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HUMAN PHYSIOLOGY

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SYLLABI-BOOK MAPPING TABLE

Human Physiology

Syllabi	Mapping in Book
BLOCK - I: CELL, CELL ORGANELLES, TISSUES AND MUSCLES **Unit I** Cell - Structure and organization of prokaryotic and eukaryotic cells. Cell and nuclear membrane, cell wall and cell envelope. Physiology of cytoplasm. **Unit II** Cell organelles - Structural organization and functions of intracellular organelles: nucleus, nucleolus, endoplasmic reticulum, golgi complex, mitochondria, chloroplast, lysosomes, peroxisomes and vacuoles. **Unit III** Tissues - Classification, structure and functions of epithelial, muscular, connective and nervous tissues. **Unit IV** Musculo skeletal system - structure and functions of bone, cartilage, muscle, joints, ligaments and tendons.	**Unit 1:** Structure of Cells **(Pages 1-16);** **Unit 2:** Introduction to Cell Organelles **(Pages 17-54);** **Unit 3:** Tissue Systems **(Pages 55-71);** **Unit 4:** Skeletal System **(Pages 72-90)**
BLOCK - II: BLOOD, CARDIOVASCULAR, RESPIRATORY AND DIGESTIVE SYSTEM **Unit V** Blood - Introduction to hematology, functions of blood, plasma proteins, erythrocytes, Hb, important indices of RBC & WBC, Functions of blood groups, ESR, blood viscosity, blood coagulation, Erythroblastosis foetalis and blood transfusion. **Unit VI** Cardiovascular system - Basic properties of the heart, cardiac output, blood pressure and factors affecting it and hypertension. Nutrition and metabolism of heart. Exercise and heart Function. Techniques to identify cardiovascular disorders -angioplasty and angiogram. **Unit VII** Respiratory system - Anatomy and physiology of respiratory organs, mechanism of respiration, gaseous exchange in lungs and tissues. Resuscitation and its methods. Respiratory disorders: dyspnoea, asphyxia, hyperpnoea, orthopnoea, **Unit VIII** Digestive system - Anatomy, composition & functions of salivary, gastric, intestinal & pancreatic secretions. Functions of bile salts, Mechanism of secretion of digestive juices and its regulation, movements of stomach, small intestine, villi, defecation. Important of liver in digestive system, anatomy and physiology.	**Unit 5:** Introduction to Hematology **(Pages 91-127);** **Unit 6:** The Cardiovascular System **(Pages 128-150);** **Unit 7:** Respiratory System **(Pages 151-171);** **Unit 8:** Digestive System **(Pages 172-218)**
BLOCK - III: EXCRETORY AND REPRODUCTIVE SYSTEM, SENSE ORGANS **Unit IX** Excretory system - Mechanism of urine formation and the role of the kidneys in water and electrolyte balance. Renal function tests. Artificial kidney, dialysis and renal transplantation. **Unit X** Reproductive system - Male and female reproductive organs: structure and functions. Menstruation, menstrual cycle, puberty, menarche, menopause, fertilization, conception, implantation. Male and female contraception's- Etiology of male and female infertility. **Unit XI** Sense organs - Physiology of vision, hearing, taste, smell and cutaneous sensations.	**Unit 9:** Excretory System **(Pages 219-235);** **Unit 10:** Reproductive System **(Pages 236-260);** **Unit 11:** Sense Organs **(Pages 261-265)**
BLOCK - IV: ENDOCRINE, EXOCRINE AND NERVOUS SYSTEM **Unit XII** Endocrine glands - pituitary, thyroid gland, parathyroid gland, pancreas, adrenal cortex and adrenal medulla. Mechanism of action of hormones. Hormonal imbalance syndromes, hypo or hyperactivity. **Unit XIII** Exocrine glands - Structure and functions of sweat, salivary, mammary, ceruminous, lacrimal, sebaceous, and mucous glands. Gland secretion syndromes. **Unit XIV** Nervous system - General anatomy of nervous system, functions of the different parts, reflexes, autonomic nervous system. Common test in neurological disorders- EEG, EMG, MRI, NCV.	**Unit 12:** Endocrine Systems **(Pages 266-289);** **Unit 13:** Exocrine Systems **(Pages 290-295);** **Unit 14:** Nervous System **(Pages 296-319)**

CONTENTS

INTRODUCTION

NOTES

Human physiology is the science of the mechanical, physical, and biochemical functions of human beings, the organs in their body and the cells that comprise these organs.

Anatomy and physiology involve the study of living organisms and their properties. Some of these properties are organization; metabolism and excretion; movement and response to stimuli; development (by differentiation or growth); reproduction; and homeostasis, or the organism's ability to maintain internal stability.

Simply put, physiology is the science that focusses on the organs and systems and their functions. Human physiology is the science of the mechanical, physical, and biochemical functions of normal humans or human tissues or organs. The principal level of focus of physiology is at the level of organs and systems.

This book, *Human Physiology* aims at providing the readers an idea of not just the respiratory, digestive, skeletal and urinary systems, but also the structure and division of cells and cell organelles. This book is divided into fourteen units that follow the self-instruction mode with each unit beginning with an Introduction to the unit, followed by an outline of the Objectives. The detailed content is then presented in a simple but structured manner interspersed with Check Your Progress Questions to test the student's understanding of the topic. A Summary along with a list of Key Words and a set of Self-Assessment Questions and Exercises is also provided at the end of each unit for recapitulation.

NOTES

BLOCK - I
CELL, CELL ORGANELLES, TISSUES AND MUSCLES

UNIT 1 STRUCTURE OF CELLS

Structure

1.0 INTRODUCTION

Cell is defined as the structural and functional unit of life. In the 1850s, an Austrian pathologist, Rudolf Virchow said every animal appears as a sum of vital units, each of which bears in itself the complete characteristics of life.

Life had come into existence in the form of primitive cells in the sea. When cell had originated, it was in the form of the lipid membrane, surrounding few biochemicals in the cytoplasm. At that time, the water of the sea was full of nutrients and the environment was believed to be a reducing one. Regular rains and lightening caused reactions between the environmental gases present in the air (nitrogen, hydrogen, oxygen etc. water vapours) to form simple organic compounds. When these compounds reached the sea through rains, many nitrogenous and non-nitrogenous organic compounds including fatty acids, acetones, amino acids and nucleic acid etc. were formed. The coincidental association of these molecules (along with the lipid molecules in the form of a lipid bilayer) might have resulted into a structure like amoeba, which might be the most primitive form of life.

In this small factory called cell, all the functions including energy metabolism and reproduction take place. This is why, the cell is also called the biological unit of life. In a multicellular organism also, each cell can perform most of the activities required for its survival. In this unit, you will study the structure and functions of various organelles of the cell and the cell division processes.

NOTES

1.1 OBJECTIVES

After going through this unit, you will be able to:

- Discuss the structure and classification of the cells
- Describe the classification of prokaryotic and eukaryotic cells
- Analyse the difference between unicellular and multicellular organisms
- Describe the components of prokaryotic cells
- Explain and analyse the physiology of cytoplasm

1.2 CELL STRUCTURE

Cells are basically divided into two types; prokaryotes and eukaryotes. Prokaryotes came into existence prior to eukaryotic cells. Prokaryotic cells have very basic structure for their survival and reproduction. These cells are independent and can perform all biological functions within one cell.

Eukaryotic cells are complex in nature and commonly they can perform all functions which are required for basic metabolic function but, they can not exist in isolation except yeast, which can remain as single cell. They associate with each other to form an organism. The cells of this group do communicate with each other and compensate various functions which are required for the existence of the particular organism.

Cells are really small and their 'smaller size' gives them the advantage of having large surface areas. The size can vary from 0.5 μ to 20 μ. The larger is the surface area, the greater is the rate of exchange of nutrients and waste material. This phenomenon can be logically understood by observing the development of an egg. A hen's egg is single cellular (few cm) but, during the developmental stages it become bi-cellular and then multi-cellular. This larger number of smaller cells makes its feasible to make the metabolism really fast. In contrast to this reality, depending upon the role of a cell, various modifications for cell size and shape are available, for example, intestinal villi folds so many times to increase the surface area for food absorption. Nerve cells extend their axon and dendrites to long distances to communicate with other cells. The biggest cell is believed to be the egg of ostrich (170X155 mm). Lengthwise the longest cells are nerve cells which can reach up to 3 to 3.5 ft.

1.2.1 Structure of a Bacterial Cell

Any cell can be divided into the following three parts:

1. Protoplasm
2. Vacuoles
3. Cell wall

NOTES

- **Protoplasm:** The whole living substance of cell can be described as protoplasm. Huxley described protoplasm as the physical basis of life and Dujardin named it Sarcode in 1835. It was termed as protoplasm by Purkinje in 1840. It can be further divided into the following two parts:
  1. Cytoplasm
  2. Nucleus

  Cytoplasm can further be divided into the following two parts:
  1. Protoplasmic membranes
  2. Mesoplasm

  Nucleus can further be divided into the following:
  - o Nuclear membrane
  - o Nucleolus
  - o Nucleoplasm and
  - o Chromosomes

  Mesoplams can further be divided into the following:
  - o Hyloplasm,
  - o Cytoplasmic organelles
  - o Metabolically inactive substances (excretory: alkaloids, essential oils, latex, tannin etc., storage products: carbohydrates, fats and oils and nitrogenous products. secretary products: enzymes, colouring matter and nectar (incase of plants)). The names of various cell organelles are endoplasmic reticulum, golgi body, mitochondria, ribosomes, lysosomes, microbodies, microtubules, plastids and cilia and flagella.
- **Vacuoles:** Vacuoles are membrane-bound organelles which are present in all plant and fungal cells and some protist, animal and bacterial cells. Vacuoles are essentially enclosed compartments which are filled with water containing inorganic and organic molecules including enzymes in solution, though in certain cases they may contain solids which have been engulfed. Vacuoles are formed by the fusion of multiple membrane vesicles and are effectively just larger forms of these. The function and importance of vacuoles varies greatly according to the type of cell in which they are present, having much greater prominence in the cells of plants, fungi and certain protists than those of animals and bacteria.
- **Cell wall:** The plasma membranes of bacteria and members of the plant kingdom and some protists are surrounded by cell walls. The organisms in the sea environment may have a coating of proteins, cellulose or glassy silica. In case of plant cells, the cell walls are made up of cellulose and other polysaccharides. The fungal cell walls are made of polysaccharides and chitin. Bacterial cell wall is made up of peptidoglycan. Figure 1.1 shows the structure of peptidoglycan in bacterial cell wall.

NOTES

In plant cell, the cell wall is secreted by the cell it surrounds. Primary cell wall is made up of cellulose and the secondary cell wall is made by secreting polysaccharides and other biochemicals. The primary cell wall is pushed out by the secondary cell wall and the primary cell walls of the two adjacent plant cell fuses together by middle lamella, made of pectin.

Cell wall provides tremendous support to the cell, for example, the big trees can bear so much of load because of the cell wall on the cells of their trunk. Cell membranes are mostly porous in nature so that the communication and transport between the cells is not affected but the actual biological activities are played by cell membranes only.

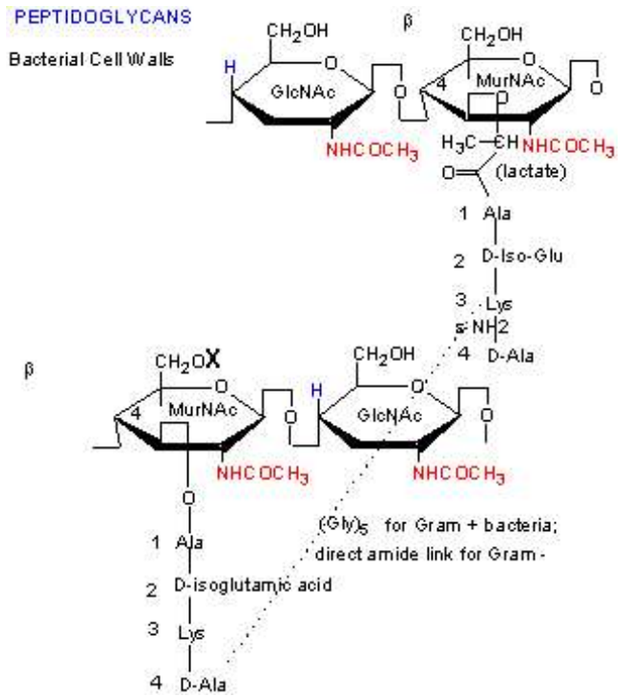

Fig. 1.1 *Structure of Peptidoglycan in Bacterial Cell Wall*

Extracellular matrix

In animal cell, the cells wall is not present, but they secrete an exracellular material called extra cellular matirx (ECM), which is a combination of glycoproteins. The main components of ECM are collagen and elastin. These two proteins are embedded into the web, formed by other proteins and this structure is now called as peptidoglycans. This ECM is connected to the plasma membrane by the help of fibronectin. They bind to the plasma membrane through integrin which is a protein of plasma membrane. Integrin milieus are important, as through them the ECM can communicate with internal cytoskeleton of the cells and the cell can actually respond if, there is any change occurs to the ECM. It can even affect the expression of certain molecules and also the migrating behaviour of the cells.

This is the way that all the cells of a particular tissue can communicate and coordinated with each other in response to particular stimuli.

Glycocalyx is present even outside the cell wall. It is made of mucopolysaccharides. If it is slimy in nature it can be washed away, but in the other case, it makes a hard capsule. As mentioned, it protects the bacteria in harsh environment and also fools the immune system of the host organism.

The plasma membrane has a similar composition as the plasma membrane of eukaryotic cells. The role of plasma membrane is to regulate the internal environment of the cell by restricting the entry and exit of various chemical constituents in the cell. It is made of mainly of phospholipids, other lipids and various type of protein located within or at periphery of the lipid bilayer.

The plasma membrane can also modify itself by folding inside the cell providing place for the attachment of various enzymes and other proteins, which have role in signal transduction etc. These folding are called as mesosomes.

The main difference between plant cell and animal cell is based on presence of cell wall, chloroplast and vacuoles. These three things are not present in animal cells.

1.3 PROKARYOTIC AND EUKARYOTIC CELLS

Cells can be classified into two types:

1. Prokaryotic cells
2. Eukaryotic cells

Both these types of cells usually have the following constituents:

- Cell membrane
- Cytoplasm
- Genetic material
- Energy currency
- Enzymes and coenzymes

These constituents are all necessary to carry out the functions of life. Table 1.1 differentiates between the two types of cells. All cells that have a membrane-bound nucleus (that contains chromosomes and DNA) are eukaryotic but the cells that lack membrane-bound nuclei are called prokaryotic cells.

Prokaryotic cells have a simple organization but eukaryotic cells show a high degree of differentiation. Prokaryotic cells include bacteria, blue or green algae, micro-plasma, spirochete, etc. They also have a remarkable amount of variation in their shapes and sizes as compared to eukaryotic cells. Prokaryotic bacteria depict four basic types:

- Bacillus
- Cocci

- Vibrio
- Spirilla and spirochetes
- Pleuropneumonia-like organism

NOTES

Prokaryotic cells lack membrane-bound organelles and the genetic material is localized within a discrete nucleoid region, while the ribosomes and inclusion bodies remain scattered in the cytoplasm matrix.

Table 1.1 *Differences between the Types of Cells*

Prokaryotic Cells	Eukaryotic Cells
Cell size is small; 3 mm in diameter	Cell size large and variable; up to 40 mm in diameter
Lack organized nucleus and genetic material is present in the form of nucleus	Well-organized nucleus
Nuclear membrane absent	Nuclear membrane present
DNA in a loose circular form but not packed into chromosomes	Linear DNA that remains packed into chromosomes
No membrane-bound organelles	Membrane-bound organelles in abundance: ER (endoplasmic reticulum) mitochondria, golgi bodies, lysosomes, etc. present
Mitochondria absent	Mitochondria present
Chloroplast absent, photosynthetic lamella may be present in photosynthetic bacteria	Chloroplast present in plant cell
Cell wall made up of murein, peptidoglycan, lipids, teicoic acid	Cell wall absent in animal cell and in plant cell, it is made up of cellulose, hemicellulose and lignin
Microtubules absent	Microtubules forming the cytoskeleton present
Different kind of pili including sex-pili and fimbiae present	Pili absent
Ribosomes are of 70S type	Ribosomes of 80S type in cytoplasm and 70S type in organelles

Unicellular and Multicellular Organisms

Unicellular organisms are those that can survive without the help of other cells. On the other hand, a multicellular organism is much more complex since there is an interdependence of the cells. These cells are specialized in a way so as to

complement the entire organism and they cannot exist independently. The types of organisms have been discussed as follows:

- **Unicellular organisms:** These single-celled organisms possess the mechanisms to move, reproduce and sense in the environment, all in one cell. Examples of unicellular organisms are amoeba and bacteria.
- **Multicellular organisms:** Organisms that are made up of many cells are termed as multicellular. A multicellular organism may be made up of a few cells (algae and some yeast forms) to several million cells (human cells). In multicellular organisms, certain cells become specialized to perform a specific function and thus, there is division of labour among the different groups of cells.

Cells with common origin, performing specific functions constitute a tissue. When several types of tissues are joined, an organ (like kidney, heart, liver, leaves, roots, etc.) is formed to carry out one or more specific functions. In a majority of animals, several organs are interrelated to perform a specific function and they form an organ system such as the digestive, reproductive or excretory system. In both plants and animals, the life of every organism begins as a single cell. The unicellular organisms spend their entire life as a single cell. In others, the number of cells increases during the course of life. Since all cells of an organism develop from pre-existing cells, they share the same genetic information. They are also capable of giving rise to new and individual cells. This potential of the cell is called totipotency.

1.3.1 Ultrastructure of Prokaryotic Cell

Let us look at the prokaryotic and eukaryotic cells in detail. The components of a prokaryotic cell are as follows:

Prokaryotic cells, bacterial cells in particular, have a chemically complex cell envelope (Figure 1.2). Through the electron microscope, the cell envelope appears to be composed of three basic layers, which can be identified as:

- Glyocalyx
- A cell wall
- A cell or plasma membrane

Although each layer of the **cell envelope** performs distinct functions, together they act as a single protective unit.

Glycocalyx

Glycocalyx is the outermost layer made up of macro-molecules like proteins, polysaccharide, starch etc. It protects the cell and helps in bacterial adhesion to the host cell. It is a virulence factor in many pathogenic bacteria. Some bacteria show a loose sheath called the slime layer, which protects the cell from loss of water and nutrients, while others may have a thick and tough covering known as the capsule and these are made up of polysaccharides, proteins, etc.

NOTES

Cell Wall

Cell wall is the second layer of the cell envelope lying below the glycocalyx. It provides strong structural support to prevent a bacterium from collapsing in a hypotonic solution (a solution having low salt concentration). This layer is rigid because of macromolecules called peptidoglycean. Gram-positive organisms contain more teichoic acid in the cell wall, while gram-negative organisms contain them in lesser quantities. In gram-positive organisms, the cell wall is 20–80 nm thick while in gram-negative organisms the cell wall is 8–12 nm thick.

Cell Membrance

Cell or plasma membrane is the component that is responsible for the relationship of the cell with the outside environment. An important character of this membrane is its permeability, that is, it is semi-permeable in nature. It is permeable to some variables with lipids (20–79 per cent), proteins (20–70 per cent), oligosaccharides (1.5 per cent) and water (20 per cent) of its total weight depending upon the tissue and organism involved. The major lipid components of the membrane are phospholipids, glycolipid and cholesterol. The membrane associated lipids are asymmetric. They are arranged in two parallel chains with polar and non-polar ends. They are also called amphipathic, that is, they contain both hydrophilic (meaning water-attracting) and hydrophobic (meaning repelling) regions. Therefore, they possess both non-polar and polar ends.

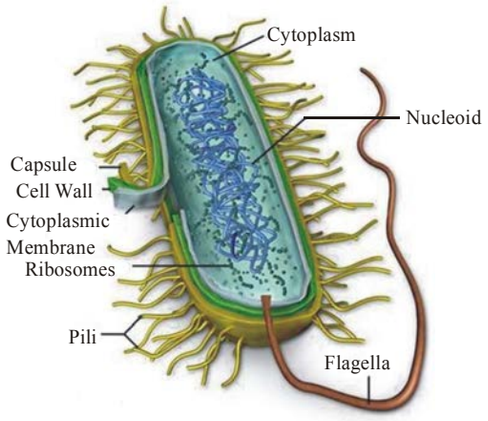

Fig. 1.2 *Structure of a Prokaryote—Bacterial Cell*

In the late 1930s, Danielle and Davson proposed that the plasma membrane was made up of a lipid layer between two continuous layers of proteins. With the development of the electron microscope, it became possible to understand the internal structure of the membrane. This membrane showed two outer layers of protein and a middle layer of phospholipids. Due to this, it came to be called the unit membrane. The polar ends interact with water and are called hydrophilic whereas non-polar ends are hydrophobic. The lipid forms the bilayer and the outer surface of membrane is hydrophilic. The hydrophobic ends are buried in the

interior, away from the surrounding water. Most of the amphipathic lipids are phospholipids.

Fluid mosaic model of cell membrane

NOTES

The fluid mosaic model (Figure 1.3) proposed by S. Jonathan Singer and Nicholson in 1972 visualized a central bilipid layer that was composed of phospholipids with their spherical polar heads on the outer surface. The two non-polar tails of each molecule are pointed inward. This particular arrangement forms a water-resistant barrier through which only lipid-soluble organisms showed movement. This membrane also had integrated protein molecules. The proteins are distinguishable as the extrinsic protein remains loosely connected to the membrane and, therefore, can be easily removed from the membrane. The rest of the proteins are integral proteins found on intrinsic proteins, which are embedded in the lipid bilayer and cannot be easily extracted. Some large integral proteins project beyond the lipid layer and are considered to be channel proteins through which the water-soluble material can pass.

Some small integral proteins can partially penetrate lipid bilayers. They are exposed to one surface only. Many integral proteins and some membrane lipids are associated with oligosaccharides, which project into extra-cellular fluid from the outer surface of the plasma membrane.

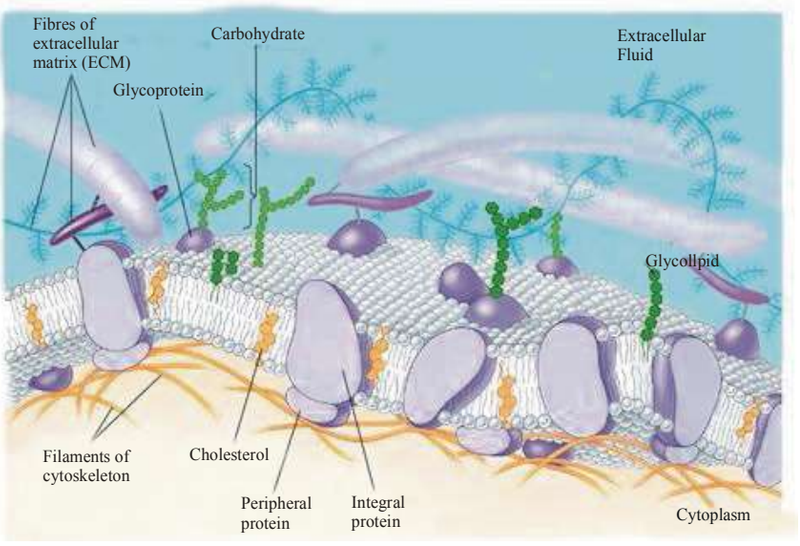

Fig. 1.3 *Fluid Mosaic Model of Cell Membrane*

The plasma membrane serves the following functions:

- It prevents the loss of essential components through the leakage.
- It helps in the movement of molecules which will not cross the membrane otherwise.
- It is used for nutrient uptake, waste secretion and protein-secretion.

NOTES

The presence of specific proteins in the membrane receptor helps in the flow of materials and information into the cell and also helps the bacteria to detect and respond to chemicals lying in their surroundings.

It serves as a selective permeability barrier allowing particular ions and molecules to pass either into or out of the cell while preventing others.

Inclusion Bodies

The reserved material of bacteria is stored in the cytoplasm as an inclusion body or as storage granule. For example, glycogen granules, phosphate granules and volutin granules, etc.

Organic inclusion bodies: These are gas vacuoles that occur in cyanobacteria. In cyanobacteria, there are purple and green photosynthetic bacteria and a few other aquatic forms that are free-floating (planktonic) because of gas vacuoles. These bacteria keep floating on the surface of water and trap sunlight for photosynthesis.

Inorganic vacuoles: These granules can adopt different colours with the basic dye and are therefore called meta-chromatic granules. At the same time, they can also act as storage reservoirs for phosphate and sulphur.

Flagellum

The bacterial flagellum is composed of three parts—the filament, the hook and the basal body (Figure 1.4).

The filament is the longest portion of the flagellum. It is made up of protein called flagellin. The filament is about 20 m in diameter and 1–70 nm in length.

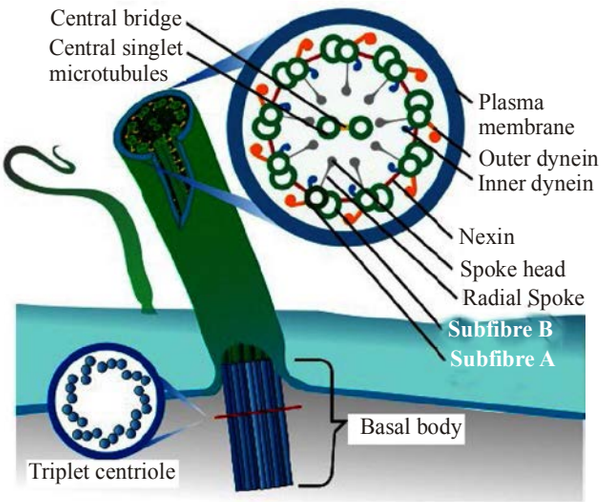

Fig. 1.4 *Flagella Structure*

The hook is different from the filament and is made up of the different protein sub-unit.

The basal body is the most complex part of the flagellum. In gram-negative bacteria, it is composed of four rings connected to central rod. The gram-positive cells have two basal body rings. The inner ring is connected to the plasma membrane while the outer ring is connected to a peptidoglycan layer. The flagellum rotates and pushes the bacterium in various directions.

Pili and Fimbrial

Pili and fimbriae are elongated, tubular structures made up of special protein called pilin, that protrudes from the bacterial cell surface. They are basically involved in the mating process between F-Positive and F-Negative bacterial forms, especially gram-negative coccobacillary forms and it is through them that genetic material is exchanged between bacteria.

Check Your Progress

1. What are organic inclusion bodies?
2. What are pili and fimbrial?
3. What is the main difference between plant cell and animal cell?

1.4 PHYSIOLOGY OF CYTOPLASM

The cell membrane has a gel-like matter which is called the cytoplasm. The gel is formed due to its contents which are water, proteins, lipids, nucleic acids, inorganic salts, etc. The fluidity provided due to the gel helps in many biochemical reactions to take place. The composition of cytoplasm has the organelles and cytosol. Many metabolic actions happen in the cytoplasm, and its subcellular structures, like ribosomes, plasmids, and cytoplasmic granules, are found in the cytoplasm.

