the ribcage, increasing the lateral dimension of the thoracic cavity during inhalation. The internal intercostal muscles aid in forced exhalation by pulling the ribs downward, reducing the volume of the thoracic cavity.

viii. **Feedback Mechanisms:**The respiratory centers receive feedback from the chemoreceptors, mechanoreceptors, and other sensory receptors to adjust respiration as needed.

ix. **Hering-Breuer Reflex:** The stretch receptors in the lungs and airways activate the Hering-Breuer reflex, which helps regulate the duration and depth of each breath. When the lungs are excessively inflated, the stretch receptors send inhibitory signals to the respiratory centers, leading to the termination of inhalation and initiation of exhalation.

x. **Ventilation-Perfusion Matching:** This process ensures that ventilation (airflow to the alveoli) matches perfusion (blood flow to the pulmonary capillaries). When there are imbalances in ventilation and perfusion, feedback mechanisms adjust the airflow and blood flow to optimize gas exchange efficiency.

xi. **Chemoreceptor Response:** Changes in arterial blood gases and pH levels detected by the chemoreceptors trigger adjustments in ventilation. Increased carbon dioxide levels or decreased arterial oxygen levels stimulate the respiratory centers to increase the rate and depth of breathing to remove excess carbon dioxide and increase oxygen intake.

xii. **Higher Brain Centers:**Higher brain centers, such as the cerebral cortex and limbic system, can influence respiration voluntarily. For example, emotions, exercise, and conscious control can modify the respiratory rate and pattern.

In summary, the regulation of respiration involves the central respiratory centers in the brainstem, neural feedback from chemoreceptors and mechanoreceptors, control of respiratory muscles, and various feedback mechanisms. This intricate coordination ensures that oxygen and carbon dioxide levels in the body are maintained within appropriate ranges to support cellular metabolism and maintain homeostasis.

5.7 GLOSSARY

Intercostal Muscles: Muscles located between the ribs that assist in the expansion and contraction of the chest cavity during breathing.

Inhalation: The process of breathing in air. It involves the contraction of the diaphragm and intercostal muscles, which expands the chest cavity and draws air into the lungs.

Exhalation: The process of breathing out air. It is primarily a passive process that relies on the relaxation of the respiratory muscles and the elastic recoil of the lungs to expel air.

Ventilation: The movement of air in and out of the lungs through inhalation and exhalation.

Pulmonary Circulation: The circulation of blood between the heart and the lungs, where oxygen is picked up and carbon dioxide is released.

Gas Exchange: The transfer of oxygen from the lungs to the bloodstream and the removal of carbon dioxide from the bloodstream to the lungs.

Respiratory Rate: The number of breaths taken per minute, typically measured as an indicator of respiratory function.

Chronic Obstructive Pulmonary Disease (COPD): A group of lung diseases, including chronic bronchitis and emphysema, that cause airflow limitation and breathing difficulties.

5.8 LET US SUM UP

The respiratory system is responsible for the exchange of gases in the body, allowing oxygen to enter and carbon dioxide to be expelled. The structure of the respiratory system includes organs such as the lungs, trachea, bronchi, and alveoli. The mechanism of breathing involves the contraction and relaxation of respiratory muscles, including the diaphragm and intercostal muscles. Respiratory volumes and capacities, such as tidal volume and total lung capacity, play a role in assessing respiratory function. Gas exchange occurs in the lungs through diffusion, where oxygen is taken up by the blood and carbon dioxide is released into the alveoli. Oxygen is transported in the blood primarily bound to hemoglobin, while carbon dioxide is transported in various forms, including as bicarbonate ions. The regulation of respiration involves central respiratory centers in the brainstem, feedback mechanisms from chemoreceptors and mechanoreceptors, and the influence of higher brain centers. These processes ensure the proper balance of gases and the efficient functioning of the respiratory system.

5.9 ANSWERS TO CHECK YOUR PROGRESS

Check your Progress I

1. The primary function of the respiratory system is to facilitate the exchange of gases (oxygen and carbon dioxide) between the body and the environment.
2. The diaphragm plays a crucial role in breathing by contracting and relaxing, causing changes in the volume of the thoracic cavity.
3. Inhalation is the process of breathing in air, which involves the contraction of the diaphragm and intercostal muscles to expand the chest cavity and draw air into the lungs.

Check your Progress II

1. Gas exchange in the lungs occurs through diffusion, where oxygen enters the bloodstream from the alveoli, and carbon dioxide is released from the bloodstream into the alveoli.
2. Respiratory volumes and capacities are used to assess respiratory function and measure parameters such as the amount of air exchanged during different phases of breathing.

3. The bronchi are the main branches of the trachea that lead to the lungs, and they help distribute air throughout the lungs.
4. The regulation of respiration ensures that the body maintains proper gas exchange, balances oxygen and carbon dioxide levels, and meets the metabolic demands of the tissues.

UNIT 6 - EXCREATORY SYSTEM

STRUCTURE

6.1 Introduction

6.1.1 Objective

6.2 Human Excretory System

6.3 Kidney

6.3.1 Structure of Kidney

6.3.2 Structure of Nephrons

6.4 Formation of Urine

6.4.1 Composition of Urine

6.5Mechanism of Concentration of the Filtrate

6.6 Function of Kidney

6.7 Function of Nephron

6.8 Ureters

6.9 Urinary Bladder

6.10 Urethra

6.11 Glossary

6.12 Let Us Sum Up

6.13 Answers to Check your Progress Exercise

6.1 INTRODUCTION

In this unit, we will learn about the excretory system is a critical system in the human body that is responsible for eliminating waste products and maintaining fluid and electrolyte balance. Its primary function is to remove metabolic waste from the body and regulate the concentration of various substances in the blood.The main organ of the excretory system is the kidney, of which there are two in the human body. Located in the upper abdominal cavity, one on each side of the spine, the kidneys consist of millions of tiny filtering units called nephrons. These nephrons filter waste products and excess substances from the blood while reabsorbing essential substances, such as water and electrolytes, back into the bloodstream.The waste products filtered by the kidneys include urea, uric acid, and creatinine, which are produced as by-products of metabolism. The kidneys remove these waste products from the bloodstream and excrete them in the form of urine. The urine then travels through tubes called ureters and is stored in the bladder until it is eliminated from the body through the urethra.

In addition to waste elimination, the kidneys also play a vital role in maintaining water and electrolyte balance. They regulate the concentration of ions, such as sodium, potassium, calcium, and phosphate, in the body. By adjusting the reabsorption and excretion of these ions, the kidneys help keep their levels within the normal range, ensuring proper cellular function.The excretory system also contributes to the regulation of acid-base balance in the body. The kidneys control the excretion of hydrogen ions and bicarbonate ions, which are important in maintaining the pH balance of body fluids. By selectively excreting or reabsorbing these ions, the kidneys help maintain the appropriate acid-base environment.Another significant function of the excretory system is its role in blood pressure regulation. The kidneys produce a hormone called renin, which plays a crucial role in controlling blood pressure. Renin influences the constriction and dilation of blood vessels and the release of aldosterone, a hormone that helps regulate fluid and electrolyte balance. These mechanisms collectively help maintain optimal blood pressure levels.While the kidneys are the primary organs of the excretory system, other organs also contribute to waste elimination. The liver plays a role in the breakdown and elimination of certain toxins and metabolic waste products. The lungs eliminate carbon dioxide, a waste product of cellular respiration, during exhalation. The skin, through sweat glands, eliminates small amounts of waste products and helps regulate body temperature.

In summary, the excretory system is responsible for eliminating waste products, regulating fluid and electrolyte balance, maintaining acid-base equilibrium, and contributing to blood pressure regulation. The kidneys are the central organs of this system, working in conjunction with other organs to ensure the proper functioning of the body's internal environment. Here are some objectives that we will learn in this unit.

6.1.1 Objectives

- Understand the importance of the excretory system in the human body.
- Recognize its role in removing waste products and maintaining homeostasis.
- Identify the organs and structures involved in the human excretory system.
- Describe the process and composition of urine formation in the kidneys.
- Understand the role of the ureter, urinary bladder and urethra in eliminating urine from the body.

6.2 HUMAN EXCRETORY SYSTEM

Let’s discuss the human excretory system, also known as the urinary system, is responsible for the elimination of waste products and the regulation of fluid and electrolyte balance in the body. It consists of several organs like kidney, ureters, urinary bladder and urethra that work together to perform these vital functions. Here's an elaboration on the human excretory system:

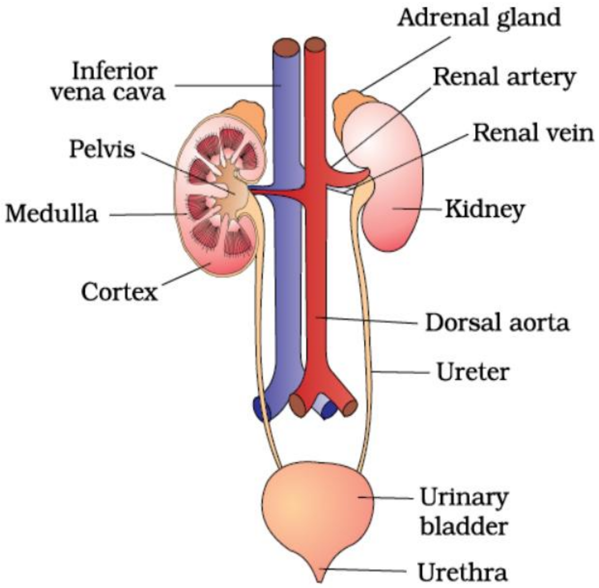

Figure: 6.1 The Human Excretory System

Source: Retrieved from NCERT

Let’s discuss the organs individually.

6.3 KIDNEY

The kidneys are vital organs in the human body that perform several essential functions, including filtration of waste products from the blood, regulation of fluid and electrolyte balance, and maintenance of blood pressure.The kidneys are bean-shaped organs located in the upper abdominal cavity, one on each side of the spine. Individual kidney of anadult human measures 10-12 cm inlength, 5-7 cm in width, 2-3 cm inthickness with an average weight of 120-170 g. They receive a rich blood supply from the renal arteries, which branch off from the aorta. Inside the kidneys, there are millions of microscopic filtering units called nephrons. Nephron consists of a renal corpuscle and a renal tubule.The renal corpuscle, composed of a glomerulus and Bowman's capsule, is responsible for the initial filtration of blood. The glomerulus is a network of tiny blood vessels called capillaries, surrounded by the Bowman's capsule. As blood flows through the glomerulus, high blood pressure forces water, dissolved substances, and waste products to pass through the capillary walls and enter the Bowman's capsule. This filtered fluid, known as the glomerular filtrate, contains water, electrolytes, glucose, amino acids, and waste products like urea and creatinine.From the Bowman's capsule, the glomerular filtrate enters the renal tubules, where further processing occurs.

The renal tubules consist of several segments, including the proximal convoluted tubule (PCT), loop of Henle, distal convoluted tubule (DCT), and collecting ducts. These segments play different roles in reabsorption, secretion, and concentration of urine.Reabsorption is the process by which the renal tubules selectively reabsorb useful substances from the glomerular filtrate back into the bloodstream. The PCT is highly involved in reabsorption and is responsible for reabsorbing the majority of filtered water, electrolytes, glucose, and amino acids. The loop of Henle, with its descending and ascending limbs, creates a concentration gradient in the kidney, allowing for the reabsorption of water and electrolytes in the DCT and collecting ducts.Simultaneously, secretion takes place in the renal tubules. Secretion is the process of actively transporting certain substances, such as hydrogen ions, drugs, and toxins, from the bloodstream into the tubules. This secretion further helps eliminate waste products and maintain the acid-base balance in the body.As the processed fluid moves through the collecting ducts, it undergoes final adjustments in water reabsorption and concentration. The collecting ducts merge together, forming larger ducts that eventually lead to the renal pelvis. From the renal pelvis, urine is transported to the urinary bladder through tubes called ureters.The kidneys also play a crucial role in regulating fluid and electrolyte balance. They adjust the excretion or reabsorption of ions such as sodium, potassium, calcium, and phosphate, depending on the body's needs. Hormones like aldosterone and antidiuretic hormone (ADH) regulate these processes and help maintain homeostasis.Additionally, the kidneys contribute to blood pressure regulation. They release the enzyme renin, which initiates a cascade of events that ultimately leads to the constriction of blood vessels and the reabsorption of water and sodium. These actions help maintain blood volume and pressure.

6.3.1 STRUCTURE OF KIDNEY

The structure of the kidney can be divided into various components that work together to perform its essential functions. Let's explore the structure of the kidney in detail:

a) **Renal Capsule:** The renal capsule is a protective layer that surrounds the kidney. It is composed of a tough, fibrous connective tissue. The primary function of the renal capsule is to provide physical support and maintain the shape of the kidney. It acts as a barrier, shielding the kidney from external trauma or injury. The renal capsule serves as a protective barrier against infections and inflammation that could potentially affect the kidney. It preventing displacement or movement that could hinder its normal functioning. It helps to prevent the spread of infections or diseases from adjacent organs or tissues into the kidney. It provides a supportive framework for the blood vessels, tubules, and nephrons within the kidney, ensuring their proper alignment and functioning.

b) **Renal Cortex:** The renal cortex is the outermost region of the kidney, characterized by its granular appearance. It contains a vast number of microscopic functional units known as nephrons. These nephrons are responsible for the filtration and initial processing of blood to produce urine. Within the renal cortex, each nephron consists of a renal corpuscle and a renal tubule. The renal corpuscle comprises a tuft of specialized capillaries called the glomerulus, which is enclosed within a cup-shaped structure called Bowman's capsule. Filtration occurs in the renal corpuscle, where blood pressure forces fluid and solutes from the glomerulus into the Bowman's capsule. This fluid, known as the glomerular filtrate, contains water, electrolytes, waste products, and small molecules such as glucose and amino acids. From the renal corpuscle, the glomerular filtrate moves into the renal tubules within the renal cortex. The renal tubules consist of several segments, including the proximal convoluted tubule (PCT), the loop of Henle, and the distal convoluted tubule (DCT). These tubular structures are involved in reabsorption, secretion, and concentration of urine. The PCT, located immediately after the renal corpuscle, is responsible for the reabsorption of essential substances such as water, glucose, amino acids, and electrolytes back into the bloodstream. It plays a crucial role in maintaining the body's fluid and electrolyte balance by selectively reabsorbing these substances. The loop of Henle extends into the medulla and is involved in the concentration of urine. It creates a concentration gradient in the surrounding tissues, enabling the reabsorption of water and electrolytes in the following segments of the renal tubules. The DCT, situated after the loop of Henle, further fine-tunes the reabsorption and secretion processes. It selectively reabsorbs additional substances and participates in the regulation of acid-base balance in the body.

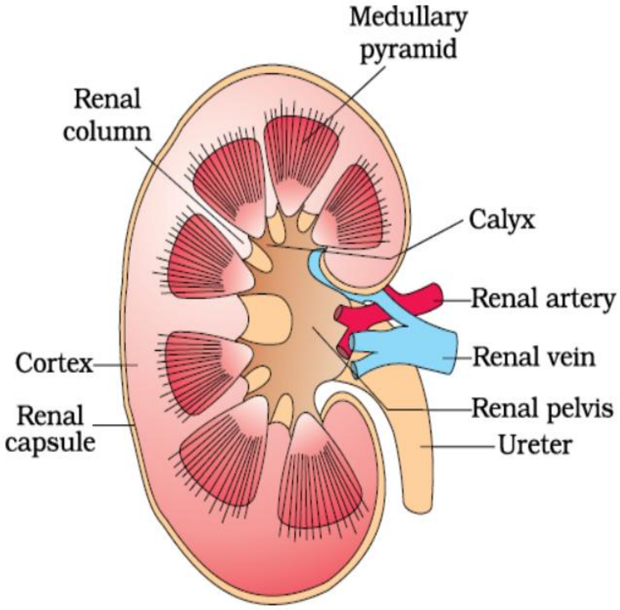

Figure: 6.2 Longitudinal section (Diagrammatic) of Kidney

Source: Retrieved from NCERT

c) **Renal Medulla:** The renal medulla is the inner region of the kidney, located deep to the renal cortex. It is composed of several distinct structures known as renal pyramids. These pyramids have a conical shape and are arranged in a radial pattern, with their bases facing the renal cortex and their apexes pointing toward the renal sinus. The renal medulla plays a crucial role in the concentration of urine, which is essential for maintaining proper fluid balance in the body. This concentration is achieved through a complex process involving the interaction of the renal tubules within the medulla. Each renal pyramid contains a network of tiny tubules called collecting ducts, which are responsible for the final adjustment of urine concentration. These collecting ducts merge together as they descend toward the renal papilla, located at the tip of each pyramid. As the collecting ducts travel deeper into the renal medulla, they pass through areas of increasing osmolarity, created by the loop of Henle of neighbouring nephrons. The loop of Henle, which extends from the renal cortex into the medulla, plays a critical role in establishing a concentration gradient within the medulla. The loop of Henle contains a descending limb and an ascending limb. The descending limb allows for the passive reabsorption of water, while the ascending limb is impermeable to water but actively reabsorbs solutes such as sodium and chloride ions. This establishes a concentration gradient in the medulla, with higher osmolarity in the deeper regions. As the collecting ducts pass through the increasingly osmotic medullary interstitium, they become more permeable to water under the influence of antidiuretic hormone (ADH). This allows for the reabsorption of water from the filtrate, leading to the concentration of urine. The concentrated urine is then transported to the renal papilla, where it is emptied into the minor calyces and eventually into the renal pelvis.The renal medulla's ability to establish and maintain a concentration gradient is crucial for water conservation and the excretion of concentrated urine, which helps regulate fluid balance and prevent excessive water loss in the body.

d) **Renal Columns:**The renal columns are important anatomical features that extend from the renal cortex into the renal medulla, creating divisions between the renal pyramids. These columns are composed of cortical tissue and serve to support and provide structural integrity to the kidney. The renal columns can be visualized as bridges of tissue that connect the outer renal cortex to the inner renal medulla. They project into the medulla and form a framework between adjacent renal pyramids. The number and size of the renal columns vary among individuals, but they are typically present throughout the kidney. The presence of the renal columns helps to maintain the overall shape and structure of the kidney. They provide support to the renal cortex and medulla, preventing collapse or distortion of these regions. By dividing the kidney into distinct renal pyramids, the renal columns assist in maintaining the organization and spatial arrangement of the nephrons, blood vessels, and collecting ducts within the renal medulla. Additionally, the renal columns play a role in facilitating blood supply to the kidney. They contain branches of the renal arteries and veins that traverse through the columns, supplying oxygenated blood to the renal cortex and medulla. This vascular network ensures the delivery of essential nutrients and oxygen to the nephrons and other structures within the kidney. Furthermore, the renal columns contribute to the formation of the renal lobes. A renal lobe consists of a renal pyramid, the overlying renal cortex, and adjacent renal columns. The renal lobes are functional units of the kidney and contain the nephrons responsible for urine production.

e) **Renal Papilla:**The renal papilla is a structure located at the tip of each renal pyramid in the kidney. It serves as the endpoint of the collecting ducts within the renal medulla and plays a vital role in the transportation of urine. The renal papillae are positioned facing the renal pelvis, which is the central cavity of the kidney that collects urine before it is further transported to the bladder. The collecting ducts, which merge and become larger as they traverse the renal medulla, ultimately converge at the renal papilla. These ducts are responsible for the final adjustments in urine concentration. As the collecting ducts approach the renal papilla, they carry urine that has undergone reabsorption and concentration processes within the medulla. The renal papillae act as outlets for the urine produced in the kidney. The urine, collected from multiple collecting ducts, is delivered into small cup-like structures called minor calyces. The minor calyces serve as initial receptacles, receiving urine from the renal papillae. From there, urine further drains into larger cup-like structures called major calyces. The renal papillae, in conjunction with the minor and major calyces, facilitate the flow of urine out of the kidney. The urine collected in the renal papillae is funneled into the minor calyces, which then merge to form the major calyces. The major calyces, in turn, unite to form the renal pelvis, which acts as a reservoir for urine within the kidney. From the renal pelvis, the urine is transported through the ureters and into the urinary bladder for temporary storage. Eventually, the stored urine is expelled from the body through the urethra during the process of urination.

f) **Renal Pelvis:**The renal pelvis is a significant anatomical structure situated in the central region of the kidney. It is characterized by its large, funnel-like shape. The primary function of the renal pelvis is to collect urine that has been produced in the kidney and transport it to the urinary bladder for temporary storage before elimination. The renal pelvis receives urine from the minor calyces, which in turn receive urine from the renal papillae. The renal papillae are the terminal points of the collecting ducts within the renal medulla. These collecting ducts carry urine that has undergone filtration, reabsorption, and concentration processes within the kidney. The renal pelvis acts as a reservoir for the collected urine. It provides a central cavity where urine from multiple minor calyces can accumulate before being further transported. The shape of the renal pelvis allows it to efficiently gather and collect urine from various regions of the kidney. Once the renal pelvis has collected a sufficient amount of urine, it contracts rhythmically to propel the urine into the ureter. The ureter is a muscular tube that connects the renal pelvis to the urinary bladder. The coordinated contractions of the renal pelvis create peristaltic waves that push urine through the ureter, ensuring its unidirectional flow towards the bladder. The renal pelvis, along with the ureters, serves as a conduit for urine transport. It ensures that the urine produced in the kidneys is efficiently conveyed to the urinary bladder for temporary storage. The smooth inner lining of the renal pelvis helps facilitate the flow of urine and prevents the accumulation of urine within the kidney, reducing the risk of backflow and potential damage to the renal tissues. Once the urine reaches the urinary bladder, it is temporarily stored until a sufficient volume accumulates. Subsequently, during the process of urination, the urinary bladder contracts, and the urine is expelled through the urethra and eliminated from the body.

g) **Calyces:**The calyces are essential components of the urinary system that are directly connected to the renal pelvis. They serve as conduits for the transport and collection of urine within the kidney. The calyces are divided into two types: major calyces and minor calyces, each playing a specific role in the urine drainage process. The minor calyces are small cup-like structures that directly receive urine from the renal papillae. The renal papillae are located at the tip of each renal pyramid in the kidney. They serve as the endpoints of the collecting ducts within the renal medulla. The urine, which has undergone filtration, reabsorption, and concentration processes within the kidney, is delivered to the minor calyces through these collecting ducts. Once the urine enters the minor calyces, it is collected and funneled towards the major calyces. The major calyces are larger cup-like structures that receive urine from multiple minor calyces. They act as a means of consolidation, allowing the urine from various regions of the kidney to be brought together in a more centralized manner. The major calyces serve as the final collection points for urine within the kidney before it is transported out of the organ. The urine collected in the major calyces is subsequently emptied into the renal pelvis, which is a large, central cavity within the kidney. From the renal pelvis, the urine continues its journey through the ureters and into the urinary bladder for temporary storage. The function of the calyces, both minor and major, is crucial for maintaining the flow and proper drainage of urine within the kidney. They facilitate the transfer of urine from the renal papillae to the renal pelvis, ensuring that the collected urine is efficiently transported and stored before being eliminated from the body.

Hopefully, you have understood the structure of kidney. Now, we will discuss the structure of nephrons.

6.3.2 STRUCTURE OF NEPHRONS

Nephrons are the essential functional units of the kidney, responsible for the intricate process of filtering blood and producing urine. Within the kidneys, there are millions of nephrons, each performing the same vital tasks. They play a crucial role in maintaining fluid balance, electrolyte levels, and waste elimination in the body. The nephron consists of two main parts: the renal corpuscle and the renal tubules. These components work together to accomplish the various stages of urine formation.

i. **Renal Corpuscle:** The renal corpuscle is a crucial component of the nephron, which is the functional unit of the kidney responsible for filtering blood and producing urine. It plays a vital role in the initial stage of urine formation. The renal corpuscle consists of two primary structures: the glomerulus and Bowman's capsule. The glomerulus is a tuft of specialized capillaries, while Bowman's capsule is a cup-like structure that surrounds the glomerulus. The glomerulus is a network of fenestrated capillaries, meaning they have tiny pores in their walls. These pores allow for the filtration of blood under high pressure. As blood flows into the glomerulus, substances such as water, electrolytes, waste

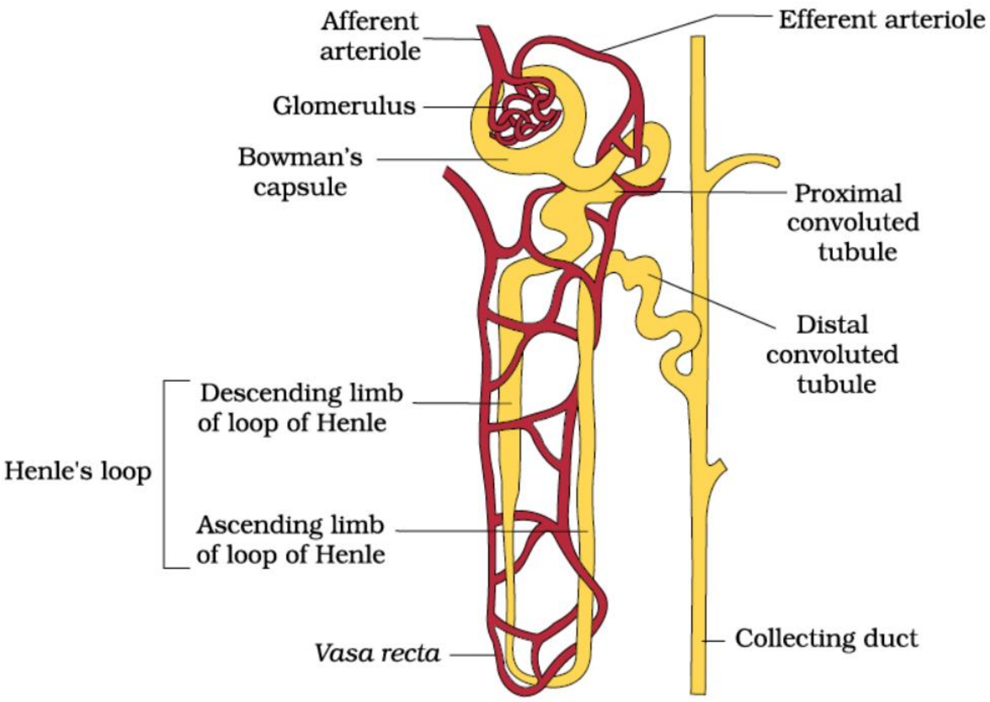

Figure: 6.3 A diagrammatic representation of a nephron showing blood vessels, duct and tubule

Source: Retrieved from NCERT

products, and small molecules are forced out of the capillaries through the pores and into Bowman's capsule. This process is known as glomerular filtration. Bowman's capsule, which envelops the glomerulus, is composed of two layers: the parietal layer and the visceral layer. The parietal layer is the outer layer and provides structural support and protection to the renal corpuscle. The visceral layer is in direct contact with the glomerulus and is made up of specialized cells called podocytes. These podocytes have extensions called foot processes that wrap around the glomerular capillaries, forming filtration slits. The filtration slits help regulate the size and selectivity of the substances that pass from the glomerulus into Bowman's capsule. The space within Bowman's capsule, known as the capsular space or urinary space, is where the filtrate collected from the glomerulus is initially accumulated. The filtrate contains water, electrolytes, waste products, and small molecules that have passed through the glomerular filtration process. Once the filtrate enters Bowman's capsule, it continues its journey through the renal tubules, where further processing, reabsorption, and secretion take place to modify its composition and concentrate the urine.

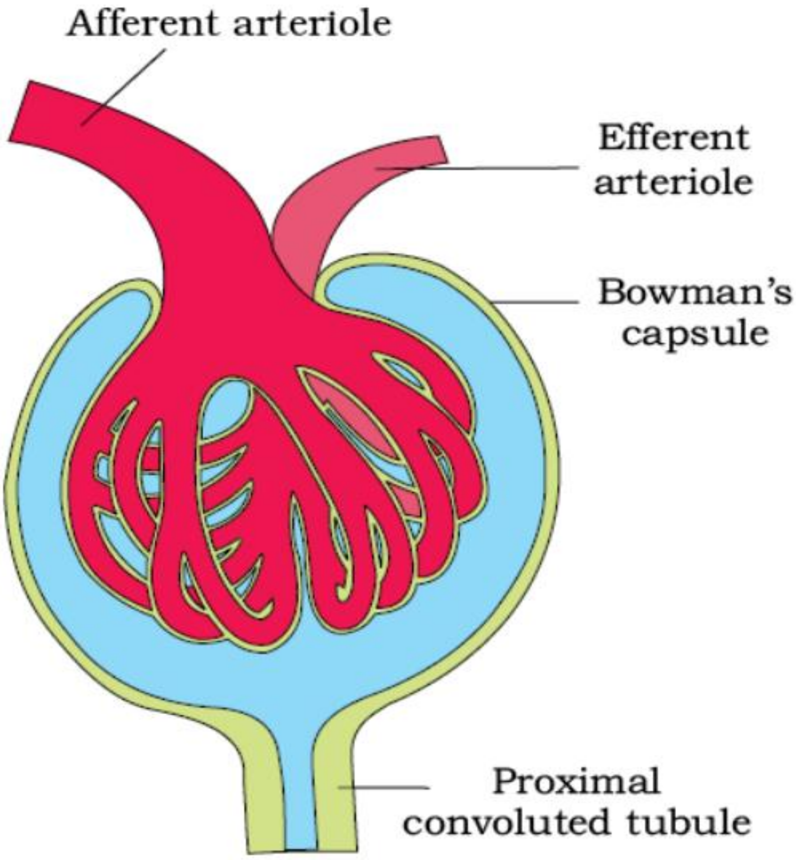

Figure: 6.4 Renal Corpuscle

Source: Retrieved from NCERT

ii. **Renal Tubules:** The renal tubule is a crucial component of the nephron, the functional unit of the kidney responsible for filtering blood and producing urine. It is involved in the processing and modification of the filtrate that is formed in the renal corpuscle. The renal tubule is a long, intricate tube that extends from Bowman's capsule, which surrounds the glomerulus, and continues through the renal cortex and renal medulla. It consists of three main segments: the proximal convoluted tubule (PCT), the loop of Henle, and the distal convoluted tubule (DCT). The proximal convoluted tubule (PCT) is the first segment of the renal tubule. It is highly coiled and located adjacent to the renal corpuscle. The PCT is responsible for the reabsorption of essential substances from the filtrate back into the bloodstream. These substances include water, glucose, amino acids, electrolytes, and various ions. The PCT is lined with specialized cells that have microvilli on their surfaces, increasing the surface area for efficient reabsorption. Following the PCT, the filtrate enters the loop of Henle, which is a U-shaped structure consisting of a descending limb and an ascending limb. The loop of Henle extends deep into the renal medulla. The descending limb allows water to passively diffuse out of the tubule, concentrating the filtrate as it descends further into the medulla. The ascending limb, on the other hand, is impermeable to water but actively transports sodium and other ions out of the tubule, leading to further concentration of the filtrate. After the loop of Henle, the

Check your Progress I:

Answer the following questions:

1. How does the excretory system maintain the body's balance of water and electrolytes?
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   …….
2. Besides waste elimination, does the excretory system serve any other functions?
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   ……
   …….
3. What are nephrons and what is their role in the kidney's structure?
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   …….

filtrate enters the distal

convoluted tubule (DCT). The DCT is located in the renal cortex and plays a crucial role in the fine-tuning of urine composition. It is involved in both reabsorption and secretion processes. In the DCT, additional reabsorption of water and ions, such as sodium, chloride, and calcium, occurs. Furthermore, the DCT is responsible for the active secretion of waste products, such as hydrogen ions and certain drugs, from the blood into the tubule for elimination. The renal tubule ultimately leads to the collecting duct, which receives the processed filtrate from multiple nephrons. The collecting ducts merge together and transport the urine towards the renal papilla, where it is then drained into the minor calyces, major calyces, and eventually the renal pelvis for further elimination from the body.

6.4 FORMATION OF URINE

The formation of urine is a complex process that takes place in the kidneys, specifically within the nephrons, which are the functional units responsible for filtering blood and producing urine. Here's an elaboration on the process of urine formation:

a) **Glomerular Filtration:** The process of urine formation begins with glomerular filtration, which occurs in the renal corpuscle. Blood enters the glomerulus, a network of specialized capillaries, and under high pressure, small molecules such as water, electrolytes, waste products, and nutrients are filtered out of the blood and into Bowman's capsule. This filtered fluid is called the glomerular filtrate.

b) **Tubular Reabsorption:** The glomerular filtrate then moves into the renal tubules, specifically the proximal convoluted tubule (PCT). The PCT is responsible for the reabsorption of essential substances from the filtrate back into the bloodstream. Water, glucose, amino acids, electrolytes, and other valuable molecules are actively or passively reabsorbed from the tubules and transported back into the surrounding capillaries. This reabsorption process helps maintain the body's fluid balance and prevents the loss of important substances.

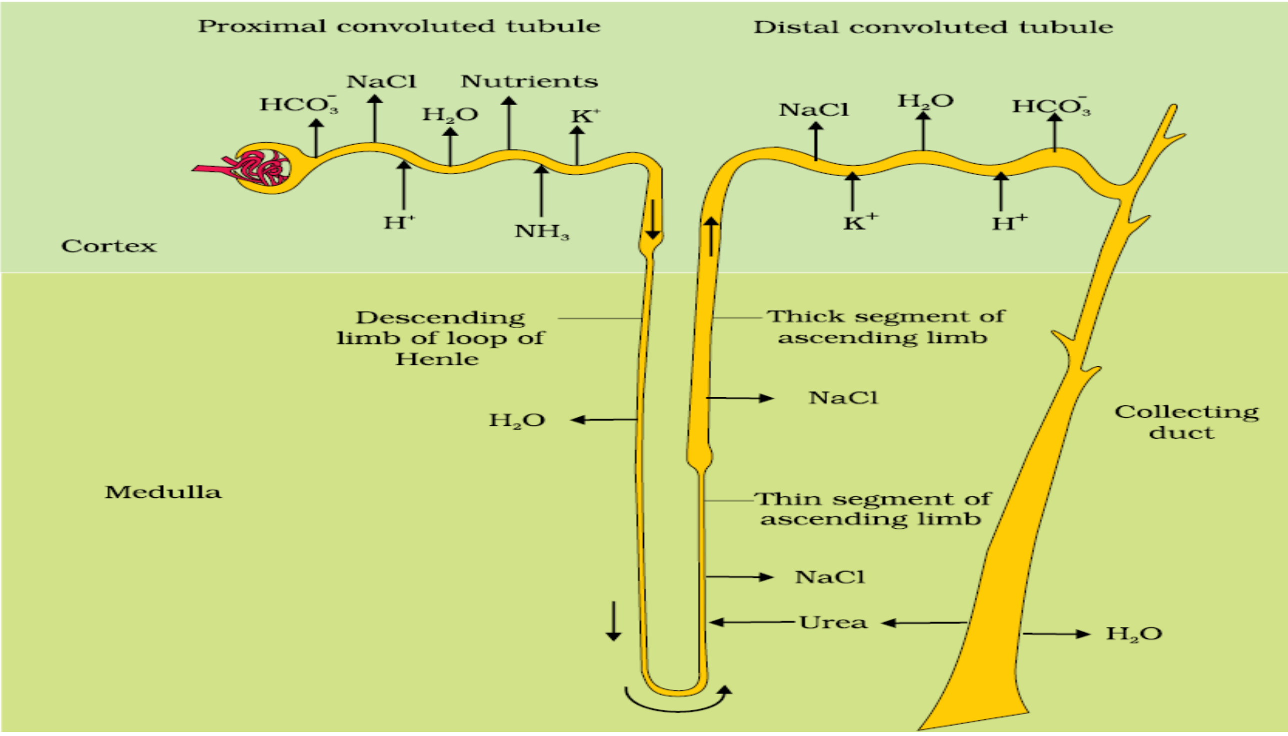

Figure: 6.5 Reabsorption and secretion of major substances at different parts of the nephron (Arrows indicate direction of movement of materials.)

Source: Retrieved from NCERT

c) **Loop of Henle:** The filtrate that leaves the PCT enters the loop of Henle, a U-shaped segment of the renal tubule. The loop of Henle consists of a descending limb and an ascending limb. As the filtrate descends into the medulla of the kidney through the descending limb, water is passively reabsorbed, concentrating the urine. In the ascending limb, sodium and other ions are actively transported out of the tubule, further contributing to urine concentration.

d) **Distal Convoluted Tubule (DCT):** The filtrate then enters the DCT, which is responsible for fine-tuning the composition of urine. In the DCT, additional reabsorption of water and ions occurs, depending on the body's needs. The DCT also plays a role in regulating the pH of the urine by actively secreting hydrogen ions or bicarbonate ions into the tubule.

e) **Collecting Duct:** The processed filtrate, now referred to as urine, leaves the DCT and enters the collecting ducts. Multiple collecting ducts merge together, forming larger ducts that traverse through the renal medulla. As the urine moves through the collecting ducts, further reabsorption of water can occur, depending on the body's hydration status. Antidiuretic hormone (ADH) regulates the permeability of the collecting ducts to water, influencing the final concentration of urine.

f) **Urine Elimination:** The urine collected by the collecting ducts drains into the renal papilla, located at the tips of the renal pyramids. From there, it enters the minor calyces, major calyces, and finally the renal pelvis. The renal pelvis connects to the ureter, which carries the urine to the urinary bladder for temporary storage until it is eventually eliminated from the body through the urethra during urination.

6.4.1 COMPOSITION OF URINE

Urine is a liquid waste product that is excreted by the kidneys. It consists of various substances that have been filtered from the blood and processed by the nephrons. Here's an elaboration on the composition of urine:

i. **Water:** The primary component of urine is water, which typically makes up around 95% of its volume. The amount of water in urine varies depending on factors such as hydration levels, environmental conditions, and overall health.

ii. **Urea:** Urea is a nitrogenous waste product that forms when proteins and amino acids are metabolized in the liver. It is the most abundant organic compound in urine and serves as an important indicator of kidney function. Urea is essential for eliminating excess nitrogen from the body.

iii. **Creatinine:** Creatinine is a waste product generated from the breakdown of creatine phosphate in muscle metabolism. It is produced at a relatively constant rate and is filtered by the kidneys. The concentration of creatinine in urine is used as a measure of kidney function.

iv. **Uric Acid:** Uric acid is a by-product of the metabolism of purine nucleotides. It is produced when cells and nucleic acids are broken down. Excess uric acid is excreted by the kidneys. High levels of uric acid in urine can indicate conditions such as gout or kidney stones.

v. **Electrolytes:** Urine contains various electrolytes, including sodium, potassium, chloride, and phosphate ions. The concentration of these electrolytes is tightly regulated by the kidneys to maintain proper fluid and electrolyte balance in the body. Imbalances in electrolyte levels can indicate kidney dysfunction or other health issues.

vi. **Other Waste Products:** Urine also contains smaller amounts of other waste products, such as ammonia, bilirubin, and various organic and inorganic compounds that are filtered from the blood by the kidneys.

vii. **Hormones and Metabolites:** Certain hormones and metabolites may be present in urine, reflecting the body's metabolic processes. For example, the hormone aldosterone and its metabolites can be detected in urine, providing information about hormone regulation and adrenal gland function.

It is important to note that the composition of urine can vary depending on factors such as diet, hydration, medications, and underlying health conditions. Changes in urine composition can be indicative of certain diseases or imbalances in the body.

6.5 MECHANISM OF CONCENTRATION OF THE FILTRATE

The mechanism of concentration of the filtrate in the kidneys involves the coordinated functioning of the Henle's loop and vasa recta, which create a counter current system. This mechanism enables mammals, including humans, to produce a concentrated urine. Here's an elaboration on the process:

The Henle's loop consists of two limbs: the descending limb and the ascending limb. The flow of filtrate in these limbs is in opposite directions, forming a counter current. The vasa recta, which are specialized capillaries, also exhibit a counter current flow pattern.The proximity between the Henle's loop and vasa recta, along with their counter current arrangement, plays a crucial role in creating and maintaining an increasing osmolarity towards the inner medullary interstitium. The osmolarity gradually increases from about 300 $mOsmolL^{-1}$ in the cortex to approximately 1200 $mOsmolL^{-1}$ in the inner medulla.The main substances involved in establishing this osmotic gradient are NaCl (sodium chloride) and urea. Sodium chloride is transported out of the ascending limb of the Henle's loop, creating a higher concentration in the interstitium. This high concentration of NaCl in the interstitium drives the movement of water out of the descending limb of the loop, resulting in the concentration of the filtrate.In the vasa recta, the descending portion picks up water as it descends towards the medulla, while the ascending portion carries away NaCl, which is exchanged with the descending limb of the loop. This exchange helps maintain the concentration gradient.Urea, another waste product, also contributes to the concentration mechanism. Small amounts of urea enter the thin segment of the ascending limb of the Henle's loop. It is then transported back into the interstitium by the collecting tubule. This recycling of urea further enhances the concentration gradient in the medullary interstitium.

Overall, this coordinated transport of NaCl and urea facilitated by the unique arrangement of the Henle's loop and vasa recta is known as the counter current mechanism. This mechanism establishes and maintains a concentration gradient in the medullary interstitium, which allows for the easy passage of water from the collecting tubule. As a result, the filtrate (urine) becomes more concentrated. Human kidneys can produce urine that is nearly four times more concentrated than the initial filtrate formed.

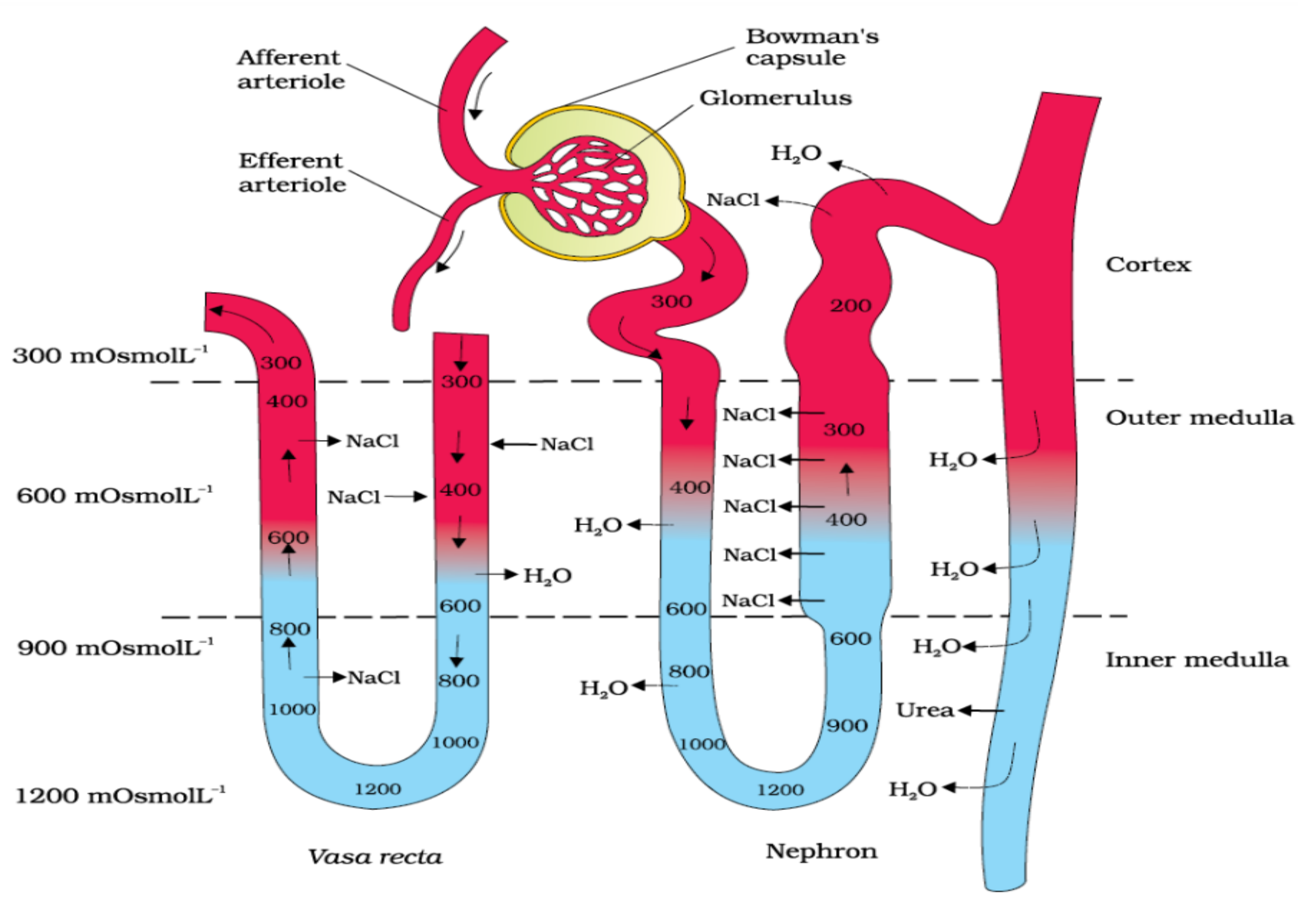

Figure: 6.6 Diagrammatic representation of a nephron and vasa recta showing counter current mechanisms

Check your Progress II:

Answer the following questions:

1. What is the first step in urine formation?

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   ……………………………………………………………………………………………………
2. What is the composition of urine?

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   ……………………………………………………………………………………………………
3. Explain the relationship between the kidneys and nephrons?

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Source: Retrieved from NCERT

6.6 FUNCTIONS OF KIDNEY

The kidneys are vital organs responsible for performing several essential functions in the body. Here's an elaboration on the functions of the kidneys:

a) **Filtration of Waste Products:** One of the primary functions of the kidneys is to filter waste products from the blood. The kidneys receive approximately 20% of the blood pumped by the heart and filter out waste substances such as urea, creatinine, excess ions (e.g., potassium, sodium), and metabolic by-products. These waste products are eliminated from the body through urine, helping maintain the overall chemical balance and homeostasis.

b) **Regulation of Fluid and Electrolyte Balance:** The kidneys play a crucial role in regulating the body's fluid and electrolyte balance. They maintain the proper concentration of various substances, such as sodium, potassium, calcium, and phosphate, in the blood. By adjusting the reabsorption and excretion of these electrolytes, the kidneys help maintain the optimal balance required for normal cellular function and nerve impulse transmission.

c) **Acid-Base Balance:** The kidneys are involved in regulating the acid-base balance of the body. They help maintain the pH of the blood within a narrow range by selectively reabsorbing or excreting hydrogen ions and bicarbonate ions. This process ensures that the body's pH remains within the normal range, allowing enzymes and other biochemical processes to function optimally.

d) **Blood Pressure Regulation:** The kidneys play a significant role in regulating blood pressure. They produce a hormone called renin, which helps control blood pressure by initiating a series of reactions that ultimately lead to the constriction of blood vessels and the retention of sodium and water. The kidneys also help regulate blood pressure by adjusting the volume of blood in the body through the control of fluid balance.

e) **Red Blood Cell Production:** The kidneys are involved in the production of red blood cells. They produce a hormone called erythropoietin, which stimulates the bone marrow to produce red blood cells. Erythropoietin release is regulated by the oxygen-carrying capacity of the blood. When oxygen levels are low, such as during anaemia or at high altitudes, the kidneys release more erythropoietin to stimulate red blood cell production.

f) **Vitamin D Activation:** The kidneys are responsible for the activation of vitamin D, a hormone that plays a crucial role in maintaining bone health and regulating calcium levels in the body. The kidneys convert an inactive form of vitamin D obtained from the diet or synthesized in the skin to its active form, which enables it to regulate calcium absorption from the intestine and promote calcium deposition in bones.

6.7 FUNCTIONS OF NEPHRON

Let’s discuss the function of nephrons. The nephrons are the functional units of the kidneys and play a crucial role in the filtration and processing of blood to produce urine. Here's an elaboration on the functions of nephrons:

a) **Filtration:** The primary function of nephrons is to filter the blood and remove waste products, excess ions, and other substances from the bloodstream. This filtration occurs in the renal corpuscle, which consists of a tuft of capillaries called the glomerulus surrounded by Bowman's capsule. As blood flows through the glomerulus under pressure, small molecules like water, electrolytes, waste products (e.g., urea, creatinine), and nutrients are filtered into Bowman's capsule to form the initial filtrate.

b) **Reabsorption:** After filtration, the filtrate passes through the renal tubules, where important substances are selectively reabsorbed back into the bloodstream. The proximal convoluted tubule (PCT) is responsible for the majority of reabsorption. It reabsorbs water, glucose, amino acids, electrolytes (e.g., sodium, potassium), and other essential molecules from the filtrate into the peritubular capillaries surrounding the tubules. This reabsorption process helps maintain the body's fluid balance and prevents the loss of valuable substances.

c) **Secretion:** Nephrons also play a role in the secretion of certain substances from the blood into the tubules. This involves the active transport of specific waste products, drugs, and excess ions (e.g., hydrogen ions) from the peritubular capillaries into the tubules for elimination in urine. Secretion occurs predominantly in the proximal convoluted tubule and distal convoluted tubule.

d) **Concentration of Urine:** The nephrons, particularly the loop of Henle, are involved in the concentration of urine. As the filtrate moves through the loop of Henle, water is passively reabsorbed from the descending limb into the surrounding blood vessels, concentrating the remaining filtrate. In the ascending limb, ions like sodium and chloride are actively transported out of the tubule, further contributing to urine concentration. This concentration process helps the body conserve water and maintain fluid balance.

e) **Acid-Base Balance:** Nephrons assist in maintaining the acid-base balance of the body. They regulate the reabsorption and secretion of hydrogen ions and bicarbonate ions, which are involved in maintaining the pH of the blood within a narrow range. By adjusting the reabsorption and secretion of these ions, nephrons help regulate the body's acid-base balance and prevent deviations from normal pH levels.

f) **Hormone Production:** Nephrons are responsible for producing and releasing hormones that regulate various bodily functions. For example, cells in the juxtaglomerular apparatus of the nephron release renin, an enzyme involved in regulating blood pressure. Additionally, specialized cells in the distal convoluted tubule produce and release hormones like aldosterone and atrial natriuretic peptide (ANP), which regulate sodium and water balance in the body.

6.8 URETERS

The ureters are important structures within the human excretory system that play a crucial role in transporting urine from the kidneys to the urinary bladder. Here's an elaboration on the function and characteristics of the ureters:

The ureters are long, muscular tubes that extend from the renal pelvis of each kidney to the urinary bladder. They are approximately 25 to 30 centimeters in length and have a diameter of about 3 to 4 millimeters. Each ureter is lined with a smooth, transitional epithelium that allows for the smooth flow of urine.The primary function of the ureters is to transport urine from the kidneys to the urinary bladder. As urine is formed in the kidneys, it enters the renal pelvis, a funnel-shaped structure located at the center of each kidney. From the renal pelvis, urine flows into the ureters through peristaltic contractions.Peristalsis is a coordinated muscular contraction that helps propel urine through the ureters. The smooth muscle layers in the walls of the ureters contract in a rhythmic, wave-like pattern, pushing urine forward. This peristaltic action occurs in sequential segments along the length of the ureters, allowing for the continuous flow of urine.

One important function of the ureters is to ensure the unidirectional flow of urine. The ureterovesical junction, where the ureters enter the urinary bladder, contains a valve-like mechanism known as the ureterovesical valve. This valve prevents the backflow of urine from the bladder into the ureters, ensuring that urine flows in one direction, from the kidneys to the bladder.The muscular walls of the ureters also contribute to their function. The smooth muscle layers undergo rhythmic contractions to propel urine, even against gravity, towards the bladder. The ureters have a unique anatomical arrangement where their walls contain both longitudinal and circular smooth muscle fibers. This arrangement aids in the peristaltic movement and efficient transport of urine.The ureters' ability to prevent the backflow of urine is important for maintaining the integrity and function of the urinary system. By ensuring the unidirectional flow of urine, the ureters help prevent the reflux of urine back into the kidneys, which could lead to urinary tract infections or other complications.

In summary, the ureters are long, muscular tubes that transport urine from the kidneys to the urinary bladder. Through peristaltic contractions and a valve-like mechanism, the ureters facilitate the unidirectional flow of urine, preventing its backflow into the kidneys. Their muscular walls and unique anatomical structure enable efficient transport of urine from the kidneys to the bladder, contributing to the overall function of the excretory system.