Ribosomes are located in cytoplasm and have a diameter of roughly 15-20 mm; they have a composition of 30S small subunits and 50S large subunits. There is a need of Mg2 for the subunits to associate. Ribosomes are composed of thirty per cent ribosomal proteins and seventy per cent ribosomal RNA.

Plasmids are tiny, spherical, twin-stranded DNA molecules and extra chromosomal genetic material. They are able to replicate individually from chromosomal DNA and communicate genes encrypting drug resistance, bacteriocins, toxins, and are also more from one bacterium to the other with the help of conjugation and transduction.

Several types of inclusion granules of cytoplasmic are referred to as cytoplasmic granules. They have an intracytoplasmic form which helps in storage of nutrients and energy and contain molecules like polysaccharides, lipids, phosphates, etc. They need not be present in the structure of the cells. They are referred to as metachromatic granules since they could tint into various colours as compared to the other structures of bacterial cells.

NOTES

The cell gets its shape with the help of Cytoplasm. It aids in filling up the cell and keeping the organelles in position. In its absence the cell will be shapeless and flattened and the substances will not have a free movement and will have difficulty in passing from one organelle to the next one. Part of cytoplasm which does not consist of organelles is the Cytosol as it is restricted with borders of a medium that fill this part of the cell and as a result do not have organelles.

Organisation of Cytosol

While the constituents of the cytosol need not be disjointed into sections due to the membrane of the cells, these constituents may not randomly mix and various levels of organization may prevent from scattering particular molecules to demarcated positions in the cytosol.

Concentration gradients: The diffusion of tiny molecules within the cytosol is very fast yet the concentration gradients are created inside the compartments of cytosol. An advance investigated illustration of this is the sparks of calcium that occur in the area surrounding the calcium channel for short duration. They have a diameter of barely 2micrometres and sustain just for a couple of milliseconds, combining of more number of sparks may result in formation if a gradient of a larger size that is referred to as calcium waves. Concentration gradients of oxygen and adenosine triphosphate might be created within the cells surrounding the groups of mitochondria, although there is not much clarity about them.

Protein complexes: In the organisation of cytosol proteins associate in order to develop protein complexes, they are made of proteins sets that have same functions; these could be enzymes which perform numerous steps in the matching metabolic pathway. This organization allows substrate channelling, this occurs when the product of an enzyme passes straight to the following enzyme in a pathway, without being released into the solution. Channelling helps in increasing the efficiency and speed of the pathway, in its absence the enzymes would be freely distributed inside the cytosol and it also helps in preventing the unstable reaction intermediates from releasing. However there is a wide range of pathways for metabolic activities with tight bounding of the enzymes and there are as many for loose association and it becomes difficult to study these complexes separated from the cell. As a result, the significance of such complexes for metabolic activity is still not understood clearly.

Protein Compartments: Few of the protein complexes comprise of a big cavity in the centre, this is detached from the rest of the cytosol. Proteasome is one such compartment, in this group of subunits create a tube like hollow consisting of proteases which damage cytosolic proteins. The tube helps them to not mix with the remaining cytosol, the tube is covered by a group of controlling proteins and these are able to identify the damaging proteins and they direct them towards the proteolytic cavity. Bacterial micro-compartments is another type of big protein compartments, these are composed of protein shell which captures different enzymes. The size of these compartments is usually around 100-200 nanometres

diagonally and is composed of proteins that are interlocked. Carboxysome is a common example of this. Protein-enclosed bacterial micro-compartments inside the cytosol are called carboxysomes

Cytoskeletal Sieving: Cytoskeleton acts as a excluding compartment even though it is not really a part of the cytosol, but as mentioned due to its form as a network of filaments it limits the dispersal of big substances in the cell. These eliminating partitions might consist of actin fibres which are much denser as compared to the rest of the cytosol and as a result it concentrates them to some parts and thus excluding them from other areas.

Functions of Cytosol

The cytosol has multiple functions as it is the place where many cell processes take place. It is the place where process of signal transduction takes place. Several processes of cytokinesis also take place here once the nuclear membrane is broken down in the mitosis. One more essential function of cytosol involves transporting of metabolites from their place of production to the place where they are going to be used. The water-soluble molecules like amino acids can be quickly diffused with the help of cytosol. On the other hand, hydrophobic molecules, like fatty acids or sterols, can be transported in the cytosol by definite binding proteins; they help in shuttling the molecules flanked in membranes of the cell. Molecules which come into the cell through endocytosis or are on the path of secretion may also be transferred with the help of the vesicles within the cytosol. Vesicles are tiny circles of fatty acid that move with the help of motor proteins alongside the cytoskeleton.

The cytosol is the place of many metabolic activities in prokaryotes and also for major chunk of metabolic activities of eukaryotes. For instance half of the cell's protein in mammals is contained in the cytosol. In yeast, the entire data is available, here metabolic rebuilding show that cytosol is the place where majority of not only metabolic processes but also metabolites take place. The chief metabolic pathways which take place animal's cytosol are protein biosynthesis, the pentose phosphate pathway, glycolysis and gluconeogenesis. It is not the same for all organisms as the localization of pathways varies, for example in plants the synthesis of fatty acids takes place in chloroplasts along with apicoplasts and apicomplexa.

Check Your Progress

4. What are ribosomes?
5. What are plasmids?

1.5 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. Organic inclusion bodies are gas vacuoles that occur in cyanobacteria. In cyanobacteria, there are purple and green photosynthetic bacteria and a

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few other aquatic forms that are free-floating (planktonic) because of gas vacuoles.

2. Pili and fimbriae are elongated, tubular structures made up of special protein called pilin, that protrudes from the bacterial cell surface. They are basically involved in the mating process between F-Positive and F-Negative bacterial forms, especially gram-negative coccobacillary forms and it is through them that genetic material is exchanged between bacteria.
3. The main difference between plant cell and animal cell is based on presence of cell wall, chloroplast and vacuoles. These three things are not present in animal cells.
4. Ribosomes are located in cytoplasm and have a diameter of roughly 15-20mm; they have a composition of 30S small subunits and 50S large subunits. There is a need of Mg2 for the subunits to associate. Ribosomes are composed of thirty per cent ribosomal proteins and seventy per cent ribosomal RNA.
5. Plasmids are tiny, spherical, twin-stranded DNA molecules and extra chromosomal genetic material. They are able to replicate individually from chromosomal DNA and communicate genes encrypting drug resistance, bacteriocins, toxins, and are also more from one bacterium to the other with the help of conjugation and transduction.

1.6 SUMMARY

- Cells are basically divided into two types; prokaryotes and eukaryotes. Prokaryotes came into existence prior to eukaryotic cells. Prokaryotic cells have very basic structure for their survival and reproduction. These cells are independent and can perform all biological functions within one cell.
- Eukaryotic cells are complex in nature and commonly they can perform all functions which are required for basic metabolic function but, they can not exist in isolation except yeast, which can remain as single cell.
- The whole living substance of cell can be described as protoplasm. Huxley described protoplasm as the physical basis of life and Dujardin named it Sarcode in 1835. It was termed as protoplasm by Purkinje in 1840.
- Vacuoles are membrane-bound organelles which are present in all plant and fungal cells and some protist, animal and bacterial cells.
- The plasma membranes of bacteria and members of the plant kingdom and some protists are surrounded by cell walls. The organisms in the sea environment may have a coating of proteins, cellulose or glassy silica. In case of plant cells, the cell walls are made up of cellulose and other polysaccharides.

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- Cell wall provides tremendous support to the cell, for example, the big trees can bear so much of load because of the cell wall on the cells of their trunk. Cell membranes are mostly porous in nature so that the communication and transport between the cells is not affected but the actual biological activities are played by cell membranes only.
- In animal cell, the cells wall is not present, but they secrete an exracellular material called extra cellular matirx (ECM), which is a combination of glycoproteins. The main components of ECM are collagen and elastin.
- The main difference between plant cell and animal cell is based on presence of cell wall, chloroplast and vacuoles. These three things are not present in animal cells.
- Prokaryotic cells have a simple organization but eukaryotic cells show a high degree of differentiation. Prokaryotic cells include bacteria, blue or green algae, micro-plasma, spirochete, etc.
- Prokaryotic cells lack membrane-bound organelles and the genetic material is localized within a discrete nucleoid region, while the ribosomes and inclusion bodies remain scattered in the cytoplasm matrix.
- Unicellular organisms are those that can survive without the help of other cells. On the other hand, a multicellular organism is much more complex since there is an interdependence of the cells.
- Cells with common origin, performing specific functions constitute a tissue. When several types of tissues are joined, an organ (like kidney, heart, liver, leaves, roots, etc.) is formed to carry out one or more specific functions.
- Cell or plasma membrane is the component that is responsible for the relationship of the cell with the outside environment. An important character of this membrane is its permeability, that is, it is semi-permeable in nature.
- The bacterial flagellum is composed of three parts—the filament, the hook and the basal body.

1.7 KEY WORDS

- **Vacuoles:** Vacuoles are membrane-bound organelles which are present in all plant and fungal cells and some protist, animal and bacterial cells.
- **Protoplasm:** The whole living substance of cell can be described as protoplasm.
- **Glycocalyx:** It is the outermost layer made up of macro-molecules like proteins, polysaccharide, starch etc. It protects the cell and helps in bacterial adhesion to the host cell.

1.8 SELF ASSESSMENT QUESTIONS AND EXERCISES

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Short Answer Questions

1. What do you understand by the term totipotency?
2. State the functions of plasma membrane.
3. What are the four basic types of prokaryotic bacteria?
4. Define the three parts of bacterial flagellum.

Long Answer Questions

1. Discuss the structure of the cell with the help of diagrams.
2. Describe the classification of prokaryotic and eukaryotic cells.
3. Analyse the difference between unicellular and multicellular organisms.
4. Describe the components of prokaryotic cells.
5. Explain in detail the physiology of cytoplasm.

1.9 FURTHER READINGS

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UNIT 2 INTRODUCTION TO CELL ORGANELLES

Structure

2.0 INTRODUCTION

Unlike prokaryotic cells, eukaryotic cells have: (1) a membrane-bound nucleus; (2) numerous membrane-bound organelles—such as the endoplasmic reticulum, Golgi apparatus, chloroplasts, mitochondria, and others; and (3) several, rod-shaped chromosomes. Because a eukaryotic cell's nucleus is surrounded by a membrane, it is often said to have a "true nucleus." The word "organelle" means "little organ," and, as already mentioned, organelles have specialized cellular functions, just as the organs of our body have specialized functions.

2.1 OBJECTIVES

After going through this unit, you will be able to:

- Analyse the different cellular compartments of the eukaryotic cells
- Describe the various parts and functions of mitochondria
- Discuss the functions of various organelles
- Analyse peroxymes as the second type of microbody

2.2 CELL ORGANELLES

In cell biology, an organelle is a specialized subunit within a cell that has a specific function. It is usually separately enclosed within its own lipid bilayer. Organelles

are identified by microscopy, and they be purified by cell fractionation. There are many types of organelles, particularly in eukaryotic cells.

2.2.1 Organelles in Eukaryotic Cell

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The different cellular compartments of the eukaryotic cells are called cell organelles. They are primarily classified as nucleus, endomembrane system which includes endoplasmic reticulum, golgi body, lysosomes, peroxisomes, mitochondria and chloroplast (in case of plant cell).

- **Nucleus:** Nucleus was discovered by Robert Brown in 1831. It is the largest cell organelle present in the eukaryotic cell. It is surrounded by nuclear membrane. This membrane generally continues with endoplasmic reticulum and is occupied by ribosomes. The membrane is interrupted by pores called nuclear pores. These pores are around 90 nm in diameter. These pores allow specialized entry from nucleus to cytoplasm and cytoplasm to nucleus. Figure 2.1 shows the structure of the nuclear membrane.

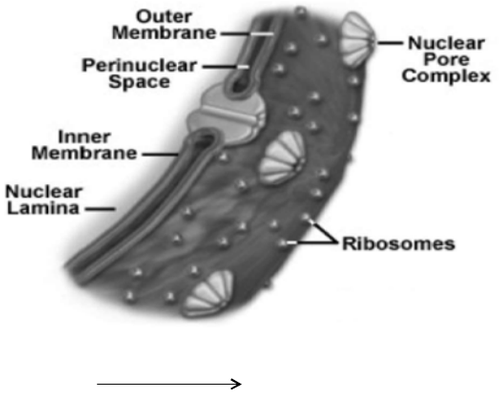

Fig. 2.1 *Structure of Nuclear Membrane*

Nucleus consists of deoxyribonucleic acid (DNA), ribonucleic acid (RNA) and several proteins. The basic (positively charged) proteins; histones are associated with DNA to form nucleosomes. Several thread like structures can be seen in the nucleus which are made up of DNA. These are called chromatins. A single human chromosome consists of millions of chromatins. Every organism has a specific number of chromosomes. In a human cell (of any type) 23 pairs/46 chromosomes are always present. Nucleus is also called the genetic repository of the cell.

Nucleus is found in each cell except mammalian erythrocytes. Most of the mammalians (except camel) erythrocytes loose their nucleus during the developmental phase. The primary objectives of loosing nucleus are to increase the surface area of the cell for oxygen exchange and to increase the flexibility of the RBCs as they have to pass through the thinnest capillaries. Figure 2.2 shows the structure of nucleus.

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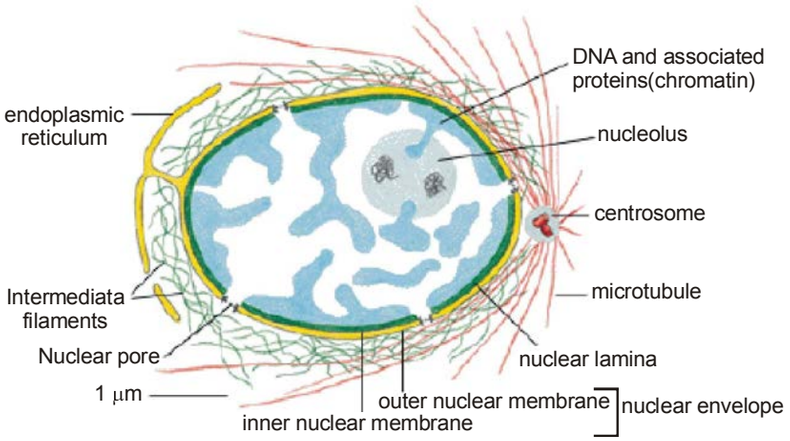

Fig. 2.2 *Structure of Nucleus*

As said earlier, the nucleus consists of DNA, nucleoplasm and a dense body called nucleolus. Nucleolus mainly consists of ribosomal (rRNA). The nucleoplasm contains many enzymes like RNA polymerase and DNA polymerase. Some cytoplasmic enzymes like enzymes for glycolysis, citric acid cycle and monophosphate shunt are also present in the nucleoplasm.

During the normal phase of cell life, the DNA is present in the form of chromatin. In this form, the proteins are loosely associated with the DNA. From this DNA, transcription of RNA occurs. The newly formed RNA then processes to form mRNA which actually codes for the proteins to be translated. This RNA moves out to the cytoplasm and there the mRNA gets translated to peptide on the ribosomes. This is called the central dogma of life. This is shown in Figure 2.3.

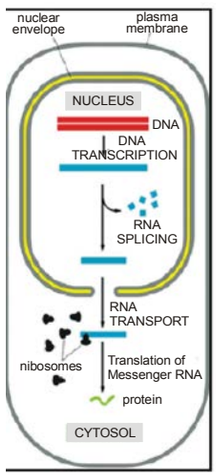

Fig. 2.3 *The Central Dogma of Life*

- **Chromosomes:** DNA is the genetic material for most of the living beings (except few retroviruses, where RNA is the genetic material). These DNA

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molecules combine with histone proteins to form chromosomes. The DNA molecules contain the hereditary information which specifies the cell structure, function and the entire life circle of an individual organism. The prokaryotic cells contain circular DNA. In case of eukaryotes, the chromosomes are present in linear form, always in pairs; one from the mother and the other from the parental side.

A definite number of 'chromosomes pairs' (homologous chromosomes) is the characteristic of an organism. These pairs and the actual chromosomal structure can only be visualized during the division. Normally they are present in the form of a thread like structure which is called chromatin. In normal conditions, the DNA loosely binds around the protein complex. This arrangement gives it a 'beads on string' like structure and is termed as nucleosomes.

During the cell division, the DNA coils very tightly around the histones. After the cell division the DNA molecules extend in thread like structure again and can not be distinguished from each other by light microscope. The structure of DNA and chromosomes is shown in Figure 2.4.

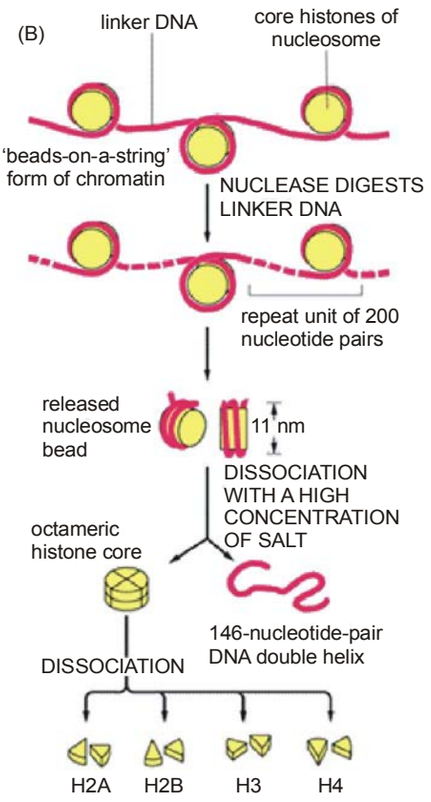

Fig. 2.4 *Arrangement of DNA around the Histone Proteins*

A typical chromosome can have the following structure; centromere, two telomere and many replication origins**.** According to location, chromosomes can

be classified in four groups; telocentric, acrocentric, metacentric and submetacentric. These are shown in Figure 2.5.

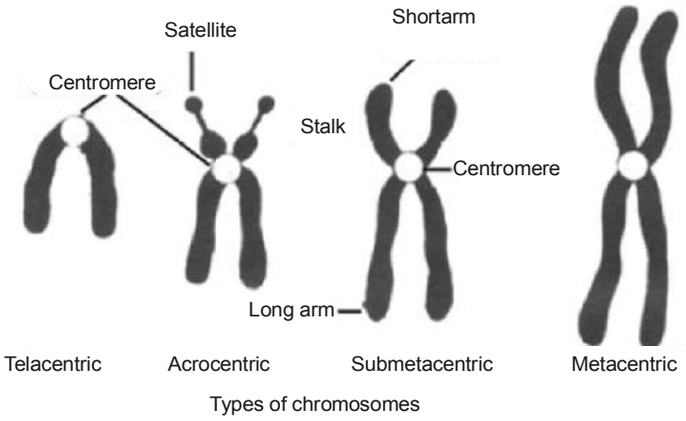

Fig. 2.5 *Types of Chromosomes according to the Location of Centeromere*

The region that is responsible for origin of replication has a specific DNA sequence**.** Centromere is a sequence element which is required for a DNA molecule to get attached to the mitotic spindle. The required equal distribution of chromosomes to all the daughter cells takes place after the cell division. As discussed above, the genetic material of an organism, in the form of DNA and DNA is present in a complex form with the histone proteins in the nucleus. Histones are relatively small proteins with a very high proportion of positively charged amino acids (lysine and arginine); the positive charge helps the histones to bind tightly to DNA (which is highly negatively charged), regardless of its nucleotide sequence. Histones only rarely disassociate from the DNA, and that is why they are likely to have an influence on any reaction that occurs on chromosomes.

The five types of histones fall into two main groups; the nucleosomal histones and the H1 histones. The nucleosomal histones are small proteins (102-135 amino acids) that are responsible for coiling the DNA into nucleosomes. These four histones, designated as H2A, H2B, H3, and H4. H3 and H4 are among the most highly conserved of all known proteins.

A particular sequence on the DNA molecule is termed as a gene, which has complete information for starting the DNA transcription, a sequence responsible for a particular function, and a sequence for termination of transcription from DNA to RNA. So, a gene can be defined as a nucleotide sequence in a DNA molecule that acts as a functional unit for the production of an RNA molecule. A chromosome is formed from a single, enormously long DNA molecule that contains a series of many genes.

DNA is a double helical structure. The two strands of DNA are coiled together in antiparrallel direction. Both the strands are complementary to each other. The four bases pair with each other in such a way that adenine (A) always

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pair with thymine (T) with the help of two hydrogen bonds and guanine (G) always pairs with cytosine (C) with the help of three hydrogen bonds. These are shown by Figure2.6 and Figure 2.7, respectively.

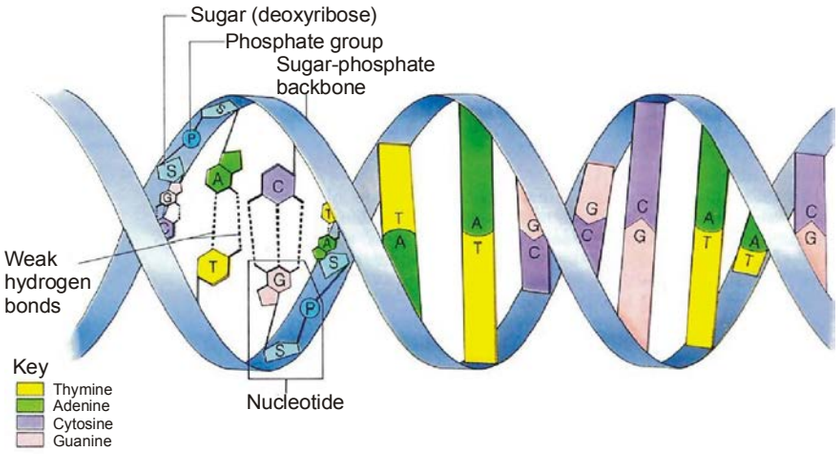

Fig. 2.6 *A Typical DNA Double Helix*

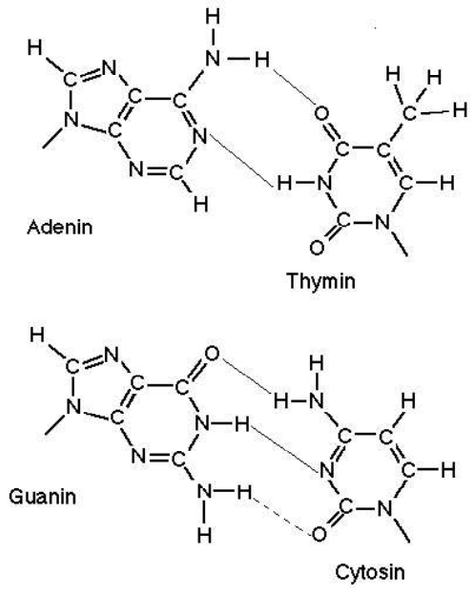

Fig. 2.7 *Hydrogen Bond Formation between Adenine and Thymine and Guanine and Cytosine*

For example, the genome of the *E.coli* bacterium contains 4.7×10^6 nucleotide pairs of DNA, present in a single double-helical DNA molecule (one chromosome). The human genome, in contrast, contains about 3×10^9 nucleotide pairs, DNA molecules of this size are 1.7 to 8.5 cm long when uncoiled, and even the slightest mechanical force will break them once the chromosomal proteins have been removed. A typical human cell thus contains a total of 46 chromosomes and about 6×10^9 nucleotide pairs of DNA.

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2.2.2 Replication of DNA

There are three theories regarding when the DNA replicates, how the other strand is synthesized. These are as follows:

1. **Conservative theory:** This theory says that the new strand is entirely newly made.
2. **Dispersive theory:** According to this theory both the old and new strands have parts of new and old strands.
3. **Semi-conservative theory:** This is the most accepted theory which says that one of the strands of the newly synthesized DNA is old and the other is entirely new.

The semi-conservative theory was proven by Meselson and Stahl experiment. They had grown the bacteria E coli in a media containing N^{15} and after several generations transferred them to normal media (having N^{14}). The logic was that the newly formed DNA will have N^{14} and will be lighter in weight.

The DNA was isolated and was centrifuged on a density gradient of CsCl for 20 hours at 40,000 rpm. They observed that the DNA extracted from the parent (grown in N^{15}) got separated as a single heavy band and the DNA taken from the two generations got an intermediate band and after three generations the DNA had one intermediate and one heavy band. These results concluded that the replication of DNA is semi-conservative in nature and the old strands of DNA act as a template for the new DNA strand to be synthesized. This is shown in Figure 2.8.

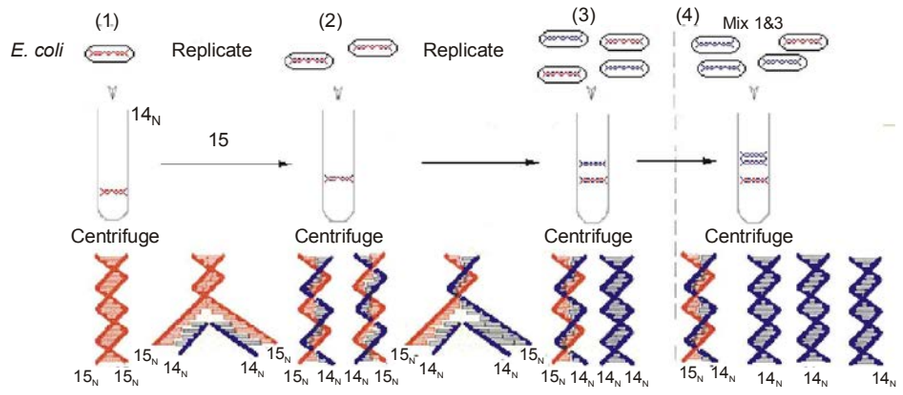

Fig. 2.8 *Meselson and Stahl experiment for proving the semi-conservative nature of DNA* replication

- **Mitochondria:** Kolliker isolated Mitochondria in 1880 from the muscle of insects. Flemming termed this organelle as fila amd and Altmann in 1890, called them bioplast. In 1897, Benda gave them the name 'mitochondria' (Mito+chondrion = thread and granules).

  Mitochondrion is called the power house of the cell. In mitochondria, higher molecules get converted to simpler molecules in a series of reaction catalyzed

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by various enzymes, and at several steps, energy is released. They are typically sausage shaped or tubular organelles. Mitochondria vary in size in shape, but generally they are rod like filamentous body of 0.5 X3 μm in size.

About 1/5th of the area inside a cell is occupied by mitochondria (~ 2000 in number). Like other cell organelles, the mitochondrion is also surrounded by double layer system and the space between them is called the perimitochondrial space which ranges from 60-100Å. The outer layer is smooth and the inner membrane is folded towards inside. These folds are called cristae, which provide a large surface area to attach the components of oxidative phosphorylation; cytochrome (cyt) b, c1, c, a and a3. The cytochrome c has two faces; a C face which is towards the cytosol and an M face which is towards the matrix. The cristae contain tennis racket shaped structures with diameter of 70-100 Å. They are called inner membrane subunits/elementary particles or oxysomes and are attached to the membrane by a stalk of 35-50 Å. They are present at a distance of 100 Å to each other. In 1963, Parsons named them as ETP = electron transport particle. It has all the enzymes required for oxidative phosphorylation.

Figure 2.9 and Figure 2.10 show the lateral and transactional views of mitochondria, respectively.

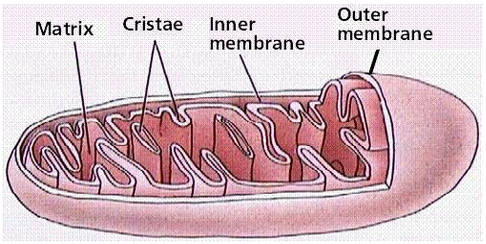

Fig. 2.9 *Lateral View of Mitochondria*

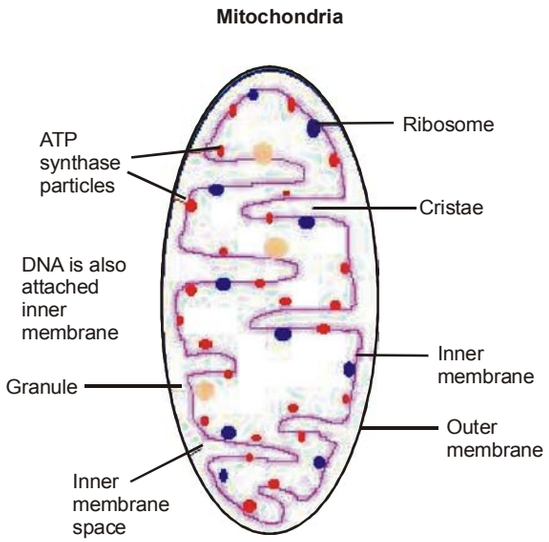

Fig. 2.10 *Transactional View of Mitochondria*

Mitochondria are dynamic in nature. This means that they can change their shape and size with time and requirement. The two mitochondria can fuse together and separate later. They can be moving around within the cytoplasm attached with the microtubules or they can be fixed to a location. In a cell like sperm they can be present wound around the flagella or within the myofibrils in the heart.

The two membranes of mitochondria are structurally and functionally different and this difference is really crucial for its activity. The outer membrane has a protein called porin. These proteins make pore like structure through which molecules of < 5kd can pass through freely, but these molecules cannot cross the inner membrane.

The inner membrane has a large amount of cardiolipin, which has four molecules of fatty acids. This cardiolipin is responsible for the selective permeability for certain ions. The mitosol of mitochondria contains many enzymes for energy metabolism of lipids, carbohydrates and proteins. Aerobic organisms are aerobic because of this cell organelle. The advantage of energy being generated in mitochodnria is that the glucose molecules get completely hydrolyzed and 30 molecules of ATP are generated in the process as compared to glycolysis which is the reaction responsible for energy production in the anaerobic cells. Besides this end products which are formed at the end of the reaction are harmless, which is not the case of anaerobic respiration. As shown in Figure 2.11, various components of electron transport system are present on the inner membrane of mitochondria. NADH dehydrogenase, Cytochrome b-c, cytochrome oxidase complex and ATP sythase are the main components.

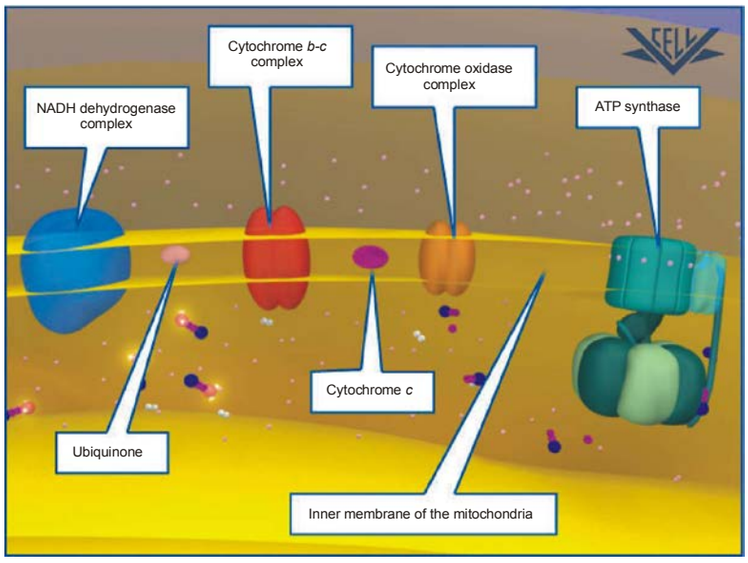

Fig. 2.11 *Components of Electron Transport System on the Inner Membrane of Mitochondria*

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There is a common pathway across various species of organisms starting from bacteria to higher organisms that energy is produced by chemiosmotic pressure (by oxidation of food). The other cell organelle chloroplast also produces energy (from sunlight) by generating a concentration gradient of protons across the membrane. The enzyme, ATP synthetase uses this energy when the proton flows back down the hill to generate ATP from ADP and Pi (inorganic phosphate). Following is the overall reaction showing generation of 36 ATP molecules from one glucose molecule. The reaction shows incomplete oxidation of glucose, which does not includes mitochondria and results in production of ethanol and less amount of energy is released (2ATPs) from one glucose molecule.

$C_6H_{12}O_6 + 6O_2 + 36\ ADP + 36\ Pi \longrightarrow 6CO_2 + 6\ H_2O + 36\ ATP$

$C_6H_{12}O_6 + Yeast \longrightarrow 2\ CO_2 + 2\ C_2H_5OH\ (ethanol) + 2\ ATP$

Several other components are also present here which are involved in the synthesis of urea and heme. Mitochodria has its own DNA. This DNA contains several genes that produce proteins essential to the mitochondria's role in oxidative metabolism. This DNA also code for the ribosomes (70S) and RNA molecules which are required for protein production inside mitochondrion. During the cell division, individual mitochondrion also divides into two. The proteins required for its metabolic function and for this division are synthesized in the cytoplasm and genes for most of these proteins are located into the nucleus. These cell organelles are believed to be originated from the prokaryotes that lived in symbiosis with earlier eukaryotes. As these are dependent upon nucleus and cytoplasm for many of their activities they now cannot survive in a cell free system.

- **Chloroplast:** Chloroplast is found in plant cells. The living beings of the entire world depend on the process of photosynthesis, for their existence. The process of photosynthesis takes place in the cell organelle present in the cells of plant kingdom. These organelles are called chloroplast. They use electrons from water and the energy of sunlight to convert atmospheric CO_2 into organic compounds. In the course of splitting water in the reaction $nH_2O + nCO_2 + \text{light} = (CH_2O)\ n + nO_2$], they liberate oxygen into the atmosphere. This oxygen is required for oxidative phosphorylation. The product generated during this process gets utilized to produce simple sugar molecules like glucose. The sugar molecules are then converted to sucrose to meet the energy requirements of other cells as well. It can also be converted to starch, which is osmotically inert and is utilized for future energy requirements.

  Like mitochondria, this cell organelle also contains its own DNA and RNA. The pigment which actually absorbs energy from light and converts it to carbohydrates is chlorophyll. It is present inside the chloroplast. Green plants are green because of this green pigment. Chloroplast has two main parts; grana and stroma. Figure 2.12 shows the structure of chloroplast.

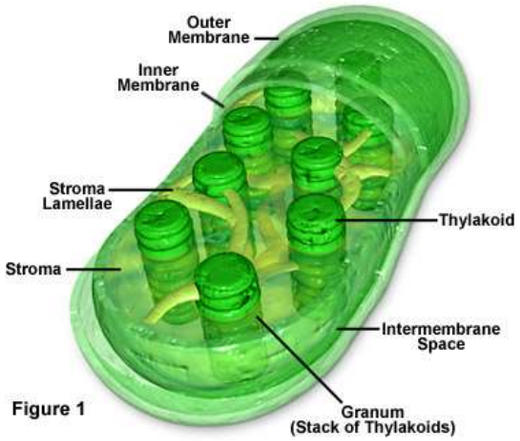

Fig. 2.12 *Structure of Chloroplast*

In many ways the chloroplast is similar to mitochondria. It is also surrounded by double layers, but it is more complex. The space between the two layers is called periplastidal space and it is 100-300 Å in width. Chloroplast also has a structure called grana, which is a collection of small structures called thylakoids**.** The light reaction of photosynthesis takes place in thylakoids. In grana, the two layers of pigment are present sandwiched between the layers of proteins. The chlorophyll molecules has hydrophilic and hydrophobic region and the hydrophilic region faces the protein layer. The group of chlorophyll molecules which is functional photosynthetically is collectively called quantasome. The dark reaction of photosynthesis takes place in stroma. Two grana are connected to each other by intergranal lamellae or stroma lamellae.

Choroplast is generally present in those parts of plants, which are exposed to the sun light. A colourless structure similar to chloroplast is found in roots. They generally store food material. The leukocytes which store starch are called as amyloplast. These structures collectively are classified as plastids. The term plastid was used by Schimper in 1885.

- **Endosymbiosis:** This term is used for those cell organelles which have originated from the prokaryotes. These are believed to be engulfed and lived inside another species of prokaryotes, which were the ancestors of eukaryotes. According to the endosymbiont theory, the engulfed prokaryotes provided their host with certain advantages associated with their special metabolic abilities. Mitochondria and chloroplast are those cell organelles which are kept in this category.
- **Endomembrane system:** It is the membrane system present within the cytoplasm. It is primarily made of 'endoplasmic reticulum' and 'golgi body', except these two lysosomes and various vesicles are also part of the same. This membrane system provides place for various metabolic activities for

example, protein synthesis and lipid synthesis. The internal membrane space of this system is called cisternal space. The two largest endomembrane systems are; endoplasmic reticulum and golgi body.

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Check Your Progress

1. What is an organelle?
2. What is endosymbiosis?
3. Who discovered the nucleus?

2.3 STRUCTURAL ORGANIZATION AND FUNCTIONS OF INTRACELLULAR ORGANELLES

The cell unit consists of several organelles or components, each of which has their own unique functions. The various organelles are as follows:

1. Nucleus

The nucleus may be considered the central component of the cell that controls the activity of the various other cell components. It contains genetic material in the form of chromatin material or genes. These genes are composed of deoxyribonucleic acid (DNA) molecules. The functions of these genes containing DNA material regulate the formation of proteins, cell division and other activities of cell organelles.

The various parts of the nucleus are as follows:

- **Nuclear membrane:** The nucleus is enclosed by a nuclear membrane. It is a proteinaceous membrane consisting of several pores. The nuclear membrane is a bilayer limiting membrane that encloses the contents of the nucleus. The outer layer of the nuclear membrane is connected to the endoplasmic reticulum. A fluid-filled space or perinuclear space is present between the two layers of a nuclear membrane. The nucleus communicates with the remaining of the cell or cytoplasm through several openings called nuclear pores. Nuclear pores are the sites for the exchange of large molecules (proteins and RNA) between the nucleus and cytoplasm.
- **Nucleolus:** The nucleus also contains a structure called the nucleolus. The nucleolus is a dense, spherical-shaped structure present inside the nucleus. Some of the eukaryotic organisms have nuclei that contain up to four nucleoli.

  The nucleolus plays an indirect role in protein synthesis by producing ribosomes. Ribosomes are cell organelles made up of RNA and proteins; they are transported to the cytoplasm, which are then attached to the endoplasmic reticulum. Ribosomes are the protein-producing structures of

a cell. The nucleolus disappears when a cell undergoes division and is reformed after the completion of cell division. These may be one or more than one in number and these consist of a large amount of ribonucleic acid (RNA) and proteins. The nucleolus has a role to play in cell division and protein synthesis.

- **Chromosomes:** Chromosomes are present in the form of strings of DNA and histones (protein molecules) called chromatin. Chromatin is further classified into heterochromatin and euchromatin. The former is a highly condensed trancriptionally inactive form, mostly present adjacent to the nuclear membrane. The latter is a delicate, less condensed organization of chromatin, which is found abundantly in a transcribing cell.

Figure 2.13 shows the structure of the nucleus.

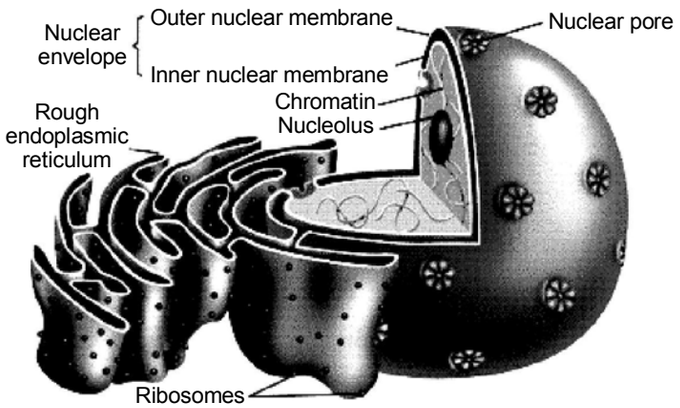

Fig. 2.13 *Structure of the Nucleus*

Functions of the nucleus

The nucleus controls the hereditary characteristics of an organism and is responsible for the protein synthesis, cell division, growth and differentiation. The following functions are carried out by a cell nucleus:

- It stores hereditary material, genes, in the form of long and thin DNA strands, referred to as chromatins.
- It facilitates the exchange of hereditary molecules (DNA and RNA) between the nucleus and rest of the cell.
- It stores proteins and RNA in the nucleolus.
- During cell division, chromatins are arranged into chromosomes.
- The nucleus is a site for transcription in which messenger RNA (mRNA) are produced for the protein synthesis.
- It facilitates the production of ribosomes in the nucleolus.
- It enables selective transportation of regulatory factors and energy molecules through nuclear pores.

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- The process of energy and nutrient metabolism in the cell is regulated by the nucleus, by directing the synthesis and functioning of enzymes, which is a type of protein.
- The selective diffusion of a cell's regulatory and energy molecules through the pores in the nuclear membrane is governed by the nucleus.

2. Mitochondria

Mitochondria are sausage-shaped structures. They are encapsulated by a bilayer membrane composed of lipids – the outer membrane and the inner membrane. The various parts of a mitochondrion are as follows:

- **Outer membrane:** The outer membrane is a relatively simple phospholipid bilayer that contains protein structures called porins that render it permeable to molecules of about 10 kilodaltons or less (the size of the smallest proteins). Ions, nutrient molecules, adenosine triphosphate (ATP) and adenosine diphosphate (ADP) can pass through the outer membrane with ease.
- **Inner membrane:** The inner membrane is convoluted into multiple shelves known as cristae. Oxidative enzymes are attached onto the cristae. The inner membrane is freely permeable only to oxygen, carbon dioxide and water. The structure of the inner membrane is highly complex, including all of the complexes of the electron transport system, the ATP synthetase complex and transport proteins. The wrinkles, or folds, are organized into lamillae (layers), called the cristae (singlular: crista). The cristae greatly increase the total surface area of the inner membrane. The larger surface area makes room for many more of these structures than if the inner membrane were shaped like the outer membrane and the space inside the inner membrane is known as the matrix space. Mitochondria are capable of self-replication and can generate new mitochondria when there is increased energy requirement.
- **Intermembrane space or intercristal space:** The membranes create two compartments and the space between these two membranes is known as the intracristal space or the intermembrane space. It has an important role in the primary function of mitochondria, which is oxidative phosphorylation.
- **Matrix:** The matrix contains the enzymes that are responsible for the citric acid cycle reactions. The matrix also contains dissolved oxygen, water, carbon dioxide, recyclable intermediates that serve as energy shuttles. Diffusion is a very slow process. Because of the folds of the cristae, no part of the matrix is far from the inner membrane. Therefore, matrix components can diffuse to inner membrane complexes and transport proteins within a relatively short time.

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Figure 2.14 shows the structure of the mitochondria.

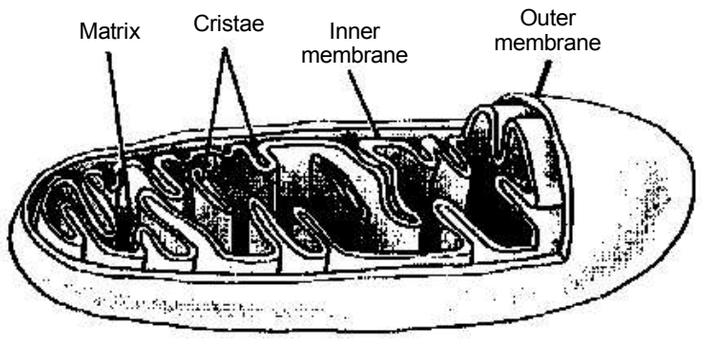

Fig. 2.14 *Structure of the Mitochondria*

Functions of the mitochondria

The functions of the mitochondria are as follows:

- **Production of energy:** The mitochondria are considered as the powerhouse of the cell as they provide energy for various essential reactions of the body. The most important mitochondrial functions in animal cells are the production of energy in the form of ATP and the regulation of cellular metabolism.

  The matrix space contains enzymes that convert fats, carbohydrates and proteins into energy. These enzymes in the matrix work in association with the oxidative enzymes on the shelves to cause oxidation of nutrients, resulting in the formation of carbon dioxide and water. Simultaneously, energy is also released in the form of ATP. The reactions that are involved in the production of ATP are collectively known as the citric acid cycle or Krebs cycle. Once food is broken down into its component parts by the process of metabolism, the food molecules are transferred to the mitochondria where they undergo further processing through the Krebs cycle to produce energy, after a number of complex reactions, in the presence of oxygen. This process of energy formation is known as *oxidative phosphorylation*. The ATP is then carried outside the mitochondrion and energy is released throughout the cell by diffusion.

- **Apoptosis or programmed cell death:** An important function is involved with apoptosis, or programmed cell death. This is carried out by an organism in the developmental phase when there are unwanted cells that need to be destroyed. Apoptosis also occurs when the body perceives infections, or as an immune system reaction to bacteria or an illness. Since oxygen is necessary for the production of ATP, in conditions where the body is combating an illness the consumption of oxygen increases due to which certain mitochondrial reactions cause the fabrication of free radicals. Free

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radicals, in surplus of the mitochondria's capability to detoxify the cell, cause harm to the mitochondria. Abnormal cell death due to malfunction can give rise to medical conditions or interfere with organ function.

- **Cell-specific functions:** Cell-specific functions include the following:
  - o Build-up, breakdown and recycling of products that are needed for the cell to function normally
  - o Formation of parts of blood and hormones such as estrogen and testosterone
  - o Synthesis of steroids
  - o Regulation of membrane potential
  - o Monitoring of cell differentiation, growth and development
  - o Cell signalling of neurons

3. Plasmids

Small structures called plasmids may also be present in prokaryotic cells and rarely in eukaryotic cells. Plasmids are double-stranded DNA not native to the regular chromosomal DNA of the organism. They are hoop-shaped, which is largely why the cell does not eliminate them. Most of the time plasmids are found in bacteria. They are fairly short, from 1 to 400 kilobase pairs, and may be found in one copy or hundreds of copies in any given cell.

Plasmid DNA is replicated separate from nuclear DNA and is usually passed on to daughter cells. Episomes are a type of plasmid that integrate into the chromosomal DNA of its host. This creates new modified bacteria that can consistently pass down traits like antibiotic resistance to its daughter cells.

Plasmids typically have three important elements:

- **Origin of replication:** Since a plasmid is an extra-chromosomal element, it cannot make use of any origin of DNA replication in a chromosome. DNA synthesis within (i.e., copying of) a plasmid depends on its having an origin of DNA synthesis of its own.
- **Selectable marker gene:** A selectable marker is not a required element of a plasmid, but it makes it possible to maintain stocks of cells that contain the plasmid uniformly. Sometimes, carrying a plasmid puts a cell at a selective disadvantage compared to its plasmid-free neighbors, so the cells with plasmids grow more slowly.
- **Cloning site:** Cloning site is a place where the DNA can be digested by specific restriction enzymes - a point of entry or analysis for genetic engineering work.

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Figure 2.15 shows a plasmid in a bacterial cell.

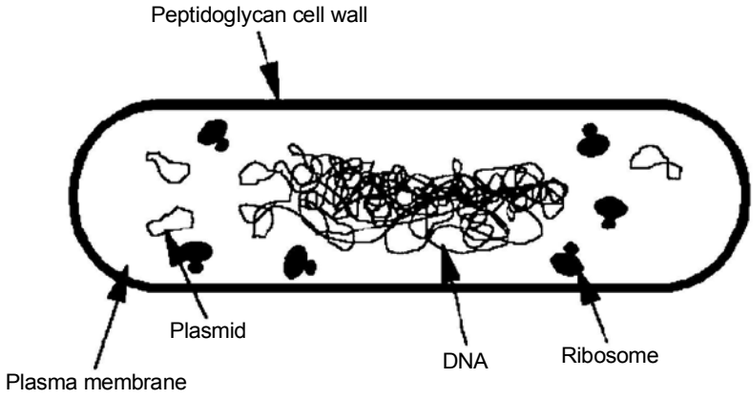

Fig. 2.15 *Plasmid in a Bacterial Cell*

Types of plasmids

Plasmids are sub-grouped into five main types based on phenotypic function. These are as follows:

(i) R or resistance plasmids carry genes encoding resistance to antibiotics.

(ii) Col plasmids confer on their host the ability to produce antibacterial polypeptides called bacteriocins that are often lethal to closely related or other bacteria. The col proteins of *Escherichia coli* are encoded by plasmids such as ColE1.

(iii) F or fertility plasmids contain the F or fertility system required for conjugation (the transfer of genetic information between two cells). These are also known as episomes because, under some circumstances, they can integrate into the host chromosome and thereby promote the transfer of chromosomal DNA between bacterial cells.

(iv) Degradative or catabolic plasmids allow a host bacterium to metabolize normally undegradable or difficult compounds such as various pesticides.

(v) Virulence plasmids confer pathogenicity on a host organism by the production of toxins or other virulence factors.

Functions of plasmids

Plasmids carry DNA with only a few genes responsible for special metabolic pathways and resistance to antibiotics. Plasmids can transfer between bacteria and it is this property that has made them important in genetic engineering.

Gene therapy

Extra-chromosomal DNA is becoming widely utilized as a gene therapy vector. Plasmid DNA offers multiple advantages over viral gene therapy vectors, including

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large packaging capacity, stability without integration and reduced toxicity. Furthermore, plasmid DNA can be delivered to many different tissues, using a variety of delivery techniques currently being developed.

Plasmids are significant tools in genetics and biochemistry, where they are commonly used to multiply or express particular genes. There are many plasmids that are commercially available for such uses. Initially, the gene to be replicated is inserted in a plasmid. These plasmids contain, in addition to the inserted gene, one or more genes capable of providing antibiotic resistance to the bacteria that harbours them. The plasmids are then introduced into bacteria by a process called transformation and these are then grown on specific antibiotics.

Bacteria which take up one or more copies of the plasmid then express the gene that bestows antibiotic resistance. This is typically a protein which can break down any antibiotics that would otherwise kill the cell. As a result, only the bacteria with antibiotic resistance can survive, the very same bacteria containing the genes to be replicated. The antibiotics will, however, kill those bacteria that did not receive a plasmid, because they have no antibiotic-resistant genes. These bacteria can be grown in large amounts, harvested and lysed to isolate the plasmid of interest.

Protein synthesis

Another major use of plasmids is to make large amounts of proteins. In this case, you grow the bacteria containing a plasmid harbouring the gene of interest. Just as the bacteria produce proteins to confer its antibiotic resistance it can also be induced to produce large amounts of proteins from the inserted gene.

4. Endoplasmic reticulum

The endoplasmic reticulum consists of a network of tubules and vesicles that are interconnected. It is surrounded by a bilayer membrane composed of lipids. The tubules and vesicles are filled with a fluid called endoplasmic matrix. They may serve specialized functions in cells, including protein synthesis, sequestration of calcium, production of steroids, storage and production of glycogen, and insertion of membrane proteins.

There are two types of endoplasmic reticulum:

(i) **Rough or granular endoplasmic reticulum:** The part of the endoplasmic reticulum onto which granules called ribosomes are attached is known as rough endoplasmic reticulum. Rough endoplasmic reticulum bears the ribosomes during protein synthesis. These ribosomes are composed of RNA and proteins and their function is to synthesize new protein molecules. The newly synthesized proteins are sequestered in sacs, called cisternae. The system then sends the proteins via small vesicles to the Golgi complex, or in the case of membrane proteins, it inserts them into the membrane. As shown in Figure 2.16, rough endoplasmic reticulum may either be vesicular or

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tubular, or it may consist of stacks of flattened cisternae that may have bridging areas connecting the individual sheets.

Ribosomes sit on the outer surfaces of the sacs or cisternae. They resemble small beads sitting in rosettes or in a linear pattern. The rough endoplasmic reticulum forms a branched reticulum that expands as the cell becomes more active in protein synthesis. Sometimes the reticulum branches out and the other times, the cisternae dilate and form large sacs that fill the cell.

(ii) **Smooth or agranular endoplasmic reticulum:** The part of the endoplasmic reticulum which is smooth and free of granules is known as smooth endoplasmic reticulum. Smooth endoplasmic reticulum is found in a variety of cell types and it serves different functions in each. It consists of tubules and vesicles that branch forming a network. In some cells, there are dilated areas like the sacs of rough endoplasmic reticulum. The network of smooth endoplasmic reticulum allows increased surface area for the action or storage of key enzymes and the products of these enzymes. In the case of smooth endoplasmic reticulum in muscle cells, the vesicles and tubules serve as a store of calcium which is released as one step in the contraction process. Calcium pumps serve to move the calcium. The smooth endoplasmic reticulum function is synthesis of lipids and they are also involved in enzymatic reactions.

Figure 2.16 shows the structure of endoplasmic reticulum.