6.9 URINARY BLADDER

The urinary bladder is an important organ within the human excretory system that plays a crucial role in storing and eliminating urine. Here's an elaboration on the function and characteristics of the urinary bladder:

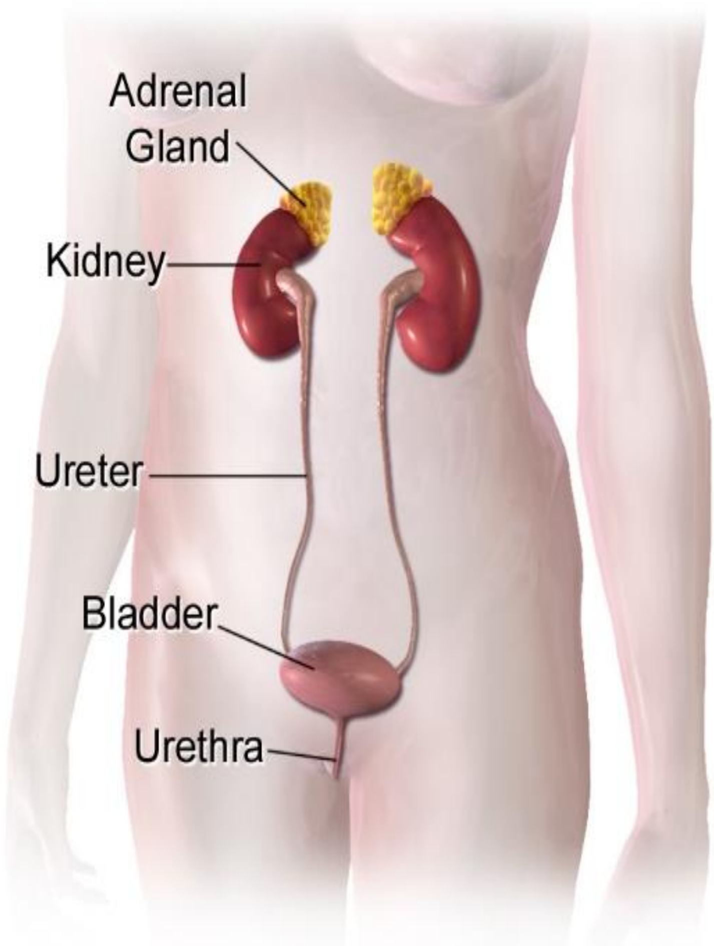

Figure: 6.7 The Urinary System

The urinary bladder is a hollow, muscular organ situated in the pelvic region, specifically in the lower abdomen. It is designed to store urine produced by the kidneys until it is voluntarily expelled from the body during the process of urination.The bladder is composed of smooth muscle tissue known as the detrusor muscle, which contracts and relaxes to facilitate urine storage and expulsion. The detrusor muscle is controlled by the autonomic nervous system, specifically the parasympathetic nervous system, which triggers the bladder to contract during urination.The bladder has the ability to expand and contract to accommodate varying volumes of urine. When empty, the bladder is relatively small and lies within the pelvic cavity. As urine accumulates, the bladder expands and rises within the abdominal cavity. This expansion is possible due to the elastic properties of the bladder wall and the presence of rugae - folds or wrinkles in the inner lining of the bladder that allow for expansion.The inner lining of the bladder is composed of a specialized transitional epithelium called the urothelium, which is impermeable to urine. This lining prevents the leakage of urine into the surrounding tissues. The smooth surface of the urothelium also helps in the smooth flow of urine during urination.

The bladder has three openings: two ureteral openings and one urethral opening. The ureteral openings connect the bladder to the ureters, which bring urine from the kidneys, while the urethral opening connects the bladder to the outside of the body through the urethra.The bladder also possesses a muscular ring-like structure called the internal urethral sphincter at the junction of the bladder and urethra. The internal urethral sphincter remains contracted to prevent the involuntary release of urine, keeping the bladder closed until a person decides to initiate the process of urination.When the bladder is full and there is a conscious decision to urinate, the detrusor muscle contracts, while the external urethral sphincter, a voluntary skeletal muscle, relaxes. This coordinated action allows urine to be expelled from the bladder through the urethra and out of the body.

In summary, the urinary bladder is a muscular organ that serves as a temporary reservoir for urine. It has the capacity to expand and contract, allowing it to store varying volumes of urine. The inner lining of the bladder prevents the leakage of urine, and the presence of the detrusor muscle facilitates the contraction and relaxation required for urination. The bladder plays a crucial role in the excretory system by storing urine until it can be voluntarily expelled from the body.

6.10 URETHRA

The urethra is a vital component of the human excretory system responsible for the passage of urine from the urinary bladder to the outside of the body. Here's an elaboration on the function and characteristics of the urethra:

The urethra is a tube-like structure that connects the urinary bladder to the external opening of the urinary system, called the urethral meatus. Its primary function is to serve as a conduit for the elimination of urine from the body.In males, the urethra has an additional function as it also plays a role in the elimination of semen during ejaculation. This makes the male urethra part of both the excretory and reproductive systems.The length and structure of the urethra differ between males and females. In males, the urethra is longer and travels through the penis, while in females, it is shorter and opens just above the vaginal opening. The length of the male urethra contributes to its role in transporting both urine and semen.The urethra is lined with a specialized epithelial tissue that provides a protective barrier and allows for the smooth passage of urine. In males, the urethral lining consists of both transitional and pseudostratified columnar epithelium, whereas in females, it is lined with stratified squamous epithelium.The external opening of the urethra, known as the urethral meatus, is located at the tip of the penis in males and just above the vaginal opening in females. It is the point of exit for urine and, in males, also for semen during ejaculation.

The process of urination, also called micturition, involves the coordinated relaxation of the muscles surrounding the urethra. In males, the external urethral sphincter, a voluntary skeletal muscle, must be consciously relaxed to allow the passage of urine. In females, the relaxation of the muscles surrounding the urethra occurs automatically during urination.

In summary, the urethra is a tube that connects the urinary bladder to the external opening of the urinary system. Its primary function is to serve as a conduit for the elimination of urine from the body. In males, it also plays a role in the elimination of semen during ejaculation. The length, structure, and lining of the urethra differ between males and females, and the urethral meatus is the point of exit for urine and, in males, semen. The urethra is an essential component of the excretory system, facilitating the elimination of waste products from the body.

Check your Progress III:

Answer the following questions:

1. What is the function of the ureter and how does it facilitate the movement of urine?
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2. Where is the urinary bladder located and what is the primary function?
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   ………………………………………………………………………………………………
3. What is the function of the urethra?
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6.11 GLOSSARY

Filtration: Filtration is the process by which blood is filtered in the kidneys, allowing waste products, water, and small molecules to pass into the renal tubules while retaining larger molecules and cells in the bloodstream.

Reabsorption: Reabsorption is the process in which valuable substances such as water, glucose, electrolytes, and amino acids are selectively reabsorbed from the renal tubules back into the bloodstream.

Secretion: Secretion is the process of selectively transferring additional waste products, drugs, and excess ions from the bloodstream into the renal tubules for elimination in urine.

Glomerulus: The glomerulus is a network of tiny blood vessels (capillaries) within the renal corpuscle where blood is filtered under pressure to form the filtrate.

Detoxification: Detoxification is the process by which the excretory system eliminates harmful substances and toxins, such as drugs and metabolic byproducts, from the body.

Homeostasis: Homeostasis is the process of maintaining a stable internal environment within the body. The excretory system plays a crucial role in maintaining homeostasis by regulating fluid balance, electrolyte levels, and waste elimination.

Osmoregulation: Osmoregulation is the regulation of water and solute concentrations in the body fluids to maintain the body's internal balance. The excretory system helps regulate osmolarity through processes such as filtration, reabsorption, and secretion.

6.12 LET US SUM UP

The human excretory system is responsible for eliminating waste products from the body and maintaining homeostasis. One of its key components is the kidney, which plays a vital role in urine formation. The kidney has a complex structure consisting of the renal cortex, renal medulla, renal pelvis, and various other structures like renal columns, renal papilla, and calyces. The formation of urine involves the filtration of blood in the nephrons, where water, waste products, electrolytes, and other substances are filtered into Bowman's capsule. The composition of urine includes water, waste products like urea and creatinine, electrolytes, and dissolved substances. The concentration of the filtrate is achieved through a mechanism involving the Henle's loop and vasa recta, creating a concentration gradient in the medullary interstitium. The kidneys have crucial functions such as maintaining fluid and electrolyte balance, regulating blood pressure, and producing erythropoietin. Nephrons are the functional units of the kidney responsible for filtration, reabsorption, and secretion. Ureters are tubes that transport urine from the kidneys to the urinary bladder, which serves as a temporary reservoir. Finally, the urethra allows the passage of urine from the bladder to the outside of the body and in males, also plays a role in the elimination of semen. These components work together harmoniously to ensure the efficient elimination of waste products and the maintenance of bodily functions.

6.13ANSWER TO CHECK YOUR PROGRESS EXERCISES

Check your Progress I

1. The excretory system, particularly the kidneys, plays a vital role in maintaining the body's fluid balance and regulating electrolyte levels. The kidneys filter the blood and selectively reabsorb water and essential electrolytes, such as sodium, potassium, and calcium, back into the bloodstream while eliminating excess substances in the form of urine.
2. the excretory system is not only involved in waste elimination but also contributes to other functions in the body. It helps regulate blood pressure by controlling fluid balance and the production of a hormone called renin. The kidneys also participate in the production of red blood cells by releasing a hormone called erythropoietin.
3. Nephrons are the microscopic units within the kidney responsible for the filtration of blood and the formation of urine. Each kidney contains millions of nephrons. They consist of a renal corpuscle, which includes a glomerulus (a network of capillaries) and a Bowman's capsule (which surrounds the glomerulus), as well as a renal tubule that extends from the Bowman's capsule.

Check your Progress II

1. The first step in urine formation is filtration. It occurs in the glomerulus of the nephron, where blood pressure forces water, waste products, and small molecules out of the glomerular capillaries and into the Bowman's capsule.
2. Urine is primarily composed of water, waste products, and various dissolved substances. The specific composition may vary, but typical components of urine include urea, creatinine, uric acid, electrolytes (such as sodium, potassium, and chloride), hormones, and various dissolved ions.

3. The kidneys contain millions of nephrons, which are the functional units responsible for the filtration and processing of blood. The kidneys consist of numerous nephrons that work together to maintain the body's fluid and electrolyte balance, remove waste products, and perform other vital functions necessary for overall health and homeostasis.

Check your Progress III

1. The ureter serves the function of transporting urine from the kidneys to the urinary bladder. The ureter utilizes peristaltic contractions, which are wave-like muscular movements, to propel urine from the kidneys to the urinary bladder.
2. The urinary bladder is located in the pelvic cavity, behind the pubic bone. The primary function of the urinary bladder is to store urine until it is expelled from the body during urination.
3. The urethra serves as a tube through which urine is eliminated from the body.

UNIT 7 ENDOCRINE SYSTEM

Structure

7.1 Introduction

7.2 Hormones and Feedback Mechanism

7.3 Overview of Endocrine Glands

7.4 Pituitary gland
7.4.1 Anterior Pitutary
7.4.2 Posterior Pituitary
7.5 Thyroid gland
7.5.1 Structure of Thyroid Gland
7.5.2 Functionsof Thyroid Glands
7.5.3 Disorder ofThyroid Gland
7.6 Parathyroid glands
7.6.1 Structure of Parathyroid Glands
7.6.2 Function of Parathyroid Glands
7.6.3 Disorder of Parathyroid Glands
7.7 Adrenal gland
7.7.1 Structure of Adrenal Glands
7.7.2 Function of Adrenal Glands
7.7.3 Disorder of Adrenal Glands
7.8 The Pancreas
7.9 Gonads
7.9.1 Testes
7.9.2 Ovaries
7.10 Placenta
7.11 Pineal gland
7.11.1 Structure of the Pineal Gland
7.11.2 Function of the Pineal Gland

7.1 INTRODUCTION

In the previous units, you have gained knowledge about the various systems that make up the human body. It is evident that each system serves a specific function. However, the coordination of these functions is facilitated by two essential systems: the endocrine system and the nervous system. Now, let us look into into the fascinating realm of the endocrine system, where we will explore the details of the endocrine glands and their vital functions. The endocrine system consists of the glands that are widely distributed in the body having no connection with each other. Glands are specialized organs or tissues in the body that produce and release substances necessary for various physiological functions. The body has numerous glands, each with its specific function and hormone production. Broadly, glands can be classified into exocrine, endocrine glands and heterocrine gland that possess both exocrine and endocrine components.

1. Exocrine glands- Exocrine glands discharge their secretions through ducts into the cavities or onto the surface. The exocrine portion of the gland facilitates the localized release of substances, such as digestive enzymes, into specific target areas. The secretions of exocrine glands include:

- Enzymes: Exocrine glands, such as the salivary glands, pancreas, and gastric glands, produce enzymes that aid in digestion. For example, amylase and lipase help break down carbohydrates and fats in the digestive system.
- Mucus: Exocrine glands in the respiratory tract, gastrointestinal tract, and reproductive system produce mucus. Mucus serves to lubricate and protect the lining of these organs and helps with the movement of substances through these passages.
- Sweat: Sweat glands, located throughout the body, produce sweat to regulate body temperature through evaporative cooling. Sweat also helps eliminate waste products and toxins from the body.
- Sebum: Sebaceous glands in the skin produce sebum, an oily substance that helps lubricate the skin and hair, preventing dryness and providing a protective barrier.
- Milk: Mammary glands in the breasts of females produce milk to nourish infants.

2. Endocrine glands- Endocrine glands lacks duct and secrete hormones directly into the bloodstream for transport to the site of action. The endocrine portion allows for the release of hormones that act on distant organs or tissues to regulate broader physiological processes.

The secretions of endocrine glands include:

- Steroid Hormones: These hormones are derived from cholesterol and include hormones such as cortisol, aldosterone, estrogen, and testosterone. They regulate a wide range of functions including metabolism, stress response, salt and water balance, and reproductive processes.
- Peptide Hormones: These hormones are made up of chains of amino acids. Examples include insulin, growth hormone, oxytocin, and parathyroid hormone. They regulate

processes such as growth and development, metabolism, water balance, and reproductive functions.

- Amino Acid-Derived Hormones: These hormones are derived from amino acids, such as tyrosine and tryptophan. Examples include thyroid hormones (T3 and T4) produced by the thyroid gland and epinephrine (adrenaline) and norepinephrine produced by the adrenal glands. They regulate metabolism, energy balance, and the body's response to stress.

3. Heterocrine glands: Heterocrine glands are unique glands that possess both exocrine and endocrine components. They have the ability to secrete substances through ducts locally, while also releasing hormones into the bloodstream to exert systemic effects. This dual functionality allows for the integration of local and systemic regulation, contributing to the overall balance and functioning of the body. For example, the pancreas is a heterocrine gland that has exocrine cells producing digestive enzymes that are released into the small intestine through a duct. On the other hand, the endocrine component of heterocrine glands is responsible for producing and releasing hormones directly into the bloodstream, similar to traditional endocrine glands. These hormones have systemic effects and are transported to target organs or tissues throughout the body to regulate various physiological processes. For example, the pancreas also contains endocrine cells called islets of Langerhans that produce and release hormones such as insulin and glucagon, which regulate blood sugar levels. Other examples of heterocrine glands include the liver, which has exocrine cells producing bile that is released into the digestive system, and endocrine cells producing hormones involved in metabolism and nutrient regulation. The testes and ovaries are also considered heterocrine glands, as they have both exocrine cells producing reproductive cells (sperm or eggs) and endocrine cells producing sex hormones.

These glands work together to regulate metabolism, growth, development, reproduction, and maintain overall homeostasis. The proper functioning of glands is crucial for maintaining overall health and homeostasis in the body. Any disruption in glandular function can lead to hormonal imbalances and various health conditions. In summary, glands play crucial roles in the body by producing and secreting substances necessary for various physiological functions. The first section in this unit we will deal with hormones and the mechanism of action in the body. In the next section, we will study the endocrine glands, their function and disorder associated with.

Objectives

After studying this unit, you will be able to:

- Illustrate the gross structure of endocrine glands.
- Describe the role of various endocrine glands in the regulation of body functions and
- Discuss the effects of over secretion and under secretion.

7.2 Hormones and Feedback mechanisms

Hormones are chemical messengers that play a crucial role in regulating various processes in the human body. Produced by endocrine glands, hormones are released into the bloodstream and travel to target cells or organs where they exert their effects. The secretion of hormones involves a complex process that is tightly regulated by the body's endocrine system. Hormones are synthesized and released by specialized endocrine glands in response to specific signals or stimuli. Let's learn an overview of the general mechanism of hormone secretion.

Hormone secretion is tightly regulated by feedback mechanisms to maintain balance in the body. Feedback mechanisms involve the monitoring of hormone levels in the bloodstream or the target organs and subsequent adjustmens in hormone production to maintain homeostasis. There are two main types of feedback mechanisms: negative feedback and positive feedback.

Negative Feedback: Negative works to maintain hormone levels within a narrow range and restore equilibrium when there are deviations from the set point. The process involves the following steps:

1. Stimulus: A stimulus triggers the release of a hormone from an endocrine gland. The stimulus can be an internal signal (e.g., low blood glucose levels) or an external signal (e.g., stress).
2. Hormone Release: In response to the stimulus, the endocrine gland secretes the hormone into the bloodstream.
3. Target Organ Response: The hormone travels to its target organs or tissues, where it exerts its effects by binding to specific receptors. This leads to a physiological response.
4. Feedback Loop: As the hormone's effects are exerted on the target organs, the target organs send signals back to the endocrine gland to regulate further hormone secretion.
5. Inhibition of Hormone Release: If hormone levels exceed the desired range, the feedback signals inhibit further hormone release. This helps prevent excessive hormone production and maintains equilibrium.

6. Restoration of Homeostasis: By inhibiting hormone release, the negative feedback loop helps restore hormone levels to their optimal range, bringing the body back to homeostasis.

Here are some examples for negative feedback which helps you to understand the mechanism:

- Insulin and glucagon play a pivotal role in regulating blood glucose levels. After a meal, the pancreas secretes insulin, facilitating the uptake of glucose into cells and thereby reducing blood glucose levels. On the other hand, when blood glucose levels drop, the pancreas releases glucagon, which stimulates the breakdown of glycogen and the release of glucose into the bloodstream, thus elevating blood glucose levels.
- The levels of thyroid hormones are regulated by a complex interplay between the hypothalamus, pituitary gland, and the thyroid gland. The hypothalamus secretes thyrotropin-releasing hormone (TRH), which stimulates the pituitary gland to release thyroid-stimulating hormone (TSH). TSH, in turn, stimulates the thyroid gland to produce and release thyroid hormones, known as triiodothyronine (T3) and thyroxine (T4). As blood levels of thyroid hormones increase, they exert negative feedback on the hypothalamus and pituitary gland, leading to a decrease in the release of TRH and TSH, ultimately regulating thyroid hormone production.

Positive Feedback: Positive feedback mechanisms, unlike negative feedback, amplify the initial stimulus, leading to an increase in hormone production. While less common in the endocrine system, positive feedback is involved in specific processes such as childbirth and lactation. The steps involved in positive feedback include:

1. Stimulus: A stimulus triggers the release of a hormone.
2. Hormone Release: The endocrine gland secretes the hormone into the bloodstream.
3. Enhanced Response: The hormone stimulates its target organs or tissues, leading to a physiological response.
4. Feedback Loop: The physiological response further stimulates hormone release, amplifying the initial stimulus.
5. Continuation of the Process: The positive feedback loop continues until the stimulus is removed or a specific endpoint is reached.

Examples of positive feedback mechanisms in the endocrine system include:

- Childbirth: During labor, the hormone oxytocin is released from the pituitary gland in response to uterine contractions. Oxytocin stimulates more powerful contractions, which further stimulate oxytocin release, creating a positive feedback loop until the baby is delivered.

- Lactation: The suckling action of a newborn at the mother's breast triggers the release of the hormone prolactin from the pituitary gland.

7.3 OVERVIEW OF ENDOCRINE GLANDS

What do you understand by the term endocrine glands and what is their role in our body? The endocrine system is a complex network of glands that produce and release hormones, which are chemical messengers that regulate various functions in the body. These hormones are secreted directly into the bloodstream and travel to target organs or tissues to exert their effects. The endocrine glands are scattered throughout the body and work together to maintain homeostasis and regulate growth, metabolism, reproduction, and many other physiological processes.

First, let us get to know about the various endocrine glands. There are six very important endocrine glands in our body. These are:

1. Pituitary Gland
2. Thyroid Gland
3. Parathyroid Glands
4. Adrenal Glands
5. Pancreas
6. Gonads (Testes and Ovaries)

Figure 7.1 gives a clear view of these glands

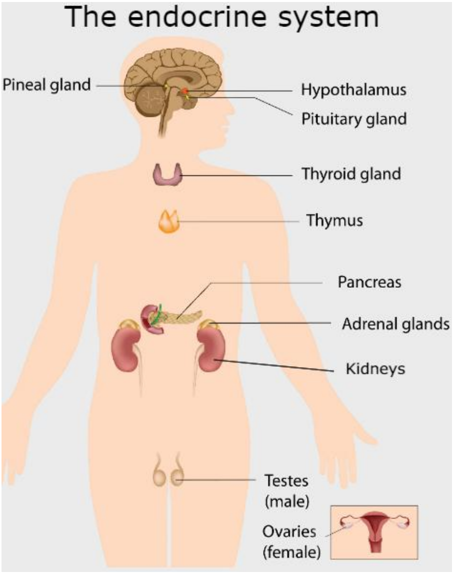

Figure 7.1 The endocrine glands (retrived from https://www.healthdirect.gov.au)

Let us now begin our discussion on endocrine glands. We shall start with the pituitary gland

7.4 Pituitary gland

The pituitary gland, also known as the hypophysis, is a small, pea-sized gland located at the base of the brain. It is often referred to as the "master gland" because it plays a crucial role in regulating the functions of other endocrine glands in the body. It consists of two main parts: the anterior pituitary (adenohypophysis) and the posterior pituitary (neurohypophysis) as you can see in figure 7.2. Each part has distinct anatomical features and functions.

Let's explore the structure and functions of the anterior and posterior pituitary in more detail.

7.4.1 Anterior Pituitary (Adenohypophysis)

The anterior pituitary is the larger portion of the pituitary gland and is composed of glandular tissue. The anterior pituitary consists of three regions: the pars distalis, the pars tuberalis, and the pars intermedia.

a) *Pars Distalis* :The *pars distalis* is the largest and most anterior part of the anterior pituitary. It is responsible for the production and secretion of several hormones, including:

- Growth hormones,
- Thyroid stimulating hormones,
- Adrenocorticotropic hormone,
- Follicle stimulating hormone,
- luteinizing hormone and
- prolactin.

b) *Pars Tuberalis*: The pars tuberalis is a thin layer of cells that wraps around the infundibulum, the stalk that connects the pituitary gland to the hypothalamus. Its exact function is not fully understood, but it may be involved in regulating hormone secretion.

c) *Pars Intermedia:* The pars intermedia is a thin region located between the pars distalis and the posterior pituitary. It produces melanocyte-stimulating hormone (MSH), which plays a role in regulating skin pigmentation.

Let us learn about these hormones secreted by anterior pituitary, one by one. We begin with growth hormone and its functions.

A. **Growth Hormone (GH):** Growth hormone (GH), also known as somatotropin, is a hormone produced and secreted by the anterior pituitary gland.

i. *Functions:* It plays a crucial role in the growth and development of tissues and organs in the body. Here are the main functions of growth hormone:

- Stimulation of skeletal growth: Growth hormone is primarily responsible for stimulating the growth of bones and skeletal muscles during childhood and adolescence. It promotes the proliferation and differentiation of cells in the epiphyseal plates of long bones, leading to bone elongation and overall growth. Deficiency of growth hormone during childhood can result in stunted growth and short stature.
- Regulation of protein synthesis: Growth hormone enhances protein synthesis in various tissues, including muscles and organs. It stimulates the uptake of amino acids by cells and promotes their incorporation into proteins. This helps in tissue repair, maintenance, and growth.
- Lipid metabolism: Growth hormone plays a role in regulating lipid metabolism by stimulating the breakdown of stored fats (lipolysis). It promotes the utilization of fatty acids as an energy source, thereby reducing the reliance on glucose for energy production. This can help prevent the excessive accumulation of body fat.
- Carbohydrate metabolism: Growth hormone influences carbohydrate metabolism by reducing the uptake and utilization of glucose in tissues such as muscles and adipose tissue. This leads to increased blood glucose levels, which helps to spare glucose for the brain's energy needs. Growth hormone also promotes the production of insulin-like growth factor 1 (IGF-1) in the liver, which has insulin-like effects on glucose metabolism.
- Stimulating IGF-1 production: Growth hormone stimulates the liver and other tissues to produce insulin-like growth factor 1 (IGF-1). IGF-1 is a hormone that mediates many of the growth-promoting effects of growth hormone. It acts on target tissues to stimulate cell growth, proliferation, and differentiation. IGF-1 is essential for the growth and development of various organs and tissues, including bones, muscles, and cartilage.

- Regulation of body composition: Growth hormone plays a role in maintaining a balanced body composition by promoting lean body mass (muscle) and reducing fat mass. It stimulates the differentiation of precursor cells into muscle cells and inhibits fat storage in adipocytes.
- Enhancing immune function: Growth hormone has immunomodulatory effects, influencing the function of the immune system. It enhances the production and activity of immune cells, such as lymphocytes and macrophages, contributing to improved immune response and defense against infections.
- Maintenance of organ function: Growth hormone is involved in the maintenance of various organs and tissues, including the heart, liver, kidneys, and immune system. It helps to preserve the function and integrity of these organs by supporting cell growth, repair, and regeneration.

ii. *Regulation:* The secretion of GH is regulated by a complex feedback system involving the hypothalamus and other factors. The hypothalamus produces and releases growth hormone-releasing hormone (GHRH), which stimulates the anterior pituitary to release GH. On the other hand, somatostatin, produced by the hypothalamus, inhibits GH release. Additionally, other factors such as sleep, exercise, stress, and nutritional status can also influence GH secretion. GH levels are highest during childhood and gradually decline with age.

iii. *Disorders:* Abnormalities in GH secretion can lead to certain disorders.

Hypersecreation: Excessive GH production in children can result in gigantism, characterized by excessive growth and unusually tall stature. In adults, excessive GH production can cause acromegaly, which leads to the enlargement of hands, feet, and facial features.

Hyposecertion: On the other hand, inadequate GH production can result in growth hormone deficiency (GHD), leading to growth retardation, delayed puberty, and other developmental issues.

Based on our previous discussion, you should now have a solid understanding of the crucial role played by growth hormone in regulating cellular nutrition, protein metabolism, and somatic growth. This is why it is commonly referred to as the Somatotrophic hormone. Now, let's shift our focus to another significant hormone called thyroid stimulating hormone (TSH), which is secreted by the anterior pituitary gland.

B. **Thyroid stimulating hormone:** Thyroid-stimulating hormone (TSH), also known as thyrotropin, is a hormone produced by the anterior pituitary gland. It plays a vital role in the regulation of thyroid gland function. TSH acts on the thyroid gland, specifically on the follicular cells, to stimulate the production and release of thyroid hormones, primarily thyroxine (T4) and triiodothyronine (T3). These hormones are essential for the regulation of metabolism, growth, development, and energy balance throughout the body. TSH regulates various steps in the synthesis and secretion of thyroid hormones. It promotes the uptake of iodine by the thyroid gland, which is essential for the synthesis of T4 and T3. TSH also stimulates the production of thyroglobulin, a protein precursor for thyroid hormones, and facilitates its iodination and storage within the thyroid follicles. Additionally, TSH enhances the release of thyroid hormones into the bloodstream.

Feedback Mechanism: The release of TSH is controlled by a negative feedback mechanism involving thyroid hormones. When the levels of T4 and T3 are low, the hypothalamus releases thyrotropin-releasing hormone (TRH), which stimulates the anterior pituitary to secrete TSH. In response to TSH, the thyroid gland synthesizes and releases more thyroid hormones. As the levels of T4 and T3 increase, they inhibit the release of TRH and TSH, creating a feedback loop to maintain thyroid hormone homeostasis.

Disorder: Abnormalities in TSH levels can have significant clinical implications. Elevated TSH levels indicate hypothyroidism, a condition characterized by an underactive thyroid gland and reduced thyroid hormone production. Conversely, decreased TSH levels suggest hyperthyroidism, where the thyroid gland is overactive and produces excessive thyroid hormones. Measurement of TSH levels is commonly used as a diagnostic tool to assess thyroid function and guide the management of thyroid disorders.

Overall, thyroid-stimulating hormone plays a crucial role in regulating thyroid gland function and maintaining the balance of thyroid hormone production in the body. Now, we will move to next hormone secreted by anterior pituitary gland i.e. Adrenocorticotropic hormone

C. Adrenocorticotropic Hormone (ACTH): Adrenocorticotropic hormone (ACTH), also known as corticotropin, is a hormone produced by the anterior pituitary gland. It plays a significant role in the regulation of the adrenal glands and the production of cortisol, a vital hormone involved in stress response and metabolism. Here are the key points about the functions of adrenocorticotropic hormone:

- *Stimulation of cortisol production:* The primary function of ACTH is to stimulate the adrenal cortex, the outer layer of the adrenal glands, to produce and release cortisol. ACTH binds to specific receptors on the adrenal cortex, which triggers a series of biochemical reactions leading to the synthesis and secretion of cortisol. Cortisol is essential for regulating blood sugar levels, suppressing inflammation, maintaining blood pressure, and responding to stress.

- *Regulation of adrenal gland activity*: ACTH not only stimulates cortisol production but also plays a role in regulating the overall activity of the adrenal glands. It promotes the growth and development of the adrenal cortex, ensuring that the glands have sufficient capacity to produce cortisol and other adrenal hormones. ACTH also influences the release of other hormones from the adrenal cortex, such as aldosterone, which regulates salt and water balance in the body.

Feedback regulation of ACTH secretion: The secretion of ACTH is regulated by a negative feedback mechanism involving cortisol. When cortisol levels in the blood are low, the hypothalamus releases corticotropin-releasing hormone (CRH), which stimulates the anterior pituitary gland to secrete ACTH. ACTH then acts on the adrenal glands to increase cortisol production. As cortisol levels rise, they inhibit the secretion of CRH and ACTH, creating a feedback loop that helps maintain cortisol homeostasis.

Response to stress: ACTH is a crucial component of the body's stress response system. During times of stress, such as physical or emotional stressors, the hypothalamus releases CRH, leading to the secretion of ACTH and subsequent cortisol release. Cortisol helps the body cope with stress by mobilizing energy reserves, suppressing immune responses, and modulating inflammation. Therefore, cortisol, also known as stress hormone

D Gonadotropic Hormones (GTH): Two important hormones that regulate the functions of the gonads are follicle-stimulating hormone (FSH) and luteinizing hormone (LH). These hormones are secreted by specialized cells called gonadotrophs in the anterior pituitary gland.

1. Follicle stimulating hormone (FSH: Follicle stimulating hormone (FSH) is a hormone released from the gonadotrops of anterior pituitary gland. It plays a critical role in the reproductive system, which is distinct in males and females. In males, FSH plays a crucial role in spermatogenesis, the process of sperm production. FSH acts on the Sertoli cells within the testes, stimulating them to support and nourish the developing sperm cells. It promotes the growth and maturation of the germ cells, which eventually develop into spermatozoa. FSH also enhances the production of androgen-binding protein (ABP), which helps concentrate testosterone within the testes, supporting spermatogenesis.

In females, FSH acts on the ovaries to stimulate the growth and development of ovarian follicles, which contain the eggs (ova). FSH helps initiate the maturation process of these follicles, promoting the release of estrogen, a hormone that plays a vital role in the menstrual cycle. As FSH levels rise, one follicle becomes dominant and continues to develop while the others regress. The dominant follicle eventually releases a mature egg in a process called ovulation.

- *Feedback regulation:* The secretion of FSH is regulated by a negative feedback mechanism involving hormones from the ovaries and testes. In females, rising estrogen levels inhibit the release of FSH, preventing the development of multiple follicles and maintaining hormonal balance during the menstrual cycle. In males, inhibin, a hormone produced by the Sertoli cells, inhibits the secretion of FSH, providing feedback control over spermatogenesis.

2. Luteinizing hormone (LH): It is a hormone produced by the anterior pituitary gland. It plays a crucial role in the regulation of reproductive processes, particularly in females and males.

In females, LH is responsible for the maturation and release of the egg from the ovaries during the menstrual cycle, a process known as ovulation. It stimulates the production of estrogen by the ovaries and helps in the development and maintenance of the corpus luteum, a temporary structure that produces progesterone.

In males, LH stimulates the production of testosterone by the testes. Testosterone is essential for the development and maturation of the male reproductive organs, including the testes and prostate gland. It also plays a role in sperm production and the maintenance of secondary sexual characteristics in males.

Regulation: The secretion of LH is regulated by a complex feedback mechanism involving the hypothalamus and the pituitary gland. The hypothalamus releases gonadotropin-releasing hormone (GnRH), which stimulates the pituitary gland to secrete LH. The levels of LH fluctuate throughout the menstrual cycle in females, with a sharp rise occurring just before ovulation.

Abnormal levels of LH can indicate certain reproductive disorders. In females, high levels of LH may be associated with conditions such as polycystic ovary syndrome (PCOS) or premature ovarian failure. In males, low levels of LH can indicate problems with the testes or hormonal imbalances.

From our discussion above, you would have got a fairly good idea that FSH and LH is essential for reproductive health and fertility in both males and females. It's important to note that FSH does not act alone but works in coordination with other hormones, such as LH, estrogen, and testosterone, to regulate the complex processes of the reproductive system.

E. Prolactin: Prolactin is produced by lactotroph cells of anterior pituitary gland. Prolactin is a hormone primarily involved in the stimulation and regulation of milk production in the mammary glands. It plays a crucial role in lactation and the maintenance of milk supply during breastfeeding. Prolactin also has effects on reproductive function and other body systems. In addition, Prolactin also inhibits the action of another hormone called dopamine, which normally suppresses milk production.

Regulation: . The balance of prolactin secretion is tightly regulated by the hypothalamus and feedback mechanisms. The hypothalamus produces a hormone called prolactin-releasing hormone (PRH), which stimulates the anterior pituitary to secrete prolactin. Conversely, another hormone called dopamine (also known as prolactin-inhibiting hormone or PIH) inhibits the release of prolactin. The balance between PRH and dopamine regulates the secretion of prolactin.

Disorders: Disorders of prolactin levels can have significant effects on fertility, menstrual cycles, and milk production, and are managed based on the underlying cause. Hyperprolactinemia is a condition characterized by high levels of prolactin in the blood. It can be caused by various factors, such as pituitary tumors, certain medications, and hormonal imbalances. Hyperprolactinemia can lead to menstrual irregularities, infertility, and milk production in non-pregnant individuals (galactorrhea). On the other hand, insufficient production of prolactin, known as hypoprolactinemia, is rare and typically not associated with specific clinical manifestations.

7.4.2 **Posterior Pituitary (Neurohypophysis)**

The posterior pituitary, also known as the neurohypophysis, is a glandular structure located at the base of the brain, directly below the hypothalamus, as you may have seen in **Figure 7.2**. It is an extension of the neural tissue and plays a crucial role in the regulation of several hormones. The posterior pituitary does not synthesize hormones itself but acts as a storage and release site for two important hormones: oxytocin and antidiuretic hormone (ADH), also known as vasopressin. These hormones are produced in the hypothalamus. They are then transported along the axons of these neurons to the posterior pituitary, where they are stored in vesicles until their release is triggered. Let's get to know about these hormones:

A. **Oxytocin:** Oxytocin is a hormone involved in various reproductive and social behaviors. In females, it plays a crucial role in childbirth and lactation. During labor, oxytocin stimulates uterine contractions, helping to facilitate childbirth. It also promotes the ejection of milk from the mammary glands during breastfeeding. In addition to its reproductive functions, oxytocin is also involved in social bonding, trust, and emotional attachment. It plays a role in promoting maternal-infant bonding and has been linked to social behaviors such as empathy and bonding between romantic partners and also known as "love hormones".

B. **Antidiuretic Hormone (ADH):** ADH is primarily involved in the regulation of water balance in the body. It acts on the kidneys to increase water reabsorption, reducing the amount of urine produced and helping to conserve water. ADH acts on the collecting ducts of the kidneys, increasing their permeability to water and allowing more water to be reabsorbed back into the bloodstream. This process helps maintain proper fluid balance and prevent excessive water loss, especially in response to dehydration or low blood volume. Hence, it is also known as vasopressin. It has a secondary effect on blood vessels, causing vasoconstriction and helping to increase blood pressure when needed. Deficiency of vasopressin causes a condition called as Diabetes insipidus, characterized by excessive thirst and the excretion of large amounts of dilute urine.

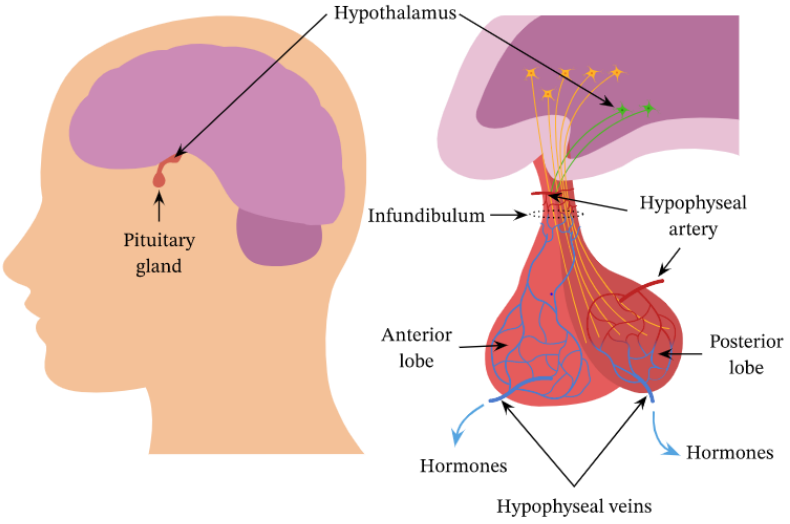

Figure 7.2 :Structure of Pituitary glands

Let us take a break here and revise what we have learnt so far. Try answering the questions given in the check your progress exercise 1.

Check Your Progress Exercise 1

1. Define gland. Enlist the different types of glands with example of each kind.
-
……
……
………......
....

2. Define hormones
………......
………......

3. Enlist the hormones secreted from anterior and posterior pituitary glands.
………...
………...
………...

4. Explain the role of hormones primary involved in the regulation of water and electrolyte balance. Where is produced from?

………

……..

……..

5. Match the following

	A	**B**
a)	Dwarfism	i Milk production
b)	ADH	ii GH excess
c)	gigantism	iii vasopressin
d)	Prolactin	iv Cortisol
e)	Stress hormone	v Deficiency of GH

7.5 Thyroid gland

The thyroid gland is an important endocrine gland located anteriorly to the trachea and esophagus, and just below the Adam's apple (cartilage that covers and protects your *voice box)*. It plays a vital role in regulating metabolism and influencing various bodily functions. Let's explore the structure and function of the thyroid gland in more detail.

7.5.1 Structure of the Thyroid Gland

The thyroid gland has a butterfly-shaped structure with two lobes connected by a narrow band of tissue called the isthmus as shown in figure 7.3. It is composed of specialized cells called follicular cells that produce and release thyroid hormones. The gland is highly vascularized, meaning it has an abundant blood supply. Within the follicular cells, the thyroid gland also contains small spherical structures called thyroid follicles. These follicles are lined with epithelial cells and are responsible for the production and storage of thyroid hormones.

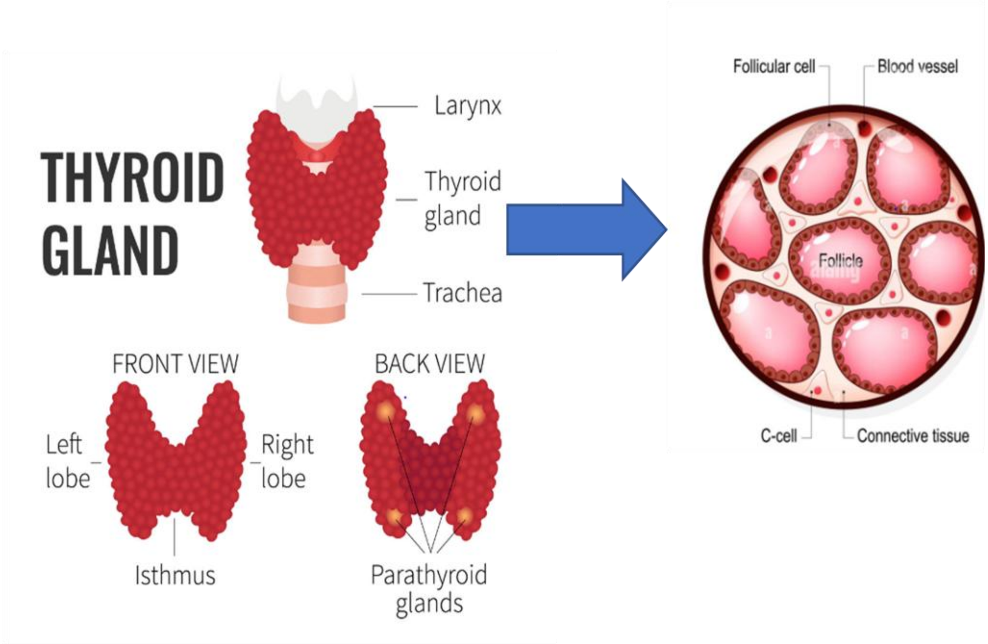

Figure 7.3 Structure of Thyroid glands (retrieved from renewed vitality)

7.5.2 Hormones of Thyroid Gland

The thyroid gland plays a crucial role in regulating metabolism, growth, and development throughout the body. It achieves this through the production and secretion of three hormones: triiodothyronine (T3), thyroxine (T4) and Calcitonin. These hormones are collectively known as thyroid hormones.

1. **Triiodothyronine (T3):** T3 is the active form of thyroid hormone and is derived from the conversion of thyroxine (T4) in peripheral tissues. T3 influences various physiological processes, including:

- *Regulation of Metabolism:* T3 increases the basal metabolic rate, which affects how the body uses energy. It plays a role in the metabolism of carbohydrates, fats, and proteins, helping to maintain proper energy balance.
- *Growth and Development:* T3 is essential for normal growth and development, especially during childhood. It influences the development of the brain, bones, and other tissues.
- *Cardiovascular Function:* T3 affects heart rate, contractility, and blood vessel dilation, helping to maintain a healthy cardiovascular system.

2. **Thyroxine (T4):** T4 is the main form of thyroid hormone produced by the thyroid gland. Although it is less potent than T3, T4 serves as a precursor for the production of T3 and helps maintain a stable supply of thyroid hormones in the body.
3. **Calcitonin:** In addition to T3 and T4, the thyroid gland also produces a peptide hormone called calcitonin. Calcitonin is involved in regulating calcium levels in the blood by inhibiting bone resorption and promoting calcium excretion by the kidneys.

Next, let us learn about the regulatory mechanism involved in the secretion of thyroid hormones.

Regulation of thyroid hormone secretion: The production and secretion of thyroid hormones are regulated by the hypothalamus-pituitary-thyroid (HPT) axis, which involves a feedback mechanism. The hypothalamus releases thyrotropin-releasing hormone (TRH), which stimulates the pituitary gland to release thyroid-stimulating hormone (TSH). TSH then acts on the thyroid gland, stimulating the synthesis and secretion of thyroid hormones.

Thyroid hormones have diverse effects on various tissues and organs in the body. They influence metabolic rate, heart rate, body temperature, growth, brain development, digestion, and many other physiological processes.

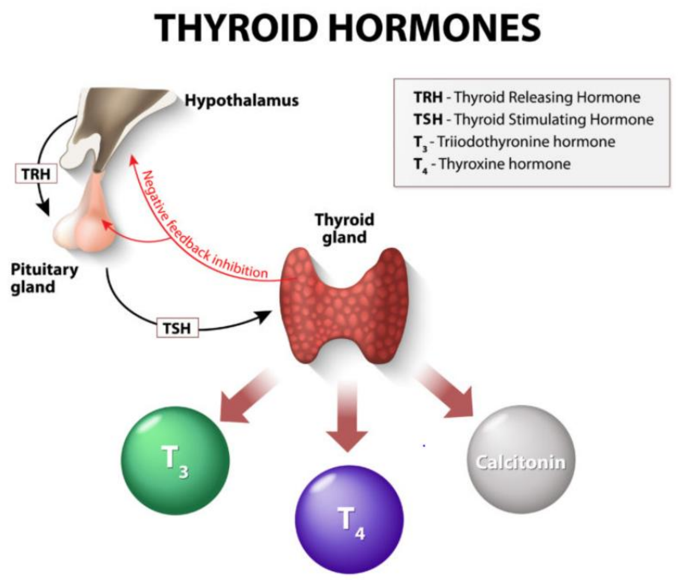

Figure 7.4: Thyroid hormones

7.5.3 Disorders of the Thyroid Gland

It plays a crucial role in regulating metabolism and producing hormones that are involved in various physiological processes. However, like any other organ, the thyroid gland can be susceptible to disorders that can affect its structure and function. Do you know what the consequences of impaired regulatory mechamsm are? What happens when there is either decreased secretion (hyposecretion) or increased secretion (hypersecretion) of the thyroid hormone ? Let's find out.

Hyposecretion (hypothyroidism) in adult life: Decreased secretion of thyroid hormone results in the development of *myxoedema*. There is a slowing of mental and physical activity. The basal metabolic rate is reduced and there is a considerable general oedema. The facial skin is coarse, thick and dry and there is a loss of hair especially from lateral regions of eyebrows.

Hyposecretion (hypothyroidism) in Childhood : Decreased secretion of thyroid hormone results in the development of the condition in children known as cretinism. *Cretinism* is a condition characterized by congenital hypothyroidism, resulting in intellectual and developmental disabilities, growth and skeletal abnormalities, and other associated features. The child is mentally retarded due to lack of development of the nervous system. The skin is thick and dry, and the face is expressionless. Pulse and respiration rates are slow, there is a general sluggishness of all the body processes. Cretins are different from pituitary dwarfs as along with the stunted growth, they have mental retardation.

Cretinism is most commonly caused by a congenital defect in the thyroid gland, an inherited enzyme deficiency (iodide trapping defect), or iodine deficiency during pregnancy. In regions where iodine deficiency is prevalent, it is a significant cause of cretinism. The condition can also occur due to genetic abnormalities or certain medications that affect the development or function of the thyroid gland.The signs and symptoms of cretinism vary depending on the severity and duration of the thyroid hormone deficiency.

Let's bring light on the Prevention of cretinism primarily involves ensuring adequate iodine intake during pregnancy and early infancy. Public health measures such as iodine supplementation programs and iodized salt have been implemented in many countries to address iodine deficiency and reduce the incidence of cretinism.

Hyperthyroidism in adult: Hyperthyroidism is the opposite of hypothyroidism, where the thyroid gland produces an excessive amount of thyroid hormones. This condition generally occurs in adult life. This is commonly caused by hyperplasia of the gland and is called *'Grave's Disease'*. It is an autoimmune condition known as Graves' disease where the body's immune system mistakenly attacks the thyroid gland, leading to excessive hormone production. Symptoms may include weight loss, rapid heartbeat, palpitations, anxiety, increased sweating, irritability, and difficulty sleeping. The excess production of thyroid hormones in hyperthyroidism leads to an accelerated metabolism and affects multiple body systems. There may or may not be *Exophthalmia,* a condition characterized by abnormal protrusion of one or both eye from the orbit

Goiter: A goiter refers to an enlarged thyroid gland. It can be caused by various factors, including iodine deficiency, inflammation (thyroiditis), overproduction of thyroid hormones (hyperthyroidism), or the presence of nodules or tumors in the thyroid gland. Depending on the underlying cause, treatment may involve medication, surgery, or radioactive iodine therapy.

Thyroid Cancer: Thyroid cancer is relatively rare but can occur in the thyroid gland. It may present as a nodule or a lump in the neck. Types of thyroid cancer include papillary carcinoma, follicular carcinoma, medullary carcinoma, and anaplastic carcinoma. Treatment involves surgery to remove the cancerous tissue, followed by radioactive iodine therapy or, in some cases, external beam radiation therapy or chemotherapy.

It is important to note that proper diagnosis and treatment of thyroid disorders require a thorough evaluation by a healthcare professional, including a physical examination, blood tests to assess thyroid hormone levels, imaging studies, and, if necessary, a biopsy of suspicious nodules. Treatment plans will depend on the specific disorder and its severity, as well as the individual's overall health. It is always recommended to seek medical advice for any concerns related to thyroid health.

7.6 PARATHYROID GLANDS

The parathyroid glands are small endocrine glands located in the neck, usually located behind or embedded within the thyroid gland. Despite their name, the parathyroid glands are separate from the thyroid gland and have different functions. Typically, there are four parathyroid glands, two on each side of the thyroid gland as shown in figure 7.3, although the number and location can vary.

7.6.1 Structure of Parathyroid Glands

Each parathyroid gland is a small, oval-shaped gland measuring a few millimeters in diameter. They are typically reddish-brown in color and have a glandular structure. The parathyroid glands are composed of two main cell types: chief cells and oxyphil cells .

1. Chief Cells: Chief cells are the main functional cells of the parathyroid glands. They are responsible for producing and secreting parathyroid hormone (PTH), also known as parathormone. PTH plays a crucial role in regulating calcium and phosphorus levels in the body.
2. Oxyphil Cells: Oxyphil cells are less abundant in the parathyroid glands compared to chief cells. Their function is not entirely clear, but they may play a role in the production of PTH or have other yet unknown functions.

7.6.2 Function of Parathyroid Glands

The parathyroid glands are primarily responsible for regulating calcium and phosphorus levels in the body through the secretion of parathyroid hormone (PTH). Here are the main functions of the parathyroid glands:

1. *Calcium Regulation:* The main role of the parathyroid glands is to regulate the levels of calcium in the blood. When blood calcium levels drop, the parathyroid glands detect this decrease and release PTH into the bloodstream. PTH acts on the bones, kidneys, and intestines to increase calcium levels. It stimulates the release of calcium from the bones, enhances the reabsorption of calcium in the kidneys, and promotes the activation of vitamin D, which facilitates calcium absorption in the intestines.

2. *Phosphorus Regulation:* In addition to calcium, the parathyroid glands also play a role in regulating phosphorus levels in the blood. PTH inhibits the reabsorption of phosphorus in the kidneys, leading to increased excretion of phosphorus in the urine.
3. *Bone Remodeling:* PTH plays a critical role in bone remodeling, which involves the continuous process of bone resorption and formation. When blood calcium levels are low, PTH stimulates the release of calcium from the bones, thus increasing blood calcium levels. This process helps maintain calcium homeostasis and ensure proper bone health.
4. *Vitamin D Activation:* PTH indirectly influences the activation of vitamin D in the kidneys. Vitamin D is essential for calcium absorption in the intestines. PTH stimulates the conversion of inactive vitamin D (calcidiol) into its active form (calcitriol), which enhances calcium absorption from the intestines and helps maintain calcium homeostasis.

Overall, the parathyroid glands and their hormone, parathyroid hormone (PTH), play a vital role in regulating calcium and phosphorus levels in the body. By acting on the bones, kidneys, and intestines, PTH helps maintain proper calcium balance, bone health, and overall mineral homeostasis.

7.6.3 Disorders of the parathyroid glands

Disorders of the parathyroid glands can result in abnormal levels of parathyroid hormone (PTH) and disturbances in calcium and phosphorus metabolism. There are two primary disorders associated with the parathyroid glands: hyperparathyroidism and hypoparathyroidism.

1. **Hyperparathyroidism:** This condition occurs when the parathyroid glands produce excessive amounts of PTH. There are two types of hyperparathyroidism:

   a. Primary hyperparathyroidism: It is the most common type and usually caused by a benign tumor or enlargement of one or more of the parathyroid glands. The excessive PTH production leads to increased levels of calcium in the blood (hypercalcemia) and decreased levels of phosphorus. Symptoms may include fatigue, weakness, kidney stones, bone pain, frequent urination, and gastrointestinal disturbances.

   b. Secondary hyperparathyroidism: This condition arises as a result of an underlying condition, such as chronic kidney disease, that disrupts the body's ability to maintain normal calcium and phosphorus levels. The parathyroid glands become overactive in an attempt to compensate for the imbalance. Treatment focuses on addressing the underlying cause and managing mineral and hormone levels.

2. **Hypoparathyroidism:** This condition occurs when the parathyroid glands produce insufficient amounts of PTH. Causes of hypoparathyroidism can include surgical removal of the parathyroid glands, autoimmune disorders, genetic factors, or damage to the glands. The lack of PTH leads to low calcium levels (hypocalcemia) and high phosphorus levels. Symptoms may include muscle cramps, twitching, numbness or tingling in the extremities, seizures, fatigue, and mood disturbances.

   Treatment involves calcium and vitamin D supplementation to restore and maintain appropriate calcium levels. Management of parathyroid disorders focuses on correcting the underlying hormonal imbalances and maintaining normal calcium and phosphorus levels. This may involve medication, dietary adjustments, and regular monitoring of blood levels. Surgical intervention may be necessary in cases of primary hyperparathyroidism or if conservative management approaches are ineffective.

7.7 Adrenal Glands

The adrenal glands are a pair of small endocrine glands located on top of the kidneys. Each adrenal gland is divided into two distinct regions: the outer adrenal cortex and the inner adrenal medulla as shown in figure 7.5. These regions have different structures and functions.

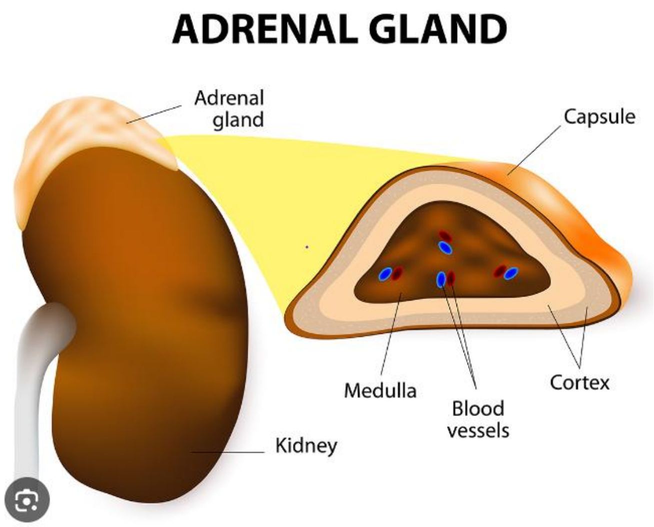

Figure 7.5: Structure of adrenal gland (retrieved from Johns Hopkins Medicine)

7.7.1 Structure of Adrenal Glands:

A. Adrenal Cortex: The adrenal cortex is the outer layer of the adrenal gland and comprises three main zones:

i. *Zona Glomerulosa:* This outermost zone produces mineralocorticoids, primarily aldosterone. Aldosterone regulates the balance of minerals, such as sodium and potassium, in the body, particularly in the kidneys.

ii. *Zona Fasciculata*: This middle zone produces glucocorticoids, mainly cortisol. Cortisol plays a vital role in metabolism, stress response, immune function, and regulation of blood sugar levels.

iii. *Zona Reticularis:* This innermost zone produces small amounts of androgens, such as dehydroepiandrosterone (DHEA) and androstenedione. These androgens have weak male hormone activity and can be converted into testosterone and estrogen in other tissues.

B. Adrenal Medulla: The adrenal medulla is the inner region of the adrenal gland and is responsible for producing and releasing catecholamines, including adrenaline (epinephrine) and noradrenaline (norepinephrine). These hormones are involved in the body's response to stress and help regulate heart rate, blood pressure, and the "fight or flight" response.

7.7.2 Functions of Adrenal Glands

Before discussing the role of adrenal glands in human body, it is important to learn about the functions of hormones secreted by adrenal glands. The adrenal glands secrete several hormones that play important roles in regulating various physiological processes in the body. The two main hormones secreted by the adrenal glands are cortisol and aldosterone, which are produced in the outer layer of the adrenal glands called the adrenal cortex. Additionally, the inner part of the adrenal glands, called the adrenal medulla, secretes adrenaline (epinephrine) and noradrenaline (norepinephrine). Here we discuss the role of these hormones in human body.

1. *Cortisol:* Cortisol is a steroid hormone that belongs to the glucocorticoid class. It plays a vital role in regulating metabolism, immune response, and stress response. Cortisol helps in the breakdown of proteins, fats, and carbohydrates for energy production. It also helps regulate blood sugar levels, suppresses inflammation, and aids in the body's response to stress.

2. *Aldosterone:* Aldosterone is a mineralocorticoid hormone that helps regulate electrolyte balance and fluid levels in the body. It acts on the kidneys, promoting the reabsorption of sodium and the excretion of potassium in urine. This process helps maintain proper blood pressure and fluid balance.
3. *Adrenaline (Epinephrine):* Adrenaline, also known as epinephrine, is a hormone and neurotransmitter that is released during the body's "fight or flight" response to stress or danger. It increases heart rate, dilates blood vessels, and elevates blood pressure. Adrenaline prepares the body for immediate physical activity and enhances overall alertness and focus.
4. *Noradrenaline (Norepinephrine):* Noradrenaline, also called norepinephrine, is a hormone and neurotransmitter that works together with adrenaline in the body's stress response. It constricts blood vessels, increasing blood pressure, and works in conjunction with adrenaline to enhance alertness and increase energy levels.

These hormones secreted by the adrenal glands play crucial roles in maintaining homeostasis, regulating metabolism, responding to stress, and ensuring proper functioning of various organs and systems in the body. They help the body adapt to changing conditions and support overall physiological balance.

The adrenal glands have essential functions in the body, contributing to various physiological processes. Let’s discuss the main functions of the adrenal glands:

- *Stress Response***:** The adrenal glands play a crucial role in the body's response to stress. When the body perceives a threat or stressor, the adrenal glands release stress hormones, particularly cortisol and adrenaline. These hormones increase heart rate, blood pressure, and blood glucose levels, preparing the body for action.
- *Mineral Balance:* The adrenal cortex produces mineralocorticoids, with the primary hormone being aldosterone. Aldosterone helps regulate the balance of minerals, such as sodium and potassium, in the body. It acts on the kidneys to increase sodium reabsorption and potassium excretion, thereby maintaining fluid and electrolyte balance.
- *Metabolism:* The adrenal cortex produces glucocorticoids, primarily cortisol, which plays a significant role in metabolism. Cortisol helps regulate blood sugar levels by promoting the breakdown of stored glycogen into glucose in the liver. It also affects protein and fat metabolism.

- *Immune Function:* Glucocorticoids, such as cortisol, have immunosuppressive effects. They regulate immune responses, reducing inflammation and suppressing immune activity to prevent excessive immune reactions.
- *Blood Pressure Regulation:* The adrenal medulla releases catecholamines, primarily adrenaline and noradrenaline, which act on the cardiovascular system to increase heart rate and blood pressure. They cause blood vessels to constrict and redirect blood flow to vital organs during times of stress or emergency.
- *Development of Secondary Sexual Characteristics:* The adrenal cortex produces small amounts of androgens, which contribute to the development of secondary sexual characteristics during puberty, such as the growth of pubic and underarm hair.

Overall, the adrenal glands are crucial for maintaining proper physiological function in response to stress, regulating mineral balance, metabolism, immune function, and blood pressure. The adrenal cortex and medulla work together to produce hormones that help the body respond to various stressors and maintain overall homeostasis.

7.7.3 Disorder of adrenal glands

Disorders of the adrenal glands can disrupt the production and balance of hormones, leading to various health conditions. The two primary disorders associated with the adrenal glands are adrenal insufficiency and adrenal gland tumors.

1. **Adrenal Insufficiency**:

   a. *Primary Adrenal Insufficiency (Addison's Disease):* This occurs when the adrenal glands do not produce sufficient amounts of cortisol and often insufficient levels of aldosterone. It is typically caused by an autoimmune reaction where the body's immune system mistakenly attacks the adrenal glands. Other causes can include infections, cancer, or certain medications. Symptoms may include fatigue, weight loss, muscle weakness, low blood pressure, darkening of the skin, and salt cravings. Treatment involves hormone replacement therapy to restore the deficient hormones.

   b. *Secondary Adrenal Insufficiency:* This condition arises due to a dysfunction in the pituitary gland or hypothalamus, which affects the release of adrenocorticotropic hormone (ACTH). ACTH stimulates the adrenal glands to produce cortisol. Causes can include pituitary tumors, pituitary surgery, or long-term corticosteroid use. Treatment involves identifying and addressing the underlying cause and providing hormone replacement therapy if necessary.

2. *Adrenal Adenoma:* These are non-cancerous tumors that develop in the adrenal glands. Most adrenal adenomas are small and do not cause symptoms. However, in some cases, they may produce excessive amounts of hormones, such as aldosterone (causing primary aldosteronism) or cortisol (causing Cushing's syndrome).

   Adrenocortical Carcinoma is a rare and aggressive cancer that originates in the adrenal cortex. It can produce excessive amounts of cortisol, aldosterone, or androgens. Symptoms may include weight gain, high blood pressure, excessive hair growth, and menstrual irregularities in women.

   We move to the next gland i.e. the pancreas. But before let's assess your progress

Check Your Progress Exercise 2

1. Where are the thyroid glands found in our body? What are the functions of thyroid gland?

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2. Discuss the role of parathyroid gland in bone health.

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3. Where is adrenal gland located in our body? What are the hormones secreted from the adrenal cortex and medulla?

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4. Match the following

A	B
a) Mineralocorticoid	i. Positery Pituitary
b) Glucocorticoid	ii. Calcitonin
c) Adrenal Medulla	iii. Aldosterone
d) Thyroid gland	iv. Epinephrine
e) Oxytocin	v. Cortisol

7.8 Pancreas

The pancreas is a vital organ located behind the stomach, surrounded by duodenum in the abdomen. It plays a crucial role in the digestive and endocrine systems. The pancreas has both exocrine and endocrine functions, with distinct structures and functions for each.

7.8.1 Structure of the Pancreas

The pancreas has a unique structure. It is composed of pancreatic exocrine cells and endocrine cells, that reflects its dual function.

1. **Exocrine Pancreas:** The exocrine pancreas accounts for the majority of the pancreas and is responsible for producing and releasing digestive enzymes. The exocrine portion of the pancreas is composed of clusters of cells called acini. These acinar cells secrete digestive enzymes into tiny ducts that eventually merge to form the main pancreatic duct. The main pancreatic duct joins the common bile duct before entering the duodenum (the first part of the small intestine). This common duct carries the pancreatic enzymes along with bile from the liver and gallbladder into the small intestine.
2. **Endocrine Pancreas**: The endocrine pancreas is made up of small clusters of cells called pancreatic islets or islets of Langerhans. These islets are scattered throughout the tissue of the pancreas. The endocrine pancreas comprises different cell types, each producing specific hormones. The main cell types within the islets of Langerhans include:

   a. **Beta Cells:** Beta cells are the most abundant cell type within the pancreatic islets and are responsible for producing and secreting insulin. Insulin plays a central role in regulating blood glucose levels by facilitating the uptake and storage of glucose in cells.

b. **Alpha Cells:** Alpha cells produce and release glucagon, a hormone that raises blood glucose levels. Glucagon acts on the liver to stimulate the breakdown of glycogen into glucose and the production of glucose from other sources.

c. **Delta Cells:** Delta cells produce somatostatin, a hormone that regulates the release of both insulin and glucagon. It acts as a regulator of hormone secretion within the pancreas and other organs.

d. **Other Cells:** The endocrine pancreas also contains smaller populations of cells, including gamma cells that secrete pancreatic polypeptide and epsilon cells that produce ghrelin. The functions of these hormones are still being studied, and their exact roles are not fully understood.

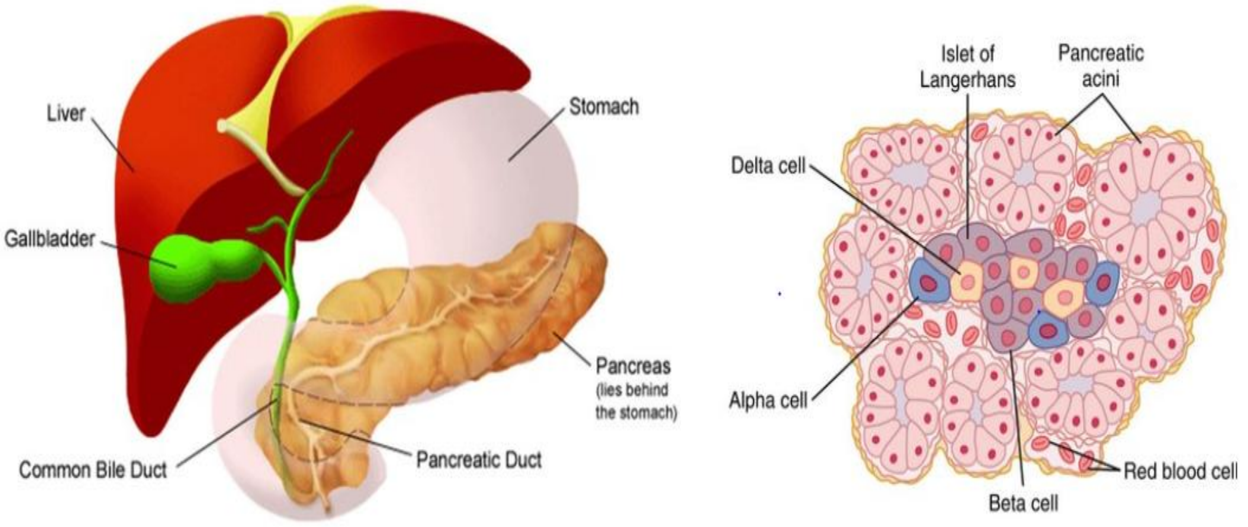

Figure 7.6: Structure of Pancreas

7.8.2 Endocrine function of the Pancreas

Here we shall focus on the endocrine cells which secrete the hormones. Let us learn about the hormones secreted from the endocrine cells of pancreas.

a. *Insulin:* Insulin is released by beta cells in response to high blood glucose levels. It promotes the uptake of glucose by cells, stimulates the liver to store glucose as glycogen, and inhibits the release of glucose from the liver.

b. *Glucagon:* Glucagon is secreted by alpha cells in response to low blood glucose levels. It stimulates the liver to release stored glucose into the bloodstream, raising blood glucose levels.

c. *Somatostatin:* Somatostatin, released by delta cells, acts as an inhibitor of insulin and glucagon secretion, helping to regulate their release.

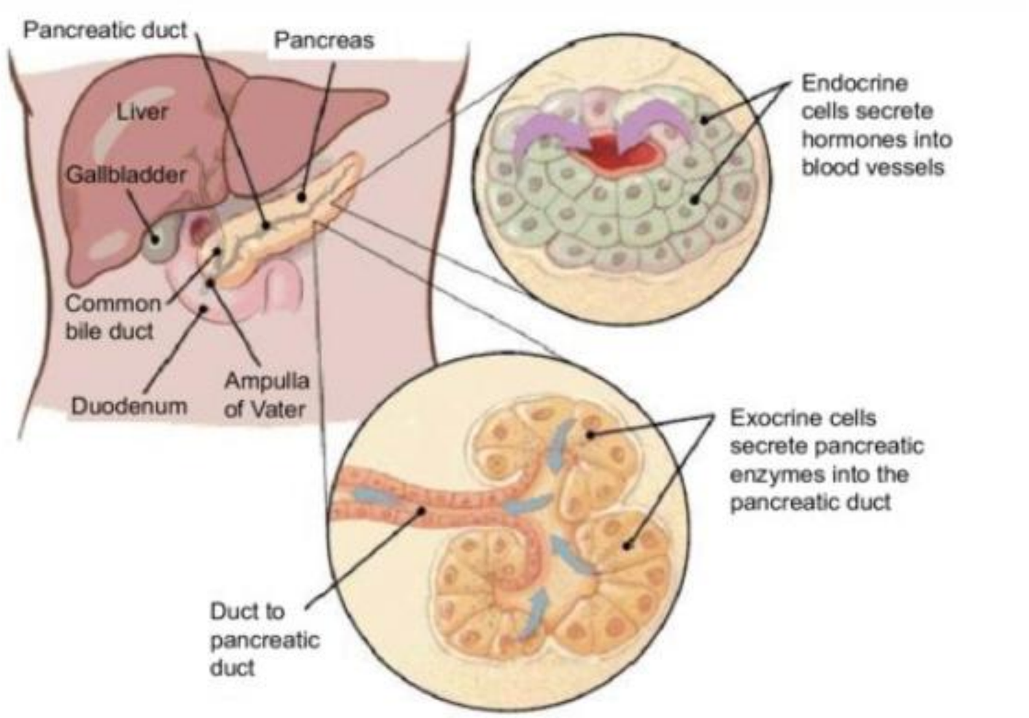

Figure 7.7: Exocrine and endocrine function of Pancreas

The pancreas is vital for maintaining proper digestion and blood glucose regulation. Dysfunction of the pancreas can lead to digestive disorders, such as pancreatitis, and metabolic disorders, such as diabetes mellitus.

7.7.3 Disorder of Pancreas

Disorders of the pancreas can affect its structure, function, and the production of essential hormones and enzymes. Some common disorders of the pancreas include:

1. **Pancreatitis:** a. Acute Pancreatitis: This is a sudden inflammation of the pancreas, often caused by gallstones or excessive alcohol consumption. It can also be triggered by certain medications, infections, or trauma. Symptoms include severe abdominal pain, nausea, vomiting, and fever. Treatment focuses on pain management, intravenous fluids, and addressing the underlying cause. b. Chronic Pancreatitis: This is a long-term inflammation of the pancreas that leads to irreversible damage. Chronic alcohol abuse is the most common cause, but it can also result from genetic conditions, blockage of the pancreatic duct, or autoimmune disorders. Symptoms include persistent abdominal pain, weight loss,

diarrhea, and diabetes. Treatment involves pain management, enzyme replacement therapy, dietary modifications, and managing complications such as diabetes.

2. **Pancreatic Cancer:** Pancreatic cancer is a malignant tumor that develops in the cells of the pancreas. It is often diagnosed at an advanced stage, making it challenging to treat. Risk factors include smoking, obesity, family history, and certain genetic conditions. Symptoms may include abdominal pain, weight loss, jaundice, digestive issues, and fatigue. Treatment options include surgery, radiation therapy, chemotherapy, and targeted therapy, depending on the stage and extent of the cancer.
3. **Diabetes**: a. Type 1 Diabetes: This is an autoimmune condition where the immune system attacks and destroys the insulin-producing cells in the pancreas. It usually develops in childhood or early adulthood. People with type 1 diabetes require lifelong insulin therapy to regulate blood sugar levels. b. Type 2 Diabetes: This is a metabolic disorder characterized by insulin resistance, where the body's cells do not respond properly to insulin. It is often associated with obesity, sedentary lifestyle, and genetic factors. Treatment includes lifestyle modifications, oral medications, and, in some cases, insulin therapy.
4. **Pancreatic Insufficiency:** This condition occurs when the pancreas does not produce enough digestive enzymes, leading to poor absorption of nutrients. It can result from chronic pancreatitis, cystic fibrosis, or other conditions. Symptoms include malabsorption, steatorrhea (fatty stools), weight loss, and nutritional deficiencies. Treatment involves pancreatic enzyme replacement therapy and dietary adjustments to improve digestion and nutrient absorption.

Other pancreatic disorders include pancreatic cysts, pancreatic pseudocysts, and pancreatic ductal abnormalities. Each condition has its own causes, symptoms, and treatment approaches.

Diagnosis of pancreatic disorders involves a combination of medical history, physical examination, blood tests to measure pancreatic enzymes and hormones, imaging studies such as CT scans or MRI, and sometimes endoscopic procedures to evaluate the pancreas.

Treatment for pancreatic disorders depends on the specific condition and may involve medication, surgery, dietary modifications, and lifestyle changes. It is important to consult with a healthcare professional for accurate diagnosis, appropriate treatment, and ongoing management of pancreatic disorders.

7.9 GONADS

Gonads are the primary reproductive organs in both males and females. They play a crucial role in the production of gametes (sperm and eggs) and the secretion of sex hormones. The gonads in males are the testes, while in females, they are the ovaries.

7.9.1 Testes

The testes are paired, oval-shaped organs located in the scrotum outside the abdominal cavity. They are composed of seminiferous tubules, which are responsible for the production of sperm cells, and interstitial cells (Leydig cells), which produce testosterone. Next, Let us look at their functions:

- *Sperm Production:* The seminiferous tubules within the testes are responsible for spermatogenesis, the process of producing mature sperm cells. The process of spermatogenesis and maintenance, relies on the actions of two key hormones produced by the pituitary gland, known as gonadotropins: follicle-stimulating hormone (FSH) and luteinizing hormone (LH).
- *Hormone Secretion:* The interstitial cells of the testes produce testosterone, the primary male sex hormone. Testosterone plays a crucial role in the development and maintenance of male reproductive tissues, secondary sexual characteristics, and sex drive.

The testes, which are the male reproductive glands, produce several hormones that are involved in the development and regulation of male reproductive function. Let us discuss the primary hormones produced by the testes here-

1. *Testosterone:* Testosterone is the main male sex hormone and is produced by Leydig cells in the testes. It plays a vital role in the development and maintenance of male reproductive organs and secondary sexual characteristics. Testosterone is involved in sperm production (spermatogenesis) and regulates various aspects of male physiology, including muscle mass, bone density, facial and body hair growth, deepening of the voice, and sex drive (libido).
2. *Dihydrotestosterone (DHT):* DHT is a potent androgen derived from testosterone through the action of an enzyme called 5-alpha-reductase. It is involved in the development of male external genitalia during fetal development and continues to contribute to the development and growth of the prostate gland during puberty and adulthood.
3. *Inhibin:* Inhibin is a hormone produced by Sertoli cells in the testes. It plays a role in the negative feedback regulation of follicle-stimulating hormone (FSH) secretion from the pituitary gland. Inhibin inhibits FSH production, thereby helping to regulate the balance between FSH and testosterone in the testes.

Having studied about the testes, next let us get to know about the ovaries

7.9.2 Ovaries

The ovaries are paired, almond-shaped organs located in the pelvic cavity. They contain numerous follicles, which are fluid-filled sacs that contain immature egg cells called oocytes.

Let us look at their functions next:

- *Egg Production*: The ovaries are responsible for the production and maturation of oocytes (eggs). Each month, a mature egg is released from one of the ovaries during ovulation.
- *Hormone Secretion:* The ovaries produce estrogen and progesterone, the primary female sex hormones. These hormones regulate the menstrual cycle, promote the development of female reproductive tissues, and play a role in the maintenance of pregnancy.

The ovaries, which are the female reproductive organs, produce several hormones that are involved in the regulation of the menstrual cycle, ovulation, and various aspects of female reproductive function. The primary hormones produced by the ovaries are:

1. *Estrogen*: Estrogen refers to a group of hormones, including estradiol, estrone, and estriol. These hormones play a crucial role in the development and maintenance of female reproductive organs and secondary sexual characteristics. Estrogen is responsible for the thickening of the uterine lining during the menstrual cycle and the development of the breasts. It also helps regulate bone density, cholesterol levels, and mood.
2. *Progesterone*: Progesterone is primarily produced by the ovaries during the second half of the menstrual cycle, following ovulation. It prepares the uterus for potential pregnancy by promoting the thickening of the uterine lining and creating a receptive environment for embryo implantation. Progesterone also helps maintain pregnancy by supporting the growth of the placenta and inhibiting contractions of the uterus.
3. *Inhibin*: Inhibin is a hormone produced by the ovaries, specifically by the granulosa cells of the developing ovarian follicles. It acts as a negative feedback regulator of FSH secretion from the pituitary gland. Inhibin inhibits FSH production, helping to regulate the balance between FSH and estrogen in the ovaries.

It's important to note that the production and regulation of these hormones can be influenced by various factors, including age, genetics, health conditions, and lifestyle factors.The proper functioning of the gonads is essential for fertility and the overall reproductive health of an individual. Any disruption in gonadal function can lead to infertility, hormonal imbalances, and reproductive disorders. It is important to maintain the health of the gonads through a balanced lifestyle, regular check-ups, and appropriate medical care.

7.9.3 Feedback mechanisms

The functions of the gonads are regulated by a complex interplay of hormones and feedback mechanisms. In males, the hypothalamus releases gonadotropin-releasing hormone (GnRH), which stimulates the anterior pituitary gland to secrete luteinizing hormone (LH) and follicle-stimulating hormone (FSH). LH and FSH act on the testes to stimulate testosterone production and sperm production, respectively. In females, GnRH from the hypothalamus stimulates the release of LH and FSH from the pituitary gland, which regulate the menstrual cycle and ovulation.

The gonads also interact with other endocrine glands and hormones to maintain reproductive function and secondary sexual characteristics. For example, in males, testosterone production is influenced by the pituitary hormone LH and the hormone inhibin, which is produced by the testes and acts as a negative feedback signal. In females, estrogen and progesterone production are regulated by the hormones LH and FSH, and they interact with hormones from the hypothalamus and pituitary gland to control the menstrual cycle.

7.10 Placenta

The placenta is a vital organ that develops in the uterus during pregnancy. It plays a crucial role in supporting the growth and development of the fetus. The placenta is disc-shaped and typically measures around 15 to 25 centimeters in diameter and 2 to 3 centimeters in thickness. It is attached to the uterine wall and is connected to the fetus through the umbilical cord. One of the primary functions of the placenta is to facilitate the exchange of nutrients, oxygen, and waste products between the mother and the fetus.

Placenta is an endocrine gland because it produces several hormones that are crucial for maintaining a healthy pregnancy. These hormones include human chorionic gonadotropin (hCG), progesterone, and estrogen. hCG helps support the pregnancy in the early stages and is the hormone detected in pregnancy tests. Progesterone helps maintain the uterine lining and supports the growth and development of the fetus. Estrogen plays a role in stimulating uterine growth and preparing the breasts for lactation.

7.11 Pineal glands

The pineal gland, also known as the pineal body or epiphysis cerebri, is a small endocrine gland located deep within the brain, in the epithalamus region. Despite its small size, the pineal gland plays a significant role in regulating various physiological processes and is often referred to as the "third eye" due to its association with light and circadian rhythms. Let's explore the structure, and endocrine function of the pineal gland.

7.11.1 Structure of the Pineal Gland

The pineal gland is a pinecone-shaped structure that measures around 8 to 12 millimeters in length. It is situated near the center of the brain, between the cerebral hemispheres. The gland consists of pinealocytes, which are the main functional cells, and glial cells, which provide support.

7.11.2 Function of the Pineal Gland

The pineal gland plays a crucial role in regulating the body's internal clock and various physiological functions. But, is the pineal gland is an endocrine gland? You would be interest to know that pineal gland secrete melatonin, the primary hormone which is released into blood and brain fluid. Its main functions is to regulate circadian rhythms (sleep/wakefulness cycle)i.e. sleep patterns, promotes sleep onset, and influences the body's internal clock. It also has antioxidant and immune-modulating effects. Furthermore, the pineal gland interacts with the hypothalamus and pituitary gland to regulate the production and secretion of reproductive hormones, such as luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Melatonin inhibits the release of these hormones, which in turn affects the regulation of the menstrual cycle and reproductive functions. Its production and secretion are influenced by the amount of light received by the retina. In the absence of light, such as during the night, the pineal gland increases its melatonin production. Let’s assess your progress.

Check Your Progress Exercise 3

1. Name the primary hormones produced by the ovaries

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2. Explain the role of pancreas in maintaining the blood glucose level.

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3. Discuss the endocrine function of planceta.

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4. Match the following

A	B
a) hCG	i. Pancreas insufficiency
b) Diabetes mellitus	ii. FSH
c) Diabetes insipidus	iii. Melatonin
d) Pineal gland	iv. Planceta
e) spermatogenesis	v. ADH deficiency

7.12 LET US SUM UP

In this unit, we learnt about endocrine glands, their functions and diseases associated with dysfunctions of the endocrine glands. We learnt that there are some endocrine glands in our body which secrete specific substance called hormones into the circulatory system. These hormones play crucial roles in maintaining homeostasis, regulating metabolism, responding to stress, and ensuring proper functioning of various organs and systems in the body.

The endocrine system plays a crucial role in regulating various bodily functions, including metabolism, growth and development, reproduction, stress response, and maintenance of homeostasis.

The endocrine glands and their hormones do not function in isolation. They interact and influence each other through complex feedback mechanisms. Studying the endocrine system you are able to understand the intricate relationships between different hormones and how they work together to maintain overall physiological balance.

7.13 GLOSSARY

Acromegaly : It is a rare hormonal disorder that occurs when the pituitary gland produces excessive amounts of growth hormone (GH). This condition is characterized by the enlargement and elongation of certain body parts, such as the hands, feet, jaw, nose, and forehead.

Addison's disease : a rare endocrine disorder caused by hyposecretion of adrenal cortex particularly cortisol and aldosterone. It is also known as adrenal insufficiency.

Creatinism : a condition characterized by severe physical and cognitive impairments resulting from inadequate levels of thyroid hormones, primarily caused by iodine deficiency during early pregnancy.

Cushing syndrome : a disorder characterized by excessive levels of the hormone cortisol in the body, resulting in a variety of physical and metabolic changes. Also known as hypercortisolism

Diabetes insipidus : a condition in which kidney are unable to prevent the excretion of water and body produces too much urine.

Dwarfism : characterized by short stature individual due to the deficiency of growth hormone in childhood.

Exopthalamas : is an abnormal protrusion of eye ball from the eye socket.

Gigantism : characterized by excessive growth of the long bones and very tall stature due to an excessive secretion of growth hormone during childhood.

Grave's disease : **a** condition characterized by the overproduction of thyroid hormone.

Melatonin : a hormone produced by the brain's pineal gland that regulate sleep patterns, promotes sleep onset, and influences the body's internal clock

Myxoedema : a condition characterized by low BMR,slow mental and physical activity due to the hypo secretion of thyroid hormone.

7.14 ANSWER TO CHECK YOUR PROGRESS

Check Your Progress Exercise 1

1. A gland is a specialized organ or group of cells within an organ that secretes substances for specific functions in the body. Glands can be classified into:
   i. Exocrine glands- Examples- sweat glands, salivary glands, and mammary glands.
   ii. Endocrine glands- Examples - pitutiary, thyroid, parathyroid, adrenal gland etc.
   iii. Heterocrine gland- Examples - pancreas

2. A hormone is a chemical substance produced by endocrine glands or specialized cells in the body that acts as a messenger to regulate and coordinate various physiological processes. Hormones are released into the bloodstream and travel to target organs or tissues, where they bind to specific receptors and exert their effects.
3. The anterior pituitary gland produces six basic hormones: Growth hormone (GH), Adrenocorticotropic hormone (ACTH), thyroid-stimulating hormone (TSH), luteinizing hormone (LH), follicle-stimulating hormone (FSH), and prolactin (PRL).The *hormones* produced by the *posterior pituitary* gland include vasopressin and oxytocin.
4. The posterior pituitary gland secretes antidiuretic hormone involved in the regulation of water and electrolyte balance. It acts on the kidneys to increase water reabsorption, reducing the amount of urine produced and helping to conserve water.
5. a-v,
   b-iii
   c-ii,
   d-i,
   e-iv

Check Your Progress Exercise 2

1. The thyroid gland located anteriorly to the trachea and esophagus, and just below the Adam's apple (cartilage that covers and protects your *voice box)*. The thyroid gland plays a crucial role in regulating metabolism, growth, and development throughout the body. In addition, it also maintains the heart rate and functionality of peripheral vascular system.
2. The primary function of the parathyroid glands is to produce and secrete parathyroid hormone (PTH) which helps to regulate calcium levels in the blood. It acts on the bones, kidneys, and intestines to ensure the proper balance of calcium in the body as follows:

a) Bones: PTH increases the release of calcium from the bones into the bloodstream.

b) Kidneys: PTH stimulates the kidneys to reabsorb more calcium from the urine, reducing its excretion.

c) Intestine: PTH indirectly enhances the absorption of calcium from the intestines by promoting the activation of vitamin D.

3. The adrenal glands, which are located on top of each kidney. Adrenal cortex secrete primary secrete two main hormones, cortisol and aldosterone. Additionally, it produces small amounts of androgens. Adrenal medulla secretes epinephrine (adrenaline) and norepinephrine (noradrenaline) hormones.

4. a-iii,
   b-v,
   c-iv,
   d-ii,
   e- i,

Check Your Progress Exercise 3

1. Progesterone and oestrogen are the primary hormones produced by the ovaries.
2. The pancreas secretes two important hormones, insulin and glucagon, which work together to regulate blood sugar. Insulin is released by beta cells in response to high blood glucose levels. It promotes the uptake of glucose by cells, stimulates the liver to store glucose as glycogen, and inhibits the release of glucose from the liver.

3. Placenta is an endocrine gland because it produces several hormones that are crucial for maintaining a healthy pregnancy. These hormones include human chorionic gonadotropin

(hCG), progesterone, and estrogen. hCG helps support the pregnancy in the early stages and. Progesterone helps maintain the uterine lining and supports the growth and development of the fetus. Estrogen plays a role in stimulating uterine growth and preparing the breasts for lactation.

4. a- iv
   b- i,
   c-v,
   d- iii,
   e-ii

UNIT 8 THE REPRODUCTIVE SYSTEM

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8.1 INTRODUCTION

In the previous units, we learnt about the physiology of various body systems. In this unit, our attention will shift towards exploring the remarkable complexities of the reproductive system. We will look into the details of both the male and female reproductive organs, uncovering their unique functions and roles. The ability to reproduce, a defining characteristic of living organisms, sets human beings apart from the non living things.

Reproduction is the biological process by which new individuals of the same species are produced, ensuring the continuity and survival of the species over generations. It involves the creation of offspring, either sexually or asexually, and is essential for the propagation and diversity of life forms. Reproduction in humans is not only a biological process but also a complex interplay of social, emotional, and cultural factors. It is a fundamental aspect of human life, intimately connected to relationships, family, and the continuation of the species. Throughout history, humans have developed various methods of contraception and assisted reproductive technologies to control fertility and overcome reproductive challenges.

In this unit, we will study about the role of different hormones that are involved in the growth and development of the sex organs. Also, this unit helps you to gain understanding some disorders which could possibly affect the normal functioning of the reproductive system. What are their possible effects? Further in this unit, we shall look at the various physiological changes taking place in the body during the periods of pregnancy and lactation. Apart from these, we shall deal with contraception. What is it? What are the different methods available? What are their benefits and limitations?

So let us get started.

Objectives

After studying this unit, you will be able to:

- Enumerate the various reproductive organs of the female and male along with their functions,
- Highlight the physiological changes during pregnancy and lactation and the role of different hormones involved.
- Enlist the different methods of contraception and their benefits and limitations, and
- Discuss the various pregnancy determination tests.

8.2 THE REPRODUCTIVE SYSTEM

The reproductive system in humans is a complex and highly specialized system responsible for the production of offspring. It involves a combination of male and female reproductive organs and structures that work together to facilitate the process of sexual reproduction.

The male and female reproductive systems exhibit distinct anatomical and physiological differences, as illustrated in figure 8.1.

Both sexes is the production of specialized reproductive cells known as gametes, which carry genetic material in the form of genes and chromosomes. The human body typically contains 46 chromosomes, organized in pairs within most cells. However, gametes, such as ova (eggs) and spermatozoa (sperm), contain only one set of chromosomes, totaling 23. When fertilization occurs, and an ovum is united with a spermatozoon, the resulting zygote carries the complete set of 23 pairs of chromosomes. These chromosomes consist of genetic material contributed equally by both the mother and the father. Following fertilization, the zygote implants itself into the uterine wall, where it undergoes growth and development over a period of approximately 40 weeks, ultimately culminating in birth.

The primary function of the male reproductive system is to produce and deliver sperm, which is the male gamete responsible for fertilizing the female egg during sexual reproduction.

When a male ejaculates, the sperm travels through the vas deferens, where it mixes with fluids from the seminal vesicles and prostate gland to form semen. The penis functions in sexual intercourse, delivering semen into the female reproductive system. The primary function of the female reproductive system is to produce and release ova, and if fertilization takes place, to provide a nurturing environment for the developing embryo and fetus until birth. Furthermore, following birth, the female reproductive system continues to nourish the newborn through the production of breast milk until the infant is capable of consuming a varied diet. In contrast, the male reproductive system functions to generate and transmit spermatozoa to the female reproductive system.

With this foundation, let us now explore the intricacies of the male reproductive system.

8.3 THE MALE REPRODUCTIVE SYSTEM

The male reproductive system is a complex network of organs and structures responsible for the production, storage, and delivery of sperm. It plays a crucial role in sexual reproduction and the continuation of the human species. In this response, we will explore the anatomy of the male reproductive system in detail, describing each organ and its function.

8.3.1 Parts of Male Reproductive System

The male reproductive system includes:

1. The scrotum which contains -
   a. two testes, and
   b. two epididymis
2. A pair of vas deferens
3. A pair of sperriiatic cords
4. A pair of seminal vesicles
5. A pair of ejaculatory ducts
6. Prostrate gland
7. Penis

Figure 8.1 illustrates these organs of the male reproductive system.

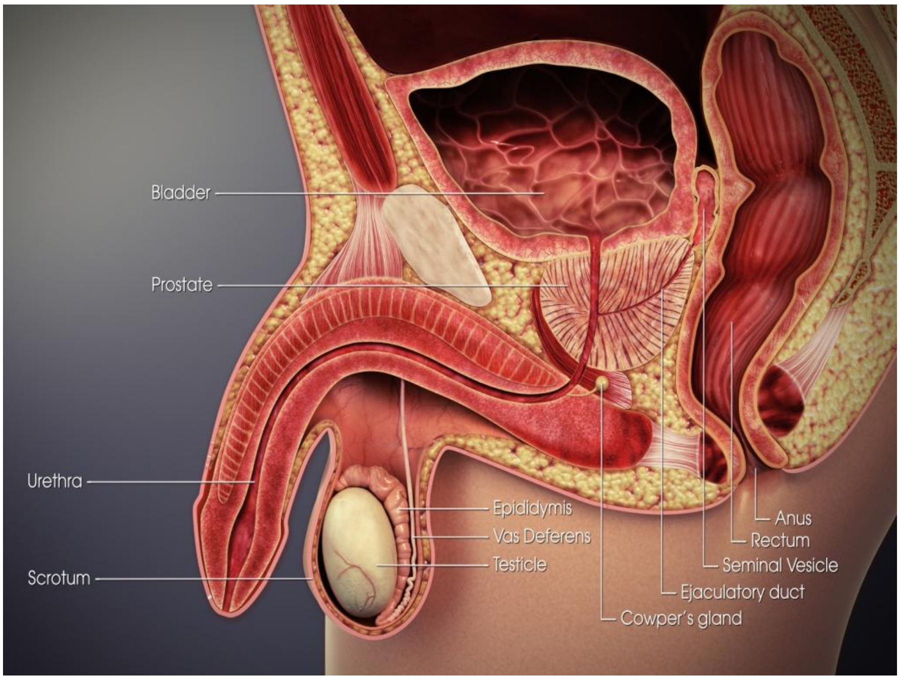

Figure 8.1 Male Reproductive system

1. **Scrotum:** The scrotum is a sac-like structure located outside the abdominal cavity, between the legs as illustrated in figure 8.2. It is composed of skin and underlying tissue. Its primary function is to protect and support the testes. The scrotum is highly sensitive to temperature changes and can adjust its position to regulate the temperature of the testes. This is important for maintaining optimal conditions for spermatogenesis, the process of sperm production. The production of sperm cells, occurs at a temperature approximately 3 degrees Celsius lower than the body temperature. This temperature regulation is crucial for the optimal development and maturation of spermatozoa.

2. **Testes:** The testes, or testicles, are the primary male reproductive organs. The testes are the primary male reproductive organs responsible for the production of sperm and the secretion of testosterone, the primary male sex hormone. They are oval-shaped glands located within the scrotum, a pouch of skin that hangs outside the body cavity, as can be seen in figure 8.2.

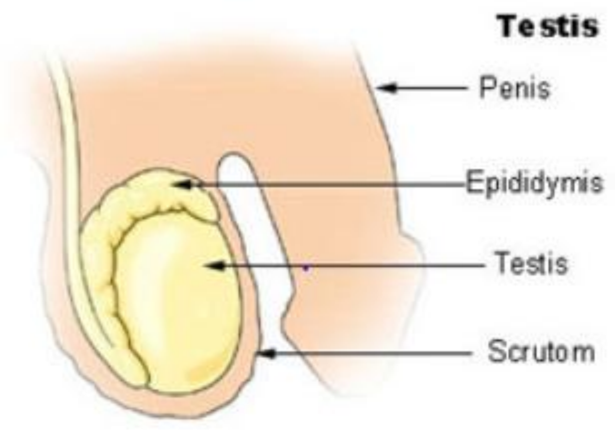

Figure 8.2: Location of Scrotum and testis

The testes are located within the scrotum, which helps maintain a slightly lower temperature than the rest of the body. This lower temperature is necessary for proper sperm production and development. Each testis is suspended within the scrotum by a spermatic cord, which consists of blood vessels, nerves, and the vas deferens.

The surface of the testes is covered by a tough, white fibrous capsule called the tunica albuginea. This capsule extends inward, forming septa that divide the testis into lobules. The lobules contain seminiferous tubules, where sperm production occurs. The testes are made up of various structures that contribute to their function in sperm production and hormone secretion. Let us move to study internal structure of testes which you can see in figure 8.3. In this response, we will explore the anatomy and gross structure of the testes in detail. These structures include:

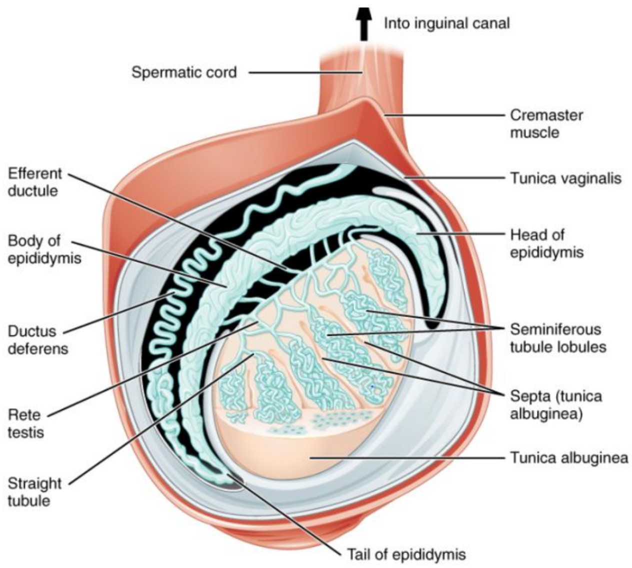

Figure 8.3: Internal structure of testes

a. *Seminiferous Tubules:* The seminiferous tubules are the functional units of the testes and are responsible for spermatogenesis, the process of sperm production. These tubules are highly coiled and make up the majority of the testicular tissue. Within the seminiferous tubules, germ cells undergo several divisions and differentiations to form mature spermatozoa.

b. *Rete Testis:* The rete testis is a network of interconnected tubules located at the posterior end of the testis. It receives spermatozoa from the seminiferous tubules and transports them to the epididymis.

c. *Epididymis:* The epididymis is a tightly coiled tube attached to the posterior surface of each testis. It serves as a storage and maturation site for sperm. The epididymis is divided into three parts: the head, body, and tail. Spermatozoa produced in the seminiferous tubules pass through the epididymis, where they gain motility and the ability to fertilize an egg.

d. *Interstitial Cells of Leydig*: The interstitial cells of Leydig are located in the spaces between the seminiferous tubules. These cells are responsible for the production and secretion of testosterone, the primary male sex hormone. Testosterone plays a crucial role in the development and maintenance of male reproductive tissues, secondary sexual characteristics, and sperm production.

e. *Blood Supply and Lymphatics:* The testes have a rich blood supply to support their metabolic needs. The testicular artery, a branch of the abdominal aorta, supplies oxygenated blood to the testes. Venous blood drains through the testicular veins, which form a network called the pampiniform plexus. The pampiniform plexus helps cool the arterial blood entering the testes by transferring heat to the venous blood, contributing to the regulation of testicular temperature.

f. Tunica Albuginea and Septa: The tunica albuginea is a tough fibrous capsule that surrounds each testis. It provides structural support and protection to the delicate internal structures of the testes. The tunica albuginea extends inward to form septa, which divide the testis into lobules. The septa contain blood vessels, lymphatics, and connective tissue.

g. Spermatic Cord: The spermatic cord is a cord-like structure that attaches each testis to the rest of the reproductive system. It consists of several components, including the vas deferens, testicular artery and veins, nerves, lymph

The testes have both endocrine and exocrine functions. Next, we will study the functions of testes.

- *Endocrine Function:* The testes produce and secrete the hormone testosterone, which plays a crucial role in male sexual development and secondary sexual characteristics. Testosterone is responsible for the growth and maintenance of male reproductive tissues, such as the prostate gland, seminal vesicles, and penis. It also contributes to muscle development, bone density, and the regulation of sex drive.

- *Exocrine Function:* The primary function of the testes is the production of sperm cells through a process called spermatogenesis. Spermatogenesis occurs within the seminiferous tubules, which are tightly coiled structures found inside the testes. Sperm cells are produced continuously from specialized cells called spermatogonia. These cells undergo several stages of division and maturation, ultimately developing into mature spermatozoa. The process of spermatogenesis is tightly regulated by hormonal signals and takes approximately 64 to 72 days. The testes are also responsible for the secretion of other substances required for the maturation and transport of sperm. These substances include fluids produced by the Sertoli cells, which nourish and support developing sperm cells, and fluids produced by the Leydig cells, which provide an optimal environment for sperm production.

3. Epididymis: The epididymis is a tightly coiled tube attached to the posterior surface of each testis. It serves as a storage and maturation site for sperm. Figure 8.4 presents a schematic representation of the epididymis. The epididymis, as you can see, consists of three parts: the head, body, and tail. Spermatozoa produced in the seminiferous tubules of the testes pass through the epididymis, where they gain motility and the ability to fertilize an egg. To the right in Figure 8.3, are shown cross-sectional representations of the epididymis is connected to the vas deferens, a duct that transports sperm from the epididymis to the urethra.

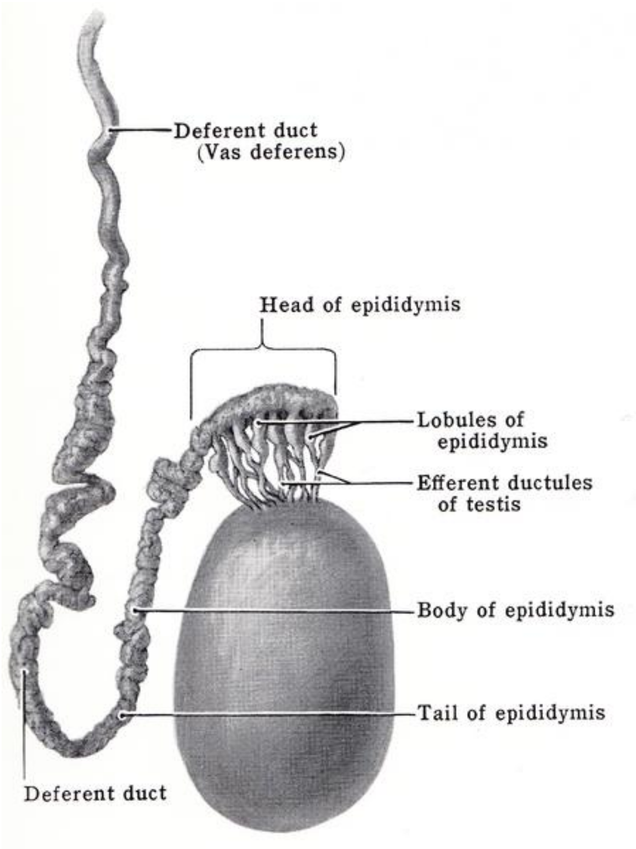

Figure 8.4: Epididymis and Vas deferens

4. Vas Deferens: The vas deferens, also known as the ductus deferens, is a muscular tube that extends from the epididymis to the pelvic cavity. Vas deferens is a latin, which literally means "carrying-away vessel". It transports mature sperm-containing fluid called *semen* from the epididymis to the urethra during ejaculation, as depicted in figure 8.4. The vas deferens is surrounded by layers of smooth muscle that help propel the sperm forward through peristaltic contractions.

5. Seminal Vesicles: The seminal vesicles are two small fibro-muscular pouches, as you can see in Figure 8.5. They are paired glands located behind the bladder and adjacent to the vas deferens, They produce a thick, yellowish fluid called seminal fluid, which constitutes a significant portion of semen. The fluid secreted by the seminal vesicles contains fructose, prostaglandins, and other substances that provide energy and nourishment to sperm, as well as enhance their motility and survival.

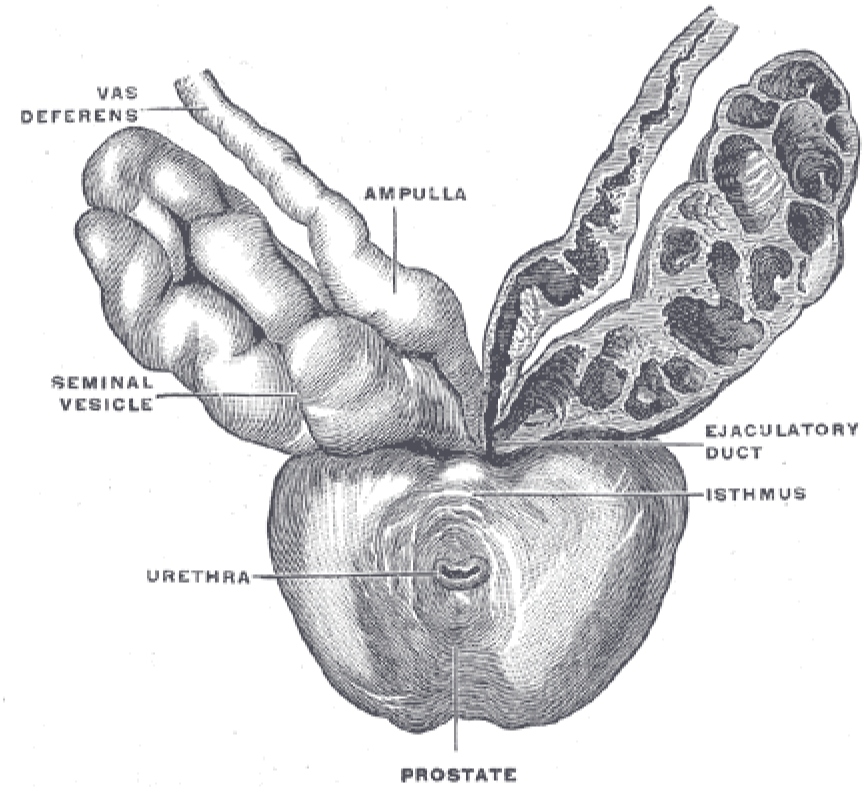

Figure 8.5: Location of seminal vesicles and Prostate

6. Ejaculatory ducts: They are 2 tubes, 2 cm long, each formed by the union of the duct from a seminal vesicle and a deferent duct. They pass through prostrate gland and join the urethra. The tissue layers are parallel as in seminal vesicles.

7.Prostate Gland: The prostate gland is a walnut-sized gland, as depicted in the Figure 8.5. lf you have a closer look at it, you will notice that the prostate situated just below the bladder, surrounding the urethra. The prostrate gland has an outer fibrous covering, layer of smooth muscles, glandular cells, columnar cells etc. It secretes a milky, alkaline fluid that makes up a significant part of semen volume. The prostatic fluid helps activate and protect sperm, and it also plays a role in neutralizing the acidity of the male urethra and the female reproductive tract, creating a more favorable environment for sperm survival and motility.

8. Bulbourethral Glands: The bulbourethral glands, also known as Cowper's glands, are small pea-sized glands located below the prostate gland as shown in figure 8.5. They secrete a clear, viscous fluid called pre-ejaculate or pre-cum. The pre-ejaculate serves as a lubricant for the urethra, neutralizing any residual urine and preparing the urethra for the passage of sperm during ejaculation.