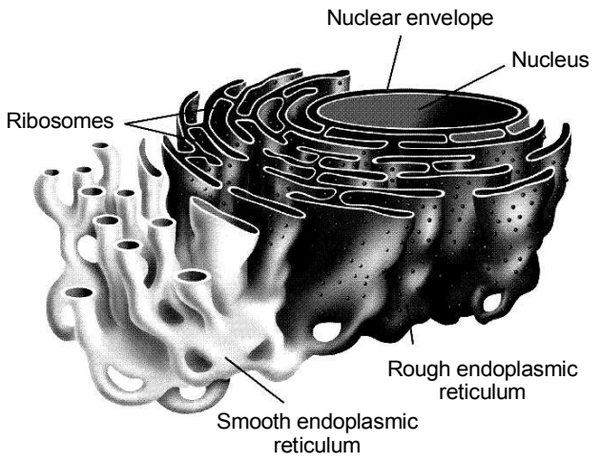

Fig. 2.16 *Structure of Endoplasmic Reticulum*

Functions of endoplasmic reticulum

The functions of the rough and smooth endoplasmic reticulum are as follows:

- **Rough endoplasmic reticulum:** The prime rough endoplasmic reticulum function is the production and processing of specific proteins at ribosomal sites that are later exported. The ribosomes in the rough endoplasmic

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reticulum do their job and create proteins which are then sent in to the rough endoplasmic reticulum for advanced processing. Rough endoplasmic reticulum function involves the creation of two types of proteins. One is the type which fortifies and gets embedded into the reticulum membrane. The other types are water-soluble membranes which after creation at ribosomal sites pass through the membrane and into the lumen. The proteins that enter are further processed inside. Just like a two-dimensional cardboard box is folded to make a box, the proteins are folded into the right three-dimensional shapes and carbohydrates may be added. Once the folding is complete, they are ready for delivery. The folding is made possible by proteins present in the lumen. The next rough endoplasmic reticulum function is to transport these ready proteins to the sites where they are required. They may also be sent to the Golgi bodies for further advanced processing, through vesicles.

- **Smooth endoplasmic reticulum:** Smooth endoplasmic reticulum functions include carbohydrate metabolism, regulation of calcium ions, synthesis of steroids and lipids, detoxification of drugs, metabolism of steroids and so on. In case of muscle cells, the smooth endoplasmic reticulum stores calcium, which is released during contraction of the muscles. This cell organelle has the function of detoxification in liver cells. Smooth endoplasmic reticulum function involves the transportation of newly synthesized proteins to other locations in the cell or outside the cell. This is achieved through a process called budding, wherein the small vesicles, which contain proteins, are detached from the smooth endoplasmic reticulum and are carried to other locations. This cell organelle also aids in converting glucose-6-phosphate to glucose, which is an important step in gluconeogenesis. Smooth endoplasmic reticulum in plant cells may connect between cells through plasmodesmata.

5. Golgi complex or Golgi apparatus

The Golgi complex is a collection of sacs, each of which is surrounded by a membrane. These sacs are arranged in a stacked manner. The Golgi apparatus has a structure that is made of cisternae, which are flattened stacks of membranes usually found in a series of five to eight. These cisternae help proteins travel from different points in cells using enzymes. In order to modify a macromolecule, cisternae's enzymes need the addition of carbohydrates and phosphates to properly label each protein for its ultimate destination. These carbohydrates and phosphates are received by the Golgi apparatus through nucleotide sugars delivered to the organelle from the cytosol.

How the proteins and vesicles pass through the Golgi apparatus structure is unclear; however, there are theories regarding the subject. According to the vesicular transport model, there are a variety of compartments located between the cis, essentially the beginning of the Golgi apparatus, and the trans, the end.

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These compartments shuttle along the macromolecules from section to section using membrane-bound carriers. The cisternal maturation model states that the vesicles fuse to each other at the cis face of the Golgi apparatus and are essentially pushed along as new vesicles fuse together behind them.

Figure 2.17 shows the structure of Golgi complex.

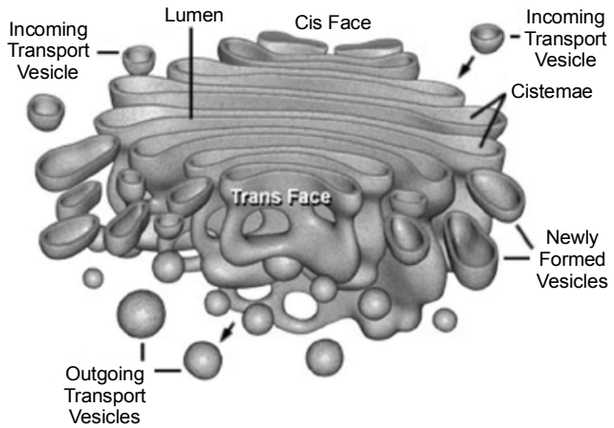

Fig. 2.17 *Structure of Golgi Complex*

Functions of Golgi complex

The functions of the Golgi complex are as follows:

- The main function of the Golgi apparatus is to be responsible for handling the macromolecules that are required for proper cell functioning. It processes and packages these macromolecules for use within the cell or for secretion. Primarily, the Golgi apparatus modifies proteins that it receives from the rough endoplasmic reticulum; however, it also transports lipids to vital parts of the cell and creates lysosomes. As part of eukaryotic cells, the Golgi apparatus works in unison with the endomembrane system. The Golgi complex functions in conjunction with the granular endoplasmic reticulum. Vesicles called 'transport vesicles' containing newly produced proteins break off from the granular or rough endoplasmic reticulum and fuse with the Golgi complex. These transported substances are processed in the Golgi complex to form secretory vesicles, lysosomes or other cytoplasmic organelles.
- Other functions of the Golgi apparatus include the production of glycosaminoglycans, which go on to form parts of connective tissues. The Golgi apparatus will use a xylose link to polymerize the glycosaminoglycans onto proteins to form proteoglycan. It then performs sulfation onto the proteoglycans to aid in signalling abilities and giving the molecule a negative charge.

- The *Bcl-2* gene that is located within the Golgi apparatus also plays a significant role in preventing apoptosis, or the destruction of the cell.

6. Lysosomes

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Lysosomes are membrane-bound structures that are formed by breaking off from the Golgi complex. They are membranous sacs filled with enzyme such as collagenase, deoxyribonuclease and ribonuclease. They are found in all eukaryotic cells and act as digester of the cell. Lysosomes are spherical bag-like structures that are bound by a single layer membrane; however, the lysosome shape and size may vary to some extent in different organisms. The lysosome size ranges between 0.1 and 1.2 μm. The membrane that surrounds the lysosome protects the rest of the cell from the hydrolytic or digestive enzymes that are contained in the lysosomes.

Lysosomes are manufactured by the Golgi apparatus, by budding, in the cell and the various digestive enzymes that are present in the lysosomes are produced in the endoplasmic reticulum. These enzymes are then transported to the Golgi apparatus and are distributed to the lysosomes. Some examples of enzymes present in the lysosomes include nucleases, proteases, lipases and carbohydrases. These enzymes are used to dissolve nucleic acids, proteins, lipids and carbohydrates, respectively. All these enzymes are typically hydrolytic and can digest cellular macromolecules. Lysosomes are acidic, with a pH of 4.8. This acidic pH is maintained by pumping protons, from the cytosol that has a pH of 7.2. The protons are pumped across the membrane via proton pumps and chloride ion channels. The membrane thus acts as a protective barrier that protects the cytosol and the rest of the cell from the hydrolytic enzymes within the lysosome.

Figure 2.18 shows the structure of a lysosome as it breaks off from the Golgi complex.

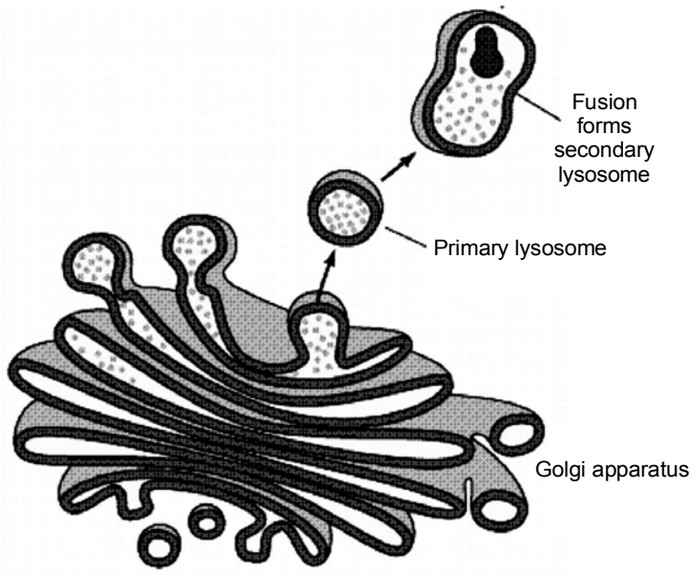

Fig. 2.18 *Structure of Lysosome*

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Function of lysosomes

The functions of lysosomes are listed as follows:

- Lysosomes act as the disposal system of the cell, whose function is to digest external material such as ingested food particles, bacteria, unwanted chemicals, toxins, organelles or even whole cells so that the materials may be recycled. They can also fuse with a feeding vacuole to digest its contents and break down complex proteins, carbohydrates, lipids and other macromolecules into simpler compounds. These simple compounds are returned to the cytoplasm and are used as new cell-building materials. They are used for digestion of cellular waste products, dead cells or extracellular material such as foreign invading microbes, which pose a threat to the cell by phagocytosis process. However, phagocytosis is just one process that helps to get rid of unwanted material in the cell.
- Lysosomes are also involved in other digestive processes including endocytosis and autophagy. Another interesting function of the lysosomes is to repair the damage to the plasma membrane. They serve as the membrane patch and help in sealing the wound in the plasma membrane. Lysosomes are also involved in programmed cell death, or autolysis, which is a catabolic process involving degradation of the cell's own components. This is the reason why lysosomes are often called as 'suicide sacs'.

7. Microtubules

Microtubules are hollow organelles that are composed of two protein subunits, that is, α-tubulin and β-tubulin, approximately 24 nm in diameter. An α, β- tubulin heterodimer is the basic structural unit of microtubules. The heterodimer does not come apart, once formed. The α- and β-tubulins, which are each about 55 kDa MW, are homologous but not identical. Along the microtubule axis, tubulin heterodimers are joined end to end to form protofilaments with alternating α and β subunits.

A staggered assembly of 13 protofilaments yields a helical arrangement of tubulin heterodimers in the cylinder wall. Each has a nucleotide binding site. α-Tubulin has a bound molecule of GTP, that does not hydrolyze. â-Tubulin may have bound GTP or GDP. The interactions holding α- and β-tubulin in a heterodimeric complex are strong enough that a tubulin subunit rarely dissociates under normal conditions. Each tubulin subunit binds two molecules of GTP. One GTP-binding site, located in α-tubulin, binds GTP irreversibly and does not hydrolyze it, whereas the second site, located on β-tubulin, binds GTP reversibly and hydrolyzes it to GDP. The second site is called the exchangeable site because GDP can be displaced by GTP.

The recently solved atomic structure of the tubulin subunit reveals that the non-exchangeable GTP is trapped at the interface between the α- and β-tubulin monomers, while the exchangeable GTP lies at the surface of the subunit.

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Figure 2.19 shows the structure of a microtubule.

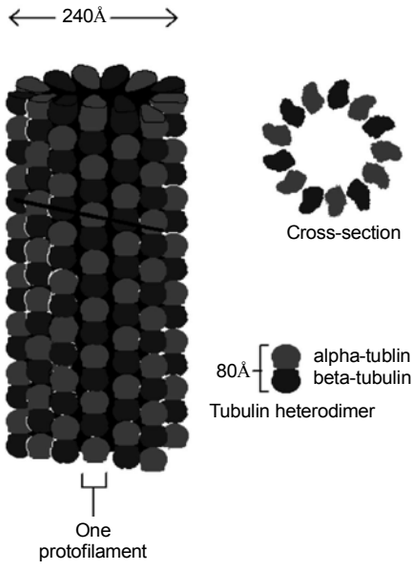

Fig. 2.19 *Structure of a Microtubule*

Functions of microtubules

The functions of microtubules are listed as follows:

- Microtubules function as part of the rigid cytoskeleton of the cell. They also present a pathway for transport of cell components such as mitochondria from one part of the cell to another.
- Mitosis process is facilitated by a subgroup of microtubules known as astral microtubules, which are microtubules originating from the centrosome that does not connect to a kinetochore. Astral microtubules develop in the actin skeleton and interact with the cell cortex to aid in orientation of spindles during cell division. They are organized around the centrosomes into radial arrays. Astral microtubules function in tandem with specialized dynein motors, which are oriented with the light chain portion attached to the cell membrane and the dynamic portion which is attached to the microtubule. This allows for dynein contraction to pull the centrosome towards the cell membrane, thus assisting in cytokinesis in plants and animals.
- Microtubules act as conveyer belts inside cells. They help to move vesicles, granules and organelles like mitochondria, and chromosomes via special attachment proteins. Vesicles get attached to microtubule associated proteins and move along the microtubule conveyer belt. The microtubule associated proteins include kinesins and dynein which move along the microtubules in opposite directions. Kinesins move vesicles along towards the plus end and dynein moves towards the minus end. This is how vesicles are moved from one region to another. This is active transport and hence, requires the

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breakdown of ATP, though it is not yet known how the energy from ATP breakdown is converted into vectorial transport.

- Also it is microtubules that join with other proteins to form more complex structures called cilia, flagella or centrioles. Microtubules also play a role in maintaining the cytoskeleton, that is, the basic structure of the cell. This is because structurally they are linear polymers of tubulin, which is a globular protein present in the cytoplasm.

Disruption of microtubules

The functioning and formation of microtubules can be disrupted by the use of certain drugs. This is the basis of using certain drugs like colchicine that help to treat cancer. These drugs inhibit polymerization by binding to tubulin and preventing its addition to the (+) ends.

8. Centrioles

Centrioles are two in number, are located within the centrosome and are composed of microtubules. Centrioles appear as two short, hollow, cylinders usually lying at right angles to each other. Each centriole is made up of nine microtubule triplets, which lie evenly spaced in a ring. There are no microtubules in the center (9+0 arrangement). The centrioles appear as two darkly staining granules, usually above the nucleus in animal cells. They are generally absent in plant cells, except in motile cells. The centrioles lie in a small mass of specialized cytoplasm called the centrosphere. They distinctly lack other cell organelles. The centrioles and the centrosphere are together described as centrosome.

When two centrioles are found next to each other, they are usually at right angles. The centrioles are found in pairs and move towards the poles (opposite ends) of the nucleus when it is time for cell division. During division, groups of threads are visible that are attached to the centrioles. Those threads are called the mitotic spindle.

Figure 2.20 shows the structure of a centriole.

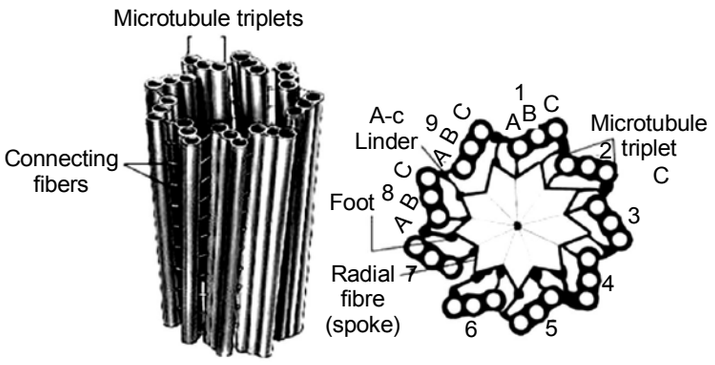

Fig. 2.20 *Structure of a Centriole*

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Functions of centrioles

The functions of centrioles are listed as follows:

- Centrioles play a crucial role at the time of cell division. At the time of cell division, they replicate to form two centrosomes, each with two centrioles. The two centrosomes then move in the opposite direction towards the opposite ends of the nucleus. From each centrosome, some thread-like microtubules appear, which are known as spindle or mitotic spindle. During cell division, the single parent cell divides itself into two daughter cells, and the spindle is responsible for separating or pulling the replicated chromosomes to the two daughter cells. So, centrioles help in the organization of the mitotic spindle as well as the completion of cytokinesis.
- Centrioles as a part of centrosome also play a significant role in cellular organization, especially in organizing the microtubules in the cytoplasm and the spatial arrangement of the cell. Even the position of the nucleus is determined by the position of the centrioles. The mother centriole (the original or older centriole from which a new centriole develops during cell division) determines the position of cilia and flagella in the organisms with these organelles. In fact, the mother centriole becomes the basal body in these organisms. A failure of the cell to make functional cilia and flagella with the help of centrioles has been found to be associated with several developmental and genetic diseases. During mammalian development, proper orientation of cilia via centriole positioning toward the posterior of embryonic node cells is considered as quite crucial for the establishment of left-right asymmetry.
- Centrioles take part in several important functions like, organization of the microtubules and formation of cilia and flagella. It is also involved in determining the position of the nucleus. Earlier, it was thought that centrioles were essential for the formation of mitotic spindle. But recent experiments in this regard have revealed that cells whose centrioles have been removed can too progress through the G1 stage of inter-phase (stage in which the cell grows and increases in mass to prepare for cell division, prior to DNA synthesis) before both the centrioles can be synthesized. Even mutant flies without centriole can be found to develop normally. However, such adult flies could not develop cilia and flagella, which emphasizes the importance of centrioles in the formation of these organelles.

9. Vacuoles

Vacuoles are membrane-bound sacs that play roles in intracellular digestion and the release of cellular waste products. In animal cells, vacuoles are generally small. They are found in both animal and plant cells but are much larger in plant cells.

Figure 2.21 illustrates a vacuole.

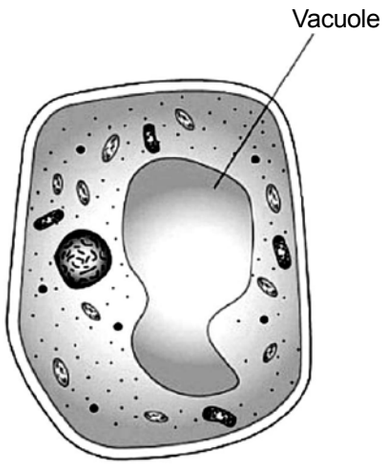

Fig. 2.21 *Vacuole*

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Functions of vacuoles

The functions of vacuoles are listed as follows:

- Vacuoles store food or any variety of nutrients a cell might need to survive. They can even store waste products so the rest of the cell is protected from contamination.
- Vacuoles maintain fluid balance (or internal hydrostatic pressure), act as cellular pumps, export unwanted substances, maintain an acidic internal pH for the cell and determine relative cell size and shape, as they can help the cell elongate rapidly. The largest and most useful vacuoles are generally found in plant cells.
- Instead of protoplasm, vacuoles are filled with a different liquid called cell sap. The composition of this sap is primarily water, but can vary from cell to cell and even from vacuole to vacuole.
- Vacuoles in different cells have differing purposes. Protists and macrophages may use food vacuoles in phagocytosis or the capture and digestion of food particles. They also use contractile vacuoles to pump out excess water so that the cell does not burst; these are most often found in freshwater protozoa like paramecium.
- Plant cells have large central vacuoles, often as large as 80 per cent of the cell interior. This vacuole holds water, enzymes, inorganic ions like calcium, and toxic byproducts that are being eliminated. The size and number of these vacuoles may change according to type of plant, life stage, and even season; that's partly because the central vacuole also performs the function of maintaining cell pressure through water storage. In plant cells, play a role

in turgor pressure. When a plant is well-watered, water collects in cell vacuoles producing rigidity in the plant. Without sufficient water, pressure in the vacuole is reduced and the plant wilts.

NOTES

10. Cytoskeleton

The cytoskeleton is a rigid framework consisting of fibres. There are three types of protein fibres (microfilaments, intermediate filaments and microtubules), and each has a corresponding motor protein that can move along the fibre carrying a cargo such as organelles, chromosomes or other cytoskeleton fibres.

The cytoskeleton is an intricate network of proteins that criss-cross the cytoplasm of cells. The cytoskeleton is composed of a wide variety of proteins. These proteins often form long twisted strands that look like electrical wires or the cables used to hold up bridges. Like these man-made components, the proteins that make up the cytoskeleton are both strong and flexible.

The cytoskeleton is made up of three kinds of protein filaments:

- **Actin filaments:** Monomers of the protein actin polymerize to form long, thin fibers. These are about 8 nm in diameter and, being the thinnest of the cytoskeletal filaments, are also called microfilaments. In skeletal muscle fibers they are called 'thin' filaments.

  The functions of actin filaments are as follows:

  - o They form a band just beneath the plasma membrane that provides mechanical strength to the cell, links transmembrane proteins (e.g., cell surface receptors) to cytoplasmic proteins and pinches dividing animal cells apart during cytokinesis.
  - o They generate cytoplasmic streaming in some cells.
  - o They generate locomotion in cells such as white blood cells and the amoeba.
  - o They interact with myosin (thick) filaments in skeletal muscle fibers to provide the force of muscular contraction.
- **Intermediate filaments:** These cytoplasmic fibers average 10 nm in diameter (and thus are 'intermediate' in size between actin filaments (8 nm) and microtubules (25 nm), as well as of the thick filaments of skeletal muscle fibers.

  There are several types of intermediate filaments, each constructed from one or more proteins characteristic of it. These are as follows:

  - o Keratins are found in epithelial cells and form hair and nails.
  - o Nuclear lamins form a meshwork that stabilizes the inner membrane of the nuclear envelope.
  - o Neurofilaments strengthen the long axons of neurons.
  - o Vimentins provide mechanical strength to muscle (and other) cells.

NOTES

Despite their chemical diversity, intermediate filaments play similar roles in the cell providing a supporting framework within the cell. For example, the nucleus in epithelial cells is held within the cell by a basketlike network of intermediate filaments made of keratins.

Different kinds of epithelia use different keratins to build their intermediate filaments. Over 20 different kinds of keratins have been found, although each kind of epithelial cell may use no more than 2 of them. Up to 85 per cent of the dry weight of squamous epithelial cells can consist of keratins.

- **Microtubules:** Microtubules are straight, hollow cylinders whose walls are made up of a ring of 13 protofilaments. They have a diameter of about 25 nm and are variable in length but can grow 1000 times as long as they are wide. They are built by the assembly of dimers of α-tubulin and β-tubulin and are found in both animal and plant cells. Microtubules grow at each end by the polymerization of tubulin dimers (powered by the hydrolysis of GTP) and shrink at each end by the release of tubulin dimers (depolymerization). However, both processes always occur more rapidly at one end, called the plus end. The other, less active, end is the minus end.

  Microtubules participate in a wide variety of cell activities. Most involve motion. The motion is provided by protein 'motors' that use the energy of ATP to move along the microtubule.

Figure 2.22 illustrates the cytoskeleton.

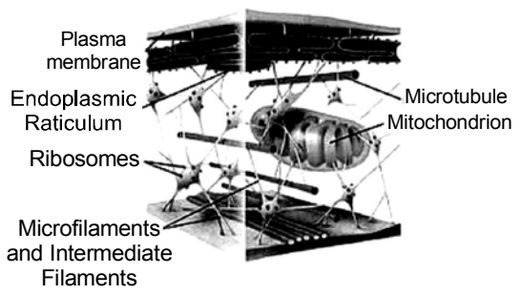

Fig. 2.22 *Structure of Cytoskeleton*

Functions of cytoskeleton

The functions of the cytoskeleton are listed as follows:

- The function of these motor proteins forming the cytoskeleton are chromosome movement in mitosis, cytoplasm cleavage in cell division, cytoplasmic streaming in plant cells, cilia and flagella movements, cell crawling and even muscle contraction in animals.
- They also maintain the shape of the cell and provide structural rigidity.
- They also allow the movement of organelles within the cell and endocytosis.

- They participate in cell division, that is, the movement of chromosomes during mitosis and meiosis and the constriction of animal cells during cytokinesis.

NOTES

11. Cilia and Flagella

Cilia and flagella are extensions of the cytoplasm, surrounded by the cell membrane, and are full of microtubules and motor proteins so is capable of complex swimming movements. Cilia and flagella are made up of microtubules, which are composed of linear polymers of globular proteins called tubulin. The core (axoneme) contains two central fibers that are surrounded by an outer ring of nine double fibers and covered by the cellular membrane. These motile appendages are constructed by basal bodies (kinetostomes), which also function as centrioles. The basal body is located at the base of each filament, anchoring it to the cell and controlling its movement. Cilia and flagella have the same structure. The only difference is that the flagella are longer. Flagella are longer than the cell, and there is usually only one or two of them, while cilia are identical in structure, but are much smaller and there are usually very many of them.

Flagella

Flagella are filamentous protein structures attached to the cell surface that provide the swimming movement for most motile procaryotes. Procaryotic flagella are much thinner than eucaryotic flagella, and they lack the typical 9 + 2 arrangement of microtubules. The diameter of a procaryotic flagellum is about 20 nm, well below the resolving power of the light microscope. The flagellar filament is rotated by a motor apparatus in the plasma membrane allowing the cell to swim in fluid environments. Bacterial flagella are powered by proton motive force (chemiosmotic potential) established on the bacterial membrane, rather than ATP hydrolysis which powers eucaryotic flagella. About half of the bacilli and all of the spiral and curved bacteria are motile by means of flagella. Very few cocci are motile, which reflects their adaptation to dry environments and their lack of hydrodynamic design. Flagella occur in protozoans like *Euglena* and in several examples of algae. They also occur in choanocytes of sponges.

The ultrastructure of the flagellum of *E. coli* is illustrated in Figure 2.23. About 50 genes are required for flagellar synthesis and function. The flagellar apparatus consists of several distinct proteins: a system of rings embedded in the cell envelope (the basal body), a hook-like structure near the cell surface, and the flagellar filament. The innermost rings, the M and S rings, located in the plasma membrane, comprise the motor apparatus. The outermost rings, the P and L rings, located in the periplasm and the outer membrane respectively, function as bushings to support the rod where it is joined to the hook of the filament on the cell surface. As the M ring turns, powered by an influx of protons, the rotary motion is transferred to the filament which turns to propel the bacterium.

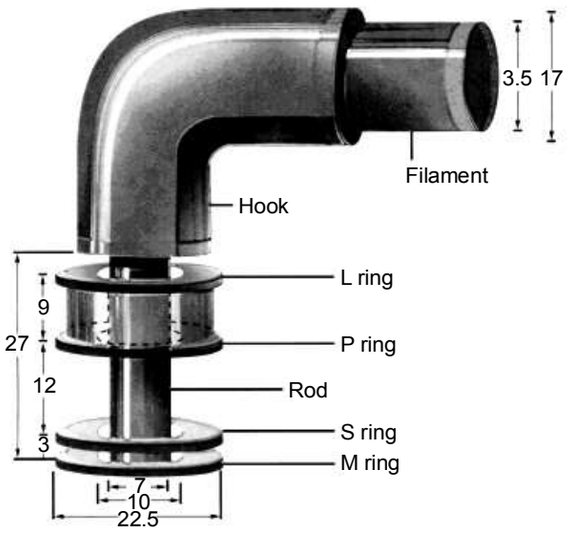

Fig. 2.23 *Ultrastructure of the Flagellum of E. coli (Copyright: Julius Adler, University of Wisconsin)*

Distribution of flagella

Flagella may be variously distributed over the surface of bacterial cells in distinguishing patterns, but basically flagella are either polar (one or more flagella arising from one or both poles of the cell) or peritrichous (lateral flagella distributed over the entire cell surface). Flagellar distribution is a genetically distinct trait that is occasionally used to characterize or distinguish bacteria. For example, among gram-negative rods, *Pseudomonas* has polar flagella to distinguish them from enteric bacteria, which have peritrichous flagella.

Figure 2.24 shows the distribution of flagella.