9. Urethra: The urethra is a tubular structure that serves as a passageway for both urine and semen. It extends from the bladder to the tip of the penis. The urethra has three regions: the prostatic urethra, which passes through the prostate gland; the membranous urethra, which traverses the pelvic floor muscles; and the penile urethra, which runs through the length of the penis. During ejaculation, the urethra carries semen out of the body through the penis.

10. Penis: The penis is the external sexual organ of the male reproductive system, as depicted in the Figure 8.1. If you have a closer look at it, you will notice that the it consists of three cylindrical bodies of erectile tissue: two corpora cavernosa and one corpus spongiosum. The corpora cavernosa fill with blood during sexual arousal, causing the penis to become erect. The corpus spongiosum surrounds the urethra and forms the glans penis, the rounded tip of the penis. The penis serves two main functions: the passage of urine through the urethra and the delivery of sperm into the female reproductive tract during sexual intercourse. The glans penis is highly sensitive to touch and plays a role in sexual pleasure.

In addition to the main organs and structures mentioned above, the male reproductive system also includes accessory glands, nerves, blood vessels, and muscles that support and regulate reproductive functions. Understanding the anatomy of the male reproductive system is essential for comprehending its functions and potential issues that can affect fertility and reproductive health. Regular check-ups, self-examinations, and seeking medical advice when necessary can help ensure the proper functioning and well-being of the male reproductive system.

So far we have looked at the male reproductive system. Next, let us look at what functions does this system perform. Certainly, we know it is a organ which makes the sperm, which along with the egg, produced by the female reproductive system, helps in reproduction.

Let us get to know the process of sperm formation i.e. spermatogenesis in greater details.

8.3.2 Spermatogenesis

Sperm development, also known as spermatogenesis, is the process by which immature sperm cells undergo a series of transformations to become mature, functional spermatozoa. Spermatogenesis occurs within the seminiferous tubules of the testes and requires approximately five cycles, or about 2 months, to generate one fully mature sperm cell. Each cycle of spermatogenesis encompasses six stages and typically takes around 16 days to complete.

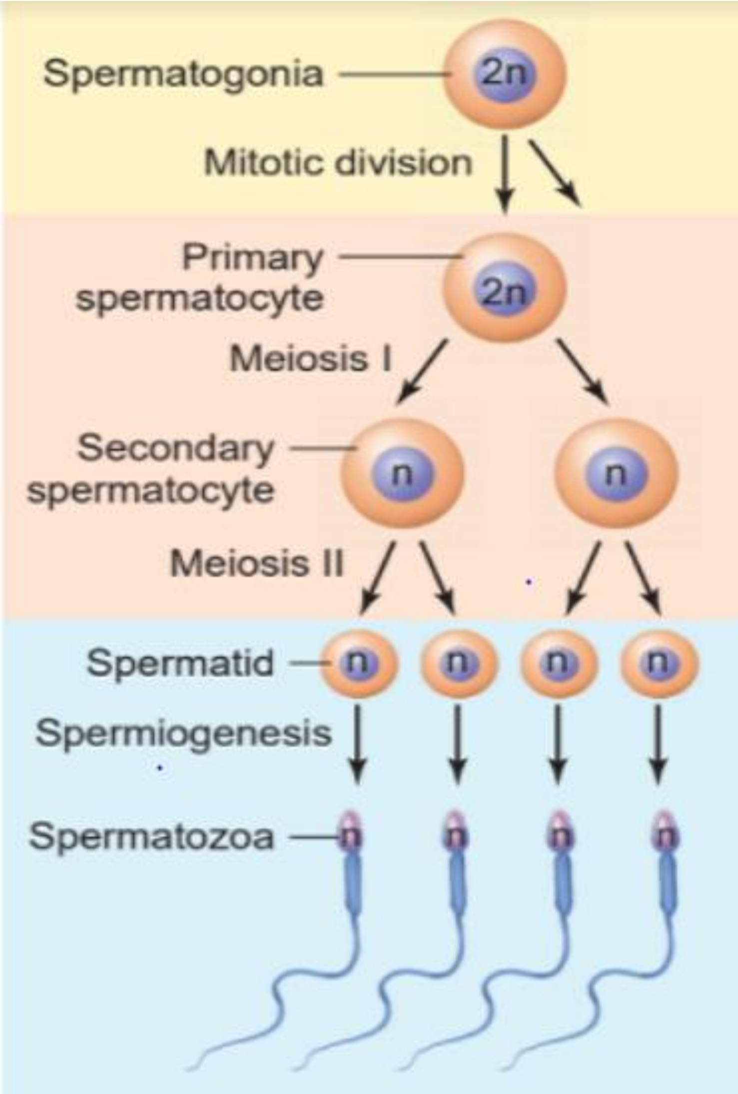

Figure 8.6: Process of Spermatogenesis

Let's explore the stages of sperm development:

1. *Spermatogonia:* Spermatogonia are the undifferentiated cells that reside along the basement membrane of the seminiferous tubules. These cells undergo mitotic division, resulting in two types of cells: Type A and Type B spermatogonia.
2. *Primary Spermatocytes:* Type B spermatogonia further differentiate into primary spermatocytes. During this stage, the primary spermatocytes undergo DNA replication, resulting in the doubling of their genetic material. Each primary spermatocyte contains 46 chromosomes in the form of 23 pairs.
3. *Secondary Spermatocytes:* Meiosis I occurs, and each primary spermatocyte divides into two secondary spermatocytes. The genetic material is halved, with each secondary spermatocyte containing 23 chromosomes.

4. *Spermatids*: Each secondary spermatocyte then undergoes meiosis II, resulting in the formation of four haploid spermatids. Haploid cells contain 23 single chromosomes instead of pairs.
5. *Spermatozoa (Sperm Cells):* Spermatids undergo a process called spermiogenesis, transforming into elongated sperm cells, or spermatozoa. The energy-generating organelles called mitochondria, located within each sperm, provide the necessary power for the tail (flagellum) to facilitate its movement. This enables the sperm to swim towards the female egg once it reaches the vagina. **Figure 8.6** provides an illustration depicting the structure and components of a spermatozoon.

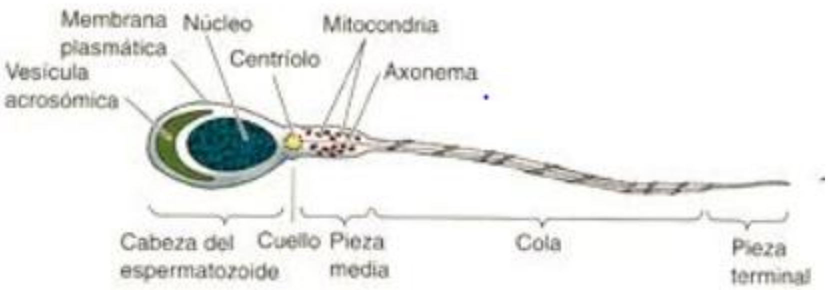

Figure 8.7: Structure of sperm

During this stage, the spermatids develop a distinct head, midpiece, and tail.

- Head: The head contains the genetic material (23 chromosomes) and is covered by a cap-like structure called the acrosome. The acrosome contains enzymes that aid in the penetration of the egg during fertilization.
- Midpiece: The midpiece contains mitochondria that provide energy for the sperm's movement.
- Tail (Flagellum): The tail, or flagellum, propels the sperm forward, allowing it to swim towards the egg.

Upon completion of spermiogenesis, the newly formed sperm cells detach from the Sertoli cells, which provide nourishment and support during the development process. The journey of spermatozoa begins in the epididymis, where they pass through the deferent duct, seminal vesicle, ejaculatory duct, and eventually reach the urethra. During ejaculation, semen is expelled from the urethra.

Semen is a fluid that comprises several components:

- *Spermatozoa*: Spermatozoa are the mature sperm cells that are capable of fertilizing an egg. They are present in the semen and are essential for reproduction.
- *Viscid Fluid:* The viscid fluid in semen provides nourishment and support to the spermatozoa, ensuring their viability and motility.
- *Lubricating Fluid:* The prostate glands contribute a thin lubricating fluid to the semen. This fluid helps facilitate the movement of sperm through the urethra during ejaculation.
- *Mucus:* The glands of the urethra secrete mucus that mixes with the other components to form semen. This mucus helps provide additional lubrication and facilitate the passage of semen.

As the spermatozoa pass through the epididymis and deferent duct, they undergo further maturation. This maturation process enables the spermatozoa to acquire the ability for independent movement within a liquid medium.

During ejaculation, the typical volume of semen expelled is around 2-5 milliliters, and it contains a concentration of 40-100 million spermatozoa per milliliter. If the spermatozoa are not ejaculated, they can be reabsorbed by the tubules.

It is important to note that sperm development is a continuous process, with millions of sperm cells being produced daily in the seminiferous tubules. The process of sperm development is ultimately controlled by the endocrine system, specifically the hypothalamic-pituitary-gonadal (HPG) axis. This axis involves the coordination of hormones among the hypothalamus, pituitary gland, and gonads (testes).

Next, let discuss the key hormones involved in regulating sperm development as follows:

1. *Follicle-Stimulating Hormone (FSH):* FSH is secreted by the anterior pituitary gland, a small gland located at the base of the brain. FSH acts on the Sertoli cells within the seminiferous tubules of the testes. It stimulates the Sertoli cells to provide essential nutrients, support, and protection to developing sperm cells during spermatogenesis. FSH also promotes the production of androgen-binding protein (ABP), which helps concentrate testosterone within the testes.
2. *Luteinizing Hormone (LH):* LH, also produced by the anterior pituitary gland, plays a vital role in stimulating the Leydig cells located in the testes. Leydig cells are responsible for the production and secretion of testosterone, the primary male sex hormone. LH stimulates the Leydig cells to produce testosterone, which is crucial for the differentiation and maturation of sperm cells.

3. *Testosterone:* Testosterone is a steroid hormone produced by the Leydig cells in the testes. It plays a central role in regulating spermatogenesis. Testosterone acts on the Sertoli cells to promote the development of spermatogonia into spermatocytes and spermatids. It also influences the maturation and functional characteristics of spermatozoa. Additionally, testosterone contributes to the development of secondary sexual characteristics in males, such as deepening of the voice, growth of facial and body hair, and increased muscle mass.

Here in this section, let us review puberty in males

8.3.3 Male Puberty

Male puberty is a phase of development in males that marks the transition from childhood to adulthood. The reproductive system in males does not become fully functional until puberty, which typically occurs between the ages of 10 and 14 years. Puberty is a phase of maturation characterized by the release of hormones that initiate and drive the changes associated with sexual development. One of the key hormones involved in male puberty is luteinizing hormone (LH), which is secreted by the anterior lobe of the pituitary gland. LH stimulates the interstitial cells within the testes to increase the production of testosterone. Testosterone is the primary male sex hormone and plays a vital role in the development of the male reproductive system and the overall maturation of the body. The increased levels of testosterone during puberty influence various aspects of development, including:

1. *Growth and Development*: Puberty is a time of rapid growth and development in males. Boys experience a growth spurt, where they may grow several inches taller within a short period. They also develop broader shoulders, a more muscular physique, and increased body mass.
2. *Sexual Maturation:* Puberty is marked by the development of secondary sexual characteristics, including the following:

- Enlargement of the testes and scrotum: The testes and scrotum increase in size as they start producing sperm.
- Penile growth: The penis grows in length and girth.
- Appearance of pubic hair: Hair begins to grow in the pubic area, starting from a few sparse hairs and gradually becoming denser and coarser.
- Facial and body hair: Hair growth becomes more prominent in the armpits, face (such as mustache and beard), chest, and other areas of the body.

- Voice changes: The larynx (voice box) grows, causing the vocal cords to lengthen and thicken. This results in a deepening of the voice.
- Development of Adam's apple: The thyroid cartilage in the throat enlarges, creating a visible prominence known as the Adam's apple.

4. *Skin Changes*: The skin becomes oilier during puberty due to increased sebum production. This can lead to acne and breakouts.
5. *Reproductive System:* The testes start producing sperm during puberty. Boys begin to experience spontaneous erections and may also have their first ejaculation, known as a nocturnal emission or "wet dream." These are normal and part of the maturation process.
6. *Emotional and Psychological Changes:* Puberty can bring about emotional and psychological changes as well. Boys may experience mood swings, increased self-awareness, heightened sexual thoughts and feelings, and a developing sense of identity.

It's important to note that the onset and progression of puberty can vary among individuals. The typical age range for the onset of male puberty is between 9 and 14 years, although it can begin earlier or later.

But before we move to the section, let us recapitulate what we have learnt so far.

Check Your Progress Exercise 1

1. Enlist the organs of the m le reproductive system.

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2. Enumerate the functions of the following organs:

a) Epididymis

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b) Vas deferens

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c) Prostrate glands

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3. Discuss the composition of semen and name of theglands that produce it.

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4. Describe the process of spermatogenesis and list the hormones involved in it.

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5. Define male puberty. Name The key hormone responsible for changes during male puberty.

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8.4 THE FEMALE REPRODUCTIVE SYSTEM

The female reproductive system is a complex and intricate system responsible for the production of eggs (ova), the process of fertilization, and the nurturing and development of a fetus during pregnancy. We have studied about the male reproductive system in the last section. We saw that the male reproductive organs are located, both inside and outside the pelvis. Unlike the male, most of the organs of the female reproductive system are located inside the pelvis. We shall look at the different organs that constitute the female reproductive system in this section

8.4.1 Parts of female reproductive system

The female reproductive system comprises both external and internal organs that work together to facilitate reproduction. These organs can be divided into two categories: the external genitalia and the internal genital organs. Each of these structures plays a crucial role in the reproductive process. The external female genitalia performs two major functions, both allowing the penis and thus the sperm to enter (in order to fertilize an ovum), as well as, protecting the more sensitive internal genital organs from pathogens, which can produce infection. The internal female genitals are: the vagina, the cervix, the uterus, the fallopian tubes and the ovaries.

Let's explore the female reproductive system in detail:

A. External Organs

1. **External genitalia**: The external genitalia, collectively known as the vulva, include the following structures as you can see in figure 8.8:

a) Mons pubis
b) Labia majora
c) Labia minora
d) Clitoris
e) Vestibule
f) Perineum

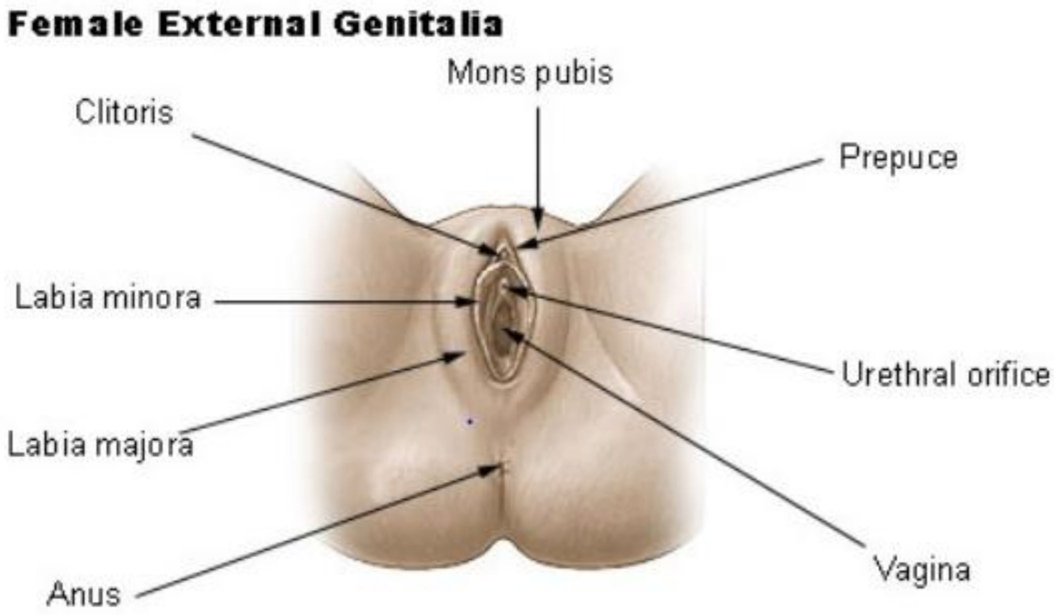

Figure 8.8: Female External Genitalia

(Source: training.seer.cancer.gov)

a) *Mons pubis:* The Mons pubis, also known as the mons veneris, is a rounded area of fatty tissue located above the pubic bone in the pelvic region of females. It is part of the external female genitalia and is one of the visible features of the vulva. Mons pubis varies in size and appearance among individuals. It is covered with pubic hair after puberty and serves as a protective cushion for the underlying structures of the pelvis. It contains sebaceous glands, which secrete oil to keep the area lubricated. This lubrication helps to reduce friction and discomfort during activities such as walking, running, or sexual intercourse.

b) *Labia majora:* The Labia majora, also known as the outer lips, are prominent folds of skin located on either side of the vaginal opening. They are a part of the external female genitalia and forms the boundary of vulva, as you see in figure 8.8. It is composed of skin, fibrous tissue, fat and sebaceous glands. The Labia majora are typically larger and more padded compared to the Labia minora (inner lips), and they enclose and protect the more delicate structures of the vulva. They are highly sensitive to touch and stimulation. They contribute to sexual arousal and pleasure by responding to tactile stimulation during sexual activity.

c) *Labia minora:* The Labia minora, also known as the inner lips, are thin, delicate folds of skin located within the Labia majora. They extend from the clitoris on both sides of the urethral and vaginal openings. They forms a protective covering, for the clitoris which is a highly sensitive structure, from direct stimulation and potential irritation. They contain sebaceous glands, which secrete oil to keep the area lubricated. This helps reduce friction and discomfort during everyday activities and sexual intercourse. The Labia minora contain a rich supply of nerve endings, making them highly sensitive to touch and stimulation. They contribute to sexual arousal and pleasure by responding to tactile stimulation during sexual activity.

It's important to note that the Labia minora, like other external genital structures, can change in appearance over time due to factors such as hormonal fluctuations, aging, or childbirth. These changes are natural and normal.

d) *Clitoris:* The clitoris is a highly sensitive and erectile organ located at the anterior junction of the Labia minora, above the urethral opening. It is a key structure in the female reproductive system and is central to sexual arousal and pleasure. The clitoris is made up of several parts. The visible portion is the clitoral glans, which is typically located at the top of the Labia minora. The glans is covered by a fold of skin called the prepuce or clitoral hood. Beneath the surface, the clitoris extends into two shafts of erectile tissue known as the corpora cavernosa, which are similar to the erectile tissue in the penis. The primary function of the clitoris is to provide sexual pleasure. The size, shape, and appearance of the clitoris can vary among individuals. Some clitorises may be more prominent and easily visible, while others may be smaller and less visible. These variations are normal and do not affect sexual function or pleasure.

e) *Vestibule:* The vestibule refers to the central area between the Labia minora in the female reproductive system. The vestibule is rich in nerve endings, making it a sensitive area to touch and sexual stimulation. Stimulation of the vestibular area can contribute to sexual pleasure and arousal.It is an important anatomical region that contains several structures involved in sexual intercourse, urination, and the reproductive process as discussed as follows:

- *Urethral Opening*: The urethral opening, also known as the urinary meatus, is located within the vestibule. It is the external opening of the urethra, which is the tube that carries urine from the bladder to the outside of the body. During urination, urine passes through the urethral opening.
- *Vaginal Opening:* The vaginal opening, also called the introitus, is

situated within the vestibule. It is the entrance to the vagina, the muscular canal that connects the external genitalia to the cervix of the uterus. The vaginal opening allows for sexual intercourse and serves as the birth canal during childbirth.

- *Bartholin's Glands:* The vestibule contains the openings of the Bartholin's glands, which are small glands located on either side of the vaginal opening. These glands secrete mucus-like fluid that helps lubricate the vaginal opening during sexual arousal. The lubrication aids in reducing friction and discomfort during sexual activity.
- *Skene's Glands:* Skene's glands, also known as the paraurethral glands, are located near the urethral opening within the vestibule. These glands produce a small amount of fluid that may contribute to sexual arousal and lubrication during sexual activity. They are often referred to as the female equivalent of the prostate gland.

g) Perineum:The area between the vaginal opening and the anus.

B. Internal Organs

The internal organs lie in .the pelvic cavity and contain vagina, the cervix, uterus, fallopian tubes and the ovaries as you can see in the figure 8.9. Let us get to know these structures.

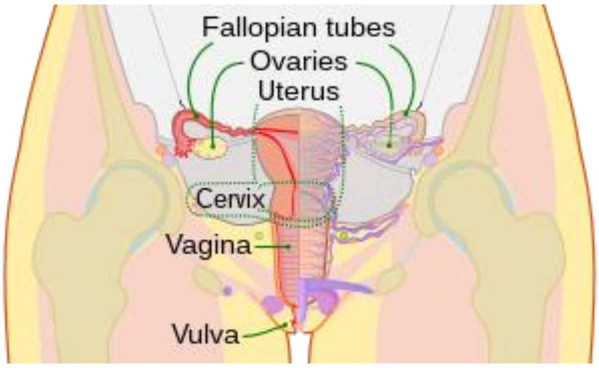

Figure 8.9: Internal Female Reproductive system

2. *Vagina:* The vagina is a muscular canal that connects the external genitalia to the cervix of the uterus as shown in figure 8.9. It is a fibro-muscular tube lined with

stratified epithelium, lies in front of anus and has rectum at the posterior part. It serves as a passageway for menstrual flow, facilitates sexual intercourse, and acts as the birth canal during delivery.

3. *Uterus*: The uterus, also known as the womb, is a hollow, pear-shaped organ where fetal development occurs. As you can see from the Figure 8.9, it lies in the pelvic cavity and is supported by surrounding organs, muscles of the pelvic floor, ligaments that suspend it from the walls of the pelvis. When the body is in the upright position, it lies in almost horizontal position. It is divided into three main parts: the fundus (upper portion), the body (central portion), and the cervix (lower narrow portion).It consists of three layers: the inner lining called the endometrium, the muscular middle layer known as the myometrium, and the outer protective layer called the perimetrium. The uterus undergoes cyclic changes during the menstrual cycle to prepare for potential pregnancy.

   Functions: What are the functions of the uterus? Let's find out.

   The functions of the uterus have been considered at the different stages in the following discussion:

- The primary function of the uterus is to provide a safe and nurturing environment for the development and growth of a fertilized egg (embryo) during pregnancy. If fertilization occurs, the fertilized egg implants into the endometrium of the uterus and receives nourishment from it. If fertilization does not occur, the endometrium is shed during menstruation.
- When fertilization occurs, the uterus expands throughout pregnancy to accommodate the growing fetus. It helps the growth of foetus during the 40 week gestation period, at the end of which the baby is born. During childbirth, the uterus undergoes coordinated contractions to facilitate the delivery of the fetus and the placenta. The initial stage of labor, known as the first stage, involves the onset of regular contractions. These contractions cause the cervix to gradually soften, thin out (efface), and open up (dilate) to allow the passage of the fetus. As labor progresses, the contractions become more intense and frequent. These powerful contractions of the uterine muscles work in a coordinated manner to push the fetus downward through the birth canal. The contractions also aid in the dilation of the cervix, allowing for the gradual enlargement of the birth canal.

- During the final stage of labor, known as the second stage, the strong contractions of the uterus, combined with the woman's voluntary pushing efforts, facilitate the expulsion of the fetus. The uterine muscles contract forcefully, exerting pressure on the baby and guiding it through the birth canal. Once the baby is born, the uterine contractions continue to help expel the placenta from the uterus.

4. *Ovaries:* The ovaries are a pair of small, oval-shaped organs located in the lower abdomen on either side of the uterus in the female reproductive system. They are integral to the reproductive process and play crucial roles in hormone production, egg development, and the menstrual cycle.

Here are some important points about the structure and function of the ovaries:

- *Structure:* The ovaries are about the size and shape of almonds. They are attached to the uterus via ligaments and are covered by a protective layer of tissue called the ovarian capsule. Each ovary contains thousands of tiny sacs called follicles, which house immature eggs or ova.
- *Egg Development:* The ovaries are responsible for the production and maturation of eggs. During a woman's reproductive years, each month, a few follicles start to develop, but usually, only one follicle becomes dominant and continues to mature. The maturing follicle releases a mature egg through ovulation, which is the process of the egg being released from the ovary into the fallopian tube.
- *Hormone Production:* The ovaries also produce and release hormones, primarily estrogen and progesterone. These hormones regulate the menstrual cycle, maintain pregnancy, and play essential roles in sexual development, bone health, and overall well-being.
- *Menstrual Cycle:* The ovaries, in coordination with other reproductive organs, orchestrate the menstrual cycle. The cycle involves a series of hormonal changes and the release of an egg for potential fertilization. The ovaries produce estrogen during the first half of the cycle, stimulating the thickening of the uterine lining. After ovulation, the ovaries produce progesterone to support the development of the uterine lining in preparation for a possible pregnancy.
- *Hormonal Regulation:* The ovaries are controlled by the hypothalamic-pituitary-gonadal axis, which involves a complex interaction of hormones. The hypothalamus releases gonadotropin-releasing hormone (GnRH), which signals the pituitary gland to

release follicle-stimulating hormone (FSH) and luteinizing hormone (LH). FSH stimulates the growth of follicles, and LH triggers ovulation.

- *Reproductive Potential:* The ovaries house a finite number of follicles containing eggs at birth. As a woman ages, the number of follicles and the quality of eggs decrease, leading to a decline in fertility and eventually menopause.

5 Fallopian tube: The fallopian tubes, also known as uterine tubes or oviducts, are a pair of slender tubes in the female reproductive system. They play a vital role in the process of fertilization and early embryonic development. Here are some important points about the fallopian tubes:

- Each fallopian tube is approximately 10-12 cm long and extends from the upper corners of the uterus. The tubes provide an environment where fertilization of the egg by a sperm can occur. It has a funnel-shaped opening called the infundibulum, which has finger-like projections called fimbriae. The fallopian tubes serve as a pathway for the eggs to travel from the ovaries to the uterus. During ovulation, when an egg is released from the ovary, it is swept into the fallopian tube by the fimbriae.. The fimbriae help in capturing and guiding the released egg (ovum) from the ovary into the fallopian tube. The fallopian tubes have tiny hair-like structures called cilia lining their inner walls. These cilia create waves of movement that help transport the fertilized egg or zygote towards the uterus. This movement is facilitated by the muscular contractions of the fallopian tubes.
- The fallopian tubes are the site of fertilization. If sexual intercourse occurs near the time of ovulation, sperm can swim up through the cervix, into the uterus, and then into the fallopian tubes. If a sperm successfully penetrates and fertilizes the egg in the fallopian tube, it forms a fertilized egg or zygote.

  As you already, If the ovum is fertilized, the zygote embeds in the uterine wall whicli relaxes to accommodate the growing foetus. It provides the right environment for the embryo and foetal growth. If the ovum is not fertilized, the cycle ends with a short period of bleeding, referred to as *menstruation.*

8.4.2 Female secondary sexual characteristics

Female secondary sexual characteristics are the physical traits that develop during puberty and distinguish females from males. These characteristics are primarily influenced by the hormones estrogen and progesterone, which are responsible for the maturation and development of the female reproductive system.

Here are some key female secondary sexual characteristics:

- *Breast Development:* One of the most noticeable changes during puberty is the development of breasts. Estrogen stimulates the growth of breast tissue, resulting in the enlargement and rounding of the breasts. The areolas also darken and become larger.
- *Body Shape:* Females typically experience changes in body shape during puberty. Estrogen influences the accumulation of fat in certain areas of the body, such as the hips, buttocks, and thighs. This contributes to the development of a more curvaceous figure and a narrower waist-to-hip ratio.
- *Growth of Pubic and Axillary Hair:* As part of sexual maturation, females develop pubic hair in the genital area and axillary hair (underarm hair). These hair growth patterns are influenced by the increase in sex hormones during puberty.
- *Menstruation:* Menarche, the onset of menstruation, is another significant aspect of female secondary sexual characteristics. It occurs when the reproductive system matures, and the ovaries release an egg each month. Menstruation is a monthly cycle characterized by the shedding of the uterine lining, which marks a woman's potential for fertility.
- *Skin Changes*: Hormonal changes during puberty can affect the skin. Some females may experience increased oil production, leading to oily or acne-prone skin. Additionally, the skin may become softer and more elastic due to changes in collagen and moisture levels.
- *Body Odor*: The increase in sweat gland activity during puberty can result in changes in body odor. Females may notice a shift in their natural scent due to hormonal changes and the presence of apocrine glands in the underarms and genital area.

  It's important to note that the onset and progression of secondary sexual characteristics can vary among individuals. While these characteristics are commonly associated with females, it's essential to recognize that gender identity may not always align with biological sex.

8.5 MENSTRUAL CYCLE

What is menstrual cycle? Menstrual cycle, is *a **series** of events that occur regularly in females every 26-30 days.* The cycle consists of a series of physiological changes in the reproductive system and is regulated by hormones. The menstrual cycle is a monthly hormonal cycle that occurs in women of reproductive age. The menstrual cycle prepares the body for potential pregnancy and involves the shedding of the uterine lining if fertilization does not occur.

8.5.1 Key Stages of the Menstrual Cycle

Menstrual cycle, in fact is a recurring cycle (beginning at menarche and ending at menopause) in which the endometrial lining of the uterus prepares for pregnancy. If pregnancy does not occur, the lining is shed at menstruation. The average menstrual cycle is 28 days.

Next, let us see the key stages of the menstrual cycle:

1. *Menstrual Phase:* The cycle begins with the menstrual phase, also known as menstruation. This phase is characterized by the shedding of the uterine lining, resulting in vaginal bleeding. It usually lasts for 3 to 7 days.
2. *Follicular Phase:* Following menstruation, the follicular phase begins. The follicular phase, also known as the *proliferative phase*.As the figure 8.10 illustrated, it is named after the development of ovarian follicles, each containing an immature egg (oocyte). During the proliferative phase, the levels of follicle-stimulating hormone (FSH) and estrogen begin to rise. FSH stimulates the growth of multiple follicles in the ovaries, each containing an immature egg (oocyte). These follicles start producing estrogen, which has several effects on the reproductive system.

   One of the primary functions of estrogen during the proliferative phase is to stimulate the thickening of the uterine lining (endometrium). The endometrium becomes enriched with blood vessels and glandular tissue in preparation for potential implantation of a fertilized egg. Estrogen also promotes the growth and development of the cervical mucus, making it more conducive for sperm to swim through the cervix and reach the egg in the fallopian tubes.
3. *Ovulation:* Midway through the menstrual cycle, ovulation occurs, asshown in figure 8.10. Ovulation is the release of a mature egg from the ovary. It is triggered by a surge in luteinizing hormone (LH), which is stimulated by high levels of estrogen. The egg is released into the fallopian tube, ready for fertilization.
4. *Luteal Phase:* After ovulation, the luteal phase begins. The ruptured follicle in the ovary transforms into a structure called the corpus luteum, which produces progesterone and some estrogen. Progesterone prepares the uterus for potential

implantation of a fertilized egg. If fertilization does not occur, the corpus luteum gradually breaks down, leading to a decline in hormone levels.

5. *Secretory Phase:* During the luteal phase, the uterine lining thickens further, preparing for the potential implantation of a fertilized egg. The endometrial glands secrete nutrients to support an embryo. If fertilization does not occur, progesterone levels decline, causing the uterine lining to shed.
6. *Menstruation:* If fertilization and implantation do not occur, the corpus luteum degenerates, hormone levels drop, and the uterine lining is shed during menstruation. When progesterone levels decreases considerably, another ovarian follicle is stimulated by FSH and the next menstrual cycle starts again with a new menstrual phase.

The duration of the menstrual cycle can vary from woman to woman but is typically around 28 days. However, cycle length can range from 21 to 35 days and still be considered normal. Factors such as hormonal imbalances, stress, nutrition, and certain medical conditions can influence the regularity and length of the menstrual cycle.

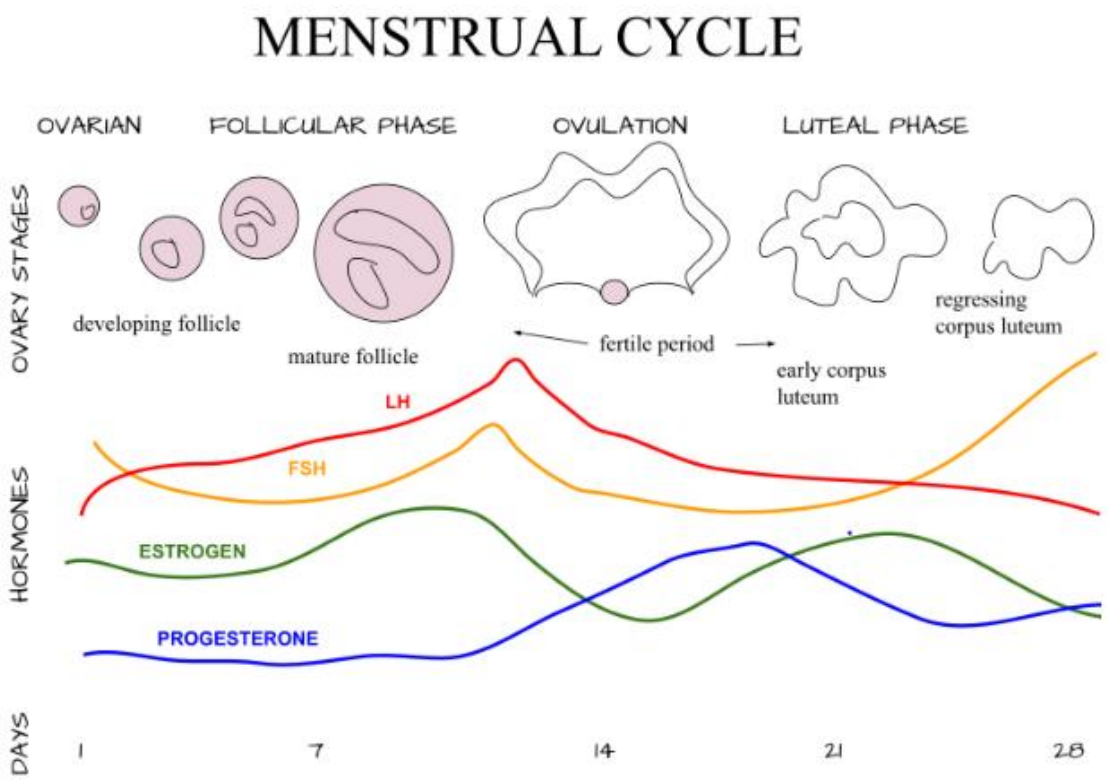

Figure 8.10: Menstrual Cycle

8.5.2 Role of Hormones in Menstrual Cycle

Hormones play a crucial role in regulating the menstrual cycle. They coordinate the physiological changes that occur in the reproductive system during each phase of the cycle. The interplay between various hormones regulates the growth and maturation of ovarian follicles, the release of the egg during ovulation, and the preparation of the uterus for potential pregnancy. Imbalances in hormonal levels can lead to irregular menstrual cycles, fertility issues, and other reproductive disorders. Understanding the role of hormones in the menstrual cycle is important for reproductive health, family planning, and the diagnosis and treatment of hormonal disorders.

The main hormones involved in the menstrual cycle are:

1. *Follicle-Stimulating Hormone (FSH):* FSH is produced by the pituitary gland and plays a key role in the early stages of the menstrual cycle. It stimulates the growth and development of ovarian follicles, each containing an immature egg (oocyte), as shown in figure 8.10. FSH also promotes the production of estrogen by the developing follicles.
2. *Estrogen*: Estrogen is primarily produced by the growing follicles in the ovaries. It has several important functions during the menstrual cycle. In the follicular phase, estrogen stimulates the thickening of the uterine lining (endometrium) and promotes the growth of blood vessels in the uterus. It also stimulates the secretion of cervical mucus, making it more favorable for sperm to reach the egg. As estrogen levels rise, they trigger a surge in luteinizing hormone (LH), which leads to ovulation.
3. *Luteinizing Hormone (LH)*: LH is also produced by the pituitary gland. It plays a critical role in ovulation, which occurs midway through the menstrual cycle. A surge in LH triggers the release of a mature egg from the ovary. This surge is usually preceded by a peak in estrogen levels, as you can see in figure 8.10. LH also stimulates the ruptured follicle in the ovary to transform into the corpus luteum.
4. *Progesterone*: Progesterone is primarily produced by the corpus luteum, which forms from the ruptured follicle after ovulation. It plays a vital role in the second half of the menstrual cycle, known as the luteal phase. Progesterone helps prepare the uterus for potential implantation of a fertilized egg by promoting the thickening of the endometrium and the secretion of nutrients and fluids. If fertilization and implantation do not occur, the corpus luteum regresses, and progesterone levels decline, leading to menstruation.
5. *Gonadotropin-Releasing Hormone (GnRH):* GnRH is released by the hypothalamus, a region of the brain. It stimulates the pituitary gland to produce FSH and LH. The

release of GnRH is regulated by a negative feedback system involving estrogen and progesterone levels. When estrogen and progesterone levels are low, GnRH secretion increases, initiating the next menstrual cycle.

8.6 MENOPAUSE

What is ***menopause?*** Menopause is a natural biological process that marks the end of a woman's reproductive years. It is defined as the permanent cessation of menstrual periods and is typically diagnosed after a woman has gone without a period for 12 consecutive months. Menopause occurs due to a gradual decline in the production of reproductive hormones, primarily estrogen and progesterone, by the ovaries.

Here are some key points about menopause:

1. **Age of Onset:** Menopause usually occurs between the ages of 45 and 55, with the average age being around 51. However, the timing can vary among women, and some may experience menopause earlier or later in life.

2. **Perimenopause:** Prior to reaching menopause, many women go through a transitional phase called perimenopause. During this time, which can last several years, hormonal fluctuations become more pronounced, leading to changes in the menstrual cycle, such as irregular periods, skipped periods, or heavier or lighter bleeding. Women may also experience symptoms such as hot flashes, night sweats, mood changes, and vaginal dryness.

3. **Hormonal Changes:** Menopause occurs when the ovaries stop releasing eggs, and estrogen and progesterone production declines significantly. This hormonal shift can have various effects on the body, including changes in bone density, cardiovascular health, and vaginal and urinary health.

4. **Symptoms:** Menopause is often associated with a range of symptoms, which can vary in intensity and duration among women. Common symptoms include hot flashes, night sweats, mood swings, sleep disturbances, vaginal dryness, decreased libido, urinary changes, and changes in skin and hair.

5. **Long-Term Health Effects**: The decline in estrogen production during menopause can have long-term effects on a woman's health. Estrogen helps protect against bone loss, so decreased estrogen levels increase the risk of osteoporosis. Additionally, the decreased estrogen may contribute to an

increased risk of heart disease and changes in cholesterol levels.

6. **Management and Treatment**: Menopausal symptoms can be managed through various approaches. Lifestyle changes, such as regular exercise, a healthy diet, and stress reduction, can help alleviate symptoms. Hormone replacement therapy (HRT), which involves taking estrogen and progesterone, may be prescribed to relieve symptoms and reduce the risk of certain health conditions. However, HRT is not suitable for everyone, and the decision to use it should be made in consultation with a healthcare professional.

Check the Progress II

1) Enlist the different organs in female reproductive system.

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2) What do you understand by fallopian tube? Enumerate its function.

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2) What is menopause? Discuss the symptoms and also mention the hormone declines during menopause.

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3) Which hormones are responsible for stimulating changes in ovaries? Also mention their roles.

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8.7 FERTILIZATION AND IMPLANTATION

8.7.1 Fertilization

Fertilization, also known as conception, is the process by which a sperm cell fuses with an egg cell to form a fertilized egg or zygote. It is a critical step in sexual reproduction and marks the beginning of the development of a new individual. Fertilization typically occurs in the fallopian tubes of the female reproductive system. When a mature egg is released from the ovary during ovulation, it travels through the fallopian tube. If sexual intercourse has taken place and sperm are present in the reproductive tract, the sperm can swim up through the cervix, uterus, and into the fallopian tube to reach the egg.

The process of fertilization involves several steps, as shown in figure 8.11. Let us discuss the several steps of fertilization:

1. *Penetration of the Ovum:* After ejaculation, the spermatozoa travel through the female reproductive tract, aided by cervical mucus and contractions of the fallopian tubes. Once they reach the ovum in the fallopian tube, they undergo capacitation, which involves biochemical and physiological changes that enable them to penetrate the egg.
2. *Fusion of Egg and Sperm:* When a sperm reaches the vicinity of the egg, it undergoes an acrosomal reaction, releasing enzymes that help it penetrate the protective layers surrounding the egg, including the zona pellucida. Once a sperm successfully penetrates the ovum, the outer layers of the egg undergo changes to prevent the entry of additional sperm. The genetic material of the sperm, contained in its nucleus, fuses with the genetic material of the egg, resulting in the formation of a zygote.
3. *Formation of the Zygote:* The egg which carries the single set of 23 chromosome fuses with sperm nuclei also containing a set of 23 chromosomes. This creates a single-cell zygote with a complete set of genetic material of 46 chromosomes. The zygote contains a combination of genetic traits from both parents, and it represents the beginning of a new individual.

4. *Cell Division and Implantation*: After fertilization, the zygote undergoes a series of cell divisions through a process called cleavage. The cells divide rapidly, forming a solid ball of cells called a morula. The morula then develops into a hollow, fluid-filled structure called a blastocyst. The blastocyst travels through the fallopian tube and reaches the uterus, where it implants into the uterine lining (endometrium).
5. *Pregnancy*: Once the blastocyst is successfully implanted, it establishes connections with the maternal blood vessels in the uterus. These connections allow for the exchange of nutrients, oxygen, and waste products between the mother and the developing embryo. The blastocyst develops further into an embryo and then into a fetus, which continues to grow and develop inside the uterus during pregnancy.

It's important to note that successful fertilization is just the first step in the complex process of human reproduction. Fertilization is a remarkable process that combines the genetic material from two individuals, resulting in the formation of a unique and genetically diverse offspring. It marks the beginning of a new life and sets in motion the complex process of embryonic development.

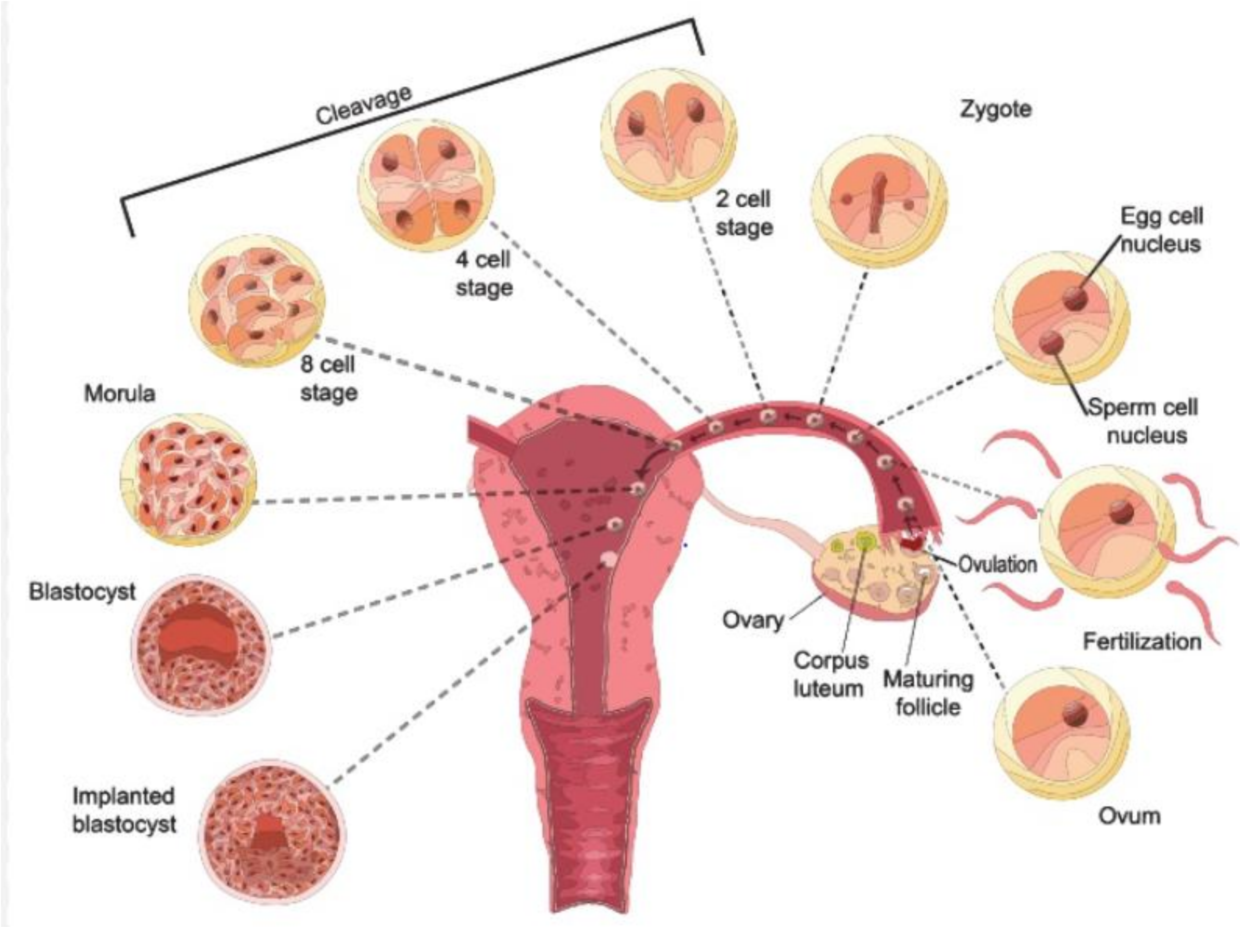

Figure 8.11: Stages of fertilization

8.7.2 Implantation

Implantation is a critical stage in human reproduction that occurs after fertilization. It refers to the attachment and embedding of the fertilized egg, known as the blastocyst, into the lining of the uterus, called the endometrium.

After fertilization, the zygote undergoes several divisions and develops into a hollow ball of cells called the blastocyst. Around six to seven days after fertilization, the blastocyst reaches the uterus and begins the process of implantation.

During implantation, the blastocyst burrows into the thickened and vascularized endometrium, specifically in the functional layer of the uterine lining. The process involves the interaction between the blastocyst and the endometrial lining, facilitated by various cellular and molecular mechanisms.

Implantation is a complex and highly regulated process. The blastocyst undergoes changes in its outer layer, called the trophoblast, which plays a crucial role in establishing a connection with the maternal blood supply. The trophoblast differentiates into two layers: the outer syncytiotrophoblast and the inner cytotrophoblast. The syncytiotrophoblast invades and erodes the endometrial tissue, allowing the blastocyst to become embedded in the uterus.

Once the blastocyst is successfully implanted, it establishes contact with the maternal blood vessels in the endometrium. This connection allows for the exchange of nutrients, gases, and waste products between the maternal circulation and the developing embryo.

Implantation is a key milestone in pregnancy, as it marks the beginning of the formation of the placenta. The placenta, which develops from the trophoblast and the maternal tissues, serves as a vital interface for nutrient and gas exchange, hormone production, and waste elimination throughout pregnancy.

The timing and success of implantation are crucial for the continuation of pregnancy. If implantation fails to occur or is disrupted, it can result in the failure of pregnancy or early pregnancy loss. However, when implantation is successful, it sets the stage for the subsequent development and growth of the embryo and the progression of pregnancy.

8.7.3 Placenta

The placenta is an organ that forms during pregnancy and serves as a vital connection between the mother and the fetus. It develops from the chorionic villi, which are finger-like projections on the embryo that attach to the uterine wall. It is formed from both maternal and fetal tissues and is responsible for various functions essential for the well-being of the developing baby. The placenta evolves during the 6$^{t‘}$ — l2 $^{t‘}$ week of pregnancy from a small mass of cells into a complex spongy network of tissues and blood vessels. At 12 weeks of pregnancy, the placenta has attained its definite form.

After 12 weeks of pregnancy, the placenta has attained its definite form. The placenta has 2 principal parts: *uterine* and *foetal.* On the maternal side, the placenta is a part of the uterine mucosa. When the blastocyst (an early preimplantation embryo) implants in the uterus at 6 — 7 days after fertilization, the uterine tissue and blood vessels breakdown to form small spaces (lacunae) that fill with maternal blood. Blood begins to circulate in the spaces at about 12 day's gestation. Figure 12.14 also highlights the relationship between maternal and foetal side. On the foetal side, the trophoblast grows and sends out root-like villi into the pools of maternal blood. These villi contain capillaries, which will exchange nutrients and waste products between the mother and the foetus.

The placenta plays a crucial role in providing oxygen, nutrients, and antibodies to the fetus, as well as removing waste products and carbon dioxide. It also produces hormones, including human chorionic gonadotropin (hCG), which supports the early stages of pregnancy.
In the early days of pregnancy; the placenta and associated structures form a tiny mass of cells, Let's explore the associated structures of the placenta in more detail:

1. *Chorionic Villi:* The chorionic villi are finger-like projections that originate from the outermost layer of the embryo, known as the chorion. These villi develop into the placenta and are the primary site of exchange between the maternal and fetal blood. The chorionic villi contain numerous blood vessels that allow for the exchange of oxygen, nutrients, and waste products between the mother and the fetus.
2. *Decidua:* The decidua is the specialized lining of the uterus that forms during pregnancy. It is composed of three distinct regions: a. Decidua basalis: This region is located at the site where the placenta attaches to the uterine wall. It contains maternal blood vessels that supply nutrients to the placenta and receive blood from the placenta. b. Decidua capsularis: This region surrounds the developing embryo and forms the inner lining of the uterus. It expands as the pregnancy progresses and eventually covers the chorionic villi, creating a protective barrier around the fetus. c. Decidua parietalis: This region lines the rest of the uterus and is not directly involved in placental attachment.
3. *Placental Membranes:* The placenta is surrounded by several membranes that provide protection and support. These membranes include: a. Amnion: The amnion is a thin,

transparent membrane that surrounds the fetus and contains the amniotic fluid, which provides cushioning and protection. b. Chorion: The chorion is the outermost fetal membrane that encloses the amnion and chorionic villi. It helps form the placenta and is involved in the exchange of substances between the mother and the fetus. c. Amniotic Sac: The amniotic sac is the fluid-filled sac formed by the amnion. It acts as a protective cushion for the developing fetus, providing a stable environment for growth.

4. *Umbilical Cord:* The umbilical cord connects the fetus to the placenta and contains blood vessels that transport nutrients and oxygen to the developing baby and remove waste products. It consists of two arteries and one vein encased in a gelatinous substance called Wharton's jelly.

Function of placenta

The placenta is a remarkable organ that serves as a lifeline between the mother and the developing fetus. The placenta plays several vital functions during pregnancy to support the growth and development of the fetus, , maintaining pregnancy, and providing a nurturing environment for the baby. Let us discussed the main functions of the placenta:

1. *Nutrient and Oxygen Exchange*: The placenta acts as a bridge between the mother and the fetus, facilitating the exchange of nutrients and oxygen. Maternal blood rich in oxygen and nutrients passes through the placenta, where these substances are transferred to the fetal blood. The placenta also filters out waste products from the fetal blood, which are then eliminated by the mother's excretory system.
2. *Hormone Production:* The placenta produces hormones that are essential for maintaining pregnancy and supporting fetal development. Some of the hormones produced by the placenta include human chorionic gonadotropin (hCG), progesterone, estrogen, and human placental lactogen (hPL). These hormones help regulate various physiological processes, promote fetal growth, and prepare the mother's body for childbirth and breastfeeding.
3. *Waste Removal:* Along with nutrient and gas exchange, the placenta aids in the removal of waste products generated by the developing fetus. Carbon dioxide and other waste materials are transferred from the fetal blood to the maternal blood through the placenta. The mother's body eliminates these waste products through her lungs and kidneys.
4. *Immune Protection:* The placenta provides a barrier of protection for the developing fetus against harmful substances and pathogens. While allowing the exchange of

essential substances, the placenta prevents the passage of certain harmful agents that could potentially harm the fetus. Additionally, the placenta transfers antibodies from the mother's blood to the fetus, providing passive immunity and protecting the baby from certain infections.