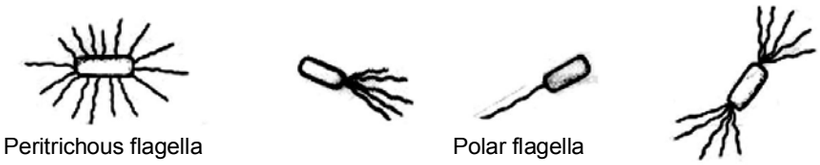

Fig. 2.24 *Distribution of Flagella*

Movements of flagella

The beating of flagella is independent and involves an undulating movement. The waves of undulation pass from the base to the tip of the flagellum. Power and recovery strokes of the flagellum move the cell forwards.

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Figure 2.25 shows the movements of flagella.

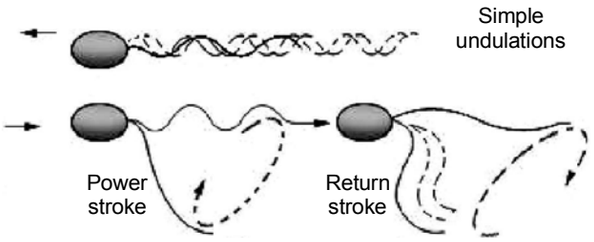

Fig. 2.25 *Movements of Flagella*

Cilia

Cilia are composed of a cylindrical array of 9 filaments consisting of a complete microtubule extending into the tip of the cilium, a partial microtubule that does not extend as far into the tip, cross-bridges of the motor protein dynein that extend from the complete microtubule of one filament to the partial microtubule of the adjacent filament. They also have a pair of single microtubules running up through the center of the bundle, producing the 9+2 arrangement. The entire assembly is sheathed in a membrane that is an extension of the plasma membrane. Cilia occur in protozoans like Paramecium and in flame cells of flatworms. They also occur in epithelial cells lining moist regions of the body.

Figure 2.26 shows the structure of cilia.

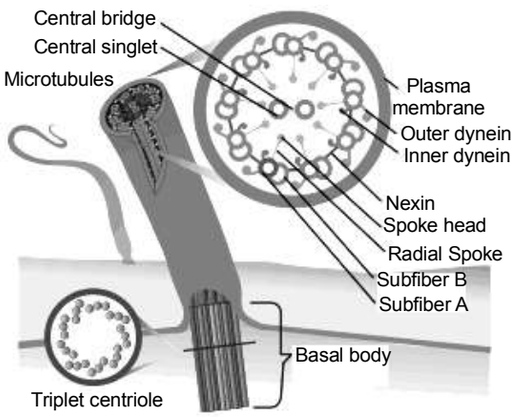

Fig. 2.26 *Structure of Cilia*

Movements of cilia

The beating of cilia occurs in two phases: power or effective phase and recovery phase. During the power phase, the cilia become straight and stiff and move against the medium such as water. This movement pushes water backwards and propels the organism forwards. In the recovery phase, the cilia become limp and return to

their original position in a curved state, offering minimum resistance to water. The whole movement can be compared to the rowing of a boat. ATP is utilized during both the phases.

Figure 2.27 shows the movements of cilia.

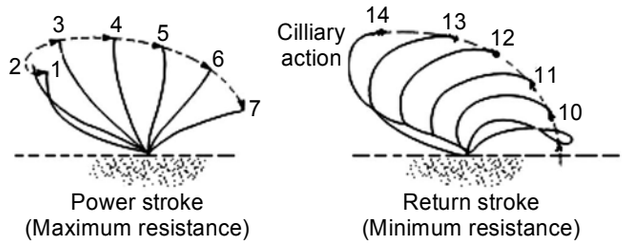

Fig. 2.27 *Movements of Cilia*

Functions of cilia and flagella

For single-celled eukaryotes, cilia and flagella are essential for the locomotion of individual organisms. Protozoans belonging to the phylum *Ciliophora* are covered with cilia. Flagella are a characteristic of the protozoan group *Mastigophora*.

In multi-cellular organisms, cilia function to move fluid or materials past an immobile cell as well as moving a cell or group of cells. The respiratory tract in humans is lined with cilia that keep inhaled dust, smog, and potentially harmful micro-organisms from entering the lungs. Cilia generate water currents to carry food and oxygen past the gills of clams and transport food through the digestive systems of snails. Flagella are found primarily on gametes, but also create the water currents necessary for respiration and circulation in sponges and coelenterates.

12. Ribosomes

Ribosomes are cell structures composed of RNA and protein. They consist of two subunits: the 60S and 40S subunits, based on their rates of sedimentation. The function of ribosomes is to synthesize proteins. The ribosomes that attach onto agranular or rough endoplasmic reticulum manufacture transmembrane proteins, while the free ribosomes manufacture proteins of the mitochondria, protein in haemoglobin.

Ribosomes found in prokaryotic cells are smaller than those of eukaryotes and are involved in protein synthesis. The rate at which bacteria divide requires a high level of protein synthesis and thus many ribosomes are needed. Thus, ribosomes may constitute as much as 40 per cent of the cell mass. Prokaryotic cells possess 70S ribosomes whereas eukaryotic cells possess 80S ribosomes. 'S' stands for Svedberg units and is a measure of how rapidly the ribosomes sediment in a centrifuge. 80S ribosomes sink the fastest because they are heaviest.

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The 70S and 80S ribosome types are directly related to the cells they are found in. Prokaryotic ribosomes are composed of two subunits: a 50S and a 30S, and when combined (although the math seems illogical) the sedimentation value is a true 70S. In eukaryotes, the two subunits are 60S and 40S and the mass of the ribosome is 80S. The ribosomes are composed of ribosomal RNA (rRNA) complexed with protein. Ribosomes attach and position messenger RNA (mRNA) to interact and align with transfer RNA (tRNA) to enable the synthesis of protein.

Figure 2.28 shows the structure of a ribosome involved in protein synthesis.

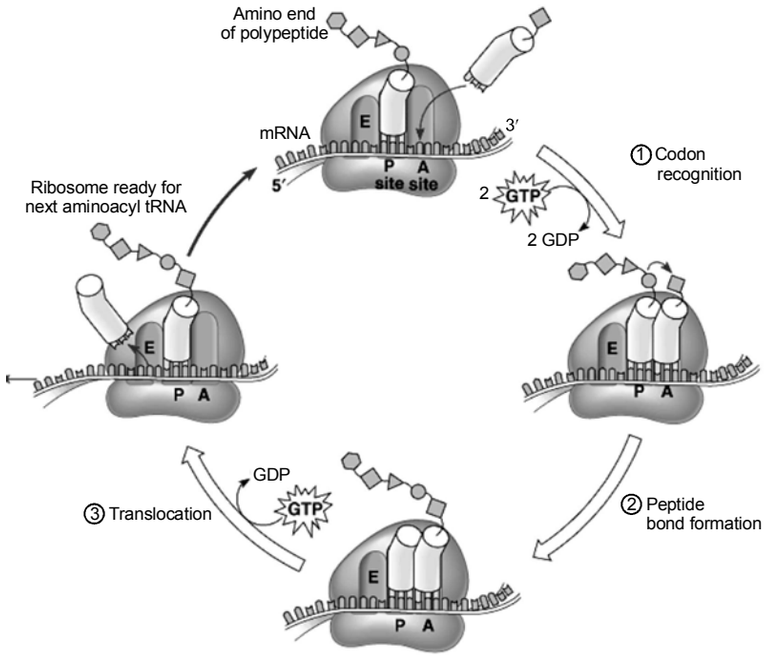

Fig. 2.28 *Structure of a Ribosome involved in Protein Synthesis*

Functions of ribosomes

The functions of ribosomes are listed as follows:

- In a cell, ribosomes are located in two regions of the cytoplasm. Some ribosomes are found scattered in the cytoplasm (referred to as free ribosomes), while others are attached to the endoplasmic reticulum (bound ribosomes). Accordingly, endoplasmic reticulum which membranes are bound with ribosomes are called rough endoplasmic reticulum (RER). Both the free ribosomes and bound ribosomes have similar structure and are responsible for production of proteins.
- Ribosomes play the role of assembling amino acids to form specific proteins, which in turn are essential for carrying out the cell's activities. As we all have a fair idea regarding production of proteins, the deoxyribonucleic acid (DNA) first produces RNA (messenger RNA or mRNA) by the process of DNA

transcription, after which genetic message from the mRNA is translated into proteins during DNA translation.

- To be more precise about protein synthesis by ribosomes, the sequence for assembling amino acids for protein synthesis are specified in the mRNA. The mRNA synthesized in the nucleus is then transported to the cytoplasm for further continuation of protein synthesis. In the cytoplasm, the two subunits of ribosomes bind around the mRNA polymers and synthesize proteins with the help of transfer RNA (tRNA), as per the genetic code. This whole process of protein synthesis is also referred to as central dogma. Usually, the proteins synthesized by the free ribosomes are utilized in the cytoplasm itself, while the protein molecules produced by the bound ribosomes are transported outside the cell.

2.4 PEROXISOMES

Peroxysomes is a second type of microbody. They have been named so by Beaufaytt and Berther in 1963. As the name suggests, they contain enzymes to produce hydrogen peroxide. As this chemical is highly toxic to the cells, one more enzyme catalase is also present which breaks down hydrogen peroxide to water and oxygen. Their size ranges from 0.2 – 1.5 μ. The inner matrix of peroxysome is surrounded by a unit membrane. In the center of the structure, nuceloid is present which made of tubules and strands. They contain enzymes like urate oxidase, beta hydroxyl acid oxidase and catalace etc.

Liver and kidney are the main organs in which detoxification by peroxisomes takes place. About a quarter of the ethanol we drink is oxidized to acetaldehyde in this way. In addition, when excess H_2O_2 accumulates in the cell, catalase converts it to H_2O ($2H_2O_2=2H_2O + O_2$).

Other than this, one more important function of this type of reaction is the β oxidation of fatty acid. The alkyl chains of fatty acids are shortened sequentially by blocks of two carbon atoms at a time that are converted to acetyl CoA and exported from the peroxisomes to the cytosol for reuse in biosynthetic reactions.

They are different from mitochondria and choroplasts in many ways. They are surrounded by a single membrane and they do not contain DNA and ribosomes. They import all their proteins from the cytosol by similar mechanisms as used in case of mitochondria or choloroplasts. They contain oxidative enzymes, such as catalase and urate oxidase, at such a high concentrations that in some cells the peroxisomes stand out in electron micrographs because of the presence of a crystalloid core, largely composed of urate oxidase.

Peroxisomes are unusually diverse organelles and even in the different cells of a single organism may contain very different sets of enzymes. They also can adapt remarkably to changing conditions. Yeast cells that are grown on sugar, for example, have small peroxisomes. But when same yeast is grown on methanol,

they develop large peroxisomes that oxidize methanol and when grown on fatty acids, they develop large peroxisomes that break down fatty acids to acetyl CoA by β oxidation.

NOTES

Check Your Progress

4. What is nucleolus?
5. What do you understand by oxidative phosphorylation?
6. Define the term 'golgi complex'.

2.5 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. In cell biology, an organelle is a specialized subunit within a cell that has a specific function. It is usually separately enclosed within its own lipid bilayer. Organelles are identified by microscopy, and they be purified by cell fractionation.
2. Endosymbiosis is used for those cell organelles which have originated from the prokaryotes. These are believed to be engulfed and lived inside another species of prokaryotes, which were the ancestors of eukaryotes.
3. Nucleus was discovered by Robert Brown in 1831. It is the largest cell organelle present in the eukaryotic cell. It is surrounded by nuclear membrane.
4. The nucleus also contains a structure called the nucleolus. The nucleolus is a dense, spherical-shaped structure present inside the nucleus.
5. Once food is broken down into its component parts by the process of metabolism, the food molecules are transferred to the mitochondria where they undergo further processing through the Krebs cycle to produce energy, after a number of complex reactions, in the presence of oxygen. This process of energy formation is known as *oxidative phosphorylation*.
6. The Golgi complex is a collection of sacs, each of which is surrounded by a membrane. These sacs are arranged in a stacked manner. The Golgi apparatus has a structure that is made of cisternae, which are flattened stacks of membranes usually found in a series of five to eight.

2.6 SUMMARY

- In cell biology, an organelle is a specialized subunit within a cell that has a specific function. It is usually separately enclosed within its own lipid bilayer. Organelles are identified by microscopy, and they be purified by cell fractionation.

NOTES

- The different cellular compartments of the eukaryotic cells are called cell organelles. They are primarily classified as nucleus, endomembrane system which includes endoplasmic reticulum, golgi body, lysosomes, peroxisomes, mitochondria and chloroplast.
- A definite number of 'chromosomes pairs' (homologous chromosomes) is the characteristic of an organism. These pairs and the actual chromosomal structure can only be visualized during the division.
- Chloroplast is found in plant cells. The living beings of the entire world depend on the process of photosynthesis, for their existence. The process of photosynthesis takes place in the cell organelle present in the cells of plant kingdom.
- The cell unit consists of several organelles or components, each of which has their own unique functions.
- Mitochondria are sausage-shaped structures. They are encapsulated by a bilayer membrane composed of lipids – the outer membrane and the inner membrane.
- Small structures called plasmids may also be present in prokaryotic cells and rarely in eukaryotic cells. Plasmids are double-stranded DNA not native to the regular chromosomal DNA of the organism. They are hoop-shaped, which is largely why the cell does not eliminate them.
- The Golgi complex is a collection of sacs, each of which is surrounded by a membrane. These sacs are arranged in a stacked manner. The Golgi apparatus has a structure that is made of cisternae, which are flattened stacks of membranes usually found in a series of five to eight.
- Microtubules are hollow organelles that are composed of two protein subunits, that is, a-tubulin and b-tubulin, approximately 24 nm in diameter. An a, b-tubulin heterodimer is the basic structural unit of microtubules. The heterodimer does not come apart, once formed.
- Ribosomes are cell structures composed of RNA and protein. They consist of two subunits: the 60S and 40S subunits, based on their rates of sedimentation. The function of ribosomes is to synthesize proteins.
- Peroxysomes is a second type of microbody. They have been named so by Beaufaytt and Berther in 1963. As the name suggests, they contain enzymes to produce hydrogen peroxide.

2.7 KEY WORDS

- **Golgi complex:** The Golgi apparatus, also called Golgi complex or Golgi body, is a membrane-bound organelle found in eukaryotic cells (cells with clearly defined nuclei) that is made up of a series of flattened stacked pouches called cisternae.

NOTES

- **Lysosome:** An organelle in the cytoplasm of eukaryotic cells containing degradative enzymes enclosed in a membrane.
- **Vacuoles:** They are storage bubbles found in cells. They are found in both animal and plant cells but are much larger in plant cells. Vacuoles might store food or any variety of nutrients a cell might need to survive.

2.8 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. Name the three theories of the replication of DNA.
2. State the functions of a nucleus.
3. What are the various types of plasmids?
4. State the functions of golgi complex.
5. What are the functions of actin filaments?

Long Answer Questions

1. Analyse the various parts of a nucleus.
2. Describe the various parts and functions of mitochondria.
3. What are peroxisomes? How are they different from mitochondria and choroplasts?
4. Analyse the three kinds of protein filaments of cytoskeleton.

2.9 FURTHER READINGS

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UNIT 3 TISSUE SYSTEMS

NOTES

Structure

3.0 INTRODUCTION

There are four types of tissues found in animals: epithelial tissue, connective tissue, muscle tissue, and nervous tissue. This unit analyses the classification and structure of various animal tissues. It also discusses the functions of tissues with the help of various figures and diagrams.

3.1 OBJECTIVES

After going through this unit, you will be able to:

- Analyse the structure and functions of epithelial tissues
- Describe the structure and functions of connective tissues
- Discuss the classification of muscular tissues
- Describe the features and structure of nervous tissue

3.2 CLASSIFICATION, STRUCTURE AND FUNCTIONS OF ANIMAL TISSUES

A group of similar and specialized cells group to form tissues to carry out a specific function. A tissue represents a group of similar cells with intercellular substances, required to perform a specific function by functioning as a unit. In multicellular organisms, cells, tissues, organs and organ systems split up the work.

Animal tissues can be classified into the following categories:

- **Epithelial tissues:** These tissues line the surface of the skin and many cavities of the body. They also cover the internal organs. The primary job

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of these tissues is to protect. Digestive juices and mucus are secreted by special cells of the epithelial tissues.

- **Muscle tissue:** This tissue helps in locomotion and movement of body and organs. Three types of muscles are present in the body namely, smooth muscles, skeletal muscles, and cardiac muscles.
- **Connective tissue:** This tissue provides strength, support and protection to the soft parts of the body.
- **Nerve tissue:** This tissue conducts nerve impulses.

3.2.1 Structure and Functions of Epithelial Tissues

Epithelial tissues are covering tissues that cover the external or internal surface of the body and its organs. These are the simplest and the least specialized animal tissues. They are non-vascular, since a direct blood supply is absent. The tissues depend upon the other underlying tissues for their nourishment. Epithelial tissues can originate from any of the three germ layers—ectoderm, mesoderm or endoderm.

The characteristics of epithelial tissues are listed as follows:

- The cells are compactly arranged on a thin, non-cellular basement membrane.
- The cells always have a definite shape.
- The cells are characterized by the presence of a large amount of cytoplasm.
- The cells are always uninucleate and the nucleus is large and prominent.
- The cells are capable of undergoing simple mitotic divisions.

Structure of epithelial tissues

Epithelial tissues are broadly classified in two as follows:

1. **Simple epithelium:** Simple epithelium is made up of a single layer of cells where all cells are in contact with basement membrane. Simple epithelium is of the following types:
   - Squamous epithelium
   - Cuboidal or cubical epithelium
   - Columnar epithelium
   - Ciliated epithelium
   - Pseudo-stratified epithelium
   - **Squamous epithelium:** It is composed of thin flat, polygonal cells that are compactly arranged on a basement membrane. Inter cellular spaces are completely absent. Each cell has a large amount of cytoplasm and a prominent nucleus. Since the arrangement of the cells resembles that of tiles on a pavement, it is commonly called as 'pavement epithelium'. It is found lining the lumen of blood vessels where it is known as endothelium. In the unused spaces in the body, it is known as mesothelium. It also

occurs in the lining of the buccal cavity, in the alveoli of lungs and in the Bowman's capsule of the nephrons. Squamous epithelium has a role in protection, excretion, gas exchange and secretion of coelomic fluid.

Squamous epithelium is represented in Figure 3.1.

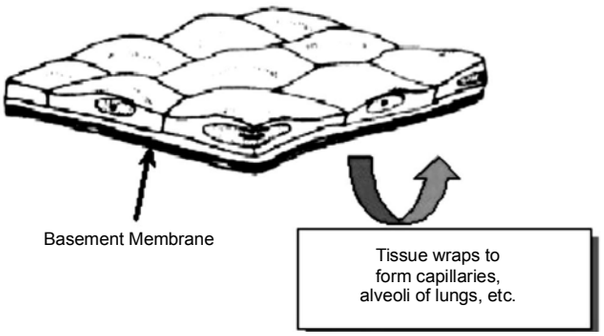

Fig. 3.1 *Squamous Epithelium*

- **Cuboidal epithelium:** In this type, the cells are Cubical in vertical section and polygonal in surface view. The cells are compactly arranged on a basement membrane. The cells contain granular cytoplasm and a single large nucleus situated in the centre. Cuboidal epithelium is found commonly in glands and their smaller ducts. Cuboidal epithelium has a role in protection, excretion, absorption, gamete formation and secretion.

  Cuboidal epithelium is represented in Figure 3.2.

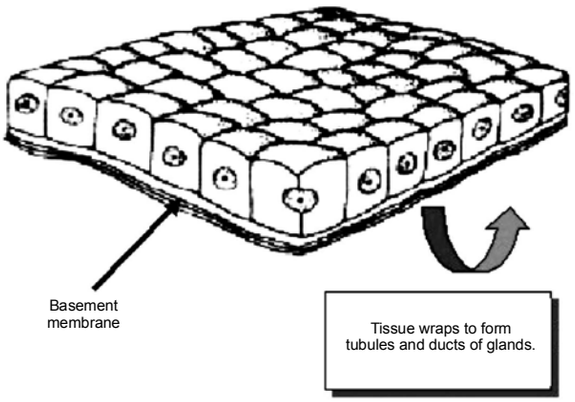

Fig. 3.2 *Cuboidal Epithelium*

- **Columnar epithelium:** In columnar epithelium, the cells are tall column or pillar like The cells are compactly arranged on a basement membrane. However, a few inter cellular spaces are present, filled with a cementing substance. The cells enclose granular cytoplasm and a single large oval nucleus, which is found more towards the basement membrane. Columnar epithelium is found lining the alimentary canal, from esophagus to anus. It is also found in some glands and their ducts and in the nephrons.

NOTES

Columnar epithelium with microvilli is known as **brush-border epithelium**. It is found in absorptive areas like intestinal mucosa, proximal convoluted tubule of nephron etc. The cells are rectangular and elongated. The length of each cell is about 2 or 3 times the breadth. The cells are compactly arranged on a basement membrane. However, a few inter cellular spaces are present, filled with a cementing substance. The cells enclose granular cytoplasm and a single large oval nucleus, which is found more towards the basement membrane. Columnar epithelium is found lining the alimentary canal, from esophagus to anus. It is also found in some glands and their ducts and in the nephrons. Squamous epithelium has a role in protection, absorption and secretion.

Columnar epithelium is represented in Figure 3.3.

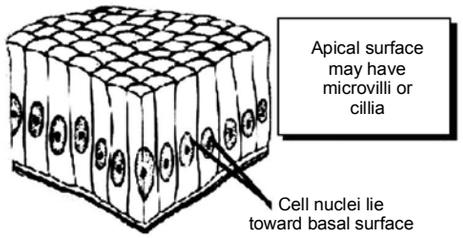

Fig. 3.3 *Columnar Epithelium*

- **Ciliated epithelium:** They are columnar epithelium characterized by the presence of numerous hair-like outgrowths called cilia. The cilia help in transportation and also function as a filtering mechanism. It is present in the regions like the nasal passage, the trachea and the fallopian tube. Ciliated epithelium is of columnar type. This comprises of columnar cells with cilia on the cell surface. Squamous epithelium maintains a flow of mucus or liquid in one direction.

  Ciliated columnar epithelium is represented in Figure 3.4.

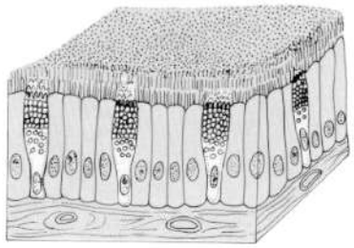

Fig. 3.4 *Ciliated Columnar Epithelium*

- **Pseudo-stratified epithelium:** Only a single layer of cells are found on a basement membrane in pseudo-stratified epithelium. However, all the cells do not reach the surface and the nuclei of the cells are found at different levels. Thus, there is a false appearance of more than one layer.

Pseudo-stratified epithelium is found in parts of the respiratory system such as nasal cavity and trachea.

Pseudo-stratified epithelium is of two types:

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(i) **Pseudo-stratified columnar epithelium:** It is made up of columnar cells. It is present in large ducts of certain glands such as parotid salivary glands. Pseudo-stratified columnar epithelium is represented in Figure 3.5.

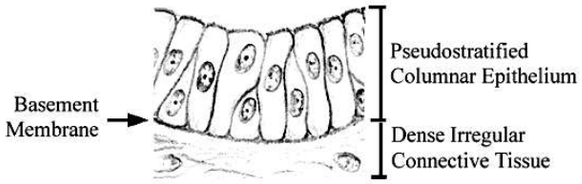

Fig. 3.5 *Pseudo-Stratified Columnar Epithelium*

(ii) **Pseudo-stratified columnar ciliated epithelium:** It is comprised of columnar cells with cilia on the free surface. This epithelium occurs in the trachea and large bronchi. Pseudo-stratified ciliated columnar epithelium is represented in Figure 3.6.

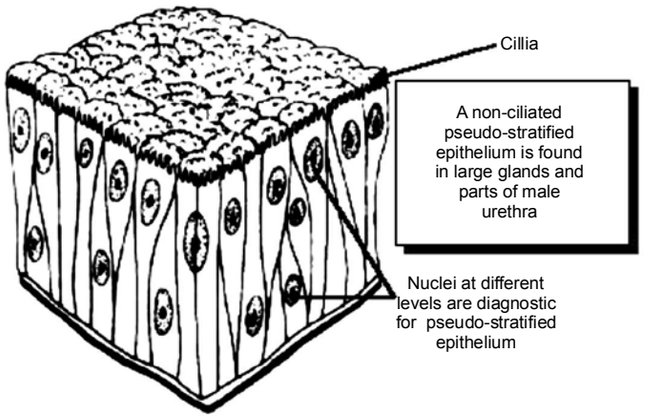

Fig. 3.6 *Pseudo-Stratified Ciliated Columnar Epithelium*

2. **Compound epithelium:** Compound epithelium is multi-layered where the cells in the lowermost layer are in contact with basement membrane. They are multi-layered where the cells in the lowermost layer are in contact with basement membrane. They are of two types:

   (i) Stratified epithelium: Stratified squamous epithelium has several layers. The cells in the deepest layer are columnar or cuboidal with oval nuclei. It is called the stratum germinativum. The middle layers have polyhedral cells and are called the stratum intermedium. The

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superficial layers are called stratum corneum. The varying types of cells of this epithelium are classified as the following:

- **Stratified squamous epithelium:** In this, more than one layer of flat, polygonal cells are found arranged on a basement membrane. It is a characteristic feature of the skin. It also occurs in the lining of the tongue and the esophagus. Stratified squamous epithelium may be of two types:
  - **Stratified keratinized squamous epithelium**: In this epithelium in the outer few layers the cells replace their cytoplasm with a hard protein called keratin. These outer layers of cells are dead and are called stratum corneum. It is common in the dry surface of skin. Stratified keratinized squamous epithelium is represented in Figure 3.7.

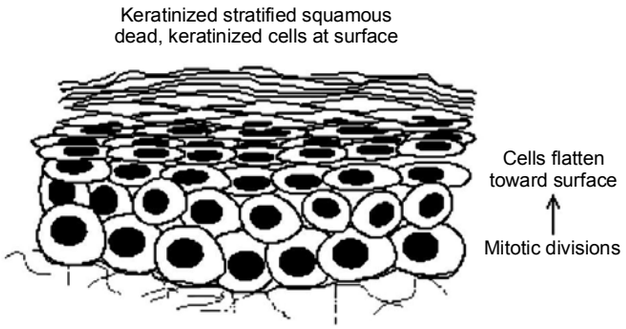

Fig. 3.7 *Stratified Keratinized Squamous Epithelium*

  - **Stratified non-keratinized squamous epithelium**: It is found in buccal cavity. Stratified non-keratinized squamous epithelium is represented in Figure 3.8.