5. *Temperature Regulation:* The placenta helps maintain a stable temperature for the developing fetus. It acts as an insulator, protecting the baby from temperature fluctuations and providing a regulated environment necessary for optimal growth and development.
6. *Endocrine Function:* In addition to hormone production, the placenta performs various endocrine functions. It produces hormones that regulate the mother's metabolic changes during pregnancy, such as insulin resistance and lipid metabolism. These hormones also help prepare the mother's breasts for lactation.

8.8 GROWTH AND DEVELOPMENT DURING PREGNANCY

8.9.1 Foetal Growth and Development

Fetal growth and development refer to the process by which a fertilized egg develops into a fully formed fetus within the mother's womb. Growth and development during pregnancy is a remarkable and complex process that involves the progressive development of the fetus, changes in the mother's body, and the establishment of the placenta to support the growing baby. This remarkable journey spans approximately nine months and involves various stages and milestones.

Intrauterine life is one of the most critical periods. Foetal development begins with fertilization of an ovum by a sperm. Three stages follow: *the zygote*, *embryo* and *foetus.* Set us look at these three stages of foetal growth and development.

1. *Zygote.* The newly fertilized ovum or zygote begins as a single cell. During the days after fertilization it divides. Within 2 weeks, the zygote embeds itself in the uterine wall (implantation). Cell division continues and as development proceeds, the zygote becomes an embryo.

2. *Embryonic Stage (Weeks 2-8):* The first eight weeks of pregnancy are

referred to as the embryonic stage. The embryonic stage begins at fertilization when the sperm fertilizes the egg, forming a single-celled zygote. The zygote undergoes rapid cell division and travels down the fallopian tube to reach the uterus. It implants into the uterine lining, and the three primary germ layers form: ectoderm, mesoderm, and endoderm. These layers give rise to different organs and tissues. During this stage, the major organ systems start to develop, including the central nervous system, heart, limbs, and digestive system. The number of cells at first doubles approximately every 24 hours. The size of the embryo changes very little. At 8 weeks, the I'll inch embryo has a complete central nervous system, a beating heart, a digestive system, well- defined fingers and toes, and the beginnings of facial features.

3. *Fetal Stage (Weeks 9-40):* The fetal stage begins around the ninth week of pregnancy and continues until birth. During this stage, the fetus undergoes significant growth and refinement of its organ systems.

   Let us briefly list the key aspects of fetal growth and development:

   As a developing fetus progresses through the stages of pregnancy, there are certain vital statistics and key developmental features that can be observed. These provide insights into the growth and well-being of the fetus. Here are some of the main vital statistics and developmental features:

1. *Size and Weight*: Throughout pregnancy, the fetus undergoes significant growth in size and weight. The following are approximate average measurements at different stages:
   - At 12 weeks: The fetus is about 2.5 to 3 inches long and weighs around 1 ounce.
   - At 20 weeks: The fetus measures about 10 inches in length and weighs around 10 ounces.
   - At 30 weeks: The fetus is approximately 15.7 inches long and weighs around 3 pounds.
   - At 40 weeks (full-term): The average length is about 19 to 21 inches, and the weight ranges from 6 to 9 pounds.

2. *Organ Development*: During pregnancy, the fetus's organs undergo continuous development and maturation. Some of the key milestones include:
    - Brain Development: The brain begins to form in the early stages of pregnancy, and by the end of the second trimester, most of the major brain structures are present. The brain continues to develop throughout the third trimester.
    - Heart Development: The heart starts beating around the fifth week of pregnancy. By the end of the first trimester, the heart is fully formed and functioning, pumping blood throughout the body.
    - Respiratory System: The lungs develop and mature during the third trimester, producing surfactant, a substance necessary for proper lung function after birth.
    - Digestive System: The digestive organs, including the stomach, intestines, and liver, develop and become functional by the end of pregnancy.
    - Skeletal System: Bones begin to ossify and harden as the fetus grows. By the end of pregnancy, most of the bones are fully formed, although some areas like the skull may still be soft and flexible to facilitate the birthing process.
3. *Movement and Sensory Development:* As the fetus develops, it becomes more active and exhibits movement. These movements can be felt by the mother, starting with gentle flutters and progressing to more pronounced kicks and rolls. Sensory development also takes place, with the fetus developing the ability to hear and respond to external sounds and stimuli.
4. *Facial Features and Limb Development*: Facial features gradually become more defined as the fetus develops. Eyes, ears, nose, and mouth take shape, and the fetus can make facial expressions. Limbs continue to grow and develop, with fingers and toes becoming distinct and fully formed.
5. *Hair, Nails, and Skin*: Hair begins to grow on the fetus's head, eyebrows, and eyelashes. Nails form on the fingers and toes. The skin, initially thin and translucent, thickens and develops layers of fat to provide insulation and protection.

8.9 LACTATION

Lactation is the process by which the mammary glands in mammals, including humans, produce and secrete milk to nourish newborn offspring. It is a complex physiological process that is primarily regulated by hormones and controlled by the body's response to the needs of the infant. Lactation begins after childbirth, triggered by hormonal changes in the mother's body. During pregnancy, the levels of estrogen, progesterone, and prolactin increase, preparing the mammary glands for milk production. However, it is not until after the delivery of the placenta that milk production is fully established. Lactating woman secretes about 500 ml milk/day in the first month which increases to about about 1L/day by the fifth month. Once lactation is initiated, the breasts undergo several physiological changes to produce and deliver milk. Understanding the anatomy of the mammary glands and their functional components is crucial for the successful establishment and continuation of lactation. Let us look at the anatomy of mammary glands, which you may recall reading earlier under the female reproductive system, are the accessory glands.

8.9.1 Mammary gland

The mammary gland is a specialized glandular structure found in mammals, including humans. It is responsible for the production and secretion of milk, which nourishes and sustains the newborn offspring.

The anatomy of the mammary gland can be described as follows:

- *Mammary Gland Structure:* Each breast contains one mammary gland, and they are typically located on the anterior chest wall. The mammary gland consists of lobes, lobules, and ducts, all surrounded by adipose (fat) tissue and supported by connective tissue.

  Each breast consists of 15 to 20 lobes of glandular tissue. Each lobe is further divided into smaller structures called lobules as you can see in figure 8.12. Lobules are the functional units of the mammary gland. They are small, grape-like clusters of milk-producing cells called alveoli. The lobules are interconnected by small ducts. Within each lobule, there are ducts that collect milk produced by the alveoli. These ducts merge to form larger lactiferous ducts, which transport the milk towards the nipple.

2. *Nipple and Areola*: The nipple is the raised, pigmented projection located at the center of the areola, which is a circular area surrounding the nipple. The nipple contains multiple small openings called lactiferous duct orifices, through which milk is

released during breastfeeding. These ducts expand to form the short lactiferous sinuses in which milk may be stored. The sinuses are continuations of the mammary ducts, which extend outward from the nipple towards the chest wall with numerous secondary branches. The ducts end in epithelial masses, which form lobules (15-20 in number). General1y,.the terminal tubules and glandular structures are most numerous during the child-bearing period and reach their full physiological development only during pregnancy and lactation

3. *Blood and Lymphatic Supply:* The mammary gland receives its blood supply from various arteries, including the internal mammary artery, lateral thoracic artery, and intercostal arteries. Veins accompanying these arteries carry deoxygenated blood away from the mammary gland. Lymphatic vessels drain excess fluid, waste products, and immune cells from the mammary gland.
4. Innervation: The mammary gland is innervated by nerves that provide sensory and motor functions. Sensory nerves play a role in nipple sensitivity and the initiation of the milk ejection reflex. Motor nerves regulate the contraction of myoepithelial cells around the alveoli and ducts, assisting in milk ejection.
5. *Hormonal Control:* Hormones play a crucial role in the development and function of the mammary gland. The placenta plays an important role. The hormones secreted by the placenta human placental *lactogen*, *prolactin* and *chorionic gonadotropin,* contribute to mammary gland growth. During pregnancy, hormonal changes, particularly the increased levels of estrogen, progesterone, and prolactin, stimulate the growth and development of the mammary gland in preparation for lactation. After childbirth, the decrease in estrogen and progesterone and the increase in prolactin and oxytocin initiate milk production and ejection.

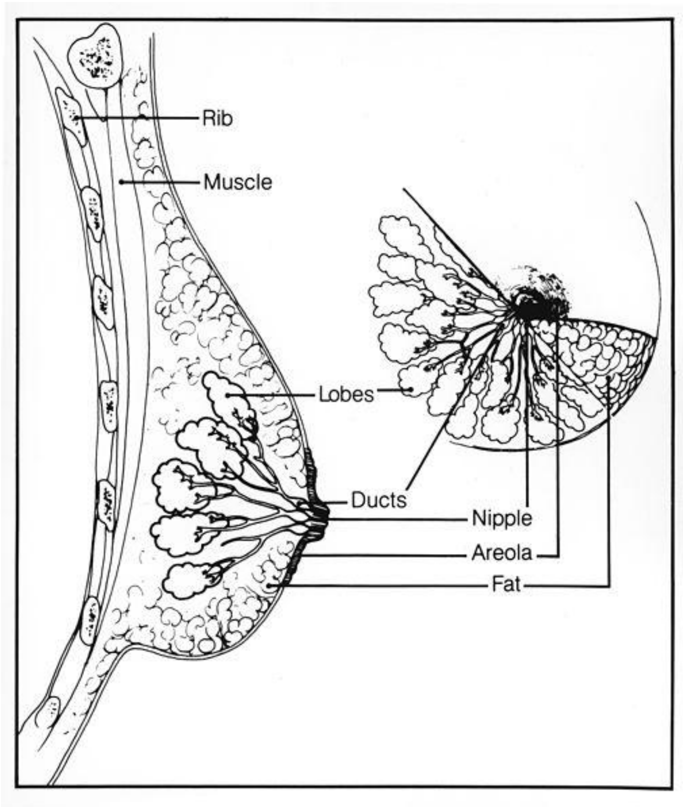

Figure 8.12: Structure of mammary gland

Next, let us look at the physiology of lactation.

8.9.2 Physiology of lactation

Physiology of lactation refers to the process by which a woman's body produces and secretes breast milk to nourish her newborn baby. Lactation is primarily controlled by hormonal regulation and involves a complex interplay of various physiological processes.

Let's explore the key aspects of the physiology of lactation:

1. **Hormonal Control:** Lactation is mainly governed by two hormones: prolactin and oxytocin.

- Prolactin: Prolactin, produced by the anterior pituitary gland, is the primary hormone responsible for milk production. During pregnancy, prolactin levels increase, preparing the breasts for milk production. After childbirth, the removal of the placenta triggers a further increase in prolactin levels, signaling the initiation of lactation.
- Oxytocin: Oxytocin, produced by the posterior pituitary gland, plays a crucial role in milk ejection or the "let-down reflex." Oxytocin is released in response to suckling or stimulation of the nipples, causing the contraction of the muscles surrounding the milk ducts and facilitating the flow of milk from the alveoli (milk-producing units) into the ducts for breastfeeding.

2. **Milk Production***:* Lactogenesis is the onset of copious milk secretion around parturition, triggered by a fall in plasma progesterone levels. Although some colostrum is secreted after delivery (2-3 days), full lactation begins later. The first 2-3 days after delivery is a period of rapid lactation initiation, followed by the longer period of maintenance of lactation. This complex neuroendocrine process is facilitated by an interplay of various hormones.

   Milk production, known as lactogenesis, occurs in several stages:

- Colostrum: In the early days after giving birth, the breasts produce colostrum, a thick, yellowish fluid rich in antibodies and essential nutrients. Colostrum is highly beneficial for the newborn's immune system and serves as the first food for the baby.
- Transitional Milk: As colostrum is gradually replaced by transitional milk, the composition of breast milk begins to change. Transitional milk is produced around 2-4 days after birth and has a higher fat content compared to colostrum.
- Mature Milk: Within a few weeks, mature milk is established. Mature milk consists of foremilk (initial milk released during a feeding session, low in fat content but high in carbohydrates and protein) and hindmilk (milk released toward the end of a feeding session, rich in fat). It provides the necessary nutrients, antibodies, enzymes, and hormones for the baby's growth and development.

Regular sucking stimulates the continuation of milk secretion. When the baby latches onto the breast and begins to suckle, the stimulation of the nerves in the nipple triggers the release of oxytocin. Oxytocin causes the contraction of the muscle cells around the alveoli, squeezing the milk into the milk ducts and facilitating its flow to the nipple. This process is known as the milk ejection reflex or the let-down reflex. Milk removal from the breast is a product of coordinated interaction between suckling of the infant and letdown reflex of the mother. As the infant commences suckling, afferent impulses generated in the receptors in the areola travel to the brain where they stimulate the release of oxytocin from the posterior pituitary. Oxytocin travels through the blood stream to the breast where it combines with specific receptors on the myoepithelial cells, stimulating them to contract and force milk from the alveoli into the mammary ducts and sinuses. Breast milk production operates on a supply and demand mechanism. The more frequently and effectively the baby feeds, the more milk is produced. Emptying the breasts through regular breastfeeding or pumping signals the body to produce more milk to meet the baby's needs. On the other hand, if breastfeeding is infrequent or inadequate, milk production may decrease.

To maintain an adequate milk supply, it is important for the mother to have a well-balanced diet, stay hydrated, and get sufficient rest. The baby's effective latch and sucking stimulate the breasts, signaling the body to continue milk production. Breastfeeding on demand, offering both breasts during each feeding session, and avoiding the use of pacifiers and bottles in the early weeks can help establish and maintain milk supply.

8.10 CONTRACEPTION

Contraception, also known as birth control, refers to the deliberate use of methods or devices to prevent pregnancy. There are various contraceptive methods available that work through different mechanisms to prevent conception. The choice of contraception depends on factors such as personal preferences, effectiveness, safety, ease of use, and individual health considerations. Here are some common types of contraception:

1. *Barrier Methods*: These methods work by creating a physical barrier between the sperm and the egg, preventing them from meeting. Examples include male and female condoms, diaphragms, and cervical caps.
2. *Hormonal Methods:* Hormonal methods use synthetic hormones to regulate the reproductive system and prevent pregnancy. These include oral contraceptive pills (commonly known as "the pill"), contraceptive patches, hormonal injections, vaginal rings, and hormonal intrauterine devices (IUDs).
3. *Intrauterine Devices* (IUDs): IUDs are small, T-shaped devices that are inserted into the uterus to prevent pregnancy. They can be hormonal (releasing progestin) or non-hormonal (copper-based) and provide long-term contraception.
4. *Emergency Contraception*: Also known as the "morning-after pill," emergency contraception is used after unprotected sex or contraceptive failure to prevent pregnancy. It is most effective when taken within 72 hours of intercourse.
5. *Sterilization*: Sterilization is a permanent form of contraception that involves surgical procedures to block or cut the fallopian tubes in women (tubal ligation) or the vas deferens in men (vasectomy). It is a non-reversible method and considered a permanent form of contraception.
6. *Natural Methods*: Natural methods rely on tracking and understanding a woman's menstrual cycle to determine fertile and non-fertile periods. This includes methods such as the fertility awareness method (FAM), basal body temperature method, and cervical mucus method.

7. *Behavioral Methods*: Behavioral methods involve modifying sexual behavior to avoid intercourse during the fertile period. This includes methods such as withdrawal (pull-out) method and lactational amenorrhea method (breastfeeding as a temporary contraceptive method).

It is important to note that no contraceptive method is 100% effective, and each method has its own advantages and disadvantages. It is recommended to consult with a healthcare provider to determine the most suitable contraceptive method based on individual needs, health considerations, and preferences.

8.11 Pregnancy Tests

Pregnancy tests are diagnostic tests that determine whether a woman is pregnant or not. These tests detect the presence of a hormone called human chorionic gonadotropin (hCG) in the woman's urine or blood. hCG is produced by the developing placenta shortly after fertilization occurs.

There are two main types of pregnancy tests: urine tests and blood tests.

1. Urine Tests:
    - Over-the-counter (OTC) urine tests: These tests are available at pharmacies and can be done at home. They usually involve collecting a urine sample in a cup or by holding the test stick in the urine stream. The test kit contains a strip or a test stick with a special chemical or antibody that reacts to hCG if it is present in the urine. The result is typically displayed as a positive or negative result.
    - Clinic-based urine tests: These tests are similar to OTC urine tests but may be performed at a healthcare provider's office or a clinic. The procedure and interpretation of the results are usually the same as OTC tests.
2. Blood Tests:
    - *Qualitative blood test*: This test measures the presence or absence of hCG in the blood. It can detect pregnancy earlier than urine tests, usually within a week after conception. The test is performed at a healthcare provider's office or a laboratory, where a blood sample is drawn from a vein. The results are reported as positive or negative.
    - *Quantitative blood test*: Also known as a beta hCG test, this test measures the exact amount of hCG in the blood. It can determine the level of hCG, which helps estimate the gestational age of the pregnancy and monitor the health of the pregnancy in some cases.

It's important to note that urine tests, especially those done at home, have a certain sensitivity level. Testing too early or with a diluted urine sample may lead to false-negative results. For more accurate results, it is recommended to wait until a missed period or follow the instructions provided with the test kit.

It's also important to remember that a positive pregnancy test should be confirmed by a healthcare professional through further evaluation, such as a physical examination and possibly an ultrasound.

Overall, pregnancy tests are reliable and convenient tools to determine pregnancy status. They provide valuable information for women who are trying to conceive or suspect they may be pregnant.

Check.Progress Exercise 3

1) Enumerate the three stages of foetal development.

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2) Define lactogenesis? Also highlight the role of hormones in the process of lacto genesis

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3) Name the hormones produced by the developing placenta shortly after fertilization.

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4) What do you understand by colostrums?

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LET US SUM

In this unit, we learnt about physiology of reproductive system, where we got an in- depth knowledge about female and male reproductive organs. We saw the role of hormones involved in development and functioning of these organs. Understanding the menstrual cycle is important for women's reproductive health, fertility, and overall well-being. Tracking the cycle can help identify any irregularities and facilitate family planning or the diagnosis of certain reproductive disorders. Various physiological changes occurring during pregnancy and lactation were also emphasized. Further, the unit focused on the different types of contraception and finally, in the last section, we learnt about various pregnancy determination tests.

GLOSSARY

Amniotic Fluid : is the fluid that surrounds and protects the developing fetus during pregnancy. It provides cushioning, regulates temperature, allows for fetal movement, and helps with the development of the fetal lungs, digestive system, and musculoskeletal system.

Blastocyst : is an early stage of embryo development that occurs about 5-7 days after fertilization. It is a hollow ball of cells with an inner cell mass that will develop into the fetus and an outer layer that will form the placenta. The blastocyst implants into the uterine lining to establish pregnancy.

Gametes **:** are reproductive cells produced by males and females. In males, gametes are called sperm cells and in females, gametes are called egg cells or ova.

Graafian follicle, : also known as a mature follicle, is a fluid-filled structure within the ovary that contains a fully developed oocyte (egg) during the follicular phase of the menstrual cycle.

Lactiferous ducts : are the ductal system within the breast that carries milk from the mammary glands to the nipple.

Scrotum : is an external sac of skin and muscle located between the thighs in males. It contains the testicles, which produce sperm and testosterone. The scrotum helps regulate the temperature of the testicles.

Spermatids : are immature male reproductive cells that are formed during spermatogenesis, the process of sperm cell production. They are the result of the division and transformation of spermatocytes. Spermatids undergo further maturation and morphological changes to eventually develop into mature spermatozoa, or sperm cells.

Vestibule : refers to the central area between the labia minora, contains the openings of the urethra and the vagina. It plays a role in sexual intercourse as it provides a passage for the insertion of the penis and serves as the site for the release of urine.

ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check your Progress I

1. The male reproductive system includes:

    1. The scrotum which contains -two testes, and two epididymis
    2. A pair of vas deferens
    3. A pair of sperriiatic cords
    4. A pair of seminal vesicles
    5. A pair of ejaculatory ducts
    6. Prostrate gland
    7. Penis

2. It serves as a storage and maturation site for sperm cells produced in the testes. It helps in the development of spermatozoa, sperm storage, and transport, allowing them to gain the ability to swim and fertilize an egg.
3. The vas deferens is a muscular tube that carries mature sperm cells from the epididymis to the urethra during ejaculation.
4. . It produces and secretes a milky fluid that forms a significant part of semen. This fluid contains substances that nourish and protect sperm, aiding in their motility and viability for successful fertilization.
5. Spermatogenesis is the process by which immature sperm cells undergo a series of transformations to become mature, functional spermatozoa. It occurs within the seminiferous tubules of the testes.
6. Male puberty is a phase of development in males that marks the transition from childhood to adulthood. One of the key hormones involved in male puberty is luteinizing hormone (LH), which is secreted by the anterior lobe of the pituitary gland.

Check your Progress II

1. The organs of the female reproductive system include the ovaries, fallopian tubes (also known as uterine tubes), uterus (womb), cervix, vagina, and external genitalia (vulva).
2. The fallopian tubes, also known as uterine tubes or oviducts, are a pair of slender tubes that connect the ovaries to the uterus in the female reproductive system. The fallopian tubes serve as a pathway for the transport of eggs from the ovaries to the uterus. It provide a site for fertilization of the egg by sperm, support early embryo development, and facilitate the movement of the embryo towards the uterus for implantation.
3. Menopause is a natural biological process that occurs in women typically around the age of 45-55. During menopause, the ovaries gradually stop producing eggs, and there is a decline in reproductive hormone levels, especially estrogen and progesterone. This hormonal shift leads to various physiological changes, such as irregular menstrual periods, hot flashes, night sweats, vaginal dryness, mood changes, and bone density loss.
4. The primary hormones responsible for stimulating changes in the ovaries are follicle-stimulating hormone (FSH) and luteinizing hormone (LH). FSH promotes the development and maturation of ovarian follicles, while LH triggers ovulation and the formation of the corpus luteum. These hormonal changes are essential for the menstrual cycle and reproductive processes.

Check your Progress III

1. The stages of fetal growth and development are:
   - *Zygote.*
   - *Embryonic Stage (Weeks 2-8)*
   - *Fetal Stage (Weeks 9-40)*
2. Lactogenesis is the onset of copious milk secretion around parturition, triggered by a fall in plasma progesterone levels Lactation is mainly governed by two hormones: prolactin and oxytocin. Prolactin stimulates milk synthesis, while oxytocin facilitates its release and flow.
3. Human Chorionic Gonadotropin (hCG)is a hormone produced by the developing placenta shortly after fertilization.
4. The first 2-3 days after delivery the breasts produce, a thick, yellowish fluid rich in antibodies and essential nutrientsis called as colostrum. Colostrum is highly beneficial for the newborn's immune system and serves as the first food for the baby.

UNIT: 9 SKELETAL SYSTEM

Structure

9.1 Introduction

Objectives

9.2 Cartilage and Bone

9.3 Classification of Skeleton

Axial Skeleton

Appendicular Skeleton

9.4 Axial Skeleton of Frog and Rabbit

Skull of Frog and Rabbit

Vertebral Column of Frog and Rabbit

Sternum of Frog and Sternum& Ribs of Rabbit

Chondrocranium in Rabbit

Jaw Suspensoria

9.5 Sternum & Ribs of Rabbit in association with pectoral and pelvic girdles: Appendicular Skeleton of Frog and Rabbit

Pectoral and Pelvic Girdles of Frog and Rabbit

Limbs of Frog and Rabbit

Appendicular skeleton of Frog & Rabbit

Sternum of Frog and Sternum & Ribs of Rabbit

Sternum & Ribs of Rabbit in association with pectoral and pelvic girdles

9.6 Auditory Region – Mammal

Development of Mammalian Ear BonesSummary

9.7 Summary

9.8 Text Questions

9.9 Answers to Text Questions

SKELETAL SYSTEM

9.1 Introduction

The entire body of a vertebrate is supported by a framework of connective tissue which packs and binds the various parts together, delimits spaces, and serves for the attachment of muscles. Doubtless primitively the vertebrates had an elongated body stiffened by the notochordal rod, and moved by a side-to-side bending more especially of the caudal region. Correlated with this mode of progression is the segmentation of the somatic or body-wall muscles, entailing the corresponding segmentation of the peripheral nervous system and the skeleton. The parts of the endoskeleton of cartilage or bone may be looked upon as local specializations of the general connective tissue system developed in those regions where the stresses are most pronounced and where the muscular attachments need most support. Although this primitive segmentation may be much modified in the adult, especially in the higher forms, and even scarcely recognisable, yet it is always distinctly shown in the embryo and persists more or less completely in lower forms. Now, in such primitive forms, the connective tissue surrounds the somatic muscle segments or myomeres, forming not only closed boxes in which they lie, but also a lining to the skin outside and to the body-cavity or coelom within. Connective tissue sheaths also surround the notochord, the neural canal enclosing the central nervous system, and the alimentary canal hanging in the coelom. Moreover, since the mesoblastic segments and the coelomic cavities are of paired origin, the body is divided into right and left halves by a longitudinal vertical median septum continuous with the sheaths enclosing the nervous system, notochord, and gut; this septum remains as a median dorsal and median ventral septum separating the myomeres, and as a median mesentery suspending the gut. The ventral mesentery below the gut disappears almost completely but the dorsal mesentery usually remains. This is formed a system of longitudinal septa and tubular coverings, and of transverse septa (myosepta, myocommata) intersegmental in position between the myomeres(Fig.1).

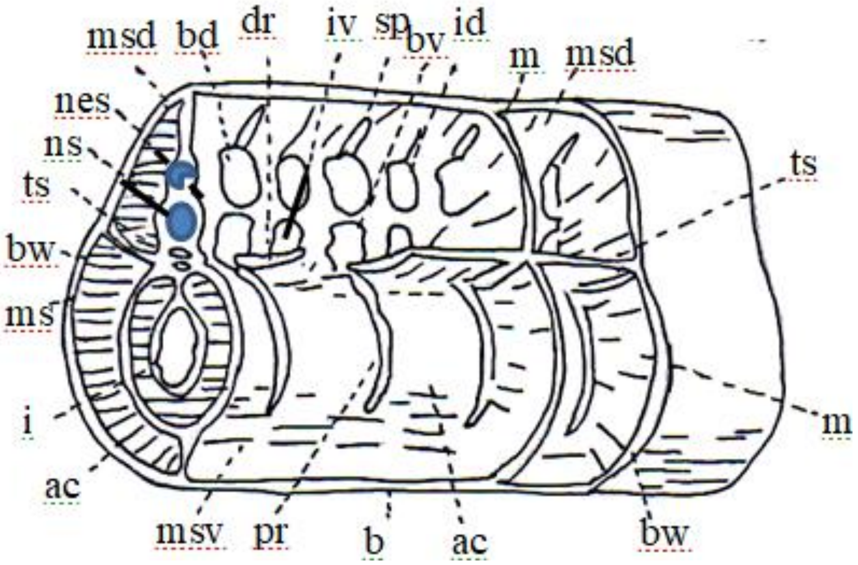


Fig. 1.Connective tissue system in the trunk of a Craniate Vertebrate showing the relation borne by the axial skeleton to the transverse and longitudinal septa. Oblique view of left side, from which the septa have been partially removed. [ac, wall of splanchnocoel; bd, basidorsal; bv, basiventral; bw, cut body wall; dr, dorsal lib; I, intestine hanging in the coelom; iv, interventral; m, transverse septum (myocomma); ms, mesentery; msd, median dorsal septum; msv, median dorsal septum; nes, neural tube; ns, notochordal sheath; pr, ventral or pleural rib; sp, supraneural spine; ls, horizontal septum; (From Goodrich, Vert. Craniata, 1909.)

Objectives:

With an appraisal of this unit you shall be able to:

- understand why cartilaginous endoskeleton or bone is required to facilitate support the general connective tissue system in regions of stress on muscular tissues.
- Understand the functional significance of notochord in the role of skeletal axis in the more primitive chordates but also provided underpinning strength to vertebral column in higher craniata.
- Understand the highlighted points that brought to notice advanced developments in skeletal system of rabbits*vis-à-vis*Amphibia.

9.2 Cartilage and bone

Cartilage and bone comprise Supportive and Connective tissues. Cartilage or gristle, is a supportive tissue consisting of a firm but elastic matrix (chondrin) secreted by small groups of rounded cartilage cells embedded within it. The exterior surface is covered by a thinmembrane, or perichondrium. Three kinds of cartilages are distinguished:- i) **Hyaline Cartilage:** This is bluish white in colour, transluscent and of homogenous texture; it covers the joint surfaces and ends of the ribs and is present in the nose and in the rings of the trachea. It is the skeletal cartilage in the embryos of all the vertebrates and in the adults of sharks and rays. It may become impregnated with calcareous salts but as such does not become bone. **Elastic Cartilage:** contains some fibres in the matrix; it is present in the external ears of mammals and in the Eustachian tubes. **Fibrocartilage:** is the most resistant type, containing a preponderance of fibres, with fewer cells and less matrix. It occurs in the pads between the vertebrae of mammals, in the pubic symphysis, and about joints subject to severe strains.

Fig. 2. The structure of bone (enlarged and diagrammatic) Three concentric lamellae around a Haversian canal, as seen in a thinly ground cross section.

True **bone or osseous tissue:** occurs only in the skeletons of bony fishes and land vertebrates (Fig. 2); it differs in structure and composition from the calcareous skeletons of echinoderms, molluscs and other invertebrates. Bone consists of a dense organic matrix (chiefly collagen) with deposits of mineral substance, especially tricalcium phosphate, $Ca_3(PO_4)_2$; the mineral part averages about 65% of the total weight. Bone forms either as replacement for previously existing cartilage (cartilage bone) or follows embryonic mesenchymal cells (membrane bone). In either case it is produced by bone cells, or osteoblasts, that secrete both the matrix and the hard material. The cells become separated and embedded but retain many minute protoplasmic connections with one another and another and with blood vessels. Bone is, therefore, a living tissue that may be resorbed in part or changed in composition. During the life of an individual the proportion of mineral gradually increases and the organic material decreases, so that bones are resilient in early youth and brittle in old age.

A bone is closely surrounded by thin fibrous periosteum, to which muscles and tendons attach. Within the periosteum are bone cells that function in growth and repair. The mineral substance is usually deposited in thin layers, or lamellae. Those beneath the peristomeum (periosteal lamellae) are parallel to the surface. Within this wall, especially in long bones, are many small tubular concentric lamellae, forming cylindrical Haversian systems. The wall of each system is of several such lamellae with a central cavity, or Haversian canal. The systems are mainly longitudinal, but the canals cross-connect so that channels are afforded for blood vessels and nerves to pass from the peristomeum to the interior marrow cavity of a bone. Individual bone cells occupy small spaces or lacunae, left between the lamellae as the mineral is deposited, and these are connected to one another by numerous minute radiating canals (canaliculi) occupied by protoplasmic processes. In flat (cancellous) bones as of the skull and in the ends of long bones, the interior lacks regular systems and is of more spongy texture. Gross sections made by sawing such bones will show that the bone fibres are arranged, like beams in arches and trusses, to resist compression stresses from the exterior. The central cavity in a long bone is filled with yellow marrow; the ends and the spaces in other bones contain red marrow, where blood cells are produced.

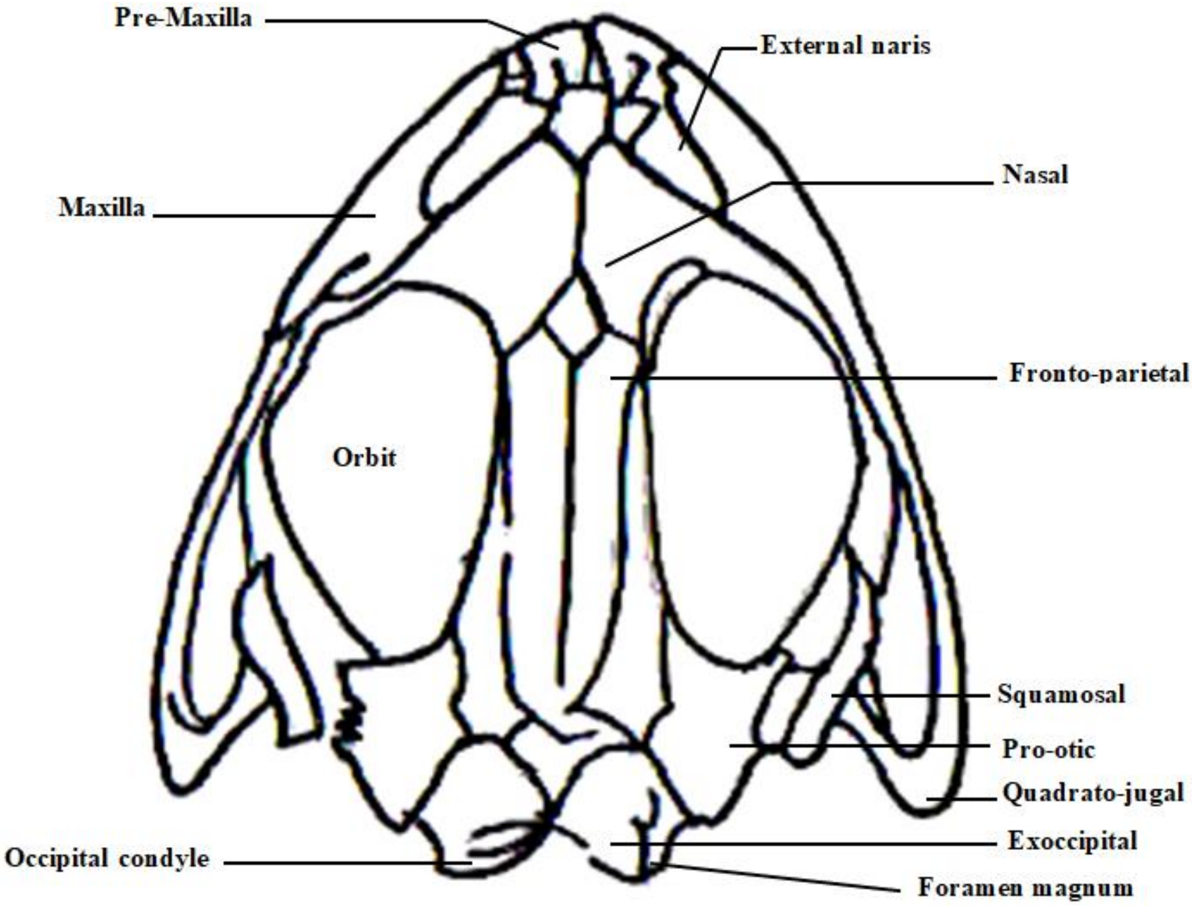
9.3 Classification of Skeleton

9.3.1 Axial Skeleton :

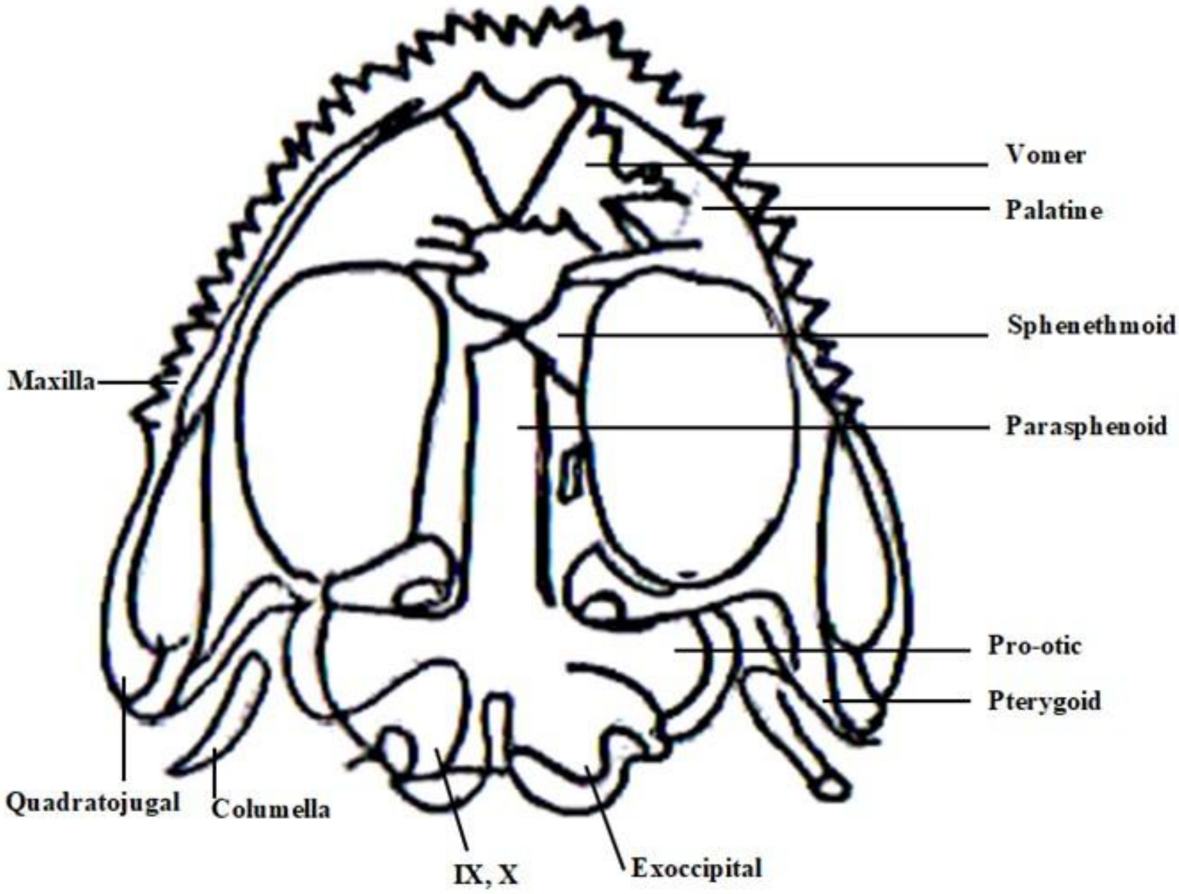
The skull, vertebral column and sternum comprise the axial skeleton (Figs. 3-5;Table 1).

The broad, flat skull comprised – (i) a narrow brain case, or cranium; (ii) the paired sense capsules of the nose and ear and large orbits for the eyes; and iii) the jaws, hyoid and cartilages of the larynx (visceral skeleton). The cranium is roofed mainly by the frontoparietals, the nasals cover the nasal capsules, the prootics house the inner ears, and posteriorly each exoccipetal bears a rounded occipital condyle. The two condyles fit depressions in the first vertebra and permit slight movement of the head on the spinal column. Between the condyle is the large opening, or foramen magnum, through which the brain and nerve cord connect. Over the roof of the mouth are two vomers that bear teeth, and the dagger-shaped parasphenoid. Each half of the upperjaw (maxillary arch) includes a pre-maxilla and maxilla with teeth and a quadratojugal, all fused to the cranium. The lower jaw (mandibular arch) on each side is a rod-like (Meckel’s) cartilage (Fig.3C).

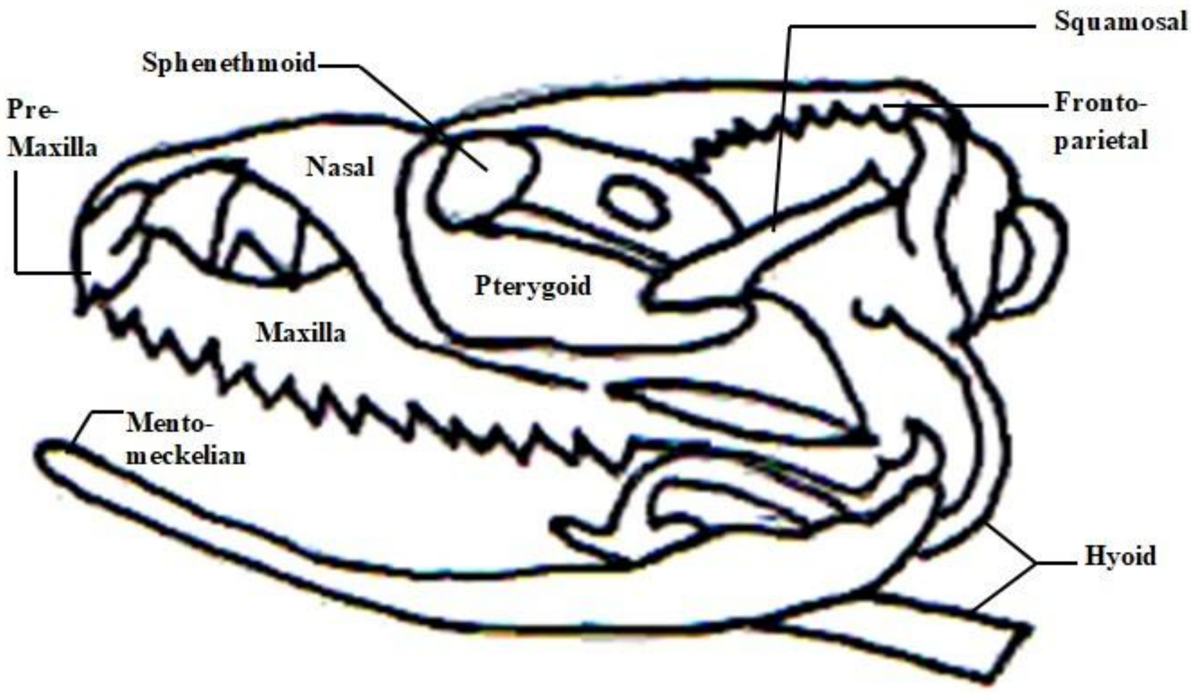
Cartilage, encased by the dentary and angulosplenial bones; the latter bone articulates to the quadrate cartilage on the cranium.


Pre-Maxilla
External naris
Nasal
Maxilla
Fronto-parietal
Orbit
Squamosal
Pro-otic
Quadrato-jugal
Exoccipital
Occipital condyle
Foramen magnum

A.


Vomer
Palatine
Sphenethmoid
Maxilla
Parasphenoid
Pro-otic
Pterygoid
Quadratojugal
Columella
IX, X
Exoccipital

B.


Squamosal
Sphenethmoid
Pre-
Maxilla
Fronto-
parietal
Nasal
Pterygoid
Maxilla
Mento-
meckelian
Hyoid

C.

Fig. 3.Skull of Frog in (A) Dorsal, (B) Ventral and (C) Lateral views. The lower jaw and hyoid cartilage are only in lateral view; cartilage stippled; II - X for cranial nerves.

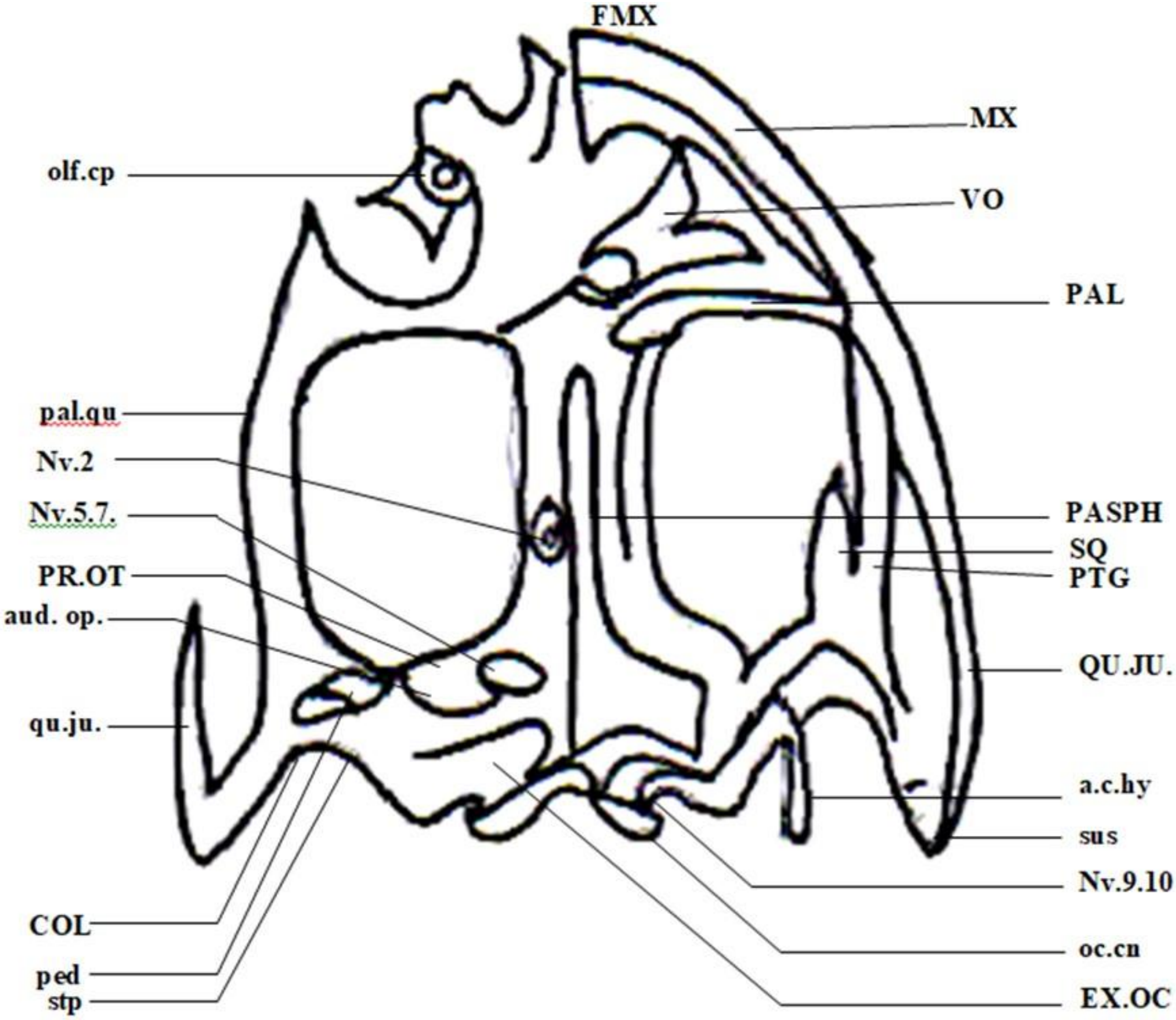


Fig 4.*Rana*- The Frog Skull. A. From beneath, with the investing bones removed on the right side (left of figure). a.c.hy, anterior cornu of hyoid; aud.cp, auditory capsule; b.hy, body of hyoid; COL, columella; DNT, dentary; EX.OC, exoccipital; for.mag., foramen magnum; FR.PA, fronto-parietal; M.MCK, mento-Meckelian; MX, maxilla; NA, nasal; Nv.2, optic foramen; Nv. 5,7, foramen for fifth and seventh nerves; Nv.9, 10, foramina for 9th and 10th nerves; oc.cn, occipital condyle; olf.cp, olfactory capsule; ot.pr, otic process; PAL, palatine; pal.qu, palatoquadrate; PA.SPH, parasphenoid; p.c.hy, posterior cornu of hyoid; ped, pedicle; PMX, premaxilla; PR.OT, pro-otic; PTG, pterygoid; QU.JU, quadratojugal; SP.ETH, sphenethmoid; SQ, paraquadrate; stp, stapes; sus (quad), suspensorium (quadrate); VO, prevomer (After Howes, slightly altered.) A minute investing bone, the septo-maxillary, which is present above the maxilla, close to the nostril, is not here represented. (From .Parker and Haswell, Zoology.)

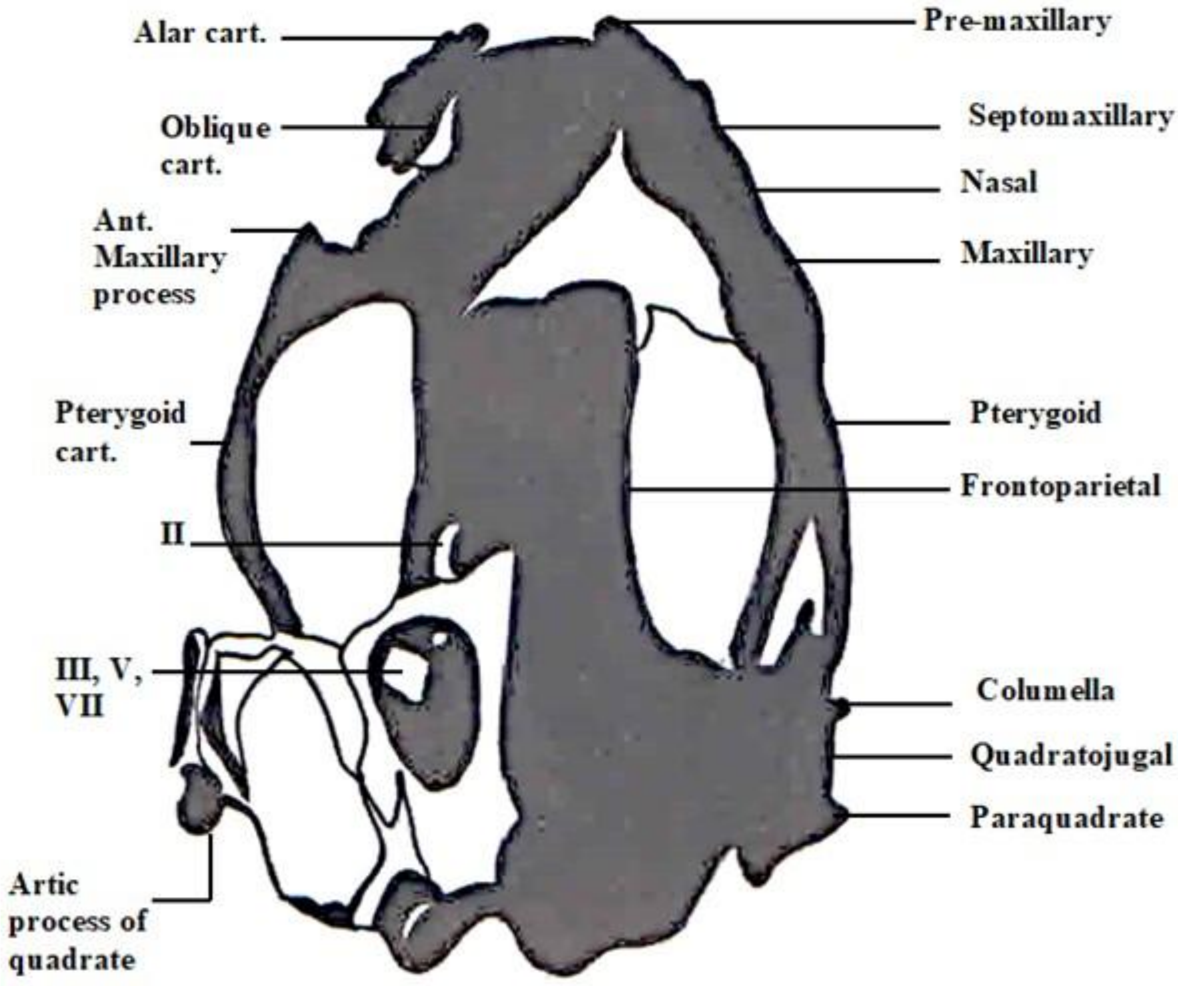


Fig. 5.Rana- The Frog Skull.From the dorsal side. The investing bones are removed on the left side. (After Guapp, from a model by Fr. Ziegler.)[From Wiedersheim, Comp. Anatomy.]

9.3.2. Appendicular Skeleton:

The spinal or vertebral column supports the body, connects to the head and limbs, and protects the nerve cord. It consists of nine vertebrae and a long thin urostyle. In the frog it is short, of few segments, and scarcely flexible, being thus unlike the column in most vertebrates. Each vertebra is made up of a spool-like centrum surmounted by a neural arch to house the nerve cord. Above the arch is a low neural spine, at either side is a broad transverse process, and at either end is a pair of zygapophyses that articulate with others on adjacent vertebrae. A frog has no ribs.

The limbs and girdles form the appendicular skeleton (Table 1). The anterior or pectoral girdle is a ں-shaped framework around the thorax that shelters organs within and supports the fore limbs; it is attached to the vertebrae by muscles. Each half includes a broad cartilaginous suprascapula dorsally, a narrower scapula laterally, and the slender clavicle and wider coracoid ventrally. The latter join to the mid-ventral breastbone, or sternum, which is largely cartilaginous and of several parts (epi-, om-, meso- and xiphi-sternum from before backward). The glenoid fossa is a shallow depression in the scapula and coracoid in which the head of the humerus in the fore limb articulates.