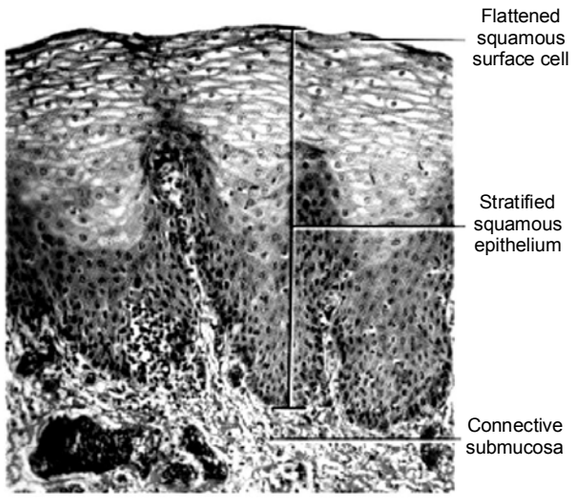

Fig. 3.8 *Stratified Non-Keratinized Squamous Epithelium*

- **Stratified cuboidal epithelium:** In this, more than one layer of cuboidal cells are found arranged on a basement membrane. It occurs in the larger ducts of sweat glands and in the lining of the pharynx. Stratified cuboidal epithelium is represented in Figure 3.9.

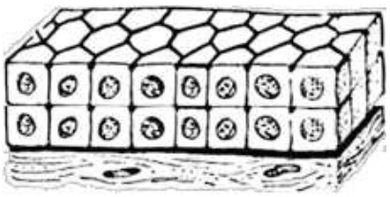

Fig. 3.9 *Stratified Cuboidal Epithelium*

- **Stratified columnar epithelium:** In this type, the epithelium has several layers of polyhedral cells with columnar cells found only in the superficial layer. There is absence of keratin. It occurs in the oral cavity, pharynx and oesophagus.

(ii) Transitional epithelium: They are stretchable epithelium in which the cells in the superficial layers are not truly squamous, cuboidal or columnar. These cells are large and rounded or conical. The epithelium allows distention. It occurs in the urinary bladder. The transitional epithelium is represented in Figure 3.10.

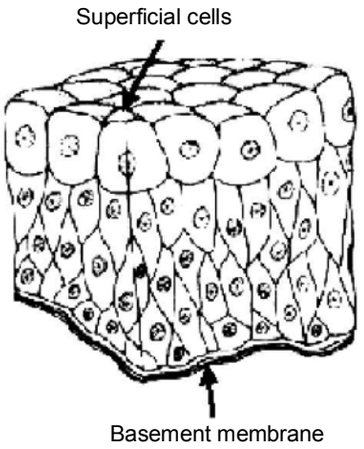

Fig. 3.10 *Transitional Epithelium*

Specialized epithelial cells

There are certain types of epithelium with special functions which are as follows:

- **Sensory epithelium:** This epithelium consists of sensory and supporting cells. The sensory cells bear sensory hairs at their free ends and nerve fibres at their other ends. The supporting cells lack sensory hairs and nerve fibres. Sensory epithelium is present in nasal chamber, retina and tongue.

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- **Myoepithelium:** It contains cells called myoepitheliocytes which contain actin and myosin filaments and are capable of contraction. Myoepithelium is present in sweat glands and mammary glands.
- **Pigmented epithelium:** The cells of this epithelium contain pigment such as in the retina and posterior part of the iris of the eye.

Functions of epithelial tissue

- **Protection:** Epithelial cells from the skin protect underlying tissue from abrasion, mechanical injury, harmful chemicals, invading bacteria and from excessive loss of water.
- **Secretion:** In glands, epithelial tissue is specialised to secrete specific chemical substances such as mucus, enzymes, hormones and lubricating fluids.
- **Sensation:** Sensory stimuli penetrate specialised epithelial cells. Specialized epithelial tissue containing sensory nerve endings is found in the skin, eyes, ears, nose and on the tongue.
- **Absorption:** Certain epithelial cells lining the small intestine absorb nutrients from the digestion of food.
- **Reduction of friction:** The smooth, tightly interlocking epithelial cells that line the entire circulatory system reduce friction between the blood and the walls of the blood vessels.
- **Cleaning:** A ciliated epithelium assists in removing dust particles and foreign bodies which have entered the air passages.
- **Excretion of wastes:** Epithelial tissues in the kidney excrete waste products from the body and reabsorb needed materials from the urine. Sweat is also excreted from the body by epithelial cells in the sweat glands.
- **Diffusion of gases:** Simple epithelium promotes the diffusion of gases, liquids and nutrients. Because they form such a thin lining, they are ideal for the diffusion of gases (e.g., walls of capillaries and lungs).

3.2.2 Structure and Functions of Connective Tissues

Connective tissue originates from the mesoderm of the embryo. It is composed of three components. These are as follows:

- Connective tissue cells, which are the adipose cells, fibroblasts, plasma cells, macrophages, lymphocytes, mesenchyme cells, chromatophores and reticular cells.
- Connective tissue fibres, which are of three types; collagen fibres, elastic fibres and reticular fibres.
- Intercellular medium, which is a mixture of carbohydrates and proteins.

Types of connective tissue

Connective tissues have different types of structures depending on their types. There are several types of connective tissue. These are as follows:

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- **Loose connective tissue or areolar tissue:** It contains loosely arranged cells and fibers in ground matrix that leave small spaces in-between. This tissue is called areolae. It is the most widely distributed tissue. It is present under the skin, around muscles and blood vessels, bone marrow and glands. It acts as a support as framework for epithelium. It contains adipocytes, fibroblasts, macrophages, mast cells, plasma cells and lymphocytes.
- **Dense connective tissue:** It consists of fibres and fibroblasts that are packed in the connective tissue. Dense connective tissues could be of regular or irregular type. They may be white fibrous connective tissues or yellow elastic connective tissues. White fibrous connective tissue forms cords called tendons which connect the skeletal muscles with the bones. It occurs in the dermis of the skin, connective tissue sheaths of muscles and adventitia. Yellow elastic connective tissue is composed of a thick, branched network of loose yellow fibres which contain scattered fibroblasts. It also contains mast cells, macrophages and adipose cells. The yellow elastic connective tissue forms ligaments which join bones to bones. It occurs in the walls of blood vessels, lungs, larynx, vocal cords, trachea and ligament flava. White fibrous connective tissue provides strong attachment between various structures such as bones and muscles. It has limited flexibility, but great strength. Yellow elastic connective tissue provides stretching of various organs. It has limited strength but great flexibility.
- **Adipose tissue:** This tissue is mainly composed of adipocytes or fat cells. Each adipose cell contains fat globules. There are two types of adipose tissue; brown fat or white fat. The adipose cells of brown fat are multilocular and brown in colour due to the presence of the pigment cytochrome. White fat adipose tissue contains large adipocytes with a single fat globule. Adipose tissue is a reserve of food or fat for the body. The sub-cutaneous fat also prevents heat loss from the body and acts like a cushion to prevent mechanical shock.
- **Specialized connective tissue:** Skeletal tissue (bones) and vascular tissue (blood) are the chief constituents of specialized connective tissue.
- **Skeletal tissue (bones):** Bones possess hard, non-pliable ground substance which is rich in calcium salts. It is the main tissue to provide structural framework to the body. Its function is to support and protect softer tissues. The long bones of the leg help in weight bearing. The bones interact with skeletal muscles to bring out movement. Bones are of two types; spongy bones and compact bones. Spongy bones consist of a network of thin and irregularly placed trabeculae covered by endosteum. They contain

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red bone marrow and are found at the ends of the long bones. Compact bones have yellow bone marrow and are relatively hard and compact. They are found in the shaft of long bones.

- **Vascular tissue (blood):** It is a mobile, fluid connective tissue with plasma and red blood cells, white blood cells and platelets. It is the chief circulating fluid and helps in transportation of various substances.
- **Pigmented connective tissue:** The cells in this tissue are pigmented and irregular in shape called chromatophores. It is present in the choroid, ciliary body and iris of the eye. Pigmented tissue imparts distinctive colour to the structures.
- **Reticular tissue:** This tissue consists of star shaped reticular cells with protoplasmic processes. These protoplasmic processes join to form a reticular network. The reticular cells contain reticular fibres. This tissue is present in the liver, spleens, lymph nodes, thymus, tonsils and bone marrow. It provides strength and support as it forms the supporting framework of many organs.

Functions of connective tissue

Connective tissue has the following functions:

- **Structural support:** The most important function of the connective tissue is to provide structural support. The skeletal tissues that comprise cartilage and bone are the main structural framework of the connective tissues. The various connective tissues that provide structural support include the ones surrounding the lymph nodes, kidney, etc. The connecting muscles to bones, the tendons and the elastic ligaments that connect two bones are specialized forms of the connective tissue that provide support.
- **Metabolic function:** Connective tissues participate in the diffusion of metabolites across the adjoining connective tissue to various tissues and cells from blood passing through the capillary beds. Before the waste metabolites return back to the blood capillaries, they are diffused from the cells and the tissues via the connective tissue. Moreover, the adipose tissue present in the hypodermis acts as an energy reserve and helps in providing heat insulation.
- **Haematopoietic cells:** The specialized connective tissues that are involved in the formation of red blood cells include the blood forming cells, the hematopoietic tissues, the bone marrow or the myeloid tissue and the lymphoid or the lymphatic tissue.

3.2.3 Structure and Functions of Muscular Tissue

Muscular tissue develops from the mesoderm of the embryo but some special muscles such as the iris of the eye and myoepithelial cells develop from the ectoderm.

Structure

Muscles of the body are formed by the elongated muscle cells termed as muscle fibres. These fibres are bound together by cells without intercellular tissue. Each fibre consists of fine fibrils called myofibrils. Any movement in the body brings a contraction and relaxation of contractile protein that is present in the muscle cells. The functions of muscle tissues depend on the type of muscle tissues and their locations in the body.

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Types of muscular tissue

There are three types of muscle tissues. These are as follows:

1. **Skeletal or striated muscle:** They are striped muscles and are voluntary as their contraction is dependent on the will. The entire muscle fibre consists of alternate dark and light patches. These dark and light patches are actually dark and light bands present on the muscle known as anisotropic bands (A-bands) and isotropic bands (I-bands), respectively. This muscle is also known as striated muscle as its appearance consists of light and dark bands that can be seen by using a light microscope. They are long, cylindrical and unbranched cells that have a number of nuclei situated towards the periphery of the muscle fibre. They are found in the muscles of the limbs, body wall, face, neck etc.

   Skeletal muscle is shown in Figure 3.11.

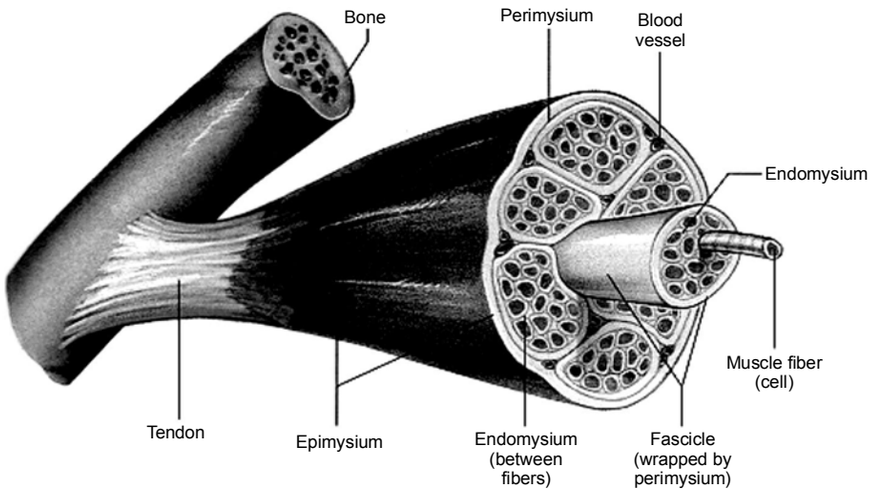

Fig. 3.11 *Skeletal Muscle*

2. **Cardiac muscle:** They are smooth, involuntary muscles. Every muscle fibre is long and cylindrical in shape. Cardiac muscle fibres are branched or Y-shaped. These fibres are attached at their ends to the adjoining fibres by thick plasma membranes known as intercalated discs. These muscles can be found in the walls of the heart and in the walls of large veins.

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Cardiac muscle is shown in Figure 3.12.

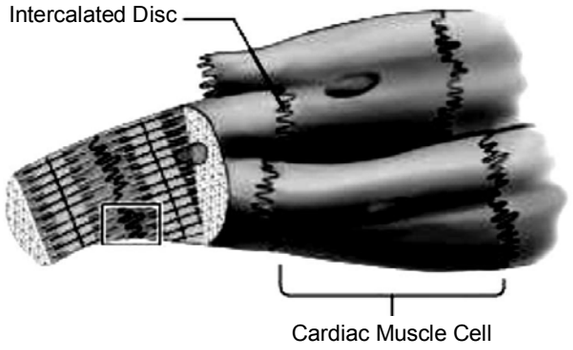

Fig. 3.12 *Cardiac Muscle*

3. **Smooth muscle:** Unlike skeletal and cardiac muscle tissue, smooth muscle is not striated. They have long, narrow, spindle shaped tapering cell, which is uninucleate. Soft threads called myofibrils run longitudinally throughout the cell. These muscles are found in the walls of the alimentary canal, and the internal organs. Unstriated muscles lead to slow and prolonged contractions that are involuntary, i.e., not under the control of the will. In the alimentary canal, they help in the movement of the food and in the blood vessels they assist the blood to flow.

   Smooth muscle is shown in Figure 3.13.

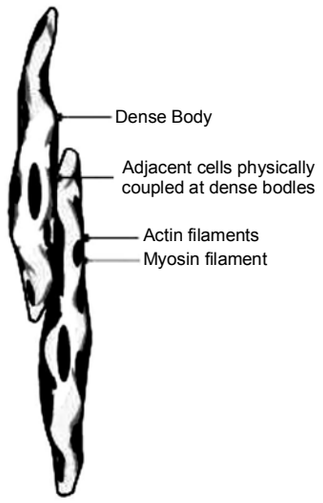

Fig. 3.13 *Smooth Muscle*

Functions of muscular tissue

Some of the functions of the muscular tissue are as follows:

- **Skeletal muscle:** The major function of the skeletal muscles is to provide locomotion and all other voluntary movements through out the body.

- **Cardiac muscle:** The main function of cardiac muscle is to pump the blood through the heart.
- **Smooth muscle:** Contractions of smooth muscle constrict the vessels they surround. Thus they help in peristalsis in the tubular viscera.

3.2.4 Structure and Functions of Nervous Tissue

Nervous tissue develops from the ectoderm of the embryo but the microgliocytes develop from the mesoderm of the embryo.

Structure of nervous tissue

Nervous tissue consists of two types of cells namely neurons, nerve fibres and neuroglial cells. When a neuron is suitably stimulated, an electrical disturbance is generated, which swiftly travels along its plasma membrane.

- **Neurons:** Neurons, the unit of nervous tissue, are excitable cells. They are the structural and functional unit of the complete nervous system. They are a microscopic structure that consists of three major parts, namely, cell body, dendrites and axons. Their individual features are as follows:
  - o Cell body or soma
  - o Dendrites
  - o Axon
- **Nerve fibres:** The axon or a dendrite of a nerve cell covered with one or more sheaths is called a nerve fibre. There are two types of nerve fibres listed as follows:
  - o Myelinated nerve fibres
  - o Unmyelinated nerve fibres
- **Neuroglial cells:** The neuroglial cell comprises the rest of the nervous tissues. They protect and support the neurons. Neuroglia constitutes of more than one half of the volume of the neural tissue in the human body.

Functions of nervous tissue

Following listed are the nervous tissue functions:

- They receive the impulses of various stimuli from the environment.
- They transmit the impulses of various stimuli.
- They respond to stimulus.
- They maintain homeostasis of body.
- They control the various activities of the body and its organs.
- They coordinate the activities of the body and its organs.

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The diagram for structure of neuron is as follows:

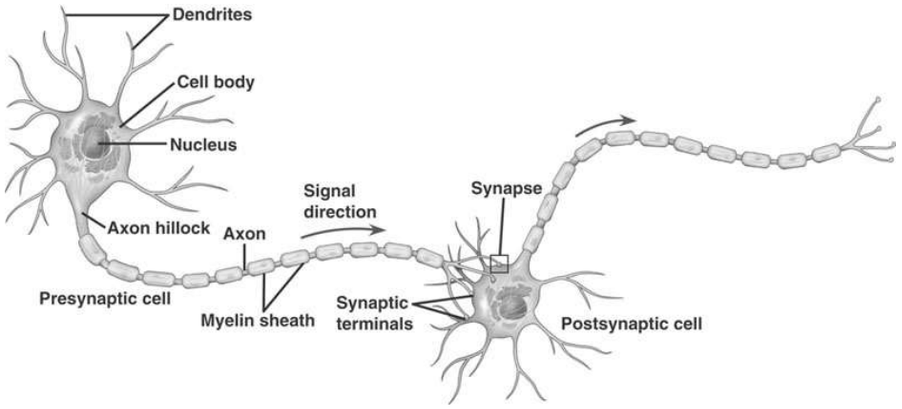

Fig. 3.14 *Structure of Nervous Tissue*

Check Your Progress

1. What are the various categories into which animal tissues can be classified?
2. List the various characteristics of epithelial tissues.
3. What does dense connective tissue consist of?
4. List some of the functions of muscular tissue.
5. Define neurons.
6. What are the two types of nerve fibres?

3.3 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. Animal tissues can be classified into the following categories: epithelial tissues (line the surface of the skin, cavities of the body, cover and protect the internal organs), muscle tissue (help in locomotion and movement of body and organs), connective tissue (provides strength, support and protection to the soft parts of the body) and nerve tissue (conducts nerve impulses).
2. The various characteristics of epithelial tissues are as follows:
   - Arranged in a compact manner on a thin, non-cellular basement membrane
   - Possess a definite shape
   - Characterized by the presence of a large amount of cytoplasm
   - Uninucleate and large and prominent nucleus
   - Capable of undergoing simple mitotic divisions

3. Dense connective tissue consists of fibres and fibroblasts that are packed in the connective tissue. Dense connective tissues could be of regular or irregular type. They may be white fibrous connective tissues or yellow elastic connective tissues.
4. Some of the functions of muscular tissue are as follows:
   - **Skeletal muscle:** The major function of the skeletal muscles is to provide locomotion and all other voluntary movements throughout the body.
   - **Cardiac muscle:** The main function of cardiac muscle is to pump blood through the heart.
   - **Smooth muscle:** Contractions of smooth muscle constrict the vessels they surround. Thus they help in peristalsis in the tubular viscera.
5. Neurons, a unit of nervous tissue, are excitable cells. They form the structural and functional unit of the complete nervous system.
6. There are two types of nerve fibres listed as follows:
   - Myelinated nerve fibres
   - Unmyelinated nerve fibres

3.4 SUMMARY

- A group of similar and specialized cells group to form tissues to carry out a specific function. A tissue represents a group of similar cells with intercellular substances, required to perform a specific function by functioning as a unit. In multicellular organisms, cells, tissues, organs and organ systems split up the work.
- Epithelial tissues are covering tissues that cover the external or internal surface of the body and its organs. These are the simplest and the least specialized animal tissues. They are non-vascular, since a direct blood supply is absent.
- Columnar epithelium is found lining the alimentary canal, from esophagus to anus. It is also found in some glands and their ducts and in the nephrons. Columnar epithelium with microvilli is known as brush-border epithelium.
- Compound epithelium is multi-layered where the cells in the lowermost layer are in contact with basement membrane. They are multi-layered where the cells in the lowermost layer are in contact with basement membrane.
- Connective tissue originates from the mesoderm of the embryo.
- Muscular tissue develops from the mesoderm of the embryo but some special muscles such as the iris of the eye and myoepithelial cells develop from the ectoderm.

NOTES

- Muscles of the body are formed by the elongated muscle cells termed as muscle fibres. These fibres are bound together by cells without intercellular tissue. Each fibre consists of fine fibrils called myofibrils.
- Skeletal or striated muscle are striped muscles and are voluntary as their contraction is dependent on the will. The entire muscle fibre consists of alternate dark and light patches.
- Cardiac muscles are smooth, involuntary muscles. Every muscle fibre is long and cylindrical in shape. Cardiac muscle fibres are branched or Y-shaped. These fibres are attached at their ends to the adjoining fibres by thick plasma membranes known as intercalated discs.
- Unlike skeletal and cardiac muscle tissue, smooth muscle is not striated. They have long, narrow, spindle shaped tapering cell, which is uninucleate.
- Nervous tissue consists of two types of cells namely neurons, nerve fibres and neuroglial cells. When a neuron is suitably stimulated, an electrical disturbance is generated, which swiftly travels along its plasma membrane.

3.5 KEY WORDS

- **Tissue:** It represents a group of similar cells with intercellular substances, required to perform a specific function by functioning as a unit.
- **Zone of elongation:** It is a zone that lies behind the growing point and in which the cells are newly formed cells that elongate rapidly, leading to an increase in the length of the root.

3.6 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. State the characteristics of epithelial tissues.
2. Briefly state the functions of epithelial tissues.
3. Comment on the structure of nervous tissue.
4. State the functions of nervous tissues.

Long Answer Questions

1. Analyse the structure of epithelial tissues.
2. Describe the structure and functions of connective tissues.
3. Discuss the classification of muscular tissues.
4. Describe the structure of a neuron with the help of a diagram.

3.7 FURTHER READINGS

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UNIT 4 SKELETAL SYSTEM

NOTES

Structure

4.0 INTRODUCTION

The skeletal system is the body system composed of bones, cartilages, ligaments and other tissues that perform essential functions for the human body. Bone tissue, or osseous tissue, is a hard, dense connective tissue that forms most of the adult skeleton, the internal support structure of the body.

The human skeleton performs six major functions; support, movement, protection, production of blood cells, storage of minerals, and endocrine regulation.

4.1 OBJECTIVES

After going through this unit, you will be able to:

- Classify the bones of the adult skeleton system
- Describe the structure and functions of joints and cartilage
- Analyse the structure and functions of muscles
- Describe the structure and functions of ligaments and tendons

4.2 STRUCTURE AND FUNCTIONS OF BONE

The skeletal system consists of bones, cartilage and joints. Skeleton is the framework of the bones which mainly supports the body and body parts to make it integrated and straight.

Functions of Skeletal System

Various functions of the skeleton system include:

1. **Protection:** The skull, vertebral column, ribs cage and pelvic girdle in this system protect various vital organs of the body.
2. **Support:** The bones of this system form a rigid framework which attached the softer tissues and organs of the body. They provide a rigid cage like structure or an internal support to the delicates organs and tissues.
3. **Movement:** Bones and cartilages are always found attached to muscles. They both work in integration. Whenever a muscle contracts, it transmits the action to the bones, to which it is attached, to help in the movement of joints.
4. **Haemopoiesis:** It is the process by which red bone marrow in adults produces white and red blood cells and platelets.
5. **Mineral storage:** The matrix of bones contains calcium and phosphorus in small amount.

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Cellular Components of Bones

Bones have the following types of cells:

- **Osteoblasts:** These are mononucleate bone-forming cells that are formed by the osteogenitor cells. They are located on the surface of osteoid seams and produce a protein mixture known as osteoid, which mineralizes to form various types of bones. Osteoblasts also manufacture hormones, such as prostaglandins, which act on the bone itself. Inactive osteoblasts form the surface of the bones.
- **Osteocytes:** They are formed by the osteoblasts that get trapped in the bone matrix, which they themselves produce. The spaces in the bones occupied by these cells are known as lacunae in the bones. They are mature bone cells.
- **Osteoclasts:** They are large, multinucleated cells located in the pits known as Howship's lacunae or resorption pits on the surface of the bones. They are the cells responsible for bone resorption (remodeling of bone to reduce its size).

Classification of the Bones of the Adult Skeleton

The skeletal system consists of 206 bones, which are classified into 80 axial bones and 126 appendicular bones. This classification of bones of adult skeleton is given in Table 4.1.

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Table 4.1 *Classification of Bones*

Axial Skeleton	**Appendicular Skeleton**
Skull: 22 bones	**Pectoral girdle:** 4 bones
14 facial bones	Scapula(2)
Maxilla (2)	Clavicle(2)
Palatine bone (2)	**Upper extremities:** 60 bones
Zygomatic bone (2)	Humerus (2)
Lacrimal bone (2)	Radius(2)
Nasal bone (2)	Ulna (2)
Vomer (1)	Carpal bone(16)
Inferior nasal	metacarpal bone (10)
Concha (2)	phalanx(28)
Mandible (1)	**Pelvic girdle: 2 bones**
8 cranial bones	Os coxae
frontal bone (1)	**Lower extremities:** 60 bones
parietal bone (2)	Femur(2)
occipital bone (1)	Tibia(2)
temporal bone (2)	fibula (2)
sphenoid bone (1)	patella (2)
ethmoid bone (1)	tarsal (14)
Auditory ossicles: 6 bones	metatarsal bone (10)
Malleus (2)	phalanx(28)
Incus (2)	
Stapes (2)	
Hyoid 1 bone	
Vertebral column: 26 bones	
Cervical vertebra (7)	
Thoracic vertebra (12)	
lumbar vertebra (5)	
sacrum (1)	
coccyx (1)	
Rib cage: 25 bones	
Rib(24)	
Sternum (1)	

Figure 4.1 shows various bones of the human skeletal system.

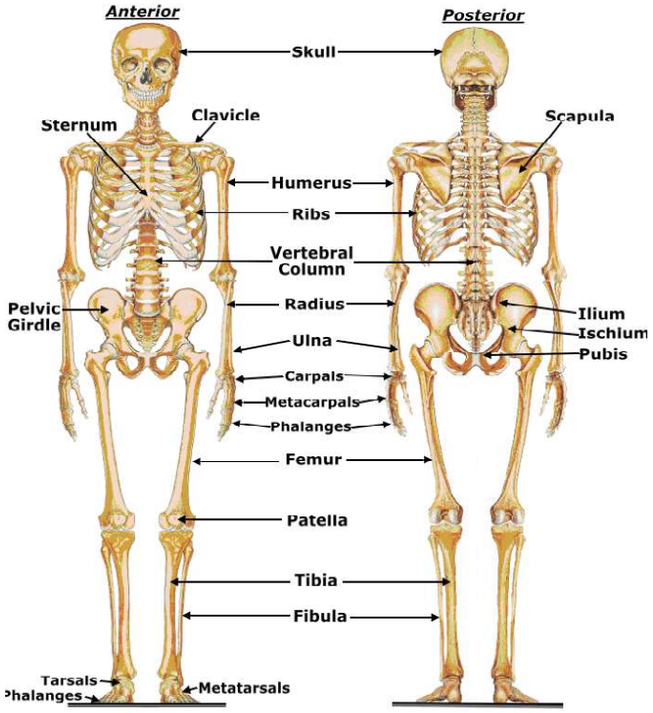

Fig. 4.1 *Human Skeletal System*

4.3 STRUCTURE AND FUNCTIONS OF CARTILAGE

Cartilage—Cartilage is a flexible connective tissue. Cartilage consists of specialized cells called **chondrocytes** which are not much in number. It has a dense network of collagen fibres firmly embedded in the **chondroitin sulphate**. It is a rubbery component present in the ground tissue. The strength of the cartilage is because of the collagen fibres and its elasticity and ability to regain its shape after deformation, is due to chondroitin sulphate. The surface of the cartilage is surrounded by **perichondrium** made up of irregular connective tissue. Cartilage has no supply for nerves or blood vessels except the perichondrium.

Cartilage is classified into three types, namely hyaline cartilage, fibrocartilage and elastic fibrocartilage.

(i) **Hyaline cartilage:** Hyaline cartilage is a smooth white-bluish tissue. It aids in the growth and repair of cartilage. It also provides flexibility, support and smooth surface for the movement of joints. It is most abundant and found in the ends of long bones that form the joints, part of trachea and

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bronchi and larynx in the nose. It also forms rings in the walls of respiratory passages. The collagen fibres are rare but lots of chondrocytes are found in the lacunae (Figure 4.2).

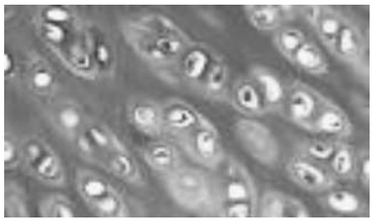

Fig. 4.2 *Hyaline Tissue*

(ii) **Fibrocartilage**: This consists of a mixture of white fibrous tissue in a matrix. It is a tough, slightly flexible, supporting tissue. Fibrocartilage is found in the pubic symphysis, intervertebral discs, meniscus and annulus fibrosus and as ligaments joining bones (Figure 4.3).

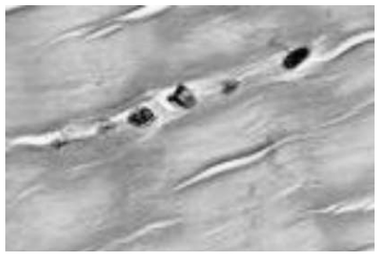

Fig. 4.3 *Fibrocartilage Tissue*

(iii) **Elastic Fibrocartilage:** This has more elastic fibres than hyaline cartilage. It is more flexible and is found in the outer ear. It supports and maintains the shape of the pinna or lobe of the ear, the epiglottis and a part of the tunica media of blood vessel wells (Figure 4.4).

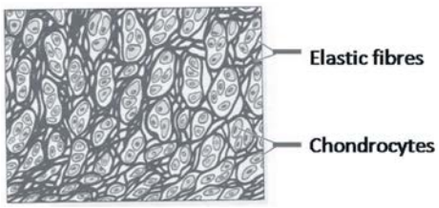

Fig. 4.4 *Elastic Fibrocartilage*

4.4 STRUCTURE AND FUNCTIONS OF JOINTS

The joints in the human body consist of the joint capsule, articular cartilage, synovial membrane and synovial (joint) cavity.

Types of Joints

There is a complex system of joints in the skeletal system in the human body. The joints support various kinds of movements of bones. Joints are classified on the basis of their manner of function into the following groups:

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- **Ball-and-socket joint:** It consists of a bone with a globular head that articulates with the cup-shaped cavity of another bone. A ball-and-socket joint provides flexibility, permitting movements in all planes, as well as rotational movement around a central axis. The hip and shoulder contain joints of this type.
- **Condyloid joint:** The ovoid condyle of one bone fits into the elliptical cavity of another bone, as in the joints between the metacarpals (bones of the palm) and phalanges (bones of the fingers and toes). This type of joint permits a variety of movements in different plane, even though rotational movement is not possible.
- **Gliding joints:** The articulating surfaces are nearly flat or are slightly curved. These joints allow sliding or back-and-forth motion and twisting movements. Gliding joints are composed of several interconnected bones with multiple joint surfaces Most of the joints within the wrist and ankle, as well as those between the articular processes of adjacent vertebrae, belong to this group.
- **Hinge joint:** The convex surface of one bone fits into the concave surface of another, as in the elbow and the joints of the phalanges. Such a joint resembles the hinge of a door in that it permits movement in one plane only. Hinged joints allow movement primarily in one direction.
- **Pivot joint:** The cylindrical surface of one bone rotates within a ring formed of bone and fibrous tissue of a ligament. Movement at such a joint is limited to rotation around a central axis. The joint between the proximal ends of the radius and the ulna, where the head of the radius rotates in a ring formed by the radial notch of the ulna and a ligament (annular ligament), is of this type. Similarly, a pivot joint functions in the neck as the head turns from one side to another. In this case, the ring formed by a ligament (transverse ligament) and the anterior arch of the atlas rotates around the dens of the axis.
- **Saddle joint:** It is formed between bones whose articulating surfaces have both concave and convex regions. The surface of one bone fits the complementary surface of the other. This physical relationship permits a variety of movements, mainly in two planes, as in the case of the joint between the carpal (trapezium) and the metacarpal of the thumb.

Types of Joint Movements

Joint movements are generally divided into four types—gliding, angular, rotation and circumduction.

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- Gliding is the simplest type of motion. It involves one surface moving over another without any rotary or angular motion. It exists between two adjacent surfaces.
- Angular motion decreases or increases the angle between two adjoining bones. The common types of angular motion are as follows:
  - o *Flexion:* It assists the bending of joints so that the angle between them decreases and the parts come closer (bending the lower limb at the knee).
  - o *Dorsiflexion:* It involves bending the foot upward at the ankle.
  - o *Plantar flexion:* It entails bending the foot at the ankle downward.
  - o *Extension:* It involves straightening parts at a joint so that the angle between them increases and the parts move farther apart (straightening the lower limb at the knee).
  - o *Hyperextension:* It entails excess extension of the parts at a joint, beyond the upright position.
  - o *Abduction:* It involves moving a part away from the midline (lifting the upper limb horizontally to form a right angle with his side of the body).
- Rotation is a movement in which the bone moves around a central point without being displaced, such as turning the head from one side to another. Medial rotation involves movement toward the midline whereas lateral rotation involves movement in the opposite direction
- Circumduction involves the movement of a part so that its end follows a circular path (moving the finger in a circular motion without moving the hand).

Table 4.2 shows some of the major joints of the human body and type of movements.

Table 4.2 *Joints and Their Movement*

Type of Joint	Joints in Human Body	Types of Movement
Hinge	Elbow, ankle and interphalangeal	This joint exhibits flexion and extension.
Pivot	Proximal radioulnar	This joint exhibits rotation.
Ball-and-socket	Shoulder and hip	This joint exhibits flexion, extension, adduction, abduction, rotation and circumduction.
Modified hinge	Tibiofemoral (knee)	This joint exhibits flexion, extension, slight rotation when flexed.
Condyloid	Wrist, metacarpophalangeal, carpometacarpal-1 and metatarsophalangeal	This joint exhibits flexion, extension, adduction, abduction and circumduction.

Check Your Progress

1. What are osteoblasts?
2. How many bones does the skeletal system consists of?
3. What is saddle joint?

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4.5 STRUCTURE AND FUNCTIONS OF MUSCLES

There are three types of muscles in the human body, which have been discussed ahead.

Skeletal muscle

The skeletal movements result from the activity of the muscles that remain attached to bones. The skeletal muscles are controlled by peripheral nervous system; it means that these muscles are under conscious or voluntary control. The basic unit of these muscles is the muscle fiber. The chief features of the skeletal muscle fibres are as follows:

- Each muscle fibre in a skeletal muscle is multinucleated, that is, it has many nuclei.
- The skeletal muscle fibres are said to be striated fibres as they have transverse streaks.
- Each muscle fibre acts independently of the surrounding muscle fibres.

Smooth muscle

The walls of the hollow internal organs of the body, for instance, bladder, uterus, blood vessels and the digestive tract consist of smooth muscles (also known as non-striated muscles). The chief features of the smooth muscles are as follows:

The contraction of the smooth muscles occurs unconsciously, that is, it is an involuntary movement.

- The cells of the smooth muscle are spindle-shaped.
- Each smooth muscle cell has one central nucleus.
- The contraction movements of the smooth muscles are slow and rhythmic.

Cardiac muscle

Cardiac muscle forms the walls of the heart. The chief features of the cardiac muscle are as follows:

- It is controlled by the autonomic nervous system, that is, its movement is involuntary.
- The cardiac muscle cell has single central nucleus like the smooth muscle.

- It is striated like the skeletal muscle.
- It is rectangular in shape.
- Its contraction is involuntary, strong and rhythmical.

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Muscles of Upper Arm and Anterior Compartment of Thigh

The muscles of the upper arm and the anterior compartment of the thigh comprise the following muscles of the human body:

- The muscles that attach the scapula to the thorax
- The muscles that attach humerus to the scapula
- The muscles that located in the arm or forearm and cause movement in the forearm, wrist and hand

Figure 4.5 shows certain muscles of the upper arm.

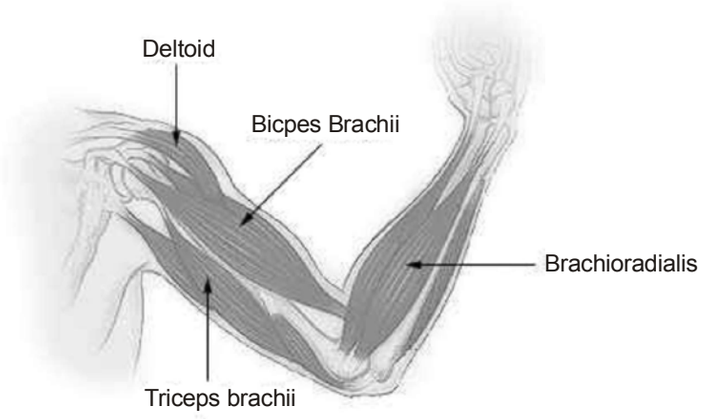

Fig. 4.5 *Muscles of the Upper Arm*

Muscles that cause movement in the shoulder and arm are:

- Trapezius
- Serratus anterior

The muscles that connect to the humerus and move the arm are as follows:

- Pectoralis major
- Latissimus dorsi
- Deltoid and rotator cuff

The muscles that cause movement in the forearm are located along the humerus. These muscles are:

- Triceps brachii
- Biceps brachii

- Brachialis
- Brachioradialis

The muscles that cause most of the movements in the wrist, hand and finger are approximately twenty in number and are located along the forearm.

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The origin of the muscles that cause movements of the thigh is located on the pelvic girdle; the insertions of these muscles are located on the femur. The largest skeletal muscle mass lies in the posterior region; it is called the gluteal muscle. The gluteal muscles abduct the thigh. The iliopsoas is an anterior muscle that flexes the thigh. Figure 4.6 shows certain muscles of the lower extremity. These muscles are:

- Muscles that cause movement in the leg are located in the thigh region.
- The leg is straightened at the knee by the quadriceps femoris muscle group.
- The hamstrings are antagonists to the quadriceps femoris muscle group; these muscles flex the leg at the knee.
- The muscles of the leg that cause movement in the ankle and foot are divided into three compartments: anterior, posterior and lateral.
- The tibialis anterior dorsiflexes the foot.
- The gastrocnemius and soleus muscles plantarflex the foot and are antagonists to the tibialis anterior.

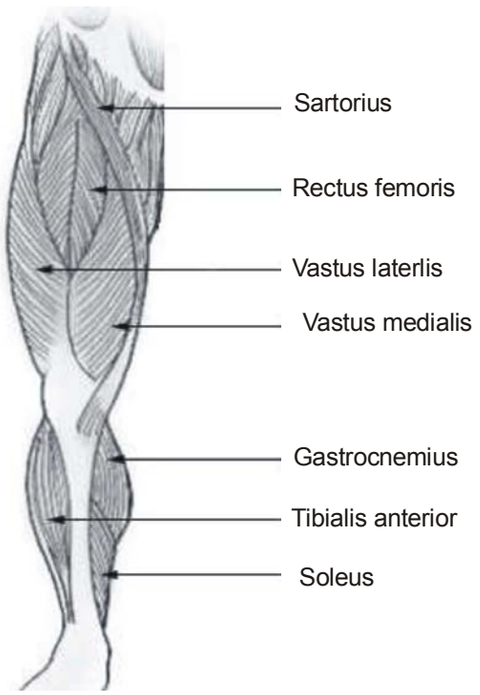

Fig. 4.6 *Muscles of the Thigh*

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The general movements such as walking and running are consequent upon the integrated action of joints, bones and skeletal muscles. The more subtle movements that cause a variety of facial expressions, the movements during respiration and the eye movements are also caused by these muscles. Specialized cells called muscle fibers constitute the muscular system. The most important function of muscle fibres is contraction.

Almost all kinds of movement in the body are a consequence of muscle contraction. However, the movements of cilia, the flagellum on sperm cells and the amoeboid motion of certain kinds of white blood cells form an exception.

Besides helping in various kinds of movement, muscle contraction also supports certain important functions in the body, such as:

- **Posture:** Muscle contraction helps maintain various postures, for example, sitting and standing. The skeletal muscles continuously make fine adjustments to keep the body in various postures, that is, stationary positions.
- **Joint stability:** The tendons of many muscles extend over joints and in this way, contribute to joint stability. This is particularly evident in the knee and shoulder joints, where muscle tendons are a major factor in stabilizing the joint.
- **Heat production:** Movements of skeletal muscles produce heat. When the internal heat of the body becomes low, the skeletal muscles begin to contract and relax involuntarily causing shivering. This increased muscle activity generates heat. In turn, muscles also respond to external heat, that is, the heat in the environment: when it is cold, muscle activity increases whereas and when the environment becomes hot the muscles get relaxed.

Blood and Nerve Supply

Skeletal muscle is highly vascular, that is, innumerable blood capillaries remain dispersed in this muscle; skeletal fibres are always completely oxygenated. Contraction of muscles temporarily decreases the flow of blood to the inner parts of the muscle. The skeletal muscle fibres have a well-developed capillary bed.

4.6 STRUCTURE AND FUNCTIONS OF LIGAMENTS AND TENDONS

Both ligaments and tendons are soft collagenous tissues. The bones are connected with each other with the help of ligament and the muscles are connected to the bone with the help of tendons. Both have a very crucial role in the biomechanics of musculoskeletal. They signify a vital part of treatment in orthopaedics. There are several challenges over repair pending in these areas and most of them are to do

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with restoration of basic movement functions of the two tissues. Similar to all biological tissues there is a hierarchical structure of ligaments and tendons which has a direct impact on the mechanical behaviour. Furthermore, both can adjust to alterations in their movement environment caused as a result of injury, illness or workout/physical activity. Therefore, ligaments and tendons are one of the examples of the structure-function concept along with the reflexively facilitated adaptation concept. They both are stringy, thick regular collagenous tissues which have the function of connecting, ligaments connect bones with each other and tendons connect muscles to the bones.

Hierarchical Ligament and Tendon Structure

The ligaments and tendons have a hierarchical structure. The hierarchical structure is provided from the prominent schematic given by Kastelic J.

The following figure represents the structure of both the tendon and ligament. They have been split into smaller fascicles and every fascicle consists of the simple fibril and the fibroblasts. The non-linear and stress-strain bonding of ligaments and tendons is essentially contributed by the crimp of the fibril. The biological cells known as the fibroblasts help in production of ligament or tendon.

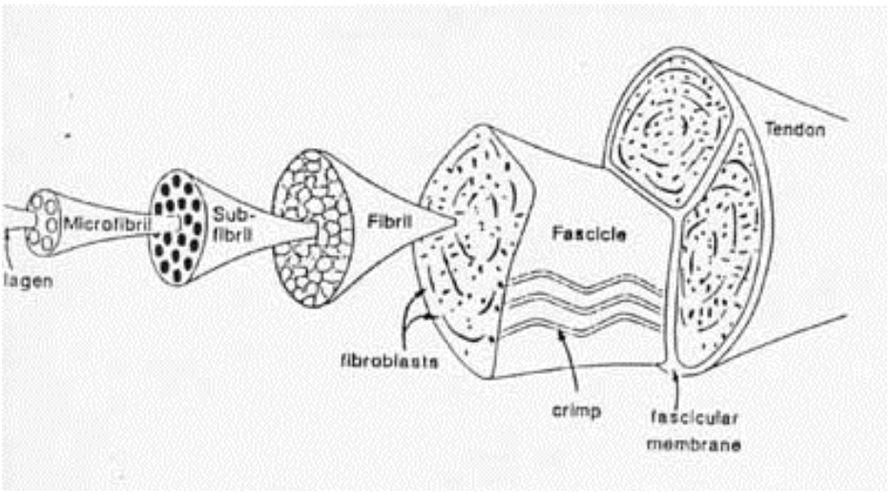

Fig. 4.7 *Hierarchical Ligament and Tendon Structure*

The biggest structure in the diagram above is the tendon (as shown) or it may be seen as the ligament. They are then divided into minor bodies termed as fascicles. The fascicle has the simple fibril of the ligament or tendon, after the fibril is the fibroblasts; these are the biological cells which are required for the production of the ligament/tendon. The crimp of the fibril has an important character in the structure; crimp's waviness contributes to the mechanism of the both ligament and the tendon. It is responsible for the taking the stress which occurs due to non-linear movement. The crimp is essentially tissues which are soft proteins.

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In terms of the specific characteristics of tendons as shown in the diagram is as follows

Structure:

- Tendons have collagen fibrils (Type I)
- Tendons have a proteoglycan matrix
- Tendons have fibroblasts, these are organised in straight lines and are parallel to each other

Primary Functions

- They are responsible for carrying tensile forces from muscle to bone
- Tendons are able to carry force compressively while they are covered over the bone in a pulley fashion.

Collagen with Type 1: Tendon's dry weight is eighty six percent, glycine is thirty three percent; proline and hdroxyprolone is fifteen percent each.

Blood Supply: The vessels are found in the covering of the tendon, the perimysium, periosteal insertion and tissues around it.

Ligaments

Structure

- Same as the tendons in hierarchical structure
- As compared to tendons the collagen fibrils are marginally small in volume fraction and organization.
- The percentage of the proteoglycan matrix is more than found in tendon
- They have fibroblasts different from the tendon

Blood Supply: Micro-vascularity via insertion site, nourishment for population of the cells and it is important for the synthesis of the surrounding substance and their restoration.

Broad Outline of Ligament and Tendon Mechanism

As seen in case of every biological tissue, the mechanical behaviour of the tendons and ligaments is significantly influenced by their hierarchical structure. Their structure is very different from the bones structure and this is because of two reasons, firstly it is very difficult to quantify their hierarchical structure as compared to the bones and secondly they both show nonlinear as well as viscoelastic behaviour in conditions of physiological loading as well and thus it becomes tough to examine the linear behaviour exhibited by the bones.

Nonlinear Elasticity

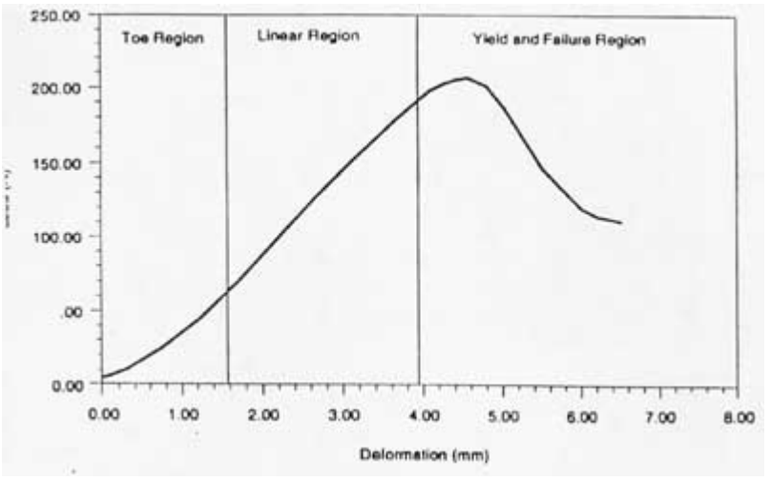

Fig. 4.8 *Stress strain curve*

In case the viscoelastic behaviour is neglected than the usual stress-strain curve of tendons and ligaments would appear somewhat like as given above:

As shown in the diagram the stress strain curve has three main regions. The first region is the toe or toe-in region, the second region is the linear region and the third region is the yield and failure. In physiologically activities of ligaments and the tendons take place mostly in the first region and few in the second region. The two regions denote a stress-strain curve that is deviating and the slope seen in the first region is not same as in the second region.

If seen from the point of view of the relationship of the structural function the first region i.e. the toe-in region signifies crimping-less of the crimp found in the collagen fibrils. The curve here is reasonably less stiff. The un-crimping of the collagen fibrils shows that the collagen fibril backbone on its own is being strained; this results in material which is stiff. The damage begins to increase once the fibrils in a human body inside the ligament or tendon start to fail, the reduced stiffness harms the ligament/tendons. Consequently an important feature of general behaviour of the ligaments and tendons is largely dependent on the structure of the crimp and their result on the damage to the collagen's fibril.

Contents of Ligaments and Tendons

Collagen: Twenty percent of the contents in tendons and ligaments are made up of collagens along with that they have seventy percent water and around two percent of ground substance. But the collagen's dry weight is in both is around seventy percent. The collagen has a very high tensile strength as it is made up of a protein which is fibrous in nature. They both do not have the same arrangement of collagen fibres. The arrangement of ligament consists of irregular and loosely filled

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network of fibres whereas the arrangement of tendons is even and forms a network of straight parallel lines.

The symmetrical arrangement of the tendons helps in handling heavy single directional tensile loads when there is movement and similarly the arrangements of ligaments helps in sustaining general direction tensile loads along with bearing the minor tensile load in varying directions. The quantity of protein elastin is less in extremity ligaments and tendons. The mechanical properties of the ligaments help them to be flexible as well as resist force due to the tensile properties, this is possible because of the ratio of fibrillar Type I collagen to Type III collagen which helps in flexibility is higher in them.

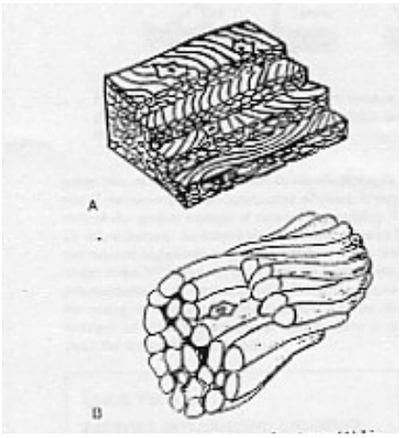

Fig. 4.9 *Ligaments and Tendons*

The Figure 4.9 A is showing ligaments with thickly filled collagen in irregular network in one common direction.

The Figure 4.9 B is showing the Tendons with their undeviating or systematic arrangement

The percentage of ground substance is very less but extremely important as it allows the movement actions during compression. Ligaments can buckle during compression and will not be able to give support.

Innervation and mechanoreceptors: The tendons have four types of nerve endings and two types of mechanoreceptors in them. The first type is referred as Ruffuni corpuscles is helps in monitoring. The second type is referred as Vater-Pacini corpuscles and third type is referred as Golgi tendon organs. The fourth type is free nerve endings these are essential in order to realise pain. All four help in important movement of the body as they are connected to the main nervous system of the body and relay the afferent sensory neural information. The Anterior Cruciate Ligament is abundantly supplied with nerves due to the mechanoreceptors. The sensory information provided helps in controlling the neuromuscular activity of the body and thus contributing towards providing stability to the joint and allowing its movements.

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External structure and Attachment into Bone: Tendons as well as ligaments are circled with movable areolar connecting tissue. Despite the fact that the tissue circling ligament is not visible but the tissue circled around tendons is called paratenon, it is clearly visible and well-formed. It provides a protective cover around the tendon that helps in smooth movement.

The term "load" in connection to the ligament and tendons refers to the force which is applied from outside on the collagen and in the same way "stress" is in reference to the resistance by the collagen, the stress is directly affected by the load. "Strain" refers to the wear and tear of the collagen which happened due to the load.

Functions of Ligament and Tendon

The primary function of the soft collagenous tissues is to connect, the ligaments help in connecting bones with each other and the tendons connect the muscles to the bones. They play a very essential role in biomechanics of living beings

Functions of Ligaments

- Provide resistance from external load and it avoids unnecessary motion
- Guides the motion of the joint thus helps in movement of two bones with each other.
- Automatically controls the full range of movement. Thus provides extra stability to the joint's movement. The motion patterns are affected by many factors such as length of the ligament, placement, stiffness, and angle of the bone.
- Provides the control over the movement.

Function of Tendons

- Transfer the tensile forces from muscle to bone
- Provides the advantage to the mechanical pulley and it then enables the muscle belly to be at the correct distance from joint, the muscle length need not be long as the pulley mechanism provided the link between the source and the inset.
- Helps in maintaining the posture of the body
- Provides the control over the movement

Check Your Progress

4. State the chief features of skeletal muscle fibres.
5. Name the muscles that cause movement in the shoulder and the arm.
6. State the primary function of the soft collagenous tissues.

4.7 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

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1. Osteoblasts are mononucleate bone-forming cells that are formed by the osteogenitor cells. They are located on the surface of osteoid seams and produce a protein mixture known as osteoid, which mineralizes to form various types of bones.
2. The skeletal system consists of 206 bones, which are classified into 80 axial bones and 126 appendicular bones.
3. Saddle joint is formed between bones whose articulating surfaces have both concave and convex regions. The surface of one bone fits the complementary surface of the other. This physical relationship permits a variety of movements, mainly in two planes, as in the case of the joint between the carpal (trapezium) and the metacarpal of the thumb.
4. The chief features of the skeletal muscle fibres are as follows:
   - Each muscle fibre in a skeletal muscle is multinucleated, that is, it has many nuclei.
   - The skeletal muscle fibres are said to be striated fibres as they have transverse streaks.
   - Each muscle fibre acts independently of the surrounding muscle fibres.
5. Muscles that cause movement in the shoulder and arm are:
   - Trapezius
   - Serratus anterior
6. The primary function of the soft collagenous tissues is to connect, the ligaments help in connecting bones with each other and the tendons connect the muscles to the bones. They play a very essential role in biomechanics of living beings.

4.8 SUMMARY

- The skeleton system consists of bones, cartilage and joints. Skeleton is the framework of the bones which mainly supports the body and body parts to make it integrated and straight.
- The skeletal system consists of 206 bones, which are classified into 80 axial bones and 126 appendicular bones.
- Cartilage is a flexible connective tissue. Cartilage consists of specialized cells called chondrocytes which are not much in number. It has a dense network of collagen fibres firmly embedded in the chondroitin sulphate. It is a rubbery component present in the ground tissue.