The posterior or pelvic girdle is a stout rigid V-shaped frame that connects the hind limbs to the body. It consists of three bones on each side, the long ilium anteriorly, the ischium posteriorly, and pubis ventrally. Where these join, there is a cup-like socket, or acetabulum, in which the head of the femur of the hind limb articulates. Each ilium has a long process, parallel to the urostyle, that attaches to a stout transverse process on the ninth, or "sacral", vertebra.

The two pairs of limbs differ in size but have similar component bones and parts as follows:

FORE LIMB Humerus Radius and Ulna (fused) Carpals Metacarpals Phalanges
(arm) (Upper arm) (forearm) (wrist) (palm of hand) (fingers)

HIND LIMB Femur Tibia and Fibula (fused) Tarsals Metatarsals Phalanges
(leg) (Thigh) (foreleg) (ankle) (sole of foot) (toes)

Table 1.General divisions of the skeleton in a land vertebrate.

Axial skeleton (median)			Appendicular skeleton (lateral, paired)	
Skull	**Vertebral column**	**Thoracic basket**	**Pectoral (anterior)**	**Pelvic (posterior)**

Cranium (Brain box) **Sense capsules (nose, eye, ear)** **Visceral arches** **(jaws, hyoid, larynx)**	**Vertebrae** **Cervical (neck)** **Thoracic (chest)** **Lumbar (lower back)** **Sacral (hip)** **Caudal (tail)**	Ribs (paired; bony or cartilaginous) Sternum (breastbone)	Shoulder girdle Scapula Clavicle Coracoid Fore limb Humerus (upper arm) Radius and ulna (forearm) Carpals (wrist) Metacarpals (palm) Phalanges (fingers)	Hip girdle (dorsal) (anterior) (posterior) Pubis Ischium Hind limb Femur (thigh) Tibia and fibula (foreleg) Tarsals (ankle) Metatarsals (sole) Phalanges (toes)

9.4 Axial Skeleton of Frog and Rabbit:

9.4.1 Skull of Frog:

Premaxilla: It is the bone of upper jaw, and a movable bone of skull of frog. It is situated in front of the nasal capsule at the anterior end of maxilla. It is a small bone and takes part to constitute snout. It bears 5 or 6 backwardly directed conical homodont teeth, and helps in opening and closing of nostrils.

Maxilla: It is a thin, long, slightly curved bone, and constitutes major part of upper jaw, as it is its marginal investing bone.It bears numerous backwardly directed conical homodont teeth, and is posteriorly joined to quadratojugal and anteriorly with pre-maxilla. It joins ventrally the palatine and the anterior limbs of pterygoid.

Quadratojugal: It is a knob-shaped bone which is an investing bone of the skull of frog.It joins maxilla anteriorly, and helps in articulation of lower jaw with upper jaw.

Quadrate: It is rod-shaped suspension cartilage that connects mandible with skull. Anteriorly it is fused with auditory capsule and posteriorly attached to the hind end of the quadratojugal. It is completely covered under pterygoid and squamosal.

Palatine: It is membranous bone of skull of frog, and is a rod-like bone. It is generally placed transversely on the ventral surface near vomer. It formed the anterior boundary of the orbit which is attached on the inner side with sphenethmoid and outside with maxilla.

Squamosal: It is the investing bone of the dorsal side of the skull of frog, which is hammer-shaped. It attaches dorso-laterally with posterior end of cranium. Its head is attached with the outer surface of auditory capsule, and also joined quadrate cartilage and pro-otic bone.

Pterygoid: It is a Y-shaped investing bone of the skull of frog, generally situated on the ventral surface of the posterior side of the skull. It joined with maxilla anteriorlyand outer end of palatine while posteriorly it connects with quadratojugal. The inner side of the bone joins with parasphenoid and auditory capsule.

9.4.2 Skull of Rabbit-

The shape and the size of the skull of rabbit differs considerably from that of the skull of frog. It consists of following parts:-

(a) **Cranium-** This is the brain box as it enclosesthe brain. It is generally made up of cartilages.

(b) **Sense capsule-** This consists of three capsules-

(i) Olfactory capsule

(ii) Auditory capsule

(iii) Optic capsule

(c) **Visceral skeleton-** It consists of the upper and lower jaw and hyoid apparatus.

Chondrocranium well ossified. Orbital region well developed. Articulation is dicondylic. Small temporal fossa present on zygomatic arch of squamosal. Few bones are spongy in nature. Turbinal bones are in many folds folds in nasal chamber. Pro-otic, epi-otic and opisthotic are fused and form a single periotic on both sides.

Auditory capsules consist of three ear ossicles (malleus, incus and stapes). Pre-frontal, post-frontal, parasphenoid and quadratojugal are absent. Pterygoid reduced and scale like. Pre-maxillae, maxillae palatine make a horizontal plate in between buccal and nasal cavities. Tympanic is flask-shaped bone called Tympanic bulla.

Dentition is thecodont, diphyodont and heterodont. Dental formula is:-

$$i = \frac{2}{1}, \quad c = \frac{0}{0}, \quad pm = \frac{3}{2}, \quad m = \frac{3}{3}, \quad = 28$$

Lower jaw is made up of two similar bones called dentary. Cranio-stylicsuspensorium of the jaw that is mandible connects with squamosal of the skull.

Disarticulated skull comprised of the following bones:-

The disarticulated skull of rabbit comprised of occipital region, squamosal, parietal,interparietal, basisphenoid, ali-sphenoid,pre-sphenoids and orbito-sphenoids, frontals,nasal, vomers, turbinals, peri-otic, and tympanic bulla. Jaw bones arePremaxilla, Maxilla, jugal, Pterygoid, Palatine and dentary.

1. **Occipital region:**

It is the posterior-most part of the skull which is covered dorsally by fronto-parietals and ventrally by parasphenoid. It has foramen magnum for the spinal cord. It is made up ofa pair of irregular exoccipitals, which surround a large foramen magnum. Each ex-occipital bears an occipital condyle, which fits in a facet in atlas vertebra. The basi and supra-occipital are absent. An auditory capsule is also attached on outer side of ex-occipital and has only pro-otic bone. The capsule communicates to outside by fenestra ovalis.

2. **Squamosal:** It is an investing bone of the skull of rabbit. It is rectangular and located ventral to palatine to form the cranial wall. It gives out zygomatic process and a posterior tympanic process. It has mandibular fossa on its surface for articulation with lower jaw.

3. **Parietal:** It is a thin, rectangular investing bone that forms roof of the brain to protect the brain. Both parietals are united in the middle. A wedge-like thin bone is called inter-pareital, found in between two parietal and supra-occipital.

4. **Inter-parietal:** It is a triangular membrane bone between parietals and supra-occipital.

5. **Fronto-parietals:** These are paired bones on the roof of cranium and are united in the middle. It is the investing bone of the cranium of frog. It is made up of frontals and parietals. It is joined anteriorly with nasal and posteriorly with pro-otic and ex-occipital.

6. **Basi-sphenoid and Ali-sphenoids**: It is a compound bone of parietal region of the cranium. The basi-sphenoid is a medium triangular bone in front of basi-occipital bearing a pituitary foramen. The bone articulates with pre-sphenoid and ali-

sphenoid. The ali-sphenoid are paired and wing-like bones on sides of basi-sphenoid and formed walls of brain-box. Each bone gives off a crest-like external pterygoid process for palatine.

7. **Pre-sphenoid and orbito-sphenoids:** It is a compound bone of frontal region of cranium. The pre-sphenoid is a median narrow and laterally compressed bone in front of basi-sphenoid. It contributed to the optic foramen and to the wall of cranium and orbit.
8. **Sphenethmoid:** It is a hollow, tubular bone visible only on sides and as a diamond shaped area above. It is a replacing bone of the skull of frog. It forms the lateral walls of the cranium. It is divided into anterior ethmoidal region and posterior sphenoidal region. It encloses the anterior part of the brain. On the ventral side of this bone is attached the parasphenoid. It helps in making the olfactory capsule.
9. **Parasphenoid:** It is a flat, invested "T" shaped or dagger-like bone, that lies along the floor of cranium. Its transverse handle extends below the auditory capsules. It is the investing bone of the cranium of frog, and is large with a dagger-like anterior end.
10. **Frontals:** It is an investing bone of the skull of rabbit. It forms the frontal parts of the roof of cranium. It has prominent suture at posterior end. It gives out laterally on inner side crescentic supra-orbial process.
11. **Columella:** It is a bone of middle ear of frog. It is small, rod-like, tubular bone. Its outer end is attached with tympanic membrane. It conducts sound vibrations upto inner ear located in the head.

12. **Nasal:** It is narrow, slender and thin investing bone of the skull of rabbit which forms the roof of olfactory chamber. These form the upper boundary of the external nostril.
13. **Turbinals:** It is a compound bone consisting of ethmo-turbinal, maxillo-turbinal and naso-turbinal. It occurs in the olfactory chamber.
14. **Septo-maxillary:** It is the bone of the skull of frog. It is situated in front of the nasal bone. It is minute and irregular in shape. Its border end forms the boundary of the external nares.
15. **Vomers:** These are membranous bones covering the floor of the olfactory capsules. It is flat, triangular bone. It makes the ventral part of the nasal chamber. The postero-lateral surface is provided with posterior teeth known as vomerine teeth.
16. **Peri-otic and Tympanic bulla:** Peri-otic is a compound bone made by fusion of pre-, epi- and opisthotic bone. It is in association with tympanic. It loosely fits with squamosal. Fenestra ovalis and rotundus bone present. Tympanic is flask shaped, membranous bone. Tympanic bulla, swollen portion for containing ear ossicles present. Stylomastoid foramen for facial nerve present.
17. **Pre-maxilla:** It is the investing bone of the upper jaw and forms the anterior-most boundary of the snout. Posteriorly it gives out nasal and palatine process. It contributes to the formation of diastema. It carries two incisors in the sockets.
18. **Maxilla:** Irregular and large investing bone which makes the large part of upper jaw. It consists of six sockets for three pre-molar and molar teeth. It gives out many processes- maxillary process, palatine process and zygomatic process. It also takes part in the formation of diastema. Anteriorly it articulates with pre-maxilla and frontal. Greater palatine foramen present.

19. **Jugal:** Jugal is a laterally compressed bone. It forms major part of zygomatic arch.
20. **Pterygoid:** It is small scale-like bone, attached vertically at the junction of palatine, ali-sphenoid and basi-sphenoid.
21. **Palatine:** Irregular-shaped bone. Anteriorly it forms hard palate and posteriorly it meets ali-sphenoid and pterygoid.
22. **Sphenethmoid:** It is a hollow, tubular bone visible only on sides and as a diamond shaped area above. It is a replacing bone of the skull of frog. It forms the lateral walls of the cranium. It is divided into anterior ethmoidal region and posterior sphenoidal region. It encloses the anterior part of the brain. On the ventral side of this bone is attached the parasphenoid. It helps in making the olfactory capsule.
23. **Parasphenoid:** It is a flat, invested "T" shaped or dagger-like bone, that lies along the floor of cranium. Its transverse handle extends below the auditory capsules. It is the investing bone of the cranium of frog, and is large with a dagger-like anterior end.

9.4.3 The vertebral column-

Great diversity occurs in the various groups not only in the number of elements serving to arch over the neural canal and to enclose the haemal canal, but the vertebral centra themselves may vary greatly. They may be of more or less complex build, may be well developed, vestigial, or altogether absent, and even may be more numerous than the segments in which they lie. Yet it is probable that the vertebrae are fundamentally homologous throughout the Craniata. The earlier scientists roughly identified arches and centra in fishes and land vertebrates; but during later years attempts have been made to compare in detail different types of vertebral column and refer them to a single scheme of homologous parts.

All animals in some phyla and some in most of the others have a firm framework, or skeleton, that gives physical support and protection for the body and often provides surfaces for the attachment of muscles. A skeleton is not absolutely essential, however, since many aquatic invertebrates and a few land forms have none. Parts of the skeleton in arthropods and vertebrates form jointed appendages that serve as levers in locomotion. In such cases there is a close mutual relation of structure and function between the skeletal parts and muscles, whereby their interaction is more efficient.

The skeleton may be a shell or other external covering (exoskeleton), as on corals, molluscs, and arthropods, or internal (endoskeleton) as with vertebrates. It is rigid on corals, many molluscs and others, but variously jointed and movable in vertebrates. Exoskeletons serving as defensive armour were present on fossil animals, such as trilobites, primitive fishes (ostracoderms), early amphibians (labyrinthodonts), and some ancient reptiles (dinosaurs); they occur also on living barnacles, some fishes, the turtles, and the armadillo.

An exoskeleton limits the ultimate size of an animal and may become so heavy that the organism must remain fixed. This is because the internal muscles cannot be large and powerful enough to move the heavy framework. The internal skeleton of a vertebrate involves far less limitation in this respect, and a number of vertebrates have attained to huge size; these include the brontosaurs and other fossil reptiles and the living elephants and rhinoceroses. Even greater size is attained by some sharks and whales whose weight is partly supported by the water).

The body framework is a jointed internal skeleton that supports the soft parts, protects vital organs, and affords attachments for muscles used in movement and locomotion. In an early frog larva it is entirely of soft gristle or cartilage, but many parts later become hard bone. Cartilage persists on the ends of limb bones to form smooth joint surfaces and in parts of the skull and limb girdles.

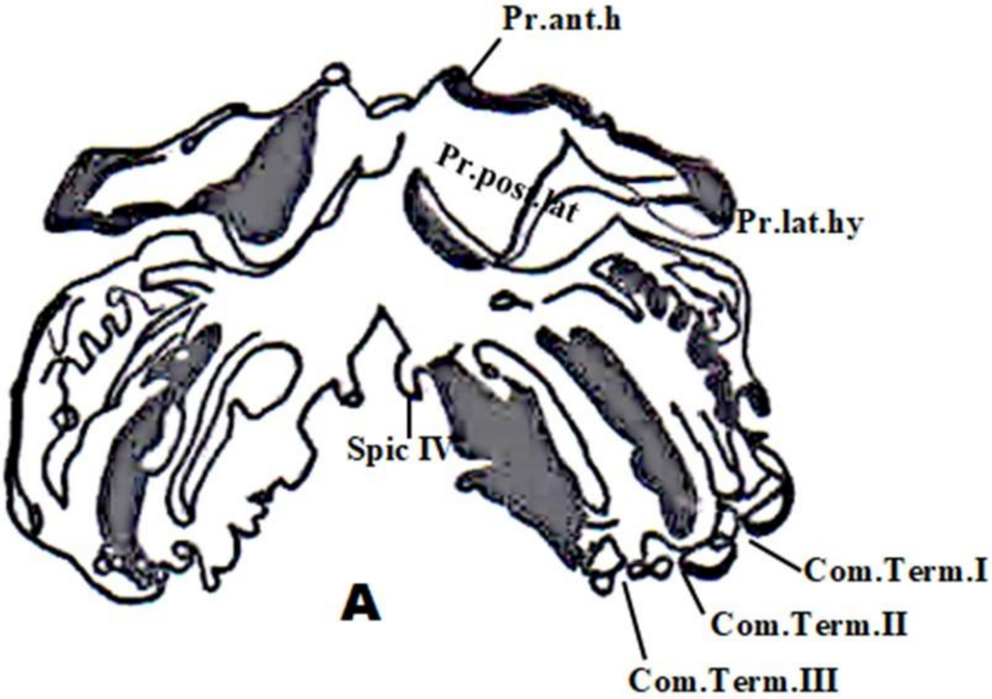
The internal skeleton has a common basic pattern of the fundamental features seen in frog. From the cyclostomes to the mammals a progressive sequence may be traced, although there are many differences in the size and form of component parts and in the presence or absence of certain elements. The essential features in a land vertebrate are given in Table 1. The skeleton supports the body, provides for attachment of muscles, and houses the brain and nerve cord. In all but the cyclostomes it includes framework for the jaws and the paired fins or limbs. The skeleton consists of cartilage in adult cyclostomes and sharks and in the embryos of all higher vertebrates, but in the adults of bony fishes to mammals it is largely of bone with cartilage over joint surfaces and in a few other places. The skeletal parts increase gradually in size by growth at the ends or margins. This continues throughout life in all except the birds and mammals, which attain to a definite size and then cease to grow.

In all chordates the first skeletal element to appear is a slender unsegmented and gelatinous rod, the notochord, that extends along the body axis between the digestive system and the nerve cord. It persists thus in Amphioxus and cyclostomes but in fishes and higher types is laterally surrounded and supplanted by the "backbone", or spinal column, separate vertebrae. On the spool-like centrum of each vertebrae is a dorsal neural arch to enclose the nerve cord. In the tails of fish each vertebra has also a ventral hemal arch around the main artery and vein of the tail. In the body or trunk region this arch is spread open and forms rib-like structures shielding the internal organs. In land vertebrates the centrum bears a pair of transverse processes as points of attachment for the true ribs of these animals (except frogs). At either end of the centrum are two articular processes by which one vertebra may turn sideways on those directly before and behind. The vertebral column of fishes comprises only trunk and tail regions, but in salamander reptiles, and mammals five regions are differentiated, as follows: neck, or cervical; chest or thoracic, with ribs; lower back, or lumbar; pelvic, or sacral, joining the hind-limb girdle; and tail, or caudal. The caudal vertebrae are reduced in man and birds. Long-bodied swimming vertebrates have the vertebrae numerous and much alike as seen in eels and similar fishes, in some salamanders (Siren), in some fossil reptiles.

9.4.4 Sternum of Frog and Sternum & Ribs of Rabbit:

Sternum of Frog:

A typical sternum (Figs. 6A-C) occurred in living Gnathostomes only in Amniota, where it occurred as a median ventral endoskeletal plate in the thoracic region. It serves for protection of organs in the thoracic cavity, for the attachment of pectoral limb muscles, and in respiratory movements, the first and a varying number of more posterior thoracic ribs being articulated to it ventrally.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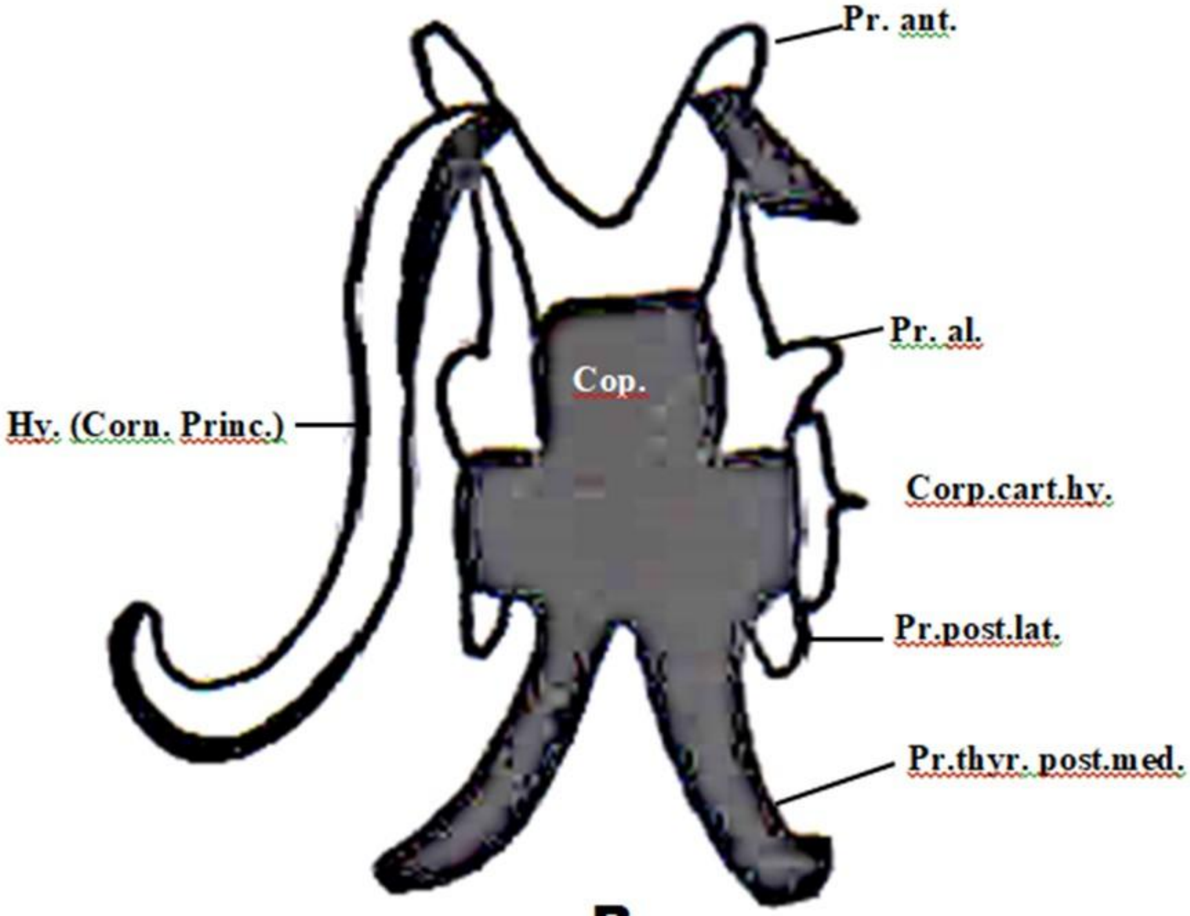
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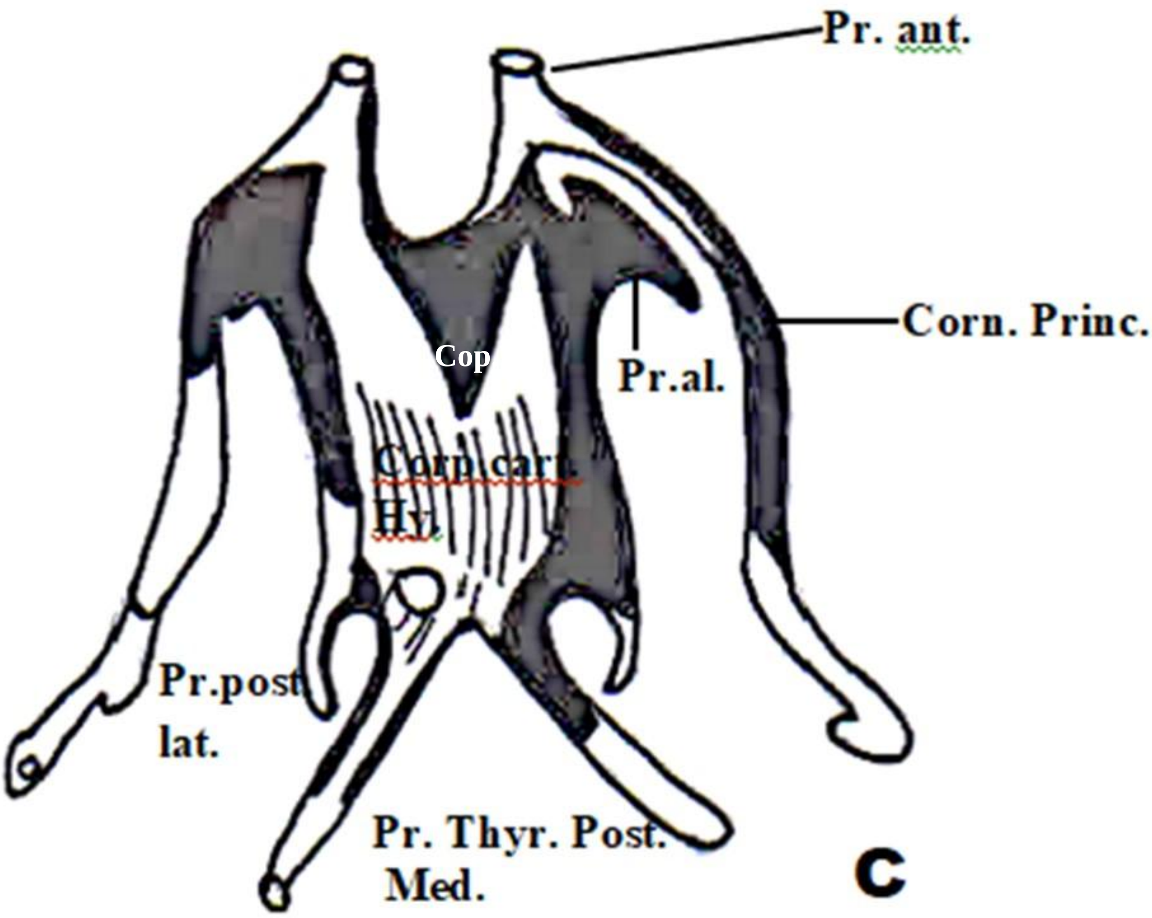


Fig.6. A. Hyobranchial skeleton of a larval frog, *Rana* sp. From the dorsal side; B. the same of a larva at the end of metamorphosis, after disappearance of the tail; C. hyoid cartilage of a young frog from the ventral side.(All are from wax models after Gaupp) (A and B in part), Branch I – IV, branchial arches; Com. Term. I – III, terminal commissures of same; cop, basal plate (copula); Hy, hyoid; Pr. And hy, Pr. Lat.hy, Pr.post.hy, anterior, lateral and posterior processes of the hyoid.; Spic. I – IV, cartilaginous processes.B (In Part) and c, Corp.cart.hy, body of hyoid cartilage; Corn.Princ., anterior cornu; Man, 'manubrium'; Pr.al, alary process; Pr.ant, anterior process; Pr.post.lat, posterior-lateral process; Pr.thyr.post.med, thyroid or postero-medial process (posterior cornu). (From Wiedersheim, Comparative Anatomy)

9.4.5 Chondrocranium in Rabbit-

Considerable doubt existed as to the development of trabeculae in mammals. Certainly the base of the prechordal cranium appears as a rule in mammals in two regions : as paired islands of cartilage lateral or postero-lateral to the hypophysis, and as a median rod extending from the hypophysis to between the nasal sacs. Later the posterior cartilages join across and spread so as to floor the pituitary fossa, and unite with the anterior rod in front and the basal plate behind. The paired posterior elements have been considered as trabeculae, but some scientists have compared these with polar cartilages. They lie, however, at first between the internal carotids. In rabbits, the internal carotids primitively enter the cranial cavity from below on the median or inner side of the trabeculae. The relative position of these parts, therefore, seems at first sight to be reversed, since the carotids pass laterally to the central 'polar' or posterior 'trabecular' plate, and the carotid foramina are later completed by the growth from the trabecular of a commisuraali-cochlearis or trabeculo-cochlearis anterior passing on the outer (lateral) side of the artery to join the cochlear region of the auditory capsule. The anterior trabeculo-cochlear commissure (commissuraalicochlearis) represented the original base of the trabecular (that region sometimes developed from a separate 'polar' element). In Placentals especially it appears to have been pushed outwards, and so come to unite more with the capsule than with the basal plate. Thus the trabeculae preserve their usual position relative to the carotids, though it is possible that these have become to some extent surrounded by the trabecular cartilage; certainly cartilage develops between them. In the ethmoid region, the nasal capsule extends backwards along the lengthening internasal septum, while the interorbital septum becomes correspondingly shortened.

Ala temporalis-

The validity of the fate of cavumepiptericum in the mammalian skull depends to a greater extent on the interpretation of the homology of the ala temporalis. The more horizontal region of this structure (processusalaris) is developed as an outgrowth from the posterior trabecular rudiment. The 5^{th} nerve and its ganglia and the vena capitislateralis lie above it; the palatine arises from the facial behind it, and pass forward (joining a sympathetic nerve) as the vidian nerve below it. It thus has the same morphological relation to surrounding structures as the basitrabecular process of lower Gnathostomes, and is doubtless homologous with it.

The fundamentally primitive character of the chondrocranium have been known alone to have preserved complete the pilaantotica (taeniaclino-orbitalis) of the original wall. This pila has disappeared in the Ditremata, its last vestiges being perhaps represented by certain small cartilages found above the Gasserian ganglion in *Lepus*, *Felis* and other mammals(Fig. 7).

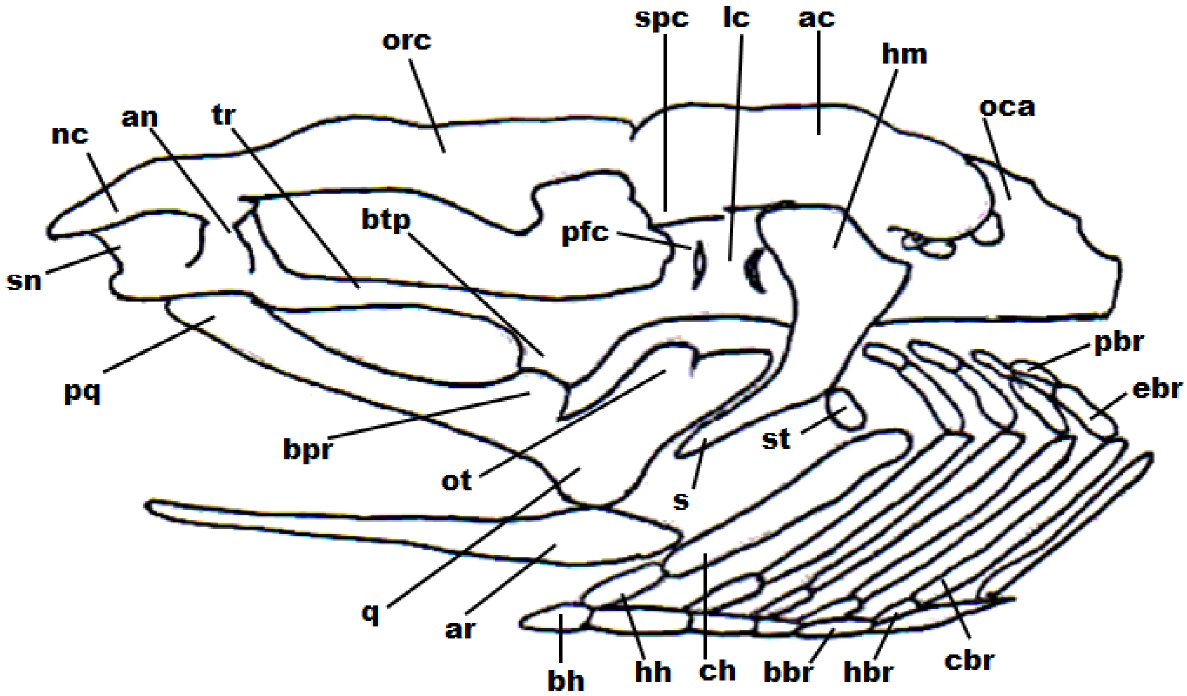


Fig. 7.Chondrocranium and visceral arches of primitive Teleostome leading to Holostean type.[ac, Auditory capsule; an, antorbital process; ar, articular region; bbr, basibranchial; bh, basihyal; bpr, basal process; btp, basitrabecular process; cbr, ceratobranchial; ch, ceratohyal; cbr, epibranchial; hbr, hypobranchial; hp, hypohyal; hm, hyomandibular; lc, lateral commissure; nc, nasal capsule; oca, occipital arch; orc, orbital; ot, otic process; pfc, prefacial commissure; pbr, pharyngobrancheal; pq, palatine region of platoquadrate; q, quadrate region; s, symplectic region; sm, septum nasi; spc, spiracular canal through postorbital process; st, stylohyal; tr, trabecula.

Dermal Bones of the Skull in Amniota:

The structure of the dermal roofing of the skull has been recognized as of the greatest value in tracing out the affinities of the Reptiles not only with each other, but also with the

Birds on one hand and the Mammals on the other. It is now admitted that the early primitive Reptilia had a complete roofinf like that of Stegocephalia and primitive Osteichthyes, pierced only for orbits, nostrils, and pineal eye; and further, that secondary openings have been formed in this roofing in different ways in the various diverging phylogenetic lines. Thus have arisen openings variously called vacuities, foramina, or fossae, leaving where necessary buttresses or arches to strengthen the skull, support the jaws and quadrates, and delimit the orbits. It is agreed that there are at least three main types of dermal roofing: (i) with one lateral temporal fossa; (20 with two lateral temporal fossae, one superior and the other inferior; (3) with no fossa at all (Fig. 8). The latter 'stegocephalian' condition is found in those primitive carboniferous Permian and Triassic reptiles which retain the original complete roofing intact, usually with all or most of the original dermal bones (Microsauria, Seymouriomorpha, Cotylosauria). Such primitive forms, in which the whole skull is built on essentially the same plan as in Stegocephalia, may be provisionally included in the Division Anapsida; probably a polyphyletic assemblage containing scarcely differentiate early representatives of several divergent groups. The Microsauria will have a frankly stegocephalian structure and are often included in the Amphibia (Fig. 8).

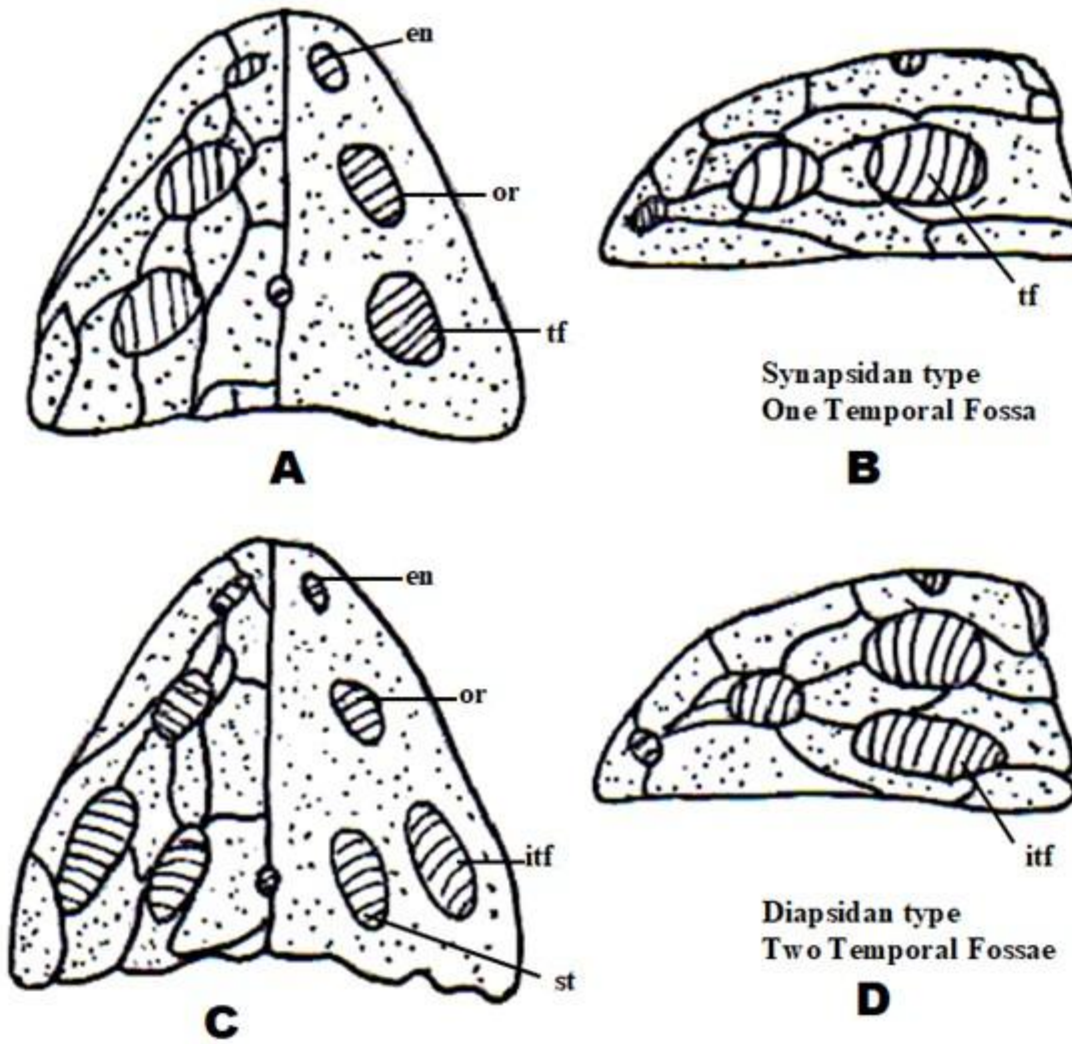


Fig. 8.Two Principal Types of Cranial Roof in Frog (A, B) and Rabbit.**(C,D)** Dorsal views on left, lateral views on right. [en, External nostril; or, orbit; p, pineal foramen; itf, stf, tf, inferior, superior and single lateral temporal fossae]

The interpretation of the palate of the mammal involves the important question of the homology of the mammalian vomer still under dispute. For long it was though that it represented the paired vomers (prevomers) of lower forms, which typically extend between the internal nostrils, and form their postero-medial boundary. It was concluded by Parker that the prevomers of lower forms correspond to the palatal processes of the premaxillae of most mammals. Later he claimed to show that these processes appear in many of the lower Mammalia as separate bones which later fuse with the premaxillae (Figs. 9-11).

Jacobson's organ, which appears to serve for smelling the liquid contents of the buccal cavity, occurs in the Amniota as a small sac, blind behind and opening in front towards the palatal surface at or near the internal nostril. It is derived in development from the wall of nasal cavity, and is supported below by the paraseptal cartilage and the prevomer which underlies it.

9.4.6 Jaw Suspensoria:

An upper jaw and a Lower jaw are the essential characteristics of the frog and other vertebrates. Skeleton of each jaw is an arch made up of identical right and left halves or rami which articulate with each other medially only at front end of the skull. Certain cartilages and bones, collectively termed as Jaw Suspensoria, serve to articulate the jaws with cranial skeleton.

(A) The Upper Jaw: (or Maxillary arch): This is firmly and immovably articulated with the cranial skeleton. In tadpole, each ramus (i.e. half) of this jaw is just a narrow, curved rod of cartilage, called pterygoquadrate cartilage bar. Later, three membrane bones become invested upon it, *viz.*, a small pre-maxilla in front, a long maxilla in the middle, and a small quadrato-jugal behind.

SUSPENSORIA OF UPPER JAW: In tadpole of a frog, small triradiate cartilaginous bar articulates each ramus of both jaws with the cranial skeleton at latter's corresponding postero-lateral angle. In adult frog, this bar is largely replaced by three membrane bones, forming the suspensorium of the corresponding ramus of upper jaw. These bones are the squamosal and pterygoid behind, and the palatine in front. The original cartilaginous bar is reduced to a small quadrate cartilage which serves as the suspensorium of the corresponding ramus of lower jaw.

(B) **LOWER JAW (i.e. mandibular arch) & ITS SUSPENSORIUM:**

This jaw is toothless and movable up and down, because it is loosely articulated with the skull only at the latter's postero-lateral angles by means of a small quadrate cartilage (suspensorium) on each side. Such a suspension of lower jaw from the skull is called autostylic. The rami of this jaw join at front end of the snout by means of an elastic ligament, forming a symphysis. Each ramus is a slender and slightly curved skeletal rod. It consists of a persistent axial core of Meckel's cartilage, most of which is covered by two membrane bones – the dentary on outer and angulo-splenial on inner sides. A small anteriormost part of Meckel's cartilage is ossified, forming a replacing bone called mentomeckelian.[mentomeckelian bones- These lie just beneath the pre-maxillae of upper jaw and serve to move these up and down to close or open the external nares. Both mentomeckelians medially join at the front end by above referred symphysis.]

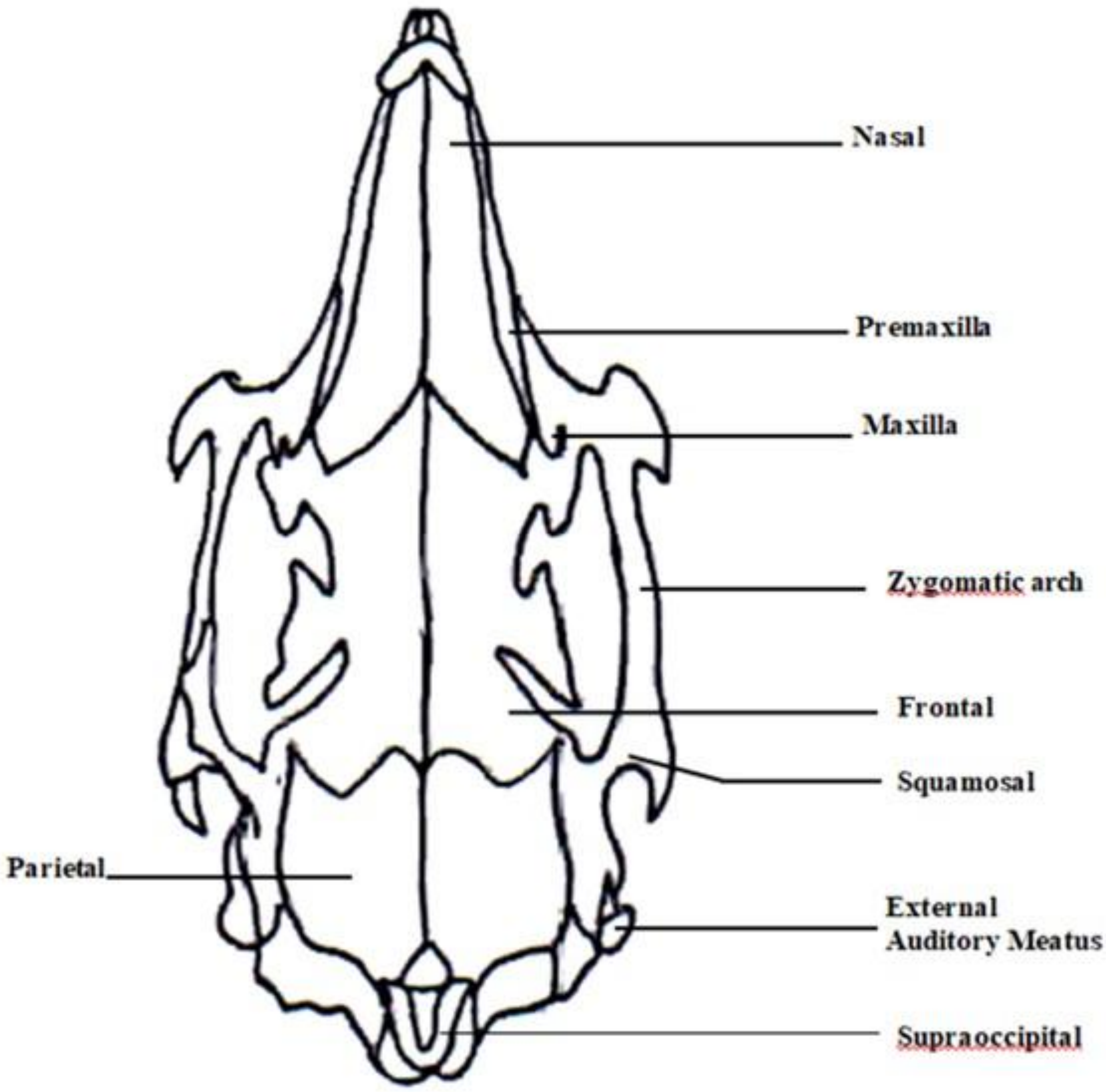


Fig. 9. A. Dorsal view of skull of *Oryctolagus*.

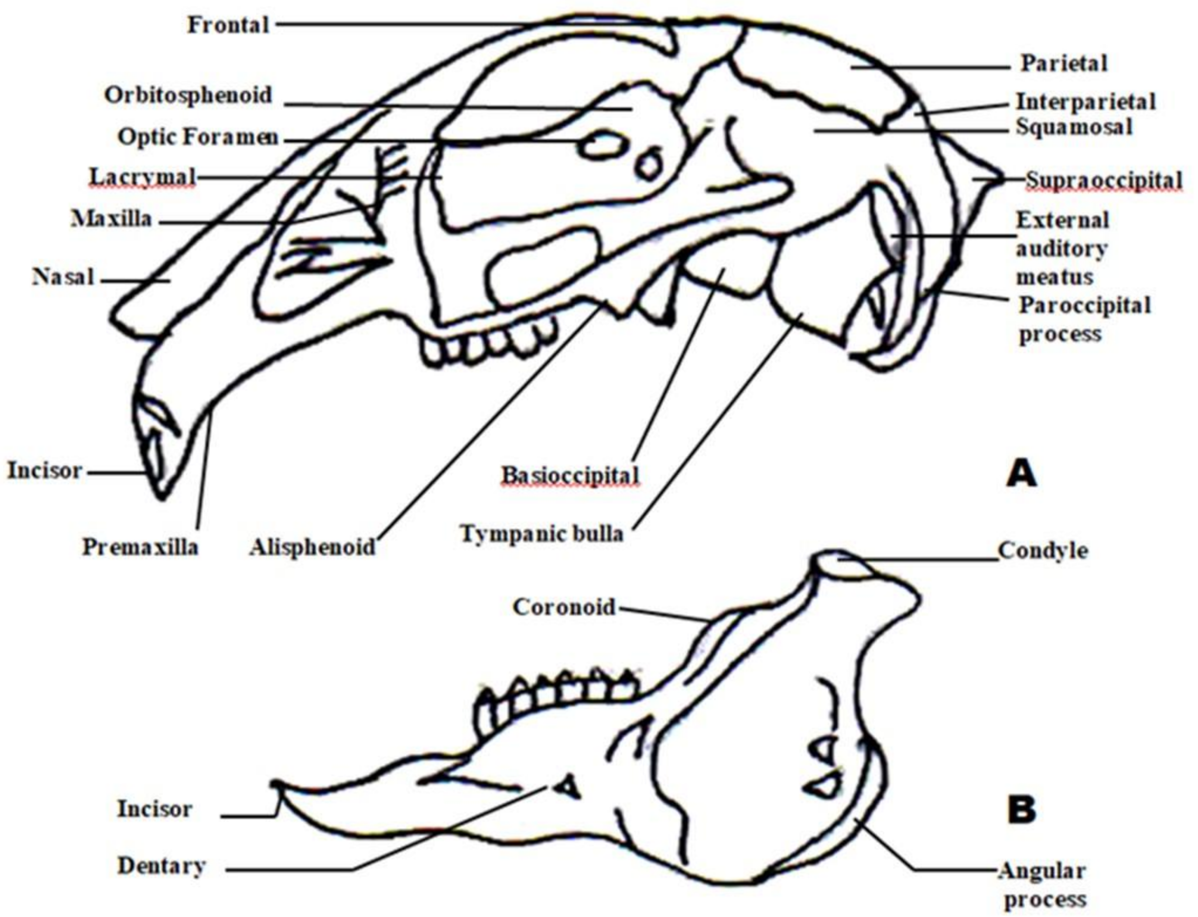


Fig.10. A. Lateral view of skull of *Oryctolagus*.

B. Lower jaw of *Oryctolagus*.

(Note the lateral fenestration of maxilla)

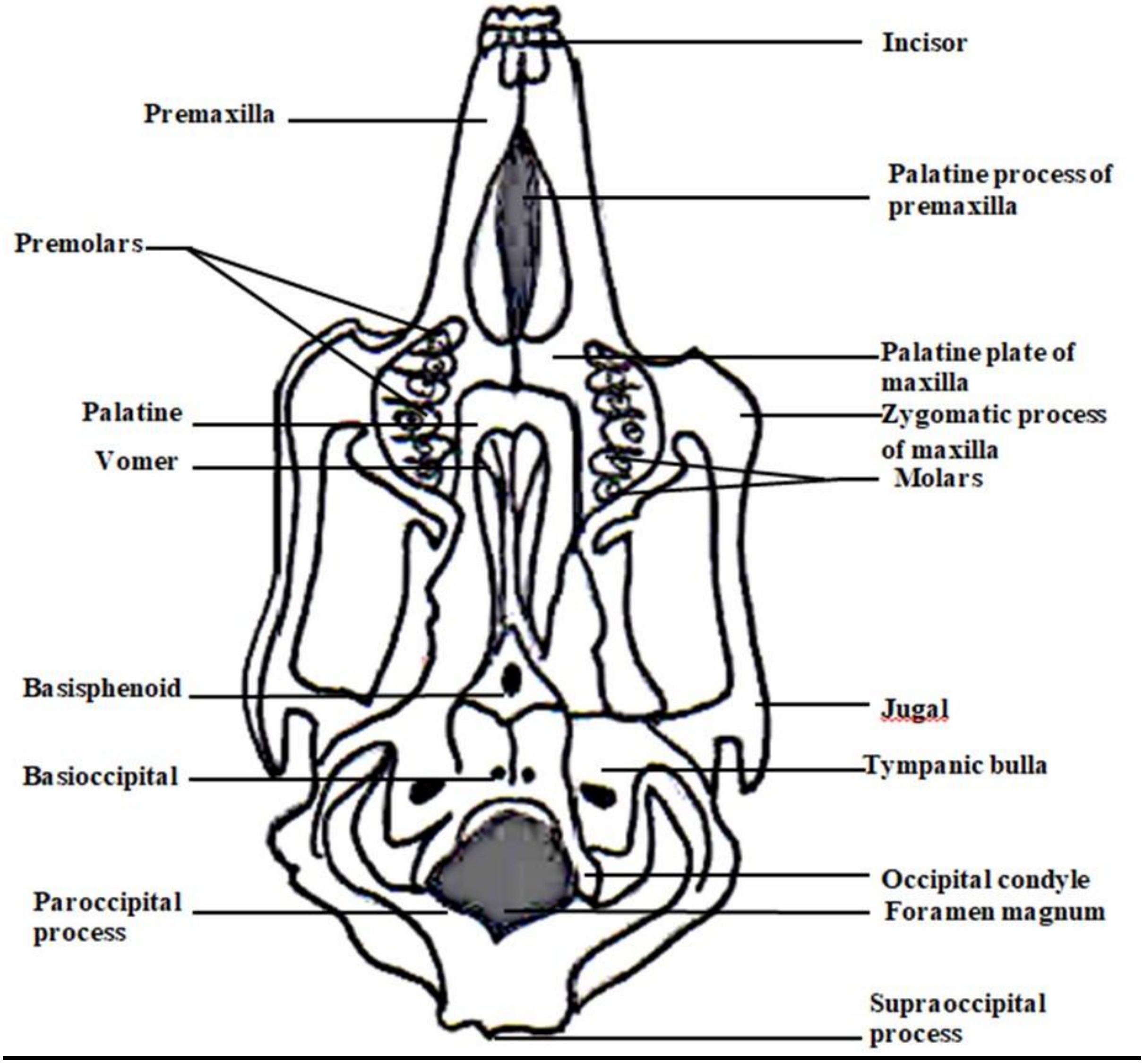


Fig. 11.Ventral view of the skull of *Oryctolagus*.

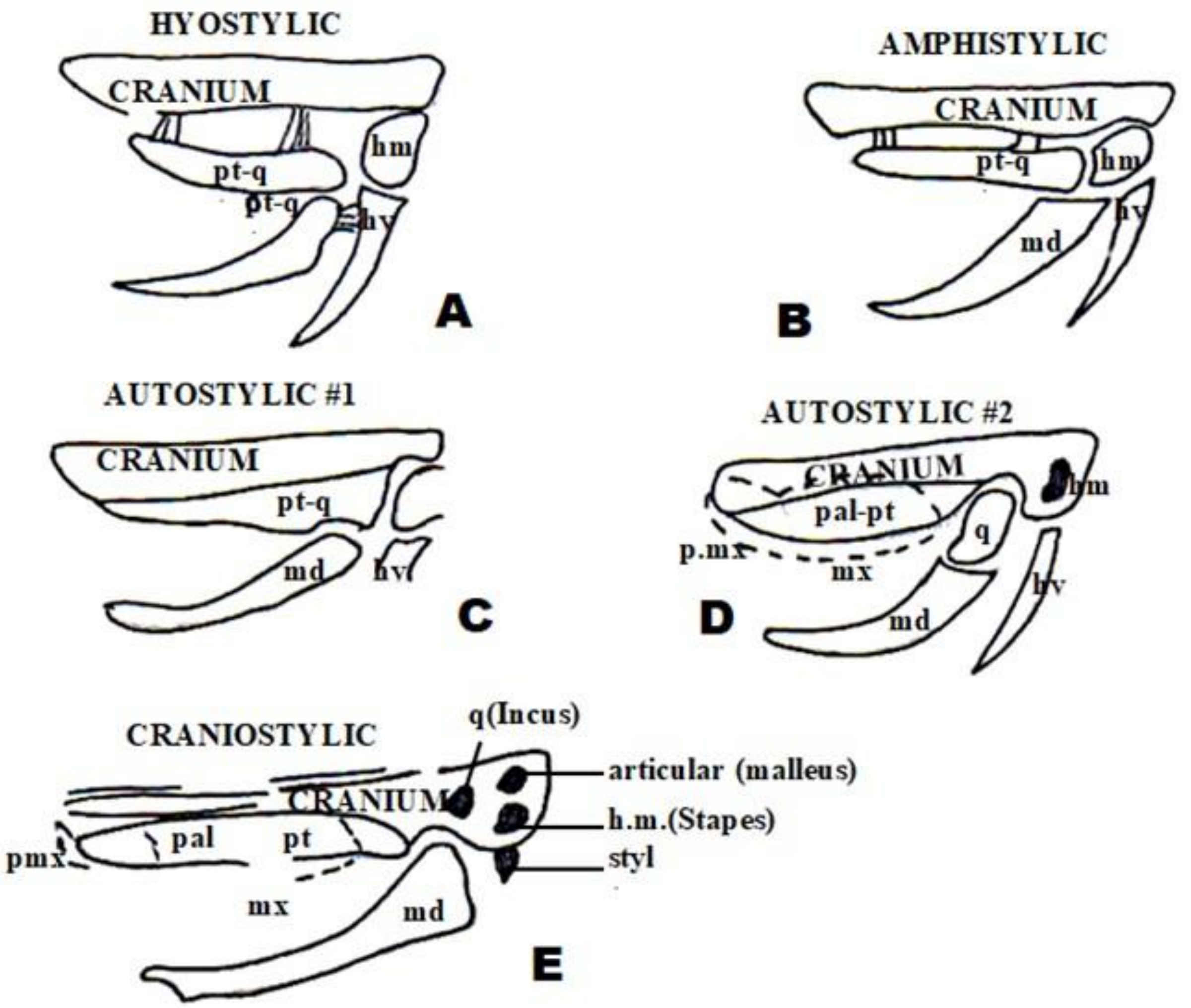


Fig. 12. Different method of suspension for the lower jaw.A. Hyostylic (elasmobranchs); B. Amphistylic(*Notradanus*, a primitive shark); C. Autostylic #1 (Holocephalans); D. Autostylic #2 (many Dipnoans, Ganoids, Teleosts, Amphibians, Reptiles and Birds); E. Craniostylic (Mammals). h.m., hyomandibular; hy, hyoid; md, mandible; mx, maxilla; pal, palantine; pt.q., pterygoquadrate; p.mx, premaxillary; q, quadrate; styl.proc., styloid process.

Orbito-Temporal Region:

There remain to be considered in various groups certain important specializations of the Orbito-Temporal Region. The fundamental constant relations of the cartilages to certain nerves and blood vessels were prominent among them. The basitrabecular process, typically developed in Lacertilia, but present in a more or less modified form in all Tetrapoda, Osteichthyes, and probably also in Chondrichthyes, is anterior to the palatine nerve, which passes down behind it and then forwards below it. In most of the higher Teleostomes the basitrabecular process is reduced and no longer meets the basal process of the palatoquadrate; but in *Lepidosteus*, among living forms, in Crossopterygii (*Megalichthys*, *Eusthenopteron*), Coelacanthini, and primitive Chondrostei and Amioidei it seems to have been well developed and to have articulated with the pterygoid region of the palatoquadrate (Fig. 7).

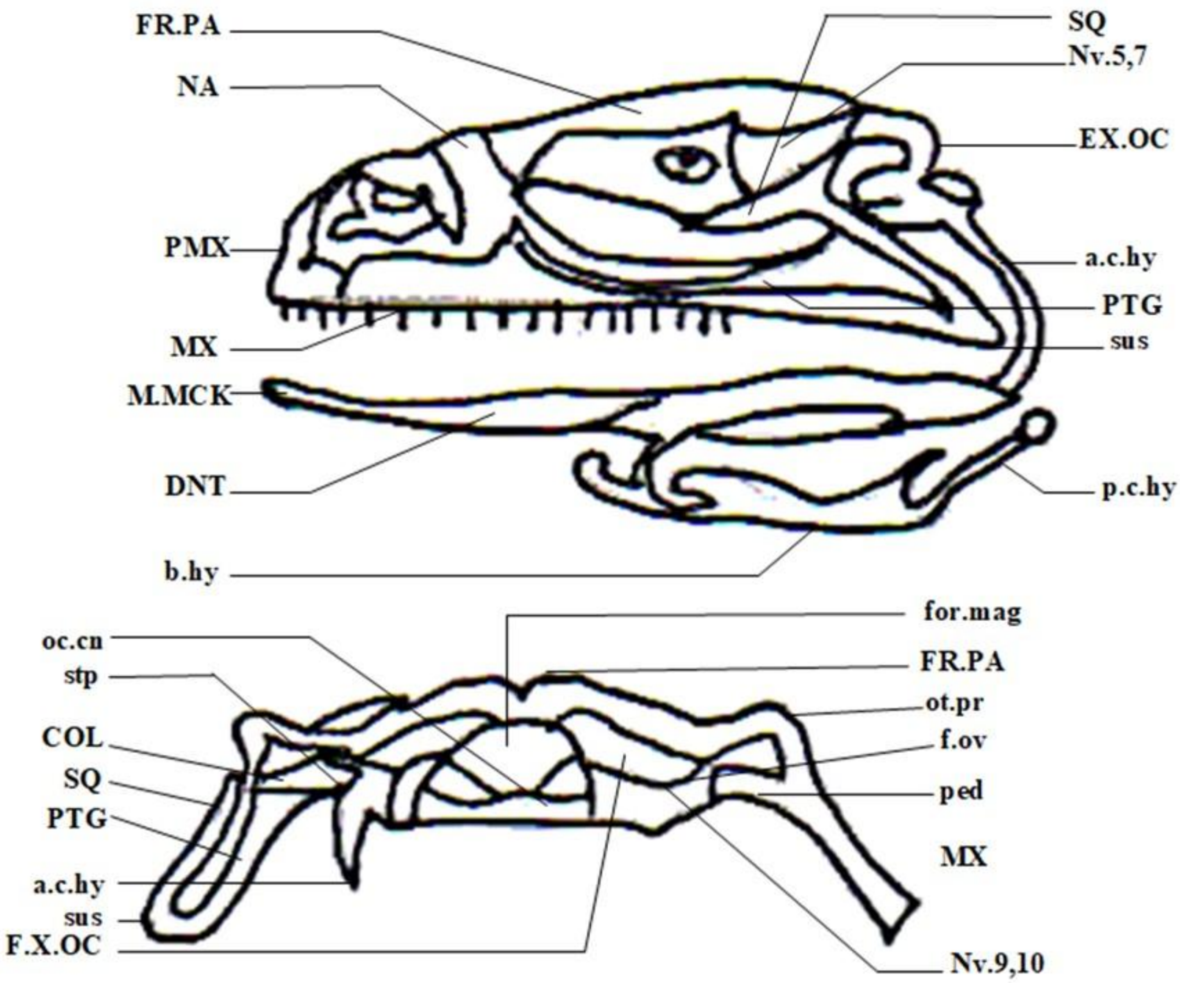


Fig. 13.*Rana*- The Frog Skull. A. from the left side, with mandible and hyoid; B. from behind, the investing bones removed at sus. a.c.hy, anterior cornu of hyoid; aud.cp, auditory capsule; b.hy, body of hyoid; COL, columella; DNT, dentary; EX.OC, exoccipital; for.mag., foramen magnum; FR.PA, fronto-parietal;

M.MCK, mento-Meckelian; MX, maxilla; NA, nasal; Nv.2, optic foramen; Nv. 5,7, foramen for fifth and seventh nerves; Nv.9, 10, foramina for 9th and 10th nerves; oc.cn, occipital condyle; olf.cp, olfactory capsule; ot.pr, otic process; PAL, palatine; pal.qu, palatoquadrate; PA.SPH, parasphenoid; p.c.hy, posterior cornu of hyoid; ped, pedicle; PMX, premaxilla; PR.OT, pro-otic; PTG, pterygoid; QU.JU, quadratojugal; SP.ETH, sphenethmoid; SQ, paraquadrate; stp, stapes; sus (quad), suspensorium (quadrate); VO, prevomer (After Howes, slightly altered.) A minute investing bone, the septo-maxillary, which is present above the maxilla, close to the nostril, is not here represented. (From .Parker and Haswell, Zoology.)

9.5 Appendicular skeleton of Frog & Rabbit:

It is adapted for articulation with the ventral ends of ribs. It is made up of 7 bony pieces forming 'sternebrae', the anteriormost of which is called 'presternum' or 'manubrium'. The 1st pair of ribs are attached to it. A pair of long, rod-like clavicle bones of the pectoral girdle are attached to its front end by means of elastic ligaments. The five sternebrae behind presternum constitute the 'mesosternum', termed Gladiolus. The ribs of 2nd pair are articulated at the joint of presternum and second sternebra. Similarly the ribs of 3rd to 6th pairs are articulated successively at the joints of remaining sternebrae of mesosternum. The ribs of 7th pair are articulated at the joint of last sternebra of mesosternum and the seventh sternebra called 'metasternum', called xiphisternum. A flattened plate-like 'xiphoid cartilage' is terminally mounted upon the metasternum.

The sternal ends of the ribs of 8th and 9th pairs are fused with those of the ribs of 7th pair. These ribs are, therefore, called 'false ribs'. The ribs of 10th, 11th and 12th pairs do not ventrally reach upto sternum. Their sternal ends are free. Hence, these are called 'floating ribs'.

9.5.1 Sternum& Ribs of Rabbit in association with pectoral and pelvic girdles:

The mammalian sternum is in the form of a comparatively narrow longitudinal bar of cartilage which becomes more or less completely segmented and ossified into median sternebrae alternating and articulating with the ventral ends of the sternal ribs. The anterior segment (manubrium sterni), however, is longer and projects beyond the articulation with the first rib. Behind the sternum usually expands into a xiphisternal cartilaginous plate or is continued into two diverging processes. When a dermal interclavicle is present it is applied to the ventral surface of the sternum.

In all Amniotes a close relation is early established between the sternum and anterior ribs which together come to encircle the thoracic cavity. But in no modern Amphibia does such a connection exist. The sternum is absent in Apoda, where it has no doubt been lost, and in Urodela, is represented by a median plate of cartilage wedged in between the posterior ventral ends of the coracoids, and widely separated from the short ribs.

It has sometimes been held that the isolated condition of the sternum in modern Amphibia is primitive, and that the connection with ribs s secondary; but judging from the structure of the dermal girdle and ribs in Stegocephalia, it seems more probable that these early Amphibia possessed a typical sternal cartilaginous plate connected with anterior ribs, and that the isolation is due to the reduction of ribs in modern forms accompanying the adoption of a different mode of respiration. Indeed it was later shown that in Anura and Urodela the sternum develops in relation to the intersegmentalmyocommata, and even in the adult, may have extending into these septa as many as four pairs of processes, apparently vestiges of ribs.

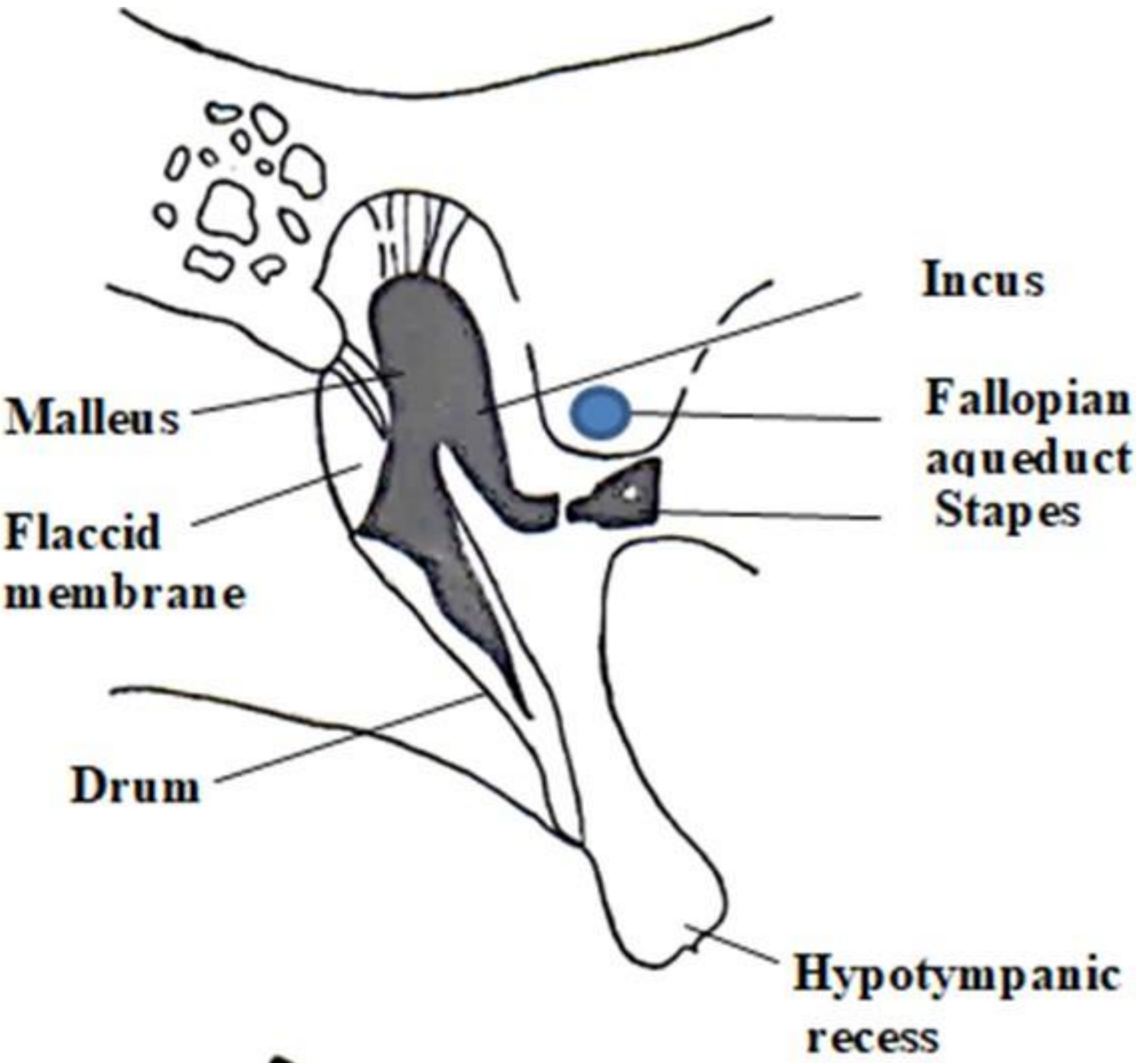
Due to absence of ribs in Anuran frogs, the sternum is articulated with pectoral girdle. It consists of two separate parts, one attached to the pectoral girdle anteriorly and the other posteriorly. The anterior part consists of a terminal flattened and almost circular plate of cartilage, called ‘episternum’, mounted upon an inverted “Y-shaped”‘omosternum’. The two arms of omosternum rest upon the clavicles of pectoral girdle. Similarly, the posterior part of sternum consists of a terminal circular plate of cartilage called ‘xiphisternum’, mounted upon a simple, rod-like ‘mesosternum’ which is articulated in front with epicoracoids of pectoral girdle. Omosternum and mesosternum are cartilage bones (Figs. 12-13).

9.6 Auditory Region – Mammal:

Development of Mammalian Ear Bones-

Remarkable similarity was observed between the structure and development of the bony constituents of the middle ear in Reptilia and Mammalia.

From the continuous blastema of the mandibular arch, anterior to the first gill pouch, are developed a dorsal element which becomes connected with the auditory capsule by the otic process, and a ventral Meckelian cartilage. The former becomes the quadrate in the Reptilia and the incus in Mammalia. The posterior end of Meckel’s cartilage forms the articular bone in the Reptilia and the malleus in the Mammalia, which becomes disconnected from the rest of the degenerating Meckelian cartilage (Fig. 14). The primitive quadrato-articular joint is represented between the incus and malleus.


Incus
Malleus
Fallopian
aqueduct
Stapes
Flaccid
membrane
Drum
Hypotympanic
recess

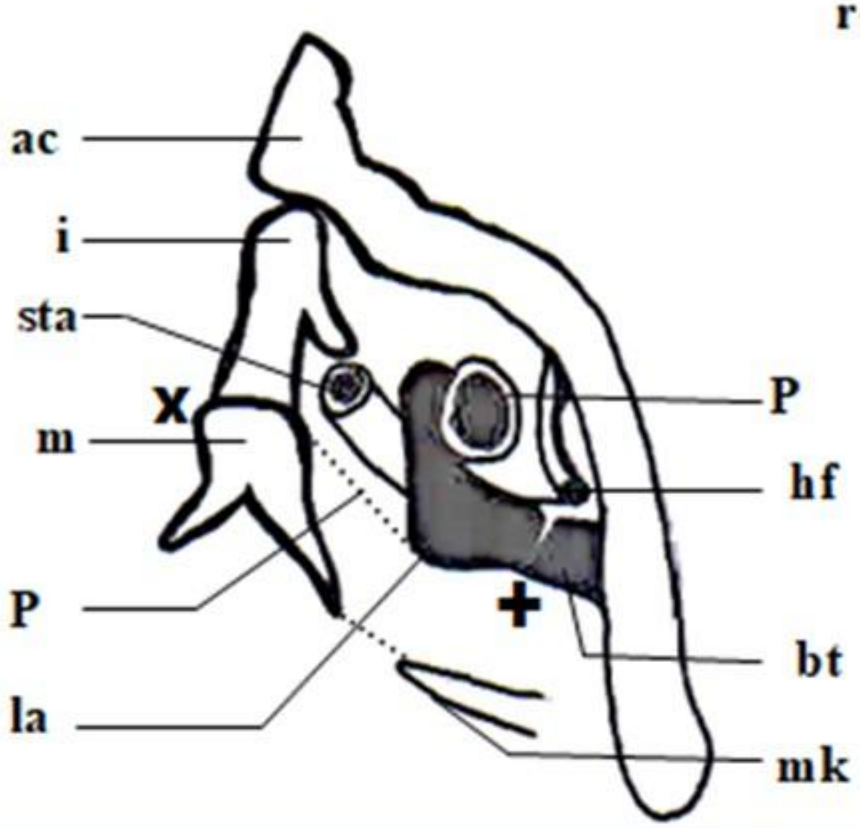

ac
i
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Fig. 14. Auditory region of mammal (embryonic stage) [Abbreviations: a, articular region of mandibular; ac, auditory capsule; bp, basal process; bt, basitrabecular process (pr. alaris); i, incus; hf, hyomandibular branch of facial nerve; la, lamina ascendens; m, malleus; mk, anterior part of Meckel's cartilage; opr, optic process; p, part of palate-quadrate which has disappeared; pr, parotic process; q, quadrate region of palate-quadrate; sta, stapedial artery; v, vena capitislateralis; +, basal (basipterygoid) articulation; x, original articulation of lower jaw.]

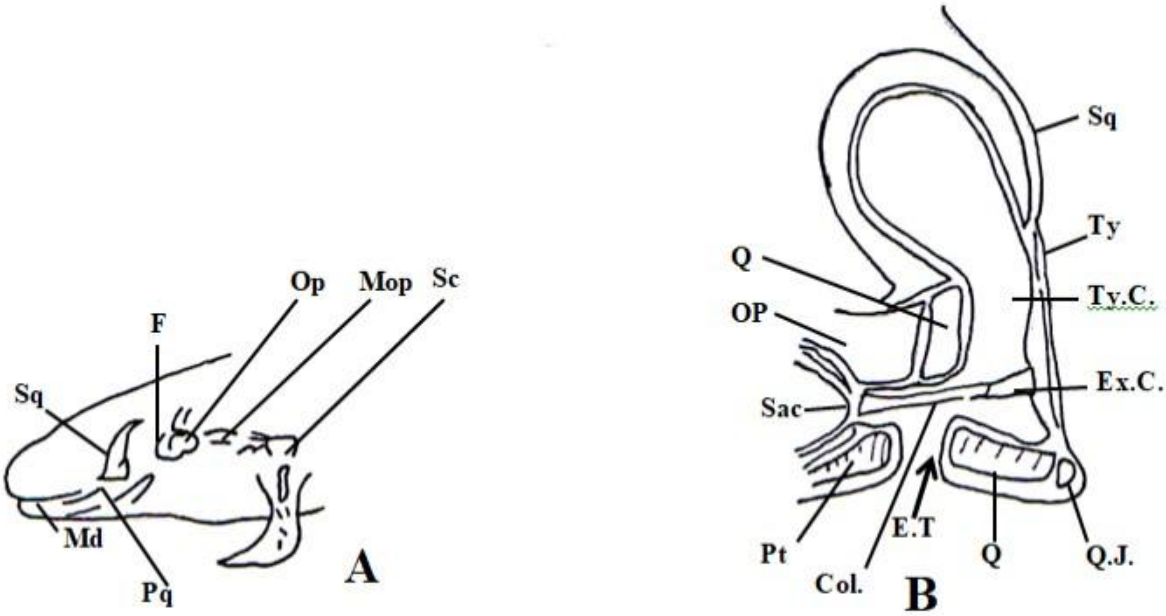


Fig. 15. Dorsal columella auris and ventral cornuhyale in the Reptilia.

From the continuous blastema of the hyoid arch posterior to the first gill-pouch are developed a dorsal columella auris and a more ventral cornuhyale in the Reptilia The columellarblastema forms later a proximal stapedial region fitting into the fenestra ovalis and a distal extra-stapedial region (Fig. 15), which usually becomes disconnected from the hyoid cornu. From this extra-stapedial region extend a dorsal process, which connects with the paroccipital process of the skull, a quadrate process, and an outer part inserted in the tympanum. In the mammal the hyoid gives rise to a proximal stapes fitting into the fenestra ovalis. There is no insertion in the tympanum; but a dorsal process for a time continuous with the hyoid cornu fuses with the crista parotica. This process (laterohyal or stylohyal) may be compared to the dorsal process of the Reptilia; but the region between it and the stapes (‘hyostapedial ligament’) does not persist. The extra-stapedial region is thus less developed in the mammal; the stapes is disconnected, and articulates now only with the incus (quadrate).

9.7 SUMMARY

- The physical make-up of body structure is collectively reflected externally after muscular enjoinments give these a shape as according to the use of different organ systems. The loosely held joints by muscular infrastructure is thus given definite shape of a particular organ in the total body framework by the bony skeleton. Two major kinds of bones, *viz*. the Cartilagenous bones and (ii) the Investing bones are the major constituents of bones conforming to the Skeletal System.
- One of the most sensitive part of skeletal system are the Ear Bone elements within the tympanic cavity of rabbit where achain of three tiny ear bones, the ‘Hammer,’ malleus; the ‘anvil,’ incus; and the ‘stirrup,’ stapes perform significant auditory role. But in frog, instead of the chain of ‘three bone elements’ only a single rod-like, ‘columella’ occurred, that extended from the ear drum directly to fenestra vestibuli.
- The axial and appendicular skeleton comprised skeleton of adult and terrestrial chordate (along with animals adapted to amphibious life), the former included the skull, vertebral column and sternum, while the latter encompassed limbs and girdles.The axial and appendicular skeletal framework was altered to a new method of locomotion on land. The vertebral column became rigid and the paired appendages with the corresponding girdles became specialized to lift the body off the ground. The skeleton of the limbs together with muscles help animals to propel across land effectively.
- The autostylic jaw suspensorium is characteristic of amphibians which differed from Holocephali in that the quadrate became distinct from the rest of the original pterygoquadrateshouldering responsibility of the suspension of lower jaw. However, in

craniostylic suspension of rabbits the lower jaw is articulated directly with cranium, and quadrate transformed to become incus bone of the middle ear.

- The hydrobranchial skeleton comprised the association of branchial arches with hyoid arch except its dorsal hyomandibular element. In frogs, it is still concerned with respiration, bearing gills in the larva and also becomes altered and adapted to support a projecting muscular tongue as well as to serve for the attachment of muscles for lowering and raising floor of the buccal cavity in respiration.
- In the Chondrocranium in Rabbit the anterior trabeculo-cochlear commissure (commissuraalicochlearis) represented the original base of the trabecular element. In Placentals especially it appears to have been pushed outwards, and so come to unite more with the capsule than with the basal plate. Thus the trabeculae preserve their usual position relative to the carotids, though it is possible that these have become to some extent surrounded by the trabecular cartilage. In the ethmoid region, the nasal capsule extends backwards along the lengthening internasal septum, while the interorbital septum becomes correspondingly shortened.

9.8 Text Questions

A. Fill in the blanks:-

1. Pelvic girdle of rabbit is distinguished from that of frog by the presence of …….
2. Foramen magnum is found at ……………..
3. Long neck of camel is due to …….
4. Ends of long bones are covered with ………..
5. Angulo-splenial is …………
6. Which of the following is a paired bone in frog ……….
7. Olecranon process is found in rabbit in ……….

8. Which one has both an endoskeleton and an exoskeleton……..

9. Vertebrae of frog are generally procoelous except ……..

10. Joint of femur with pelvic girdle is ……………..

11. Sternum of rabbit consists of……….

12. In frog, Y-shaped bone is …………

13. Humerus differs from femur in having a……..

14. Exoskeleton is not found in …………

15. Lower jaw of rabbit articulates with …………

B. Explain the comparative characteristics of skull between frog and rabbit.

9.9 Answers to Text Questions:

A.1. Pelvic girdle of rabbit is distinguished from that of frog by the presence of ……obturator foramen.

2. Foramen magnum is found at …base of skull…………..

3. Long neck of camel is due to …increase in length of neck vertebrae….

4. Ends of long bones are covered with …cartilage……..

5. Angulo-splenial is ……a bone in lower jaw of frog……

6. Which of the following is a paired bone in frog …septomaxillary…….

7. Olecranon process is found in rabbit in …ulna forming the elbow…….

8. Which one has both an endoskeleton and an exoskeleton…snake……..

9. Vertebrae of frog are generally procoelous except …eighth and ninth…..

10. Joint of femur with pelvic girdle is …ball and socket…………..

11. Sternum of rabbit consists of……6 sternebrae, a xiphisternum,and a xiphoid cartilage….

12. In frog, Y-shaped bone is …pterygoid……….

13. Humerus differs from femur in having a…deltoid ridge…..

14. Exoskeleton is not found in ……frog……….

15. Lower jaw of rabbit articulates with ……squamosal…….

B. Comparative characteristics of skull between frog and rabbit:-

i. Frog-

a. Cranial skeleton indistinguished into cranial and facial regions.Instead its division into occipital, cranial and olfactory segments.

b. Skull somewhat triangular and dorsoventrally flattened; broader than long; not bent in snout.

c. Auditory capsules not lodged in cranial segment of skull; each is formed by a pro-otic bone.

d. Occipital segment small; has only 2 cartilagenous bones, the exoccipitals, around foramen magnum; no paroccipital processes.

e. Eye orbits form as depressions of skin and not as sockets in skull; separated from each other by cranial skeleton itself (platybasic).

ii. Rabbit-

a. Differentiation of cranial and facial regions is evident from the dividion of Cranial skeleton into cranial and facial regions. Occipital, parietal and frontal segments conform to cranial region.

b. Skull longer than broad, not flattened, but bent in front in the snout.

c. Auditory capsules lodged in cranial skeleton; each is formed by a tympanic bone and reinforced by a compound periotic bone.

d. Occipital segment large; has 4 cartilage bones around foramen magnum – dorsal supraoccipital, ventral basioccipital and lateral occipitals having paroccipital processes.septum (tropibasic).

e. Eye orbits form assockets in skull;separated from each otheronly by a thin interorbital.

UNIT: 10 Central Nervous System

Course content

- Review of structure and function of a neuron
- Conduction of nerve impulse
- Synapses and the role of neurotransmitters
- Organization of the central nervous system
- Structure and function of Brain and spinal cord
- Afferent and efferent nerves
- Blood Brain Barrier

- Cerebrospinal fluid
- Hypothalamus and its role in various body functions-obesity memory etc.

Course objectives

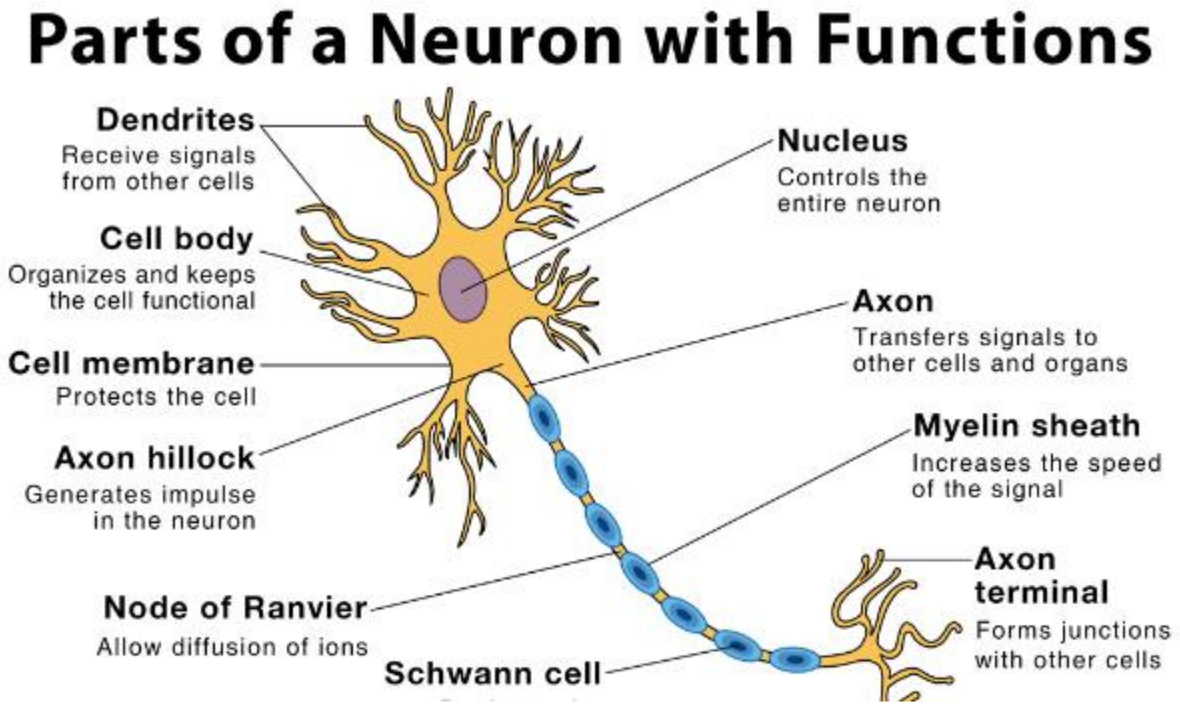
- The students will be able to identify the features of the nervous system
- The students will be able to explain parts of a neuron
- The students will be able explain the parts of the brain: cerebrum, cerebellum, brain stem, pituitary, gland, and hypothalamus
- The students will be able to explain the structure and function of spinal cord
- The students will be able to explain the difference between autonomic nerves and somatic nerves
- The students will be able to explain the difference betweenafferent and efferent nerves
- The students will be able to explain blood brain barrier and cerebrospinal fluid
- The students will be able to identify the features of the Hypothalamus and its functions

Nervous System

Introduction to Nervous System:

According to biology, an animal's nervous system coordinates its movements and sensory data by sending and receiving signals to and from various regions of its body. The nervous system notices bodily-impacting environmental changes, and then collaborates with the endocrine system to react to such occurrences.All bodily functions are under the direction of the nervous system. It moves more quickly than the body's other control system, the endocrine system.

Review of structure and function of Neuron:



The structural and operational unit of the nervous system is the neuron, according to definition. It is also known as a nerve cell. A neuron has a nucleus and all the organelles are located in the cytoplasm, much like every other cell in the body. It differs from other cells in two respects, though:

1. The axon and dendrites of a neuron are branches or processes.
2. The centrosome is absent in neurons;

Structure of Neuron:

Three components make up each neuron:

Body of a nerve cell

1. Nerve cell body
2. Dendrite

3. Axon

The processes of a neuron are made up of the dendrite and axon combined.Axons are often lengthy processes whereas dendrites are typically small processes. Typically, dendrites and axons are referred to as nerve fibres.

<u>Neuronal Body:</u>

The soma or perikaryon are other names for the nerve cell body. It has an amorphous structure and is made up of neuroplasm, a mass of cytoplasm encased in a cell membrane.

A sizable nucleus, Nissl bodies, neurofibrils, mitochondria, and the Golgi apparatus are all found in the cytoplasm. Only nerve cells, *not* other cells, contain Nissl bodies and neurofibrils.

Each neuron has a single, centrally located nucleus.One or two conspicuous nucleoli can be seen in the nucleus. Centrosomes are *not* found in the nucleus. So, unlike other cells, nerve cells cannot proliferate.

Nissl body

Small basophilic granules called Nissl bodies or Nissl granules are present in the cytoplasm of neurons and are named for their discoverer. Other than in Axon Hillock, these bodies are widespread throughout Soma. Nissl bodies are known as *tigroid substances* because, after being properly stained, they cause the soma to seem *tigroid or speckled*. Nissl granules exit the soma and enter the dendrites, but not the axon. So, under a microscope, Nissl granules help to identify dendrites from axons.

Ribosomes

Ribosomes are found in the Nissl bodies, which are membrane organelles. Consequently, the creation of proteins in these bodies is important.Thus, these organisations are worriedwith the neurons producing proteins.Axonal flow carries the proteins made in the soma to the axon.

Neurofibrils

The soma and the nerve both include networks of thread-like structures called neurofibrils.Another distinguishing trait of the neurons is the presence of neurofibrils.

Mitochondria

The soma and axon both contain mitochondria. Similar to other cells, the nerve cell's mitochondria serve as its centre of power, producing ATP.

Golgi Equipment

The nerve cell body's golgi apparatus resembles that of other cells. It deals with the preparation and granulation of proteins.

Dendrite

The neuron's branched process, or dendrite, is constantly branching. There might or might not be a dendrite. If existent, it might exist in a single or multiples. Neurofibrils and Nissl granules can be seen on the dendrite.The essence of dendrite is conductivity. It sends impulses to the body of the nerve cell.

Axon

Axon length exceeds dendritic length. There is just one axon per neuron. The nerve cell body's axon hillock is where the axon emerges. The axon extends far beyond the body of the nerve cell.The longest axon is around one metre long.

The structure of the Nerve

A. Fasciculus is a collection of many axons. Together, several fasciculi make up a nerve.The areolar membrane, which forms the tubular sheath, surrounds the whole nerve. The epineurium is the name of this sheath. Perineurium covers each fasciculus, and endoneurium covers each nerve fibre.Axoplasm refers to the lengthy central core of cytoplasm found in the axon. The tubular sheath-like membrane known myelin sheath covers the axoplasm.

B. TheAxolemma of a non-myelinated nerve fibre, which is an extension of the nerve cell body's cell membrane. The axis cylinder of the nerve is made up of the axoplasm and axolemma.Neurofibrils, mitochondria, and axoplasmic vesicles are all found in axoplasm. Nissl bodies, however, are not present in the axon. A membrane known as the neurilemma covers the nerve fiber's axis cylinder.

Fibres of unmyelinated nerve

The nerve fibre that was previously reported is a nonmyelinated nerve fibre, meaning it is not protected by a myelin sheath.

Fibres of myelinated nerve

Myelinated nerve fibres are the nerve fibres that have a myelin coating to protect them.

Myelin Sheath

The Myelinated nerve fibre is protected by a substantial lipoprotein coating called the *myelin sheath*. The sheath surrounding the myelin is *not* continuous. At certain periods, it is absent. The **Node of Ranvier** is the region where the myelin sheath is missing. Internode refers to the portion of a nerve fibre that is between two nodes. The white hue of the nerve fibres is a result of the myelin coating.

Conduction of nerve impulse

Electric signals that travel along dendrites to produce an action potential or a nerve impulse are referred to as nerve impulses. The entry and exit of ions from the cell cause an action potential. Specifically, sodium and potassium ions are involved. Through sodium and potassium channels as well as the sodium-potassium pump, they are transported into and out of the cell.

The existence of active and electronic potentials along the conductors causes nerve impulses to conduct. A synapse allows for the internal signal transmission between cells. Nerve conductors have low axial resistance and relatively high membrane resistance. The electrical synapse is used by vertebrates in their retina, heart, and escape reflexes. They are primarily utilised when quick action and precise timing are required. When the action potential reaches this synapse, the ionic currents cross the two cell membranes.

The axon, or nerve fibre, is shaped like a cylinder and is lined on the outside with an axolemma and filled with axoplasm within. The ECF completely submerges the nerve filaments. The solution is in the extracellular fluid, or ECF, and axoplasm ionic form.

The positively charged sodium ions balance out the negatively charged chloride ions outside of the axon. The potassium ions present in the axoplasm neutralise negatively charged protein molecules. A neuron's membrane is -ve on the inside and +ve on the outside. The difference in charge would be due to resting potential. The membrane would be polarised since the charge differential may range from 70 to 90 millivolts.The axon membrane is where the pump is situated. Currently, sodium ions are pumped from axoplasm to ECF and potassium ions are pushed from ECF to axoplasm.

When a stimulus is provided to the membrane of a nerve fibre, the sodium-potassium pump ceases to function. Mechanical, pharmacological, or electrical stimulation are all possible. Positive charges are present inside and negative charges are present outside of the membrane as a result of the potassium ions rushing outside and the sodium ions rushing inside.

Synapses

Synapse is the junction between the two neurons. It is not the anatomical continuation. But, it is only a physiological continuity between two nerve cells.

Classification of synapse

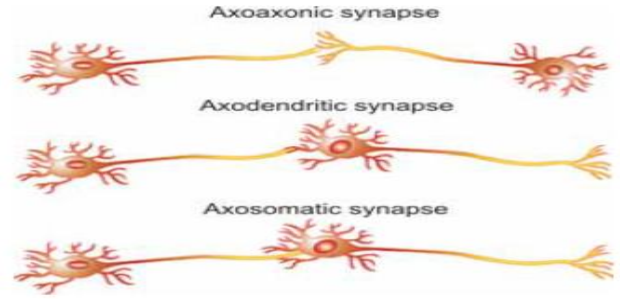
Synapse is classified by two methods, anatomical classification and functional classification.

Anatomical classification

Synapse is formed by axon of one neuron ending on the cell body, dendrite or axon of the next neuron.

Depending upon the ending of axon, the synapse is classified into three types :

1. **Axoaxonic synapse** in which axon of one neuron terminates on axon of another neuron
2. **Axodendritic synapse** in which axon of one neuron terminates on dendrite of another neuron
3. **Axosomatic synapse** in which axon of one neuron ends on soma (cell body) of another neuron.



Functional classification

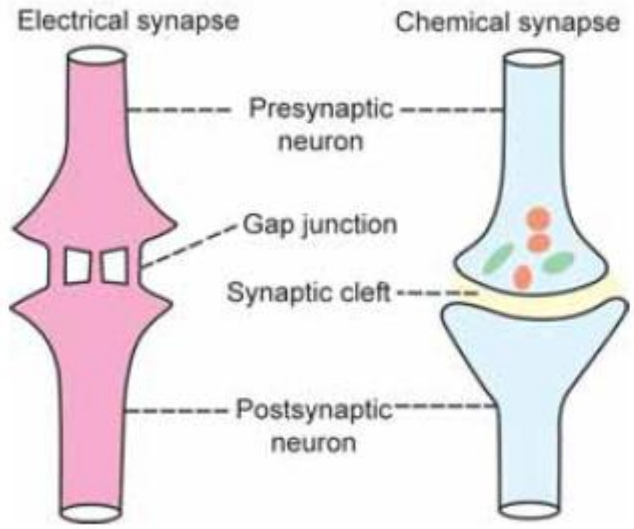
Function classification depends upon of mode of impulse transmission. On this basis, synapse is classified into two types:

1. Electrical Synapse

Electrical synapse is the synapse in which the physiological continuity between the presynaptic and the postsynaptic neurons is provided by thegap junction between these two neurons.There is direct exchange of ionsbetween the two neurons though the gap junction. So, the action potential reaching the terminal portion of presynaptic neuron directly enters the postsynaptic neuron.

2. Chemical Synapse

Chemical synapse is the junction between a nerve fiber and a muscle fiber or between two nerve fibers, through which the signals are transmitted by the release of chemical transmitter. In the chemical synapse, there is no continuity between the presynaptic and postsynaptic neurons. These two neurons are separated by a space called synaptic cleft between the two neurons.



The axon membrane is where the pump is situated. Currently, sodium ions are pumped from axoplasm to ECF and potassium ions are pushed from ECF to axoplasm.When a stimulus is provided to the membrane of a nerve fibre, the sodium-potassium pump ceases to function. Mechanical, pharmacological, or electrical stimulation are all possible. Positive charges are present inside and negative charges are present outside of the membrane as a result of the potassium ions rushing outside and the sodium ions rushing inside.

Either the nerve fibres are depolarized or the action potential is said to be present. The nerve impulse is the name for the action potential that is moving across the membrane. There are around +30 mV. Once the action potential is established, the sodium-potassium

The transfer of nerve impulses from one neuron to another requires synapses. Synapses are the way by which neurons, which are specialised to convey messages to specific target cells, do this. The plasma membrane of the target (postsynaptic) cell and the plasma membrane of the signal-passing neuron are in close proximity at a synapse. The enormous arrays of molecular machinery that connect the two membranes and carry out the signalling process are present at both the presynaptic and postsynaptic locations. Many synapses have an axon for the presynaptic component and a dendrite or soma for the postsynaptic component. Additionally, astrocytes communicate with synaptic neurons, reacting to synaptic activity to control neurotransmission

Synaptic adhesion molecules (SAMs), which protrude from both the pre- and post-synaptic neuron and cling together where they overlap, stabilise synapses at least chemical synapses in place. SAMs may also help create and maintain synapses.

Either the nerve fibres are depolarized or the action potential is said to be present. The nerve impulse is the name for the action potential that is moving across the membrane. There are around +30 mV. Once the action potential is complete, the sodium-potassium pump begins to work. The axon membrane will thereafter undergo repolarization in order to reach a resting potential.

Now, the steps are completed in the opposite sequence. This is the opposite of what happened during an action potential.Sodium ions will be pushed outside while potassium ions be rushed within. During the refractory phase, impulse would not be passed across the nerve fibre.

When it comes to white fibres, saltatory proliferation occurs. That is, when the speed of the nerve impulse rises, the impulse leaps from node to node. Compared to non-medullated nerve fibres, it is around twenty times quicker. The diameter of the fibre would be important for nerve impulse transmission. For instance, a frog's nerve impulse is 30 metres per second while a mammal's nerve impulse is one twenty metres per second.

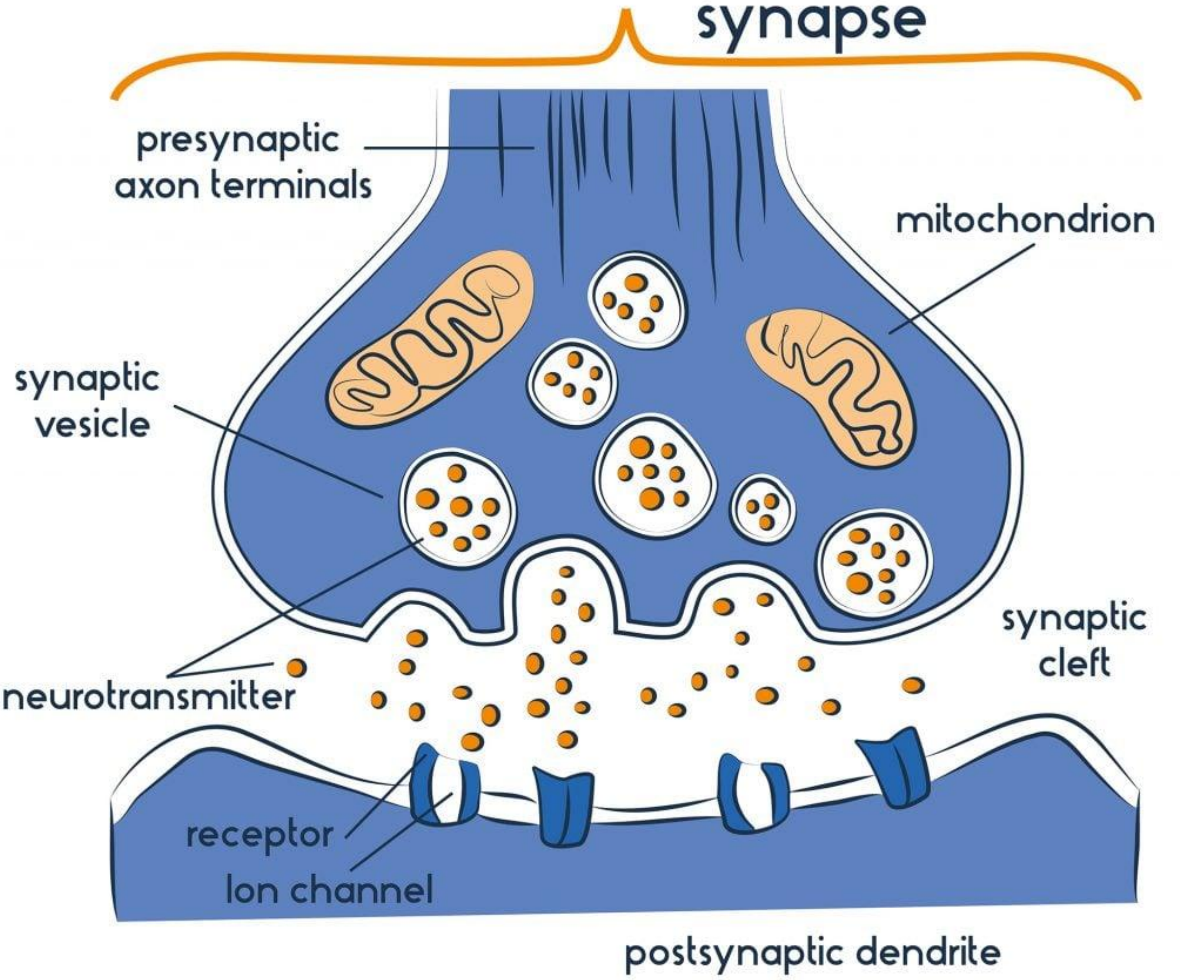
Purpose of synapse

The synapse's job is to transfer electrical impulses from one neuron to another. Some synapses do, however, block the impulses.

Consequently, there are two categories of synapses:

1. Synapses with an excitatory function that send impulses
2. Synapses with inhibitory function, which prevent impulses from being sent.

Role of neurotransmitters:



A neuron releases a signalling chemical called a neurotransmitter across a synaptic gap to influence another cell. The target cell, also known as the cell receiving the signal, might be a glandular or muscular cell in addition to another neuron. In the synaptic cleft, where they may

interact with receptors on the target cell, neurotransmitters are released from synaptic vesicles. The receptor that the neurotransmitter attaches to determines how the neurotransmitter affects the target cell. Numerous neurotransmitters are produced from easy-to-find, abundant precursors such amino acids, which are frequently converted in a few number of biosynthetic steps.

The proper operation of sophisticated neurological systems depends on neurotransmitters. Humans have an unknown number of distinct neurotransmitters, nonetheless, more than 100 have been located.Glutamate, GABA, acetylcholine, glycine, and norepinephrine are typical neurotransmitters. Precursor molecules that are plentiful in the cell are used to create neurotransmitters, which are often created in neurons. Peptides, monoamines, and amino acids are among the several classes of neurotransmitters. A single amino acid is changed to create monoamines. Tryptophan, for instance, is an amino acid that is the precursor of serotonin. Neuropeptides, also known as peptide transmitters, are proteins that are frequently produced together with other transmitters to have a modulatory impact. Like ATP, purine neurotransmitters are produced by nucleic acids. Nitric oxide and carbon monoxide, two metabolic byproducts, are components of other neurotransmitters.At the axon terminal of the presynaptic neuron, synaptic vesicles, which are grouped together near to the cell membrane, are where neurotransmitters are often kept. The metabolic gases carbon monoxide and nitric oxide, for example, are synthesised and released right after an action potential without ever being stored in vesicles.

Release

Typically, an electrical signal termed an action potential in the presynaptic neuron causes a neurotransmitter to be released at the presynaptic terminal. However, little or "baseline" release also happens in the absence of electrical stimulation. Neurotransmitters are released into the synaptic cleft and diffuse across it before binding to certain receptors on the postsynaptic neuron's membrane.

Interaction of receptors

Neurotransmitters diffuse across the synapse after being released into the synaptic cleft, where they can interact with receptors on the target cell. The type of target cell receptors found at the synapses determines how the neurotransmitter behaves. Neurotransmitter binding can cause the postsynaptic neuron to be excited, inhibited, or modulated depending on the receptor.

Elimination

In the synaptic cleft, acetylcholine is broken down into acetic acid and choline.

Neurotransmitters need to be taken out of the synaptic cleft in order to prevent persistent activation of receptors on the post-synaptic or target cell.[6] One of three processes removes neurotransmitters:

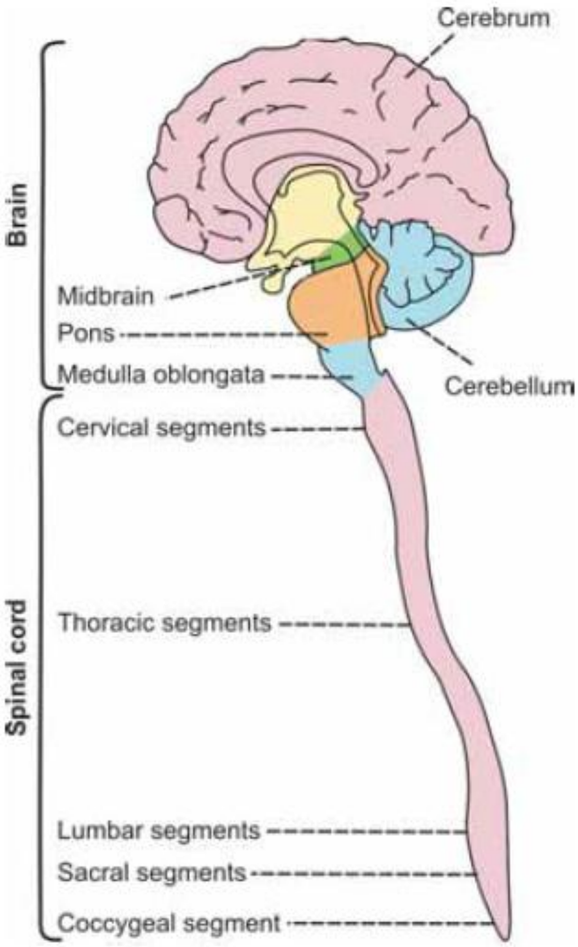
1.Diffusion: Neurotransmitters diffuse out of the synaptic cleft and are taken up by glial cells in this way. The extra neurotransmitters are absorbed by these glial cells, which are mainly astrocytes. Neurotransmitters are either pumped back into or degraded by enzymes in glial cells.