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- Hyaline cartilage is a smooth white-bluish tissue. It aids in the growth and repair of cartilage. It also provides flexibility, support and smooth surface for the movement of joints. It is most abundant and found in the ends of long bones that form the joints, part of trachea and bronchi and larynx in the nose.
- Fibrocartilage consists of a mixture of white fibrous tissue in a matrix. It is a tough, slightly flexible, supporting tissue. Fibrocartilage is found in the pubic symphysis, intervertebral discs, meniscus and annulus fibrosus and as ligaments joining bones.
- The joints in the human body consist of the joint capsule, articular cartilage, synovial membrane and synovial (joint) cavity.
- There is a complex system of joints in the skeletal system in the human body. The joints support various kinds of movements of bones.
- Joint movements are generally divided into four types—gliding, angular, rotation and circumduction.
- The origin of the muscles that cause movements of the thigh is located on the pelvic girdle; the insertions of these muscles are located on the femur. The largest skeletal muscle mass lies in the posterior region; it is called the gluteal muscle.
- The general movements such as walking and running are consequent upon the integrated action of joints, bones and skeletal muscles. The more subtle movements that cause a variety of facial expressions, the movements during respiration and the eye movements are also caused by these muscles.
- Almost all kinds of movement in the body are a consequence of muscle contraction. However, the movements of cilia, the flagellum on sperm cells and the amoeboid motion of certain kinds of white blood cells form an exception.
- Movements of skeletal muscles produce heat. When the internal heat of the body becomes low, the skeletal muscles begin to contract and relax involuntarily causing shivering. This increased muscle activity generates heat.
- Skeletal muscle is highly vascular, that is, innumerable blood capillaries remain dispersed in this muscle; skeletal fibres are always completely oxygenated. Contraction of muscles temporarily decreases the flow of blood to the inner parts of the muscle.

4.9 KEY WORDS

- **Hyaline cartilage:** Hyaline cartilage is a smooth white-bluish tissue. It aids in the growth and repair of cartilage. It also provides flexibility, support and smooth surface for the movement of joints.

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- **Gliding joints:** The articulating surfaces are nearly flat or are slightly curved. These joints allow sliding or back-and-forth motion and twisting movements. Gliding joints are composed of several interconnected bones with multiple joint surfaces.
- **Flexion:** It assists the bending of joints so that the angle between them decreases and the parts come closer (bending the lower limb at the knee).

4.10 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. State the functions of the skeletal system.
2. What are the three types of cartilages?
3. Briefly state the types of joint movements.
4. State the chief features of the cardiac muscle.
5. What are the primary functions of tendons?

Long Answer Questions

1. How are the bones of an adult skeleton classified? Discuss.
2. Describe the structure and functions of joints.
3. Analyse the structure and functions of muscles.
4. Describe the structure and functions of ligaments and tendons.

4.11 FURTHER READINGS

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BLOCK - II
BLOOD, CARDIOVASCULAR, RESPIRATORY AND DIGESTIVE SYSTEM

UNIT 5 INTRODUCTION TO HEMATOLOGY

Structure

5.0 INTRODUCTION

Blood is a special bodily fluid that is present in human and animal bodies. It delivers nourishment and oxygen to and removes waste materials from organs and tissues. An adult person has 5-6 litres of blood that constitutes approximately 7-8 per cent of the total body weight. The constituents of blood are plasma and blood cells (red blood cells, white blood cells and thrombocytes). Plasma, which is the

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yellow-coloured watery component of blood, accounts for approximately 55 per cent of the total blood volume. It helps to transport blood cells in the body, maintain optimum temperature, control the pH level and maintain the electrolyte balance in the body. Red blood cells, also known as erythrocytes, contain haemoglobin (Hb or Hgb), primarily made of iron, and carry oxygen. Deficiency of red blood cells in the blood leads to anaemia. White blood cells, also known as leucocytes, play a major part in building up the immune system in the body. Platelets enable the formation of blood clots, which leads to healing of wounds.

In this unit, you will learn about the various aspects of blood, such as its composition, morphology, clotting, etc. You will also learn about the functions of blood groups, blood viscosity, coagulation and transfusion.

5.1 OBJECTIVES

After going through this unit, you will be able to:

- Describe the functions of blood
- Understand the composition and functions of blood plasma
- Identify clotting factors and explain the mechanism of blood clotting
- Describe the morphology of red and white blood cells and platelets, their functions and development
- Understand the composition and function of haemoglobin
- Identify the various blood groups in the body
- Describe the mechanism of blood transfusion

5.2 COMPOSITION AND FUNCTIONS OF BLOOD

Blood is a special bodily fluid that delivers nourishment and oxygen to and transports waste products away from cells. In all vertebrates, blood is composed of plasma and blood cells. Plasma, a watery liquid (approximately 90 per cent by volume), accounts for approximately 55 per cent of blood. It contains dissolved proteins, glucose, mineral ions, hormones, carbon dioxide, platelets and blood cells. The blood cells are mainly red blood cells (RBCs; known as erythrocytes), white blood cells (WBCs; known as leukocytes), thrombocytes and platelets. RBCs make up the majority of blood cells. These contain haemoglobin, an iron-containing protein, which helps to transport oxygen across the body. Carbon dioxide, present in plasma as dissolved bicarbonate ion, is transported extracellularly.

Functions

The functions of blood within the body are as follows:

- It supplies oxygen to tissues.

- It supplies nutrients such as glucose, amino acids and fatty acids. These nutrients are dissolved in the blood or bound to plasma proteins.
- It removes wastes, which include carbon dioxide, urea, lactic acid, etc, from the body.
- It is involved in the circulation of white blood cells and detection of foreign material by antibodies. These functions are referred to as immunological functions.
- It takes part in coagulation—the body's self-repair mechanism to stop the bleeding in case of a cut in any part of the body.
- It also facilitates the messenger functions, including the transport of hormones and the signalling of tissue damage.
- It regulates body pH (the normal pH of blood is in the range of 7.35–7.45).
- It regulates the core body temperature.
- It also performs hydraulic functions.

5.3 BLOOD CELLS

Blood comprises the following three types of cells (occasionally called *corpuscles*)

1. Erythrocytes or red blood cells
2. Leukocytes or white blood cells
3. Thrombocytes or platelets

Let us discuss these cells in detail.

1. Red Blood Cells

Red blood cells (RBCs; erythrocytes) constitute the majority part of blood cells. Their role is to transport oxygen to the cells and tissues. Haemoglobin is the chief component of RBCs, which are released when the iron atoms in the haeme temporarily bind to oxygen molecules in the lungs. Erythrocytes are produced in the gall bladder in embryos. Later on, it is produced in their liver and in the end in the bone marrow. In mammals, erythrocytes lose their nucleus and take the form of flattened circles, with a thin centre. In the human body, there are approximately 4.3 million (women) and 4.8 million (men) erythrocytes in 1 mL of blood.

The characteristics of erythrocytes may be summarized as follows:

- They are tiny (8ì), biconcave and disc-shaped cells.
- They do not have nucleus, mitochondria and ribosomes.
- They contain haemoglobin, which binds O_2 (and CO).
- They are made in the bone marrow and live about 120 days.
- They are destroyed and recycled by the liver.

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2. White Blood Cells

White blood cells (WBCs; leukocytes) are produced in the bone marrow and also in the thymus and spleen. Because they are also produced in the lymph nodes, they are also known as lymphocytes. Leukocytes are the most diverse cells, both in terms of morphology and functionality. Usually, there are between 4×10^9 and 1.1×10^{10} white blood cells in 1 litre blood, which makes up approximately 1 per cent blood in a healthy adult.

Leukocytes comprise the following:

- Granulocytes (about 60 per cent)
- Monocytes (about 4 per cent)
- Lymphocytes (about 36 per cent)

The characteristics of leukocytes may be summarized as follows:

- Leukocytes are colourless cells and possess a nucleus.
- Leukocytes function in defending the body against pathogens.
- There are several types of leukocytes, such as neutrophils, eosinophils, basophils, lymphocytes and monocytes.
- The function of neutrophils is to defend the body against bacterial or fungal infection.
- The primary function of eosinophils is to deal with parasitic infections.
- Basophils are mainly accountable for allergic and antigen responses by releasing the chemical histamine causing inflammation.
- Lymphocytes are common in the lymphatic system of the body. They produce antibodies—the specific defence proteins.
- Monocytes share the 'vacuum cleaner' (phagocytosis) function of neutrophils, but they survive much longer.
- White blood cells are often characterized as granulocytes or agranulocytes. Polymorphonuclear leukocytes are known as granulocytes, while mononuclear leucocytes are known as agranulocytes.
- Leukocytes are made in the bone marrow and lymphatic tissue.

You will learn more about white blood cells in section 5.8.

3. Platelets

Platelets, or thrombocytes, are oval shaped and have a single nucleus in the cell. They are produced in the bone marrow. There are approximately 2,00,000-4,00,000 platelets in 1 mL blood, and these initiate the clotting of blood. Thrombokinase, released when blood vessels are cracked, is an enzyme that starts the process of transformation of fibrinogen into blood fibrin.

The important features of platelets are listed as follows:

- Platelets are produced in blood cell formation in bone marrow.
- Around 1 x 10^{11} platelets are produced each day by an average healthy adult.
- The platelet production is regulated by thrombopoietin, which is a hormone produced by the liver and kidneys.
- Old platelets are destroyed by phagocytosis in the spleen and by Kupffer cells in the liver.
- The main function of platelets is the maintenance of haemostasis, which is achieved primarily by the formation of thrombi.

You will learn more about platelets in section 5.9.

Check Your Progress

1. What does plasma contain?
2. Name the three types of cells that blood comprises?
3. Where are the white blood cells or leukocytes mainly produced?

5.4 COMPOSITION AND FUNCTIONS OF PLASMA

Blood plasma makes up approximately 55 per cent of whole blood. It is a fluid that acts as the blood's liquid medium. The volume of blood plasma is approximately 2.7-3 litres in a human. It contains water (more than 90 per cent), proteins (approximately 8 per cent) and other components; circulates dissolved nutrients such as glucose, amino acids and fatty acids; and gets rid of waste products like carbon dioxide, urea and lactic acid.

The important components of plasma are as follows:

- Serum albumin
- Blood-clotting factors
- Immunoglobulins
- Lipoprotein particles
- Various electrolytes

The term 'serum' refers to plasma from which the clotting proteins have been removed.

Functions

The functions of plasma are as follows:

- The plasma keeps the osmotic pressure of the body liquids and Ph-factor at the constant level.

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- The Plasma contains dissolved substances. Most of these are useful and are carried to places where they are to be stored or used.
- The liver is able to remove excess amino acids from blood plasma and add some of those which are needed.
- Vitamins are carried by plasma from the ileum to all other parts of the body.

Hormones are secreted by endocrine glands and carried in blood plasma to target organs.

5.5 BLOOD CLOTTING

It is crucial to sustain the flow of blood post a vascular injury to ensure the survival of a living being. Haemostasis is such a complex process that can put an end to the bleeding process. It is the process of retaining blood within a damaged blood vessel. This process involves more than one event that occur as per a predetermined sequence following vascular injury. Vascular constriction is the initial phase of this process, which confines blood flow to the area of injury. After this, platelets are activated by thrombin and collect at the site of injury. This is done by forming a temporary, loose platelet plug. Fibrinogen, a protein, is mainly responsible for stimulating the clumping of platelets, done by binding to collagen that is exposed due to the rupture of the endothelial lining of vessels. When the platelets are activated, they release nucleotide, adenosine diphosphate (ADP) and eicosanoid, TXA_2, serotonin, phospholipids, lipoproteins and other proteins vital to initiate the coagulation cascade. In addition, the platelets that have been activated change their shape to accommodate the formation of the plug.

To ensure the initially loose platelet plug remains stable, a fibrin mesh, referred to as the clot, forms and traps the plug. If the plug contains only platelets, it is referred to as a white thrombus; if it contains red blood cells, it is referred to as a red thrombus. Finally, to ensure normal blood flow is resumed after the healing of the wound, the clot must be dissolved. This dissolving occurs through plasmin action.

Intrinsic and extrinsic pathways lead to the formation of fibrin clots. Although, distinct mechanisms initiate these pathways, they converge on a common pathway that results in the formation of clots. Both these pathways are complex and require different proteins known as clotting factors. Under normal physiological conditions, the most relevant event of haemostasis is the formation of fibrin clots in response to tissue injury. This is due to the extrinsic pathway getting activated. The intrinsic pathway is activated by the formation of a red thrombus, or clot, in response to an abnormal vessel wall in the absence of tissue injury. Under normal physiological conditions, the intrinsic pathway has low significance. Clinically, the activation of the intrinsic pathway has the most significance, due to the contact of vessel wall with lipoprotein particles—very-low-density lipoproteins (VLDLs), large

lipoprotein particles and chylomicrons. The intrinsic pathway can also be activated by the vessel wall contact with bacteria. This obviously demonstrates the role of hyperlipidemia in the generation of atherosclerosis.

5.5.1 Activation of Platelets and the von Willebrand Factor (vWF)

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Platelets must hold on to exposed collagen, release the contents of their granules and aggregate, for haemostasis to take place. The von Willebrand factor (vWF) acts as a mediator in the adhesion of platelets to the collagen exposed on endothelial cell surfaces. It is a complex multimeric glycoprotein that is produced by and stored in the alpha-granules of platelets. It is also synthesized by megakaryocytes and is associated with subendothelial connective tissue. von Willebrand disease (vWD) is caused by the inherited deficiencies of vWF. vWF is a bridge between collagen fibrils and a specific glycoprotein complex on the surface of platelets (GPIb-GPIX-GPV). The GPIb part of the complex has two proteins: GPIbá and GPIbâ encoded by separate genes. The significance of the relation between the GPIb-GPIX-GPV complex of platelets and vWF can be seen by the inheritance of disorders of bleeding caused by faults in three of the four proteins of the complex. The most common of this is the Bernard-Soulier syndrome (also referred to as the giant platelet syndrome).

vWF not only acts as a conduit between platelets and exposed collagen on endothelial surfaces but also binds to and stabilizes coagulation factor VIII. This binding is required for factor VIII to survive in the circulation. Platelets are initially activated by the induction of thrombin binding to specific receptors on the surface of platelets. This initiates a signal transduction cascade. The thrombin receptor is coupled to a G-protein that, in turn, activates phospholipase C-γ (PLC-γ). PLC-γ hydrolyzes phosphatidylinositol-4, 5-bisphosphate (PIP2) leading to the formation of inositol trisphosphate (IP3) and diacylglycerol (DAG). IP3 induces the release of intracellular Ca^{2+} stores and DAG activates protein kinase C (PKC).

Ca^{2+}, when released intracellularly, activates phospholipase A2 (PLA2), which then hydrolyzes membrane phospholipids, leading to arachidonic acid being liberated. The release of arachidonic acid leads to an increase in the production and subsequent release of thromboxane A2 (TXA2). TXA2 is an inducer and potent vasoconstrictor of platelet aggregation that operates by binding to receptors that work through the PLC-γ pathway. Myosin light chain kinase (MLCK) is another enzyme that is activated by the released intracellular Ca^{2+} stores. The activated MLCK phosphorylates the light chain of myosin which then interacts with actin. This results in changed platelet morphology and motility.

Phosphorylation and activation of a specific 47,000-Dalton platelet protein are some of the many effects of PKC. This activated protein induces the release of platelet granule contents; one of which is ADP. ADP further stimulates platelets increasing the overall activation cascade. The important role of ADP in platelet activation can be appreciated from the use of the ADP receptor. The activation of

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platelets is required for their consequent aggregation to a platelet plug. On the other hand, the role of activated platelet surface phospholipids is equally important in the activation of the coagulation cascade.

Table 5.1 lists the various clotting factors.

Table 5.1 *List of Clotting Factors*

Factor	Trivial Name(s)	Pathway	Characteristic
Prekallikrein (PK)	Fletcher factor	Intrinsic	Functions with HMWK and factor XII
High molecular weight kininogen (HMWK)	Contact activation cofactor; Fitzgerald, Flaujeac Williams factor	Intrinsic	Cofactor in kallikrein and factor XII activation, necessary in factor XIIa activation of XI, precursor for bradykinin (a potent vasodilator and inducer of smooth muscle contraction
I	Fibrinogen	Both	
II	Prothrombin	Both	Contains N-term. *gla* segment
III	Tissue Factor	Extrinsic	
IV	Calcium	Both	
V	Proaccelerin, labile factor, accelerator (Ac-) globulin	Both	Protein cofactor
VI	Accelerin	Both	This is Va, redundant to Factor V
VII	Proconvertin, serum prothrombin conversion accelerator (SPCA), cothromboplastin	Extrinsic	Endopeptidase with *gla* residues
VIII	Antihemophiliac factor A, antihemophilic globulin (AHG)	Intrinsic	Protein cofactor
IX	Christmas Factor, antihemophilic factor B,plasma thromboplastin component (PTC)	Intrinsic	Endopeptidase with *gla* residues
X	Stuart-Prower Factor	Both	Endopeptidase with *gla* residues
XI	Plasma thromboplastin antecedent (PTA)	Intrinsic	Endopeptidase
XII	Hageman Factor	Intrinsic	Endopeptidase
XIII	Protransglutaminase, fibrin stabilizing factor (FSF), fibrinoligase	Both	Transpeptidase

Source: http://themedicalbiochemistrypage.org/home.html

Table 5.2 presents the functional classification of clotting factors.

Table 5.2 *Functional Classification of Clotting Factors*

Zymogens of Serine Proteases	**Activities**
Factor XII	Binds to exposed collagen at site of vessel wall injury, activated by high-MW kininogen and kallikrein
Factor XI	Activated by factor XIIa
Factor IX	Activated by factor XIa in presence of Ca^{2+}
Factor VII	Activated by thrombin in presence of Ca^{2+}
Factor X	Activated on surface of activated platelets by tenase complex and by factor VIIa in presence of tissue factor and Ca^{2+}
Factor II	Activated on surface of activated platelets by prothrombinase complex
Cofactors	**Activities**
Factor VIII	Activated by thrombin; factor VIIIa is a cofactor in the activation of factor X by factor IXa
Factor V	Activated by thrombin; factor Va is a cofactor in the activation of prothrombin by factor Xa
Factor III (tissue factor)	A subendothelial cell-surface glycoprotein that acts as a cofactor for factor VII
Fibrinogen	**Activity**
Factor I	Cleaved by thrombin to form fibrin clot
Transglutaminase	**Activity**
Factor XIII	Activated by thrombin in presence of Ca^{2+}; stabilizes fibrin clot by covalent cross-linking
Regulatory/Other Proteins	**Activities**
von Willebrand factor	Associated with subendothelial connective tissue; serves as a bridge between platelet glycoprotein GPIb/IX and collagen
Protein C	Activated to protein Ca by thrombin bound to thrombomodulin; then degrades factors VIIIa and Va
Protein S	Acts as a cofactor of protein C; both proteins contain *gla* residues
Thrombomodulin	Protein on the surface of endothelial cells; binds thrombin, which then activates protein C
Antithrombin III	Most important coagulation inhibitor, controls activities of thrombin, and factors IXa, Xa, XIa and XIIa

Source: http://themedicalbiochemistrypage.org/home.html

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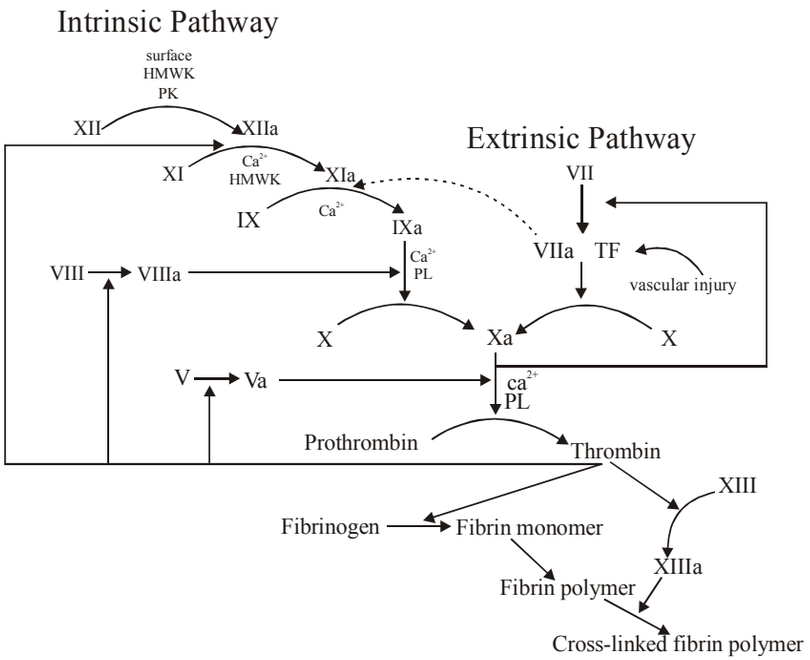

Fig. 5.1 *The Clotting Cascades (HMWK = high molecular weight kininogen. PK = prekallikrein. PL = phospholipid)*

Source: http://themedicalbiochemistrypage.org/home.html

The cascade (which has less in vivo significance in normal physiological circumstances than the extrinsic cascade) is initiated when contact is made between blood and exposed negatively charged surfaces. As shown in Figure 5.1, the extrinsic pathway is initiated upon vascular injury which leads to exposure of tissue factor or TF (also identified as factor III), a subendothelial cell-surface glycoprotein that binds phospholipid. The green dotted arrow represents a point of cross-over between the extrinsic and intrinsic pathways. The two pathways converge at the activation of factor X to Xa. Factor Xa has a role in the further activation of factor VII to VIIa as depicted by the green arrow. Active factor Xa hydrolyzes and activates prothrombin to thrombin. Thrombin can then activate factors XI, VIII and V furthering the cascade. Ultimately, the role of thrombin is to convert fribrinogen to fibrin and to activate factor XIII to XIIIa. Factor XIIIa (also termed transglutaminase) cross-links fibrin polymers solidifying the clot.

5.5.2 The Kallikrein-Kinin System in Coagulation

The Kallikrein-Kinin system or simply kinin system is a poorly delineated system of blood proteins that play a role in inflammation, blood pressure control, coagulation and pain. Bradykinin and kallidin, its important mediators, are vasodilators that act on many cell types. The system consists of a number of large proteins, some small polypeptides and a group of enzymes that activate and deactivate the compounds.

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Proteins: High-molecular-weight kininogen (HMWK) and low-molecular-weight kininogen (LMWK) are precursors of the polypeptides. They have no activity of themselves. HMWK is produced by the liver together with prekallikrein. It acts mainly as a cofactor on coagulation and inflammation, and has no intrinsic catalytic activity. LMWK is produced locally by numerous tissues and secreted together with tissue kallikrein.

Polypeptides: Bradykinin (BK), which acts on the B2 receptor and slightly on B_1, is produced when kallikrein releases it from HMWK. It is a nonapeptide with the amino acid sequence Arg-Pro-Pro-Gly-Phe-Ser-Pro-Phe-Arg. Kallidin (KD) is released from LMWK by the tissue kallikrein. It is a decapeptide. KD has the same amino acid sequence as Bradykinin with the addition of a lysine at the N-terminus. Thus it is sometimes referred to as Lys-Bradykinin. HMWK and LMWK are formed by alternative splicing of the same gene.

Enzymes: Kallikreins (tissue and plasma kallikrein) are serine proteases that liberate kinins (BK and KD) from the kininogens, which are plasma proteins that are converted into vasoactive peptides. Prekallikrein is the precursor of the plasma kallikrein. It can only activate kinins after being activated itself by factor XIIa or other stimuli.

Carboxypeptidases are present in two forms: M and N. N circulates and M is membrane-bound. Carboxypeptidases remove arginine residues at the carboxy-terminus of BK and KD. Angiotensin-converting enzyme (ACE), also termed kininase II, inactivates a number of peptide mediators, including bradykinin.

Defects of the kinin-kallikrein system in diseases are not generally recognized. The system is the subject of much research due to its relationship to the inflammation and blood pressure systems. It is known that kinins are inflammatory mediators that cause dilation of blood vessels and increased vascular permeability. Kinins are small peptides produced from kininogen by kallikrein and are broken down by kininases. They act on phospholipase and increase arachidonic acid release and thus prostaglandin (PGE2) production.

5.5.3 Prothrombin to Thrombin Activation

The activation of factor X to factor Xa is the common point in both pathways. Prothrombin (factor II) to thrombin (factor IIa) is activated by Factor Xa. Thrombin, then, changes fibrinogen into fibrin. The activation of thrombin takes place on the surface of activated platelets and involves the formation of a prothrombinase complex. This complex is made up of platelet phospholipids, phosphatidylinositol and phosphatidylserine, Ca2+, factors Va and Xa, and prothrombin. Factor V is a cofactor in the formation of the prothrombinase complex. This is similar to the role of factor VIII in the formation of tenase complex. Akin to activation of factor VIII, factor V is activated to factor Va in terms of minute amounts. Factor V is inactivated by higher levels of thrombin. Factor Va binds to specific receptors on the surfaces of activated platelets and forms a complex with prothrombin and

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factor Xa. Prothrombin is a 72,000-Dalton, single-chain protein containing ten gla residues in its *N*-terminal region. Within the prothrombinase complex, prothrombin is cleaved at two sites by factor Xa. This cleavage generates a two-chain active thrombin molecule containing an A and a B chain which are held together by a single disulfide bond.

Thrombin also plays a significant role in the regulation of coagulation. It combines with thrombomodulin present on endothelial cell surfaces to form a complex that changes protein C into protein Ca. The cofactor proteins S and Ca degrade factors Va and VIIIa, thereby constricting the activity of these two factors in the coagulation cascade.

5.5.4 Controlling the Thrombin Levels

If the body is unable to control the level of active thrombin circulating in the body, it would lead to dreadful consequences. Thrombin activity can be regulated by two main mechanisms. The inactive prothrombin is the predominant form of thrombin in circulation, and its activation needs the pathways of proenzyme activation for the coagulation cascade. At each step in the cascade, feedback mechanisms control the balance between active and inactive enzymes.

The activation of thrombin is also regulated by four specific thrombin inhibitors, of which antithrombin III is the most important because it inhibits the activities of factors IXa, Xa, XIa and XIIa. Antithrombin III activity is potentiated due to heparin by the following means:

- Heparin binds to a specific site on antithrombin III. This produces an altered conformation of the protein, and the new conformation has a higher affinity for thrombin as well as its other substrates.
- This effect of heparin lays the foundation for its clinical role as an anticoagulant.
- Heparan and heparan sulfate are the naturally occurring heparin activators of antithrombin III. These are present on the surface of vessel endothelial cells and they controls the activation of the intrinsic coagulation cascade.

Thrombin activity is also inhibited by the following: α_2-macroglobulin, heparin cofactor II and α_1-antitrypsin. Although a minor player in thrombin regulation α_1-antitrypsin is the primary serine protease inhibitor of human plasma. Its physiological significance is that the lack of this protein plays a causative role in the development of emphysema.

5.5.5 Fibrinogen to Fibrin Activation

Three pairs of polypeptides, that is, $([A\alpha][B\beta][\gamma])_2$, make up fibrinogen (factor I). Disulfide bonds covalently link the six chains near their *N*-terminals. The A and B portions of the Aα and Bβ chains