2. Enzyme degradation: Enzymes are proteins that degrade neurotransmitters.

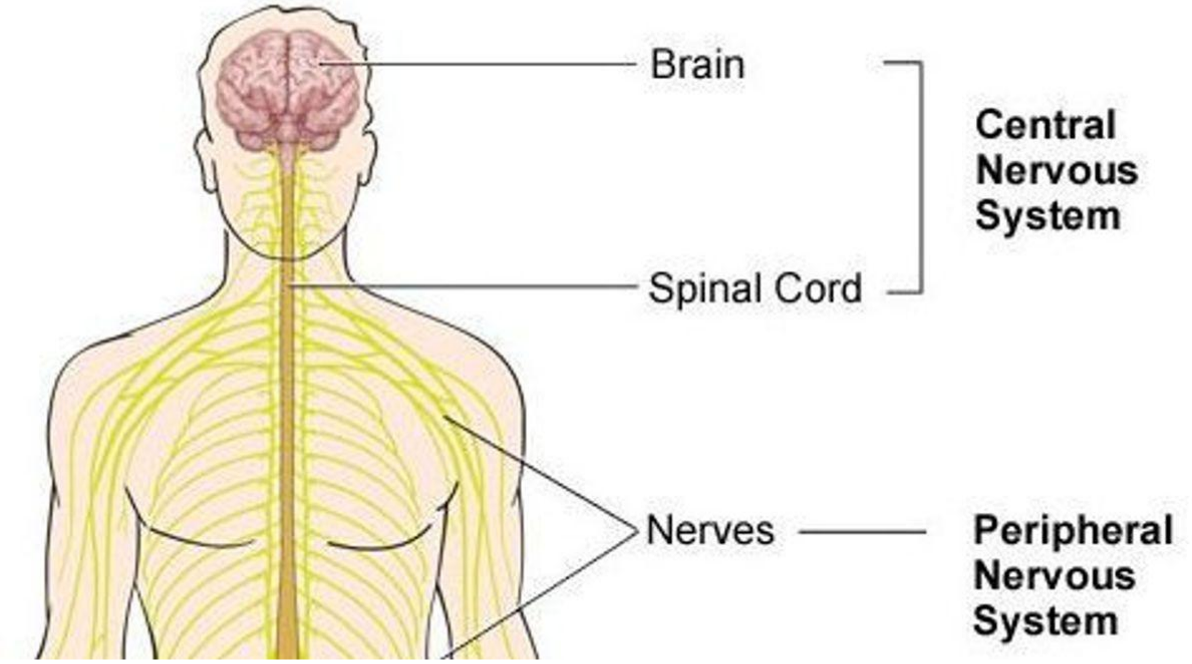
3.Reuptake: Thepre-synaptic neuron reabsorbs neurotransmitters. Neurotransmitters are pumped from the synaptic cleft back into the axon terminals (the presynaptic neuron), where they are stored for later use, via transporters, or membrane transport proteins.

For instance, acetylcholine is excreted by having the enzyme acetylcholinesterase cleave its acetyl group; the leftover choline is then taken up and recycled by the pre-synaptic neuron to produce further acetylcholine. Other neurotransmitters can diffuse away from the synaptic connections they are intended to affect, and they are then either removed from the body by the kidneys or destroyed by the liver. Each neurotransmitter has extremely particular routes for breakdown at regulatory locations that can be addressed by medicine or the body's regulatory system. A dopamine transporter responsible for dopamine reuptake is blocked by cocaine. Without the transporter, dopamine diffuses from the synaptic cleft considerably more slowly and keeps on activating the target cell's dopamine receptors.

Structure of nervous system: The nervous system is primarily split into two sections.

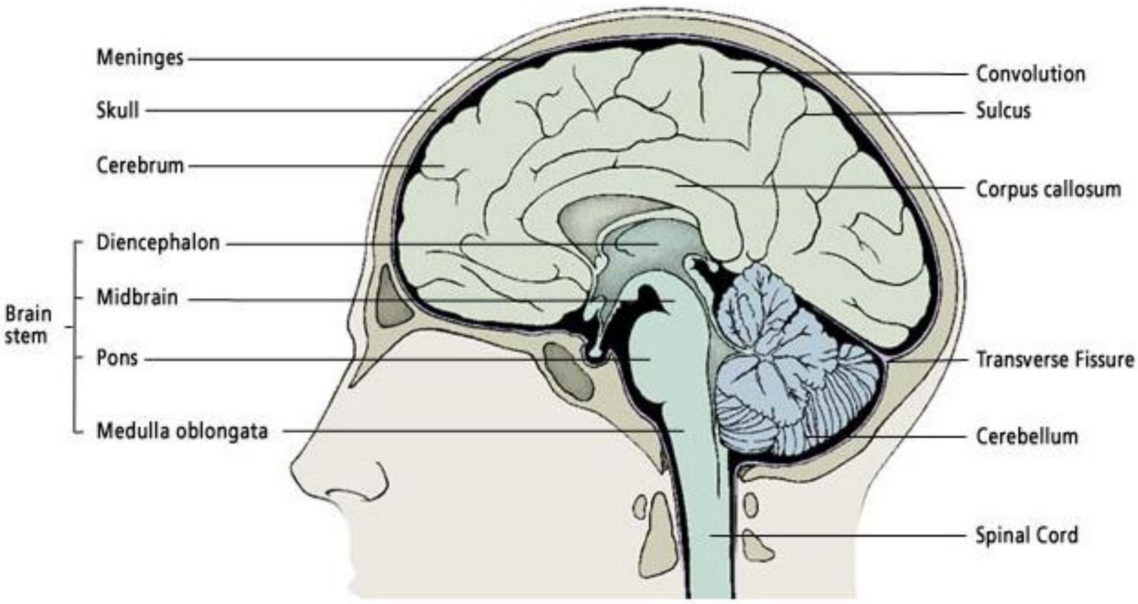


First, the central nervous system and Second, the peripheral nervous system.



Central nervous system

Structure and function of Brain



The brain and spinal cord are components of the central nervous system (CNS). Neurons and the supporting cells known as neuroglia combine to make it. The grey matter and white matter, which make up the brain and spinal cord, are organised in two layers.The nerve cell bodies and the proximal ends of the nerve fibres that emerge from the nerve cell body make up the grey matter. Nerve cells make up the white matter.White matter is located in the centre of the brain, whereas grey matter is located on the periphery. Grey matter and white matter are found in different parts of the spinal cord.

The skull contains the brain. It continues as the spinal cord passes through the foramen magnum of the vertebral canal.

Brain Components

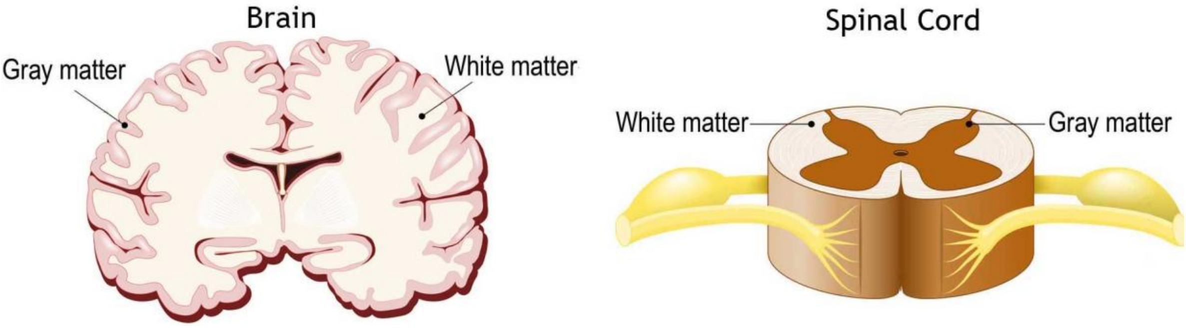
Brain, Nerves and Spine

The brain is a complex organ that controls thought, memory, emotion, touch, motor skills, vision, breathing, temperature, hunger and every process that regulates our body. Together, the brain and spinal cord that extends from it make up the central nervous system, or CNS.

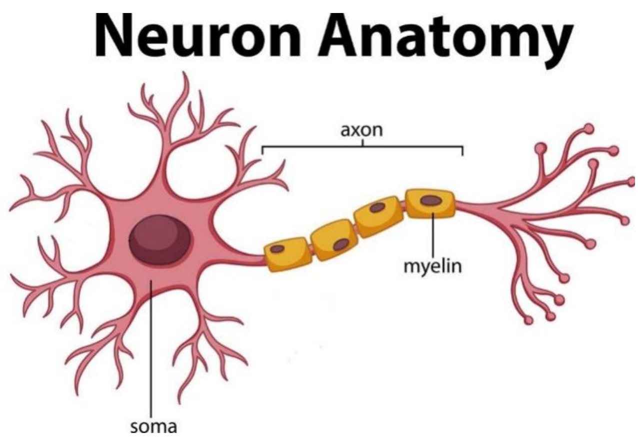
Weighing about 3 pounds in the average adult, the brain is about 60% fat. The remaining 40% is a combination of water, protein, carbohydrates and salts. The brain itself is a not a muscle. It contains blood vessels and nerves, including neurons and glial cells.

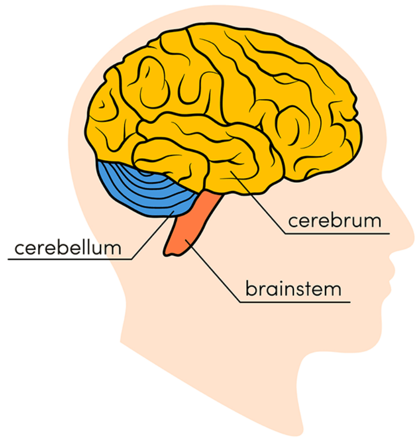
What isgray matter and white matter?

Gray and white matter are two different regions of the central nervous system. In the brain, gray matter refers to the darker, outer portion, while white matter describes the lighter, inner section underneath. In the spinal cord, this order is reversed: The white matter is on the outside, and the gray matter sits within.



Gray matter is primarily composed of neuron somas (the round central cell bodies), and white matter is mostly made of axons (the long stems that connects neurons together) wrapped in myelin (a protective coating). The different composition of neuron parts is why the two appear as separate shades on certain scans.





Each region serves a different role. Gray matter is primarily responsible for processing and interpreting information, while white matter transmits that information to other parts of the nervous system.

How does the brain work?

The brain sends and receives chemical and electrical signals throughout the body. Different signals control different processes, and brain interprets each. Some make you feel tired, for example, while others make you feel pain.

Some messages are kept within the brain, while others are relayed through the spine and across the body's vast network of nerves to distant extremities. To do this, the central nervous system relies on billions of neurons (nerve cells).

Main Parts of the Brain and Their Functions

At a high level, the brain can be divided into the cerebrum, brainstem and cerebellum.

Cerebrum

The cerebrum (front of brain) comprises gray matter (the cerebral cortex) and white matter at its center. The largest part of the brain, the cerebrum initiates and coordinates movement and regulates temperature. Other areas of the cerebrum enable speech, judgment, thinking and reasoning, problem-solving, emotions and learning. Other functions relate to vision, hearing, touch and other senses.

Cerebral Cortex

Cortex is Latin for "bark," and describes the outer gray matter covering of the cerebrum. The cortex has a large surface area due to its folds, and comprises about half of the brain's weight. The cerebral cortex is divided into two halves, or hemispheres. It is covered with ridges (gyri) and folds (sulci). The two halves join at a large, deep sulcus (the interhemispheric fissure, AKA the medial longitudinal fissure) that runs from the front of the head to the back. The right hemisphere controls the left side of the body, and the left half controls the right side of the body. The two halves communicate with one another through a large, C-shaped structureof white matter and nerve pathways called the corpus callosum. The corpus callosum is in the center of the cerebrum.

Brainstem

The brainstem (middle of brain) connects the cerebrum with the spinal cord. The brainstem includes the midbrain, the pons and the medulla.

- **Midbrain.** The midbrain (or mesencephalon) is a very complex structure with a range of different neuron clusters (nuclei and colliculi), neural pathways and other structures. These features facilitate various functions, from hearing and movement to calculating responses and environmental changes. The midbrain also contains the substantianigra, an area affected by Parkinson's disease that is rich in dopamine neurons and part of the basal ganglia, which enables movement and coordination.
- **Pons.** The pons is the origin for four of the 12 cranial nerves, which enable a range of activities such as tear production, chewing, blinking, focusing vision, balance, hearing and facial expression. Named for the Latin word for "bridge," the pons is the connection between the midbrain and the medulla.
- **Medulla.** At the bottom of the brainstem, the medulla is where the brain meets the spinal cord. The medulla is essential to survival. Functions of the medulla regulate many bodily activities, including heart rhythm, breathing, blood flow, and oxygen and carbon dioxide levels. The medulla produces reflexive activities such as sneezing, vomiting, coughing and swallowing.

The **spinal cord** extends from the bottom of the medulla and through a large opening in the bottom of the skull. Supported by the vertebrae, the spinal cord carries messages to and from the brain and the rest of the body.

Cerebellum

The cerebellum ("little brain") is a fist-sized portion of the brain located at the back of the head, below the temporal and occipital lobes and above the brainstem. Like the cerebral cortex, it has two hemispheres. The outer portion contains neurons, and the inner area communicates with the cerebral cortex. Its function is to coordinate voluntary muscle movements and to maintain posture, balance and equilibrium. New studies are exploring the cerebellum's roles in thought, emotions and social behavior, as well as its possible involvement in addiction, autism and schizophrenia.

Brain Coverings: Meninges

Three layers of protective covering called **meninges** surround the brain and the spinal cord.

- The outermost layer, the **dura mater**, is thick and tough. It includes two layers: The periosteal layer of the dura mater lines the inner dome of the skull (cranium) and the meningeal layer is below that. Spaces between the layers allow for the passage of veins and arteries that supply blood flow to the brain.
- The **arachnoid** mater is a thin, weblike layer of connective tissue that does not contain nerves or blood vessels. Below the arachnoid mater is the cerebrospinal fluid, or CSF. This fluid cushions the entire central nervous system (brain and spinal cord) and continually circulates around these structures to remove impurities.
- The **pia mater** is a thin membrane that hugs the surface of the brain and follows its contours. The pia mater is rich with veins and arteries.

Lobes of the Brain and What They Control

Each brain hemisphere (parts of the cerebrum) has four sections, called lobes: frontal, parietal, temporal and occipital. Each lobe controls specific functions.

- **Frontal lobe.** The largest lobe of the brain, located in the front of the head, the frontal lobe is involved in personality characteristics, decision-making and movement. Recognition of smell usually involves parts of the frontal lobe. The frontal lobe contains Broca's area, which is associated with speech ability.
- **Parietal lobe.** The middle part of the brain, the parietal lobe helps a person identify objects and understand spatial relationships (where one's body is compared with objects around the person). The parietal lobe is also involved in interpreting pain and touch in the body. The parietal lobe houses Wernicke's area, which helps the brain understand spoken language.
- **Occipital lobe.** The occipital lobe is the back part of the brain that is involved with vision.
- **Temporal lobe.** The sides of the brain, temporal lobes are involved in short-term memory, speech, musical rhythm and some degree of smell recognition.

Deeper Structures within the Brain

Pituitary Gland

Sometimes called the "master gland," the pituitary gland is a pea-sized structure found deep in the brain behind the bridge of the nose. The pituitary gland governs the function of other glands in the body, regulating the flow of hormones from the thyroid, adrenals, ovaries and testicles. It receives chemical signals from the hypothalamus through its stalk and blood supply.

Hypothalamus

The hypothalamus is located above the pituitary gland and sends it chemical messages that control its function. It regulates body temperature, synchronizes sleep patterns, controls hunger and thirst and also plays a role in some aspects of memory and emotion.

Amygdala

Small, almond-shaped structures, an amygdala is located under each half (hemisphere) of the brain. Included in the limbic system, the amygdalae regulate emotion and memory and are associated with the brain's reward system, stress, and the "fight or flight" response when someone perceives a threat.

Hippocampus

A curved seahorse-shaped organ on the underside of each temporal lobe, the hippocampus is part of a larger structure called the hippocampal formation. It supports memory, learning, navigation and perception of space. It receives information from the cerebral cortex and may play a role in Alzheimer's disease.

Pineal Gland

The pineal gland is located deep in the brain and attached by a stalk to the top of the third ventricle. The pineal gland responds to light and dark and secretes melatonin, which regulates circadian rhythms and the sleep-wake cycle.

Ventricles and Cerebrospinal Fluid

Deep in the brain are four open areas with passageways between them. They also open into the central spinal canal and the area beneath arachnoid layer of the meninges.

The ventricles manufacture **cerebrospinal fluid**, or CSF, a watery fluid that circulates in and around the ventricles and the spinal cord, and between the meninges. CSF surrounds and cushions the spinal cord and brain, washes out waste and impurities, and delivers nutrients.

Blood Supply to the Brain

Two sets of blood vessels supply blood and oxygen to the brain: the **vertebral arteries** and the **carotid arteries.**

The external carotid arteries extend up the sides of neck, and are where you can feel pulse when you touch the area with fingertips. The internal carotid arteries branch into the skull and circulate blood to the front part of the brain.

The vertebral arteries follow the spinal column into the skull, where they join together at the brainstem and form the **basilar artery**, which supplies blood to the rear portions of the brain. The **circle of Willis**, a loop of blood vessels near the bottom of the brain that connects major arteries, circulates blood from the front of the brain to the back and helps the arterial systems communicate with one another.

Cranial Nerves

Inside the cranium (the dome of the skull), there are 12 nerves, called cranial nerves:

- Cranial nerve 1: The first is the **olfactory nerve,** which allows for sense of smell.
- Cranial nerve 2: The **optic nerve** governs eyesight.
- Cranial nerve 3: The **oculomotor nerve** controls pupil response and other motions of the eye, and branches out from the area in the brainstem where the midbrain meets the pons.
- Cranial nerve 4: The **trochlear nerve** controls muscles in the eye. It emerges from the back of the midbrain part of the brainstem.
- Cranial nerve 5: The **trigeminal nerve** is the largest and most complex of the cranial nerves, with both sensory and motor function. It originates from the pons and conveys sensation from the scalp, teeth, jaw, sinuses, parts of the mouth and face to the brain, allows the function of chewing muscles, and much more.
- Cranial nerve 6: The **abducens nerve** innervates some of the muscles in the eye.
- Cranial nerve 7: The **facial nerve** supports face movement, taste, glandular and other functions.
- Cranial nerve 8: The **vestibulocochlear nerve** facilitates balance and hearing.
- Cranial nerve 9: The **glossopharyngeal nerve** allows taste, ear and throat movement, and has many more functions.
- Cranial nerve 10: The **vagus nerve** allows sensation around the ear and the digestive system and controls motor activity in the heart, throat and digestive system.
- Cranial nerve 11: The **accessory nerve** innervates specific muscles in the head, neck and shoulder.
- Cranial nerve 12: The **hypoglossal nerve** supplies motor activity to the tongue.

The first two nerves originate in the cerebrum, and the remaining 10 cranial nerves emerge from the brainstem, which has three parts: the midbrain, the pons and the medulla.

Peripheral nervous system

All of the body's neurons and their associated functions make up the peripheral nervous system (PNS). It is made up of spinal nerves that emerge from the spinal cord and cranial nerves that emerge from the brain. Once more, it is broken down into two sections:

First, the somatic nervous system and Second, the autonomic nervous system.

Somatic nervous system

Somatic processes are addressed by the somatic nervous system. The nerves that supply the skeletal muscles are part of it. The skeletal muscles under the direction of the somatic nervous system dictate how the body moves.

Autonomic nervous system

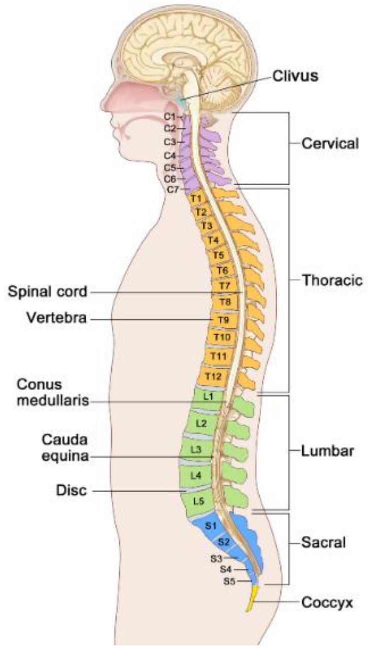
The regulation of visceral or vegetative functions is the responsibility of the autonomic nervous system. Therefore, it is also known as the vegetative or involuntary nervous system. Sympathetic and parasympathetic divisions make up the two halves of the autonomic nervous system.

Structure and function of spinal cord

In the vertebral canal, the spinal cord is loosely positioned.

It runs from the foramen magnum, above, and up to the lower border of the first lumbar vertebra below, where it is continuous with the medulla oblongata.

Segments of Spinal Cord



Spinal cord is made up of 31 segments:

Cervical segments = 8

Thoracic segments = 12

Lumbar segments = 5

Sacral segments = 5

Coccygeal segment = 1

In fact, the spinal cord is a continuous structure. The appearance of the segment is given by the nerves arising from the spinal cord which are called spinal nerve.

Spinal Nerves

Cervical spinal nerves = 8

Thoracic spinal nerves = 12

Lumbar spinal nerves = 5

Sacral spinal nerves = 5

Coccygeal nerve = 1

The segments of spinal cord correspond to the 31 pairs of spinal nerves in a symmetrical manner: The spinal nerves are:

Nerve Roots

An anterior (ventral) root and a posterior (dorsal) root make up each spinal nerve. Through the corresponding intervertebral foramina, both roots on either side exit the spinal cord.

Internal anatomy of the spinal cord

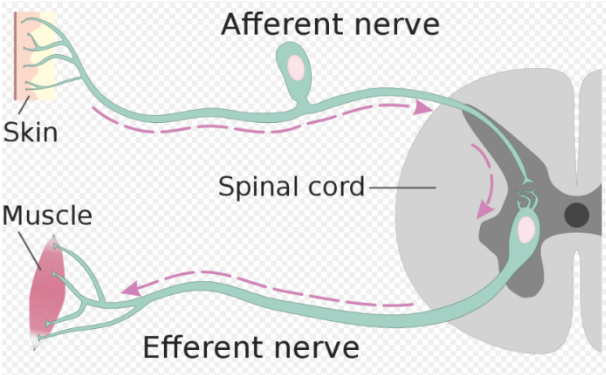
The inner grey matter and the outside white matter make up the spinal cord's neural tissue

Gray matter of spinal cord

The spinal cord's grey matter is made up of nerve cell bodies, dendrites, and fragments of axons. It is positioned in the centre and has the appearance of a letter H while taking the shape of butterfly wings.

There is a canal called the spinal canal that runs through the exact centre of grey matter.

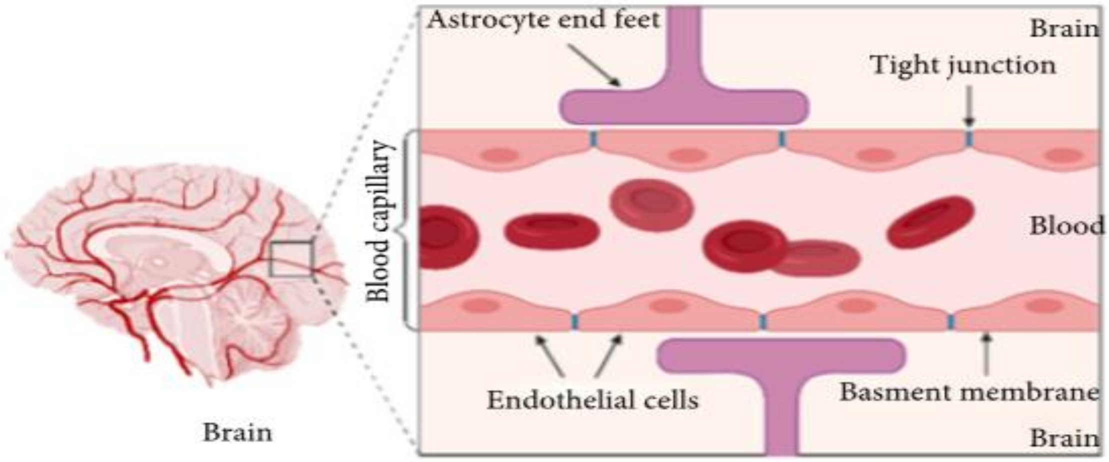
Afferent and Efferent Nerves



The terms *"afferent neurons"* and *"efferent neurons"* refer to several varieties of neurons that, respectively, make up the motor and sensory limbs of the peripheral nervous system. The fundamental unit of the nervous system's structure and operation are neurons, which are electrically excitable cells. A typical neuron is made up of nerve fibres that extend from the cell body and include the dendrites and axon, as well as a cell body that houses all of the cell's organelles. While the axon delivers messages out from the cell body towards the synapse, where the neuron connects with one or more other neurons, the dendrites are brief, branching extensions that take in signals from other neurons. The term *"nerve"* refers to a group of parallel-operating axons.

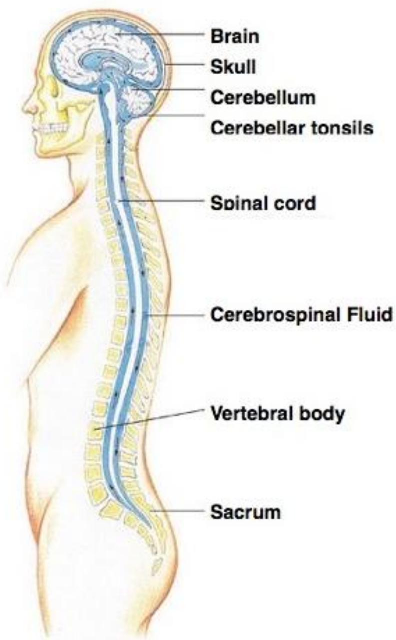
Afferent and efferent neurons are categorised according to the direction that information passes through the nervous system. Efferent neurons transmit motor information out from the central nervous system to the body's muscles and glands, whereas afferent neurons transfer information from sensory receptors in the skin and other organs to the central nervous system (i.e., the brain and spinal cord). Although they are not directly coupled, afferent and efferent nerve fibres cooperate to perceive and react to numerous stimuli. The interneuron, also known as an association neuron, functions as a relay between the two to allow communication between them.

BLOOD BRAIN BARRIER



Blood arteries, which flow throughout the body, are responsible for carrying oxygen and vital nutrients to all of the organs. Not everything that travels through the body may, however, enter the brain. The blood arteries in the brain differ just a little. Some chemicals can enter the walls of the brains while others cannot because of a special barrier. The blood-brain barrier is a special type of security. Some compounds can travel across this barrier without being blocked, while others may not. This is significant because it allows the brain to access the compounds it needs to operate while blocking out the toxic ones. Therefore, the blood-brain barrier is crucial for maintaining the health of our bodies and minds.

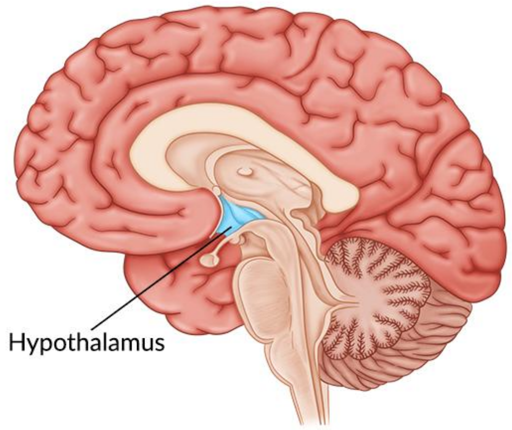
CSF



Brain and spinal cord are surrounded by a clear, colourless fluid called cerebrospinal fluid (CSF). Central nervous system is made up of brain and spinal cord. Everything you do, including how you move, breathe, see, think, and more, is coordinated and under its direction. Brain and spinal cord are protected from trauma or shock by cerebral spinal fluid, which functions as a cushion. Additionally, the fluid aids in the efficient operation of central nervous system and eliminates waste from the brain.

A CSF analysis is a series of tests that utilise a sample of cerebrospinal fluid to assist identify disorders that impact the central nervous system, including diseases of the brain, spinal cord, and other organs.

HYPOTHALAMUS



Hypothalamus is a structure located in the brain. It serves as the primary connection between neurological system and endocrine system.Body maintains homeostasis, a stable state of equilibrium, thanks to the hypothalamus.
Peripheral nervous system, which also reacts to signals from outside body, sends chemical messages to hypothalamus from nerve cells in peripheral nervous system and brain.

The primary job of hypothalamus is to respond to these signals in order to maintain body stable or in a condition of internal equilibrium. hypothalamus serves as body's "smart control" coordination centre, similar to how house may have a system to flawlessly coordinate all activities. Hypothalamus assists in controlling:

1.Body temperature.

2.Blood pressure.

3.Hunger and thirst.
4.Sense of fullness when eating.
5.Mood.
6.Sex drive.
7.Sleep
Many of hypothalamus' *"body balancing"* functions are accomplished by either directly affecting the autonomic nerve system or by controlling hormones autonomic nerve system regulates a number of vital biological processes, including heart rate and respiration.

The *"chemical messengers"* that go through bloodstream from one area of body to another are hormones. A particular organ or another endocrine gland,which releases more hormones are the two ways that hormones interact.
One's hypothalamusproduces several hormones that are otherwise keptin posterior pituitary)on its own.provides hormone-based signals to pituitary gland, which then either releases hormones that directly impact a region of body or sends another hormone-based signal to a separate gland in body, which then releases its hormone.For many different forms of learning and memory, hypothalamic neurons are necessary.

• Hypothalamus-specific neurotransmitters alter synaptic strength in in vitro preparations, indicating that the hypothalamus may regulate memory without affecting attention or motivation.

• It is important to characterise the evolutionary benefits of hypothalamic effect on logic gates for memory updating.
By regulating food intake, energy expenditure, and body fat reserves, the hypothalamus is crucial in controlling body weight. The systems that regulate satiety and hunger are known to be disrupted in hypothalamic obesity, which is thought to be brought on by anatomical damage to the hypothalamus, radiation therapy or the removal of a brain tumour, as well as genetic disorders in the hypothalamus.

Exercises
Question 1: Whatare Neurons?Describe the structure and function of Neurons. Why are they so important to our bodies?
Question 2: Explain the Structure and function of the Brain and spinal cord?

Question 3: Writeshort notes on (a) Blood Brain Barrier(b) CSF

Question 4: Describe in brief what are synapses? What is the mechanism of conduction of nerve impulses?

Question 5:What is Hypothalamus? Write down its role in various body functions?

Answers

Question 1: What are Neurons? Describe the structure and function of Neurons. Why are they so important to our bodies?

Answer 1:

Structure and function of Neuron:see text for the diagram

The structural and operational unit of the nevous system is the neuron, according to definition. It is also known as a nerve cell. A neuron has a nucleus and all the organelles are located in the cytoplasm, much like every other cell in th2e body. It differs from other cells in two respects, though:

1. The axon and dendrites of a neuron are branches or processes
2. The centrosome is absent in neurons

Structure of Neuron:

Three components make up each neuron:

Body of a nerve cell

1. Nerve cell body
2. Dendrite
3. Axon

The processes of a neuron are made up of the dendrite and axon combined. Axons are often lengthy processes whereas dendrites are typically small processes. Typically, dendrites and axons are referred to as nerve fibres.

Neuronal Body:

The soma or perikaryon are other names for the nerve cell body. It has an amorphous structure and is made up of neuroplasm, a mass of cytoplasm encased in a cell membrane.

A sizable nucleus, Nissl bodies, neurofibrils, mitochondria, and the Golgi apparatus are all found in the cytoplasm. Only nerve cells, *not* other cells, contain Nissl bodies and neurofibrils.

Each neuron has a single, centrally located nucleus.One or two conspicuous nucleoli can be seen in the nucleus. Centrosomes are *not* found in the nucleus. So, unlike other cells, nerve cells cannot proliferate.

Nissl body

Small basophilic granules called Nissl bodies or Nissl granules are present in the cytoplasm of neurons and are named for their discoverer. Other than in Axon Hillock, these bodies are widespread throughout Soma. Nissl bodies are known as *tigroid substances* because, after being properly stained, they cause the soma to seem *tigroid or speckled*. Nissl granules exit the soma and enter the dendrites, but not the axon. So, under a microscope, Nissl granules help to identify dendrites from axons.Ribosomes are found in the Nissl bodies, which are membrane organelles. Consequently, the creation of proteins in these bodies is important.Thus, these organisations are worried with the neurons producing proteins.Axonal flow carries the proteins made in the soma to the axon.The soma and the nerve both include networks of thread-like structures called neurofibrils.Another distinguishing trait of the neurons is the presence of neurofibrils.The soma and axon both contain mitochondria. Similar to other cells, the nerve cell's mitochondria serve as its centre of power, producing ATP.The nerve cell body's golgi apparatus resembles that of other cells. It deals with the preparation and granulation of proteins.

The neuron's branched process, or dendrite, is constantly branching. There might or might not be a dendrite. If existent, it might exist in a single or multiples. Neurofibrils and Nissl granules can be seen on the dendrite. The essence of dendrite is conductivity. It sends impulses to the body of the nerve cell.Axon length exceeds dendritic length. There is just one axon per neuron. The nerve cell body's axon hillock is where the axon emerges. The axon extends far beyond the body of the nerve cell. The longest axon is around one metre long.

Question 2: Explain the Structure and function of the Brain and spinal cord?

Answer 2: Structure and function of Brain

The brain and spinal cord are components of the central nervous system (CNS). Neurons and the supporting cells known as neuroglia combine to make it. The grey matter and white matter, which make up the brain and spinal cord, are organised in two layers.The nerve cell bodies and the proximal ends of the nerve fibres that emerge from the nerve cell body make up the grey matter. Nerve cells make up the white matter.SWhite matter is located in the centre of the brain, whereas grey matter is located on the periphery. Grey matter and white matter are found in different parts of the spinal cord.

The skull contains the brain. It continues as the spinal cord passes through the foramen magnum of the vertebral canal.

Brain Components

Brain, Nerves and Spine

The brain is a complex organ that controls thought, memory, emotion, touch, motor skills, vision, breathing, temperature, hunger and every process that regulates our body. Together, the brain and spinal cord that extends from it make up the central nervous system, orCNS.Weighing about 3 pounds in the average adult, the brain is about 60% fat. The remaining 40% is a combination of water, protein, carbohydrates and salts. The brain itself is a not a muscle. It contains blood vessels and nerves, including neurons and glial cells.

Gray and white matter are two different regions of the central nervous system. In the brain, gray matter refers to the darker, outer portion, while white matter describes the lighter, inner section underneath. In the spinal cord, this order is reversed: The white matter is on the outside, and the gray matter sits within.Gray matter is primarily composed of neuron somas (the round central cell bodies), and white matter is mostly made of axons (the long stems that connects neurons together) wrapped in myelin,a protective coating. Each region serves a different role. Gray matter is primarily responsible for processing and interpreting information, while white matter transmits that information to other parts of the nervous system.

The brain sends and receives chemical and electrical signals throughout the body. Different signals control different processes, and brain interprets each. Some make you feel tired, for example, while others make you feel pain.

Some messages are kept within the brain, while others are relayed through the spine and across the body's vast network of nerves to distant extremities. To do this, the central nervous system relies on billions of neurons.

Main Parts of the Brain and Their Functions

At a high level, the brain can be divided into the cerebrum, brainstem and cerebellum.

See text for the diagram

The cerebrum (front of brain) comprises gray matter (the cerebral cortex) and white matter at its center. The largest part of the brain, the cerebrum initiates and coordinates movement and regulates temperature. Other areas of the cerebrum enable speech, judgment, thinking and reasoning, problem-solving, emotions and learning. Other functions relate to vision, hearing, touch and other senses.The cortex has a large surface area due to its folds, and comprises about half of the brain's weight.The cerebral cortex is divided into two halves, or hemispheres. It is covered with ridges (gyri) and folds (sulci). The two halves join at a large, deep sulcus (the interhemispheric fissure, also known as the medial longitudinal fissure) that runs from the front of the head to the back. The right hemisphere controls the left side of the body, and the left half controls the right side of the body. The two halves communicate with one another through a large, C-shaped structure of white matter and nerve pathways called the corpus callosum. The corpus callosum is in the center of the cerebrum.The brainstem (middle of brain) connects the cerebrum with the spinal cord. The brainstem includes the midbrain, the pons and the medulla.

- **Midbrain.** The midbrain (or mesencephalon) is a very complex structure with a range of different neuron clusters (nuclei and colliculi), neural pathways and other structures. These features facilitate various functions, from hearing and movement to calculating responses and environmental changes. The midbrain also contains the substantianigra, an area affected by Parkinson’s disease that is rich in dopamine neurons and part of the basal ganglia, which enables movement and coordination.
- **Pons.** The pons is the origin for four of the 12 cranial nerves, which enable a range of activities such as tear production, chewing, blinking, focusing vision, balance, hearing and facial expression. Named for the Latin word for “bridge,” the pons is the connection between the midbrain and the medulla.
- **Medulla.** At the bottom of the brainstem, the medulla is where the brain meets the spinal cord. The medulla is essential to survival. Functions of the medulla regulate many bodily activities, including heart rhythm, breathing, blood flow, and oxygen and carbon dioxide levels. The medulla produces reflexive activities such as sneezing, vomiting, coughing and swallowing.

The **spinal cord** extends from the bottom of the medulla and through a large opening in the bottom of the skull. Supported by the vertebrae, the spinal cord carries messages to and from the brain and the rest of the body.

Cerebellum

The cerebellum (“little brain”) is a fist-sized portion of the brain located at the back of the head, below the temporal and occipital lobes and above the brainstem. Like the cerebral cortex, it has two hemispheres. The outer portion contains neurons, and the inner area communicates with the cerebral cortex. Its function is to coordinate voluntary muscle movements and to maintain posture, balance and equilibrium. New studies are exploring the cerebellum’s roles in thought, emotions and social behavior, as well as its possible involvement in addiction, autism and schizophrenia.

Brain Coverings: Meninges

Three layers of protective covering called **meninges** surround the brain and the spinal cord.

- The outermost layer, the **dura mater**, is thick and tough. The **arachnoid** mater is a thin, weblike layer of connective tissue that does not contain nerves or blood vessels. Below the arachnoid mater is the cerebrospinal fluid, or CSF. The **pia mater** is a thin membrane that hugs the surface of the brain and follows its contours. The pia mater is rich with veins and arteries.

  Each brain hemisphere (parts of the cerebrum) has four sections, called lobes: frontal, parietal, temporal and occipital. Each lobe controls specific functions.

- **Frontal lobe.** The largest lobe of the brain, located in the front of the head, the frontal lobe is involved in personality characteristics, decision-making and movement. Recognition of smell usually involves parts of the frontal lobe. The frontal lobe contains Broca's area, which is associated with speech ability.
- **Parietal lobe.** The middle part of the brain, the parietal lobe helps a person identify objects and understand spatial relationships (where one's body is compared with objects around the person). The parietal lobe is also involved in interpreting pain and touch in the body. The parietal lobe houses Wernicke's area, which helps the brain understand spoken language.
- **Occipital lobe.** The occipital lobe is the back part of the brain that is involved with vision.
- **Temporal lobe.** The sides of the brain, temporal lobes are involved in short-term memory, speech, musical rhythm and some degree of smell recognition.

Deeper Structures within the Brain

Pituitary Gland

Sometimes called the "master gland," the pituitary gland is a pea-sized structure found deep in the brain behind the bridge of the nose. The pituitary gland governs the function of other glands in the body, regulating the flow of hormones from the thyroid, adrenals, ovaries and testicles. It receives chemical signals from the hypothalamus through its stalk and blood supply.

Hypothalamus

The hypothalamus is located above the pituitary gland and sends it chemical messages that control its function. It regulates body temperature, synchronizes sleep patterns, controls hunger and thirst and also plays a role in some aspects of memory and emotion.

Amygdala

Small, almond-shaped structures, an amygdala is located under each half (hemisphere) of the brain. Included in the limbic system, the amygdalae regulate emotion and memory and are associated with the brain's reward system, stress, and the "fight or flight" response when someone perceives a threat.

Hippocampus

A curved seahorse-shaped organ on the underside of each temporal lobe, the hippocampus is part of a larger structure called the hippocampal formation. It supports memory, learning, navigation and perception of space. It receives information from the cerebral cortex and may play a role in Alzheimer's disease.

Pineal Gland

The pineal gland is located deep in the brain and attached by a stalk to the top of the third ventricle. The pineal gland responds to light and dark and secretes melatonin, which regulates circadian rhythms and the sleep-wake cycle.

Ventricles and Cerebrospinal Fluid

Deep in the brain are four open areas with passageways between them. They also open into the central spinal canal and the area beneath arachnoid layer of the meninges.

The ventricles manufacture **cerebrospinal fluid**, or CSF, a watery fluid that circulates in and around the ventricles and the spinal cord, and between the meninges. CSF surrounds and cushions the spinal cord and brain, washes out waste and impurities, and delivers nutrients.

Blood Supply to the Brain

Two sets of blood vessels supply blood and oxygen to the brain: the **vertebral arteries** and the **carotid arteries.**

Cranial Nerves

Inside the cranium (the dome of the skull), there are 12 nerves, called cranial nerves:

- Cranial nerve 1: The first is the **olfactory nerve,** which allows for sense of smell.
- Cranial nerve 2: The **optic nerve** governs eyesight.
- Cranial nerve 3: The **oculomotor nerve** controls pupil response and other motions of the eye, and branches out from the area in the brainstem where the midbrain meets the pons.
- Cranial nerve 4: The **trochlear nerve** controls muscles in the eye. It emerges from the back of the midbrain part of the brainstem.
- Cranial nerve 5: The **trigeminal nerve** is the largest and most complex of the cranial nerves, with both sensory and motor function. It originates from the pons and conveys sensation from the scalp, teeth, jaw, sinuses, parts of the mouth and face to the brain, allows the function of chewing muscles, and much more.
- Cranial nerve 6: The **abducens nerve** innervates some of the muscles in the eye.

- Cranial nerve 7: The **facial nerve** supports face movement, taste, glandular and other functions.
- Cranial nerve 8: The **vestibulocochlear nerve** facilitates balance and hearing.
- Cranial nerve 9: The **glossopharyngeal nerve** allows taste, ear and throat movement, and has many more functions.
- Cranial nerve 10: The **vagus nerve** allows sensation around the ear and the digestive system and controls motor activity in the heart, throat and digestive system.
- Cranial nerve 11: The **accessory nerve** innervates specific muscles in the head, neck and shoulder.
- Cranial nerve 12: The **hypoglossal nerve** supplies motor activity to the tongue.

The first two nerves originate in the cerebrum, and the remaining 10 cranial nerves emerge from the brainstem, which has three parts: the midbrain, the pons and the medulla.

Peripheral nervous system

All of the body's neurons and their associated functions make up the peripheral nervous system (PNS). It is made up of spinal nerves that emerge from the spinal cord and cranial nerves that emerge from the brain. Once more, it is broken down into two sections:

First, the somatic nervous system and Second, the autonomic nervous system.

Structure and function of spinal cord

In the vertebral canal, the spinal cord is loosely positioned.

It runs from the foramen magnum, above, and up to the lower border of the first lumbar vertebra below, where it is continuous with the medulla oblongata.

Segments of Spinal Cord

Spinal cord is made up of 31 segments:

Cervical segments = 8

Thoracic segments = 12

Lumbar segments = 5

Sacral segments = 5

Coccygeal segment = 1

In fact, the spinal cord is a continuous structure. The appearance of the segment is given by the nerves arising from the spinal cord which are called spinal nerve.

Spinal Nerves

The segments of spinal cord correspond to the 31 pairs of spinal nerves in a symmetrical manner: The spinal nerves are:

Cervical spinal nerves = 8

Thoracic spinal nerves = 12

Lumbar spinal nerves = 5

Sacral spinal nerves = 5

Coccygeal nerve = 1

Question 3: Write short notes on (a) Blood Brain Barrier (b) CSF

Answer 3: (a) Blood Brain Barrier

Blood arteries, which flow throughout the body, are responsible for carrying oxygen and vital nutrients to all of the organs. Not everything that travels through the body may, however, enter the brain. The blood arteries in the brain differ just a little. Some chemicals can enter the walls of the brains while others cannot because of a special barrier. The blood-brain barrier is a special type of security. Some compounds can travel across this barrier without being blocked, while others may not. This is significant because it allows the brain to access the compounds it needs to operate while blocking out the toxic ones. Therefore, the blood-brain barrier is crucial for maintaining the health of our bodies and minds.

Answer 3: (b) CSF

Brain and spinal cord are surrounded by a clear, colourless fluid called cerebrospinal fluid (CSF).Central nervous system is made up ofbrain and spinal cord. Everything you do, including how you move, breathe, see, think, and more, is coordinated and under its direction. Brain and spinal cord are protected from trauma or shock by cerebral spinal fluid, which functions as a cushion. Additionally, the fluid aids in the efficient operation of central nervous system and eliminates waste from the brain.

A CSF analysis is a series of tests that utilise a sample of cerebrospinal fluid to assist identify disorders that impact the central nervous system, including diseases of the brain, spinal cord, and other organs.

Question 4: Describe in brief what are Synapses? What is the mechanism of conduction of nerve impulses?

Answer 4: **Synapses**

Synapse is the junction between the two neurons. It is not the anatomical continuation. But, it is only a physiological continuity between two nerve cells.

Classification of synapse

Synapse is classified by two methods, anatomical classification and functional classification.

Anatomical classification

Synapse is formed by axon of one neuron ending on the cell body, dendrite or axon of the next neuron.

Depending upon the ending of axon, the synapse is classified into three types :

1. **Axoaxonic synapse** in which axon of one neuron terminates on axon of another neuron
2. **Axodendritic synapse** in which axon of one neuron terminates on dendrite of another neuron
3. **Axosomatic synapse** in which axon of one neuron ends on soma (cell body) of another neuron.

Functional classification

Function classification depends upon of mode of impulse transmission. On this basis, synapse is classified into two types:

1. Electrical Synapse

Electrical synapse is the synapse in which the physiological continuity between the presynaptic and the postsynaptic neurons is provided by the gap junction between these two neurons.There is direct exchange of ions between the two neurons though the gap junction. So, the action potential reaching the terminal portion of presynaptic neuron directly enters the postsynaptic neuron.

2. Chemical Synapse

Chemical synapse is the junction between a nerve fiber and a muscle fiber or between two nerve fibers, through which the signals are transmitted by the release of chemical transmitter.

See text for the diagram

The axon membrane is where the pump is situated. Currently, sodium ions are pumped from axoplasm to ECF and potassium ions are pushed from ECF to axoplasm. When a stimulus is provided to the membrane of a nerve fibre, the sodium-potassium pump ceases to function. Mechanical, pharmacological, or electrical stimulation are all possible. Positive charges are present inside and negative charges are present outside of the membrane as a result of the potassium ions rushing outside and the sodium ions rushing inside.

Either the nerve fibres are depolarized or the action potential is said to be present. The nerve impulse is the name for the action potential that is moving across the membrane. There are around +30 mV. Once the action potential is established, the sodium-potassium

The transfer of nerve impulses from one neuron to another requires synapses. Synapses are the way by which neurons, which are specialised to convey messages to specific target cells, do this. The plasma membrane of the target (postsynaptic) cell and the plasma membrane of the signal-passing neuron are in close proximity at a synapse. The enormous arrays of molecular machinery that connect the two membranes and carry out the signalling process are present at both the presynaptic and postsynaptic locations. Many synapses have an axon for the presynaptic component and a dendrite or soma for the postsynaptic component. Additionally, astrocytes communicate with synaptic neurons, reacting to synaptic activity to control neurotransmission

Synaptic adhesion molecules (SAMs), which protrude from both the pre- and post-synaptic neuron and cling together where they overlap, stabilise synapses at least chemical synapses in place. SAMs may also help create and maintain synapses.

Either the nerve fibres are depolarized or the action potential is said to be present. The nerve impulse is the name for the action potential that is moving across the membrane. There are around +30 mV. Once the action potential is complete, the sodium-potassium pump begins to work. The axon membrane will thereafter undergo repolarization in order to reach a resting potential.

Now, the steps are completed in the opposite sequence. This is the opposite of what happened during an action potential.

Purpose of synapse

The synapse's job is to transfer electrical impulses from one neuron to another. Some synapses do, however, block the impulses.

Consequently, there are two categories of synapses:

1. Synapses with an excitatory function that send impulses
2. Synapses with inhibitory function, which prevent impulses from being sent.

Role of neurotransmitters:

See text for the diagram

A neuron releases a signalling chemical called a neurotransmitter across a synaptic gap to influence another cell. The target cell, also known as the cell receiving the signal, might be a glandular or muscular cell in addition to another neuron. In the synaptic cleft, where they may

interact with receptors on the target cell, neurotransmitters are released from synaptic vesicles. The receptor that the neurotransmitter attaches to determines how the neurotransmitter affects the target cell. Numerous neurotransmitters are produced from easy-to-find, abundant precursors such amino acids, which are frequently converted in a few number of biosynthetic steps.

The proper operation of sophisticated neurological systems depends on neurotransmitters. Humans have an unknown number of distinct neurotransmitters, nonetheless, more than 100 have been located. Glutamate, GABA, acetylcholine, glycine, and norepinephrine are typical neurotransmitters. Precursor molecules that are plentiful in the cell are used to create neurotransmitters, which are often created in neurons. Peptides, monoamines, and amino acids are among the several classes of neurotransmitters. A single amino acid is changed to create monoamines. Tryptophan, for instance, is an amino acid that is the precursor of serotonin. Neuropeptides, also known as peptide transmitters, are proteins that are frequently produced together with other transmitters to have a modulatory impact. Like ATP, purine neurotransmitters are produced by nucleic acids. Nitric oxide and carbon monoxide, two metabolic byproducts, are components of other neurotransmitters. At the axon terminal of the presynaptic neuron, synaptic vesicles, which are grouped together near to the cell membrane, are where neurotransmitters are often kept. The metabolic gases carbon monoxide and nitric oxide, for example, are synthesised and released right after an action potential without ever being stored in vesicles.

Release

Typically, an electrical signal termed an action potential in the presynaptic neuron causes a neurotransmitter to be released at the presynaptic terminal. However, little or "baseline" release also happens in the absence of electrical stimulation. Neurotransmitters are released into the synaptic cleft and diffuse across it before binding to certain receptors on the postsynaptic neuron's membrane.

Interaction of receptors

Neurotransmitters diffuse across the synapse after being released into the synaptic cleft, where they can interact with receptors on the target cell. The type of target cell receptors found at the synapses determines how the neurotransmitter behaves. Neurotransmitter binding can cause the postsynaptic neuron to be excited, inhibited, or modulated depending on the receptor.

Elimination

In the synaptic cleft, acetylcholine is broken down into acetic acid and choline.

Neurotransmitters need to be taken out of the synaptic cleft in order to prevent persistent activation of receptors on the post-synaptic or target cell.One of three processes removes neurotransmitters:

1.Diffusion2. Enzyme degradation: Enzymes are proteins that degrade neurotransmitters.

3.Reuptake:

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Question 5: What is Hypothalamus? Write down its role in various body functions?

Answer 5: The hypothalamus is located above the pituitary gland and sends it chemical messages that control its function. It regulates body temperature, synchronizes sleep patterns, controls hunger and thirst and also plays a role in some aspects of memory and emotion.

HYPOTHALAMUS

See text for the diagram

Hypothalamus serves as the primary connection between neurological system and endocrine system. Body maintains homeostasis, a stable state of equilibrium, thanks to the hypothalamus.

Peripheral nervous system, which also reacts to signals from outside body, sends chemical messages to hypothalamus from nerve cells in peripheral nervous system and brain.

The primary job of hypothalamus is to respond to these signals in order to maintain body stable or in a condition of internal equilibrium. hypothalamus serves as body's "smart control" coordination centre, similar to how house may have a system to flawlessly coordinate all activities. Hypothalamus assists in controlling:

1.Body temperature.

2.Blood pressure.

3.Hunger and thirst.

4.Sense of fullness when eating.

5.Mood.

6.Sex drive.

7.Sleep

Many of hypothalamus' *"body balancing"* functions are accomplished by either directly affecting the autonomic nerve system or by controlling hormones. Autonomic nerve system regulates a number of vital biological processes, including heart rate and respiration.

The *"chemical messengers"* that go through bloodstream from one area of body to another are hormones. A particular organ or another endocrine gland,which releases more hormones are the two ways that hormones interact.
One's hypothalamus produces several hormones that are otherwise kept (in posterior pituitary) on its own. provides hormone-based signals to pituitary gland, which then either releases hormones that directly impact a region of body or sends another hormone-based signal to a separate gland in body, which then releases its hormone. For many different forms of learning and memory, hypothalamic neurons are necessary.

• Hypothalamus-specific neurotransmitters alter synaptic strength in in vitro preparations, indicating that the hypothalamus may regulate memory without affecting attention or motivation.

• It is important to characterise the evolutionary benefits of hypothalamic effect on logic gates for memory updating.By regulating food intake, energy expenditure, and body fat reserves, the hypothalamus is crucial in controlling body weight. The systems that regulate satiety and hunger are known to be disrupted in hypothalamic obesity, which is thought to be brought on by anatomical damage to the hypothalamus, radiation therapy or the removal of a brain tumour, as well as genetic disorders in the hypothalamus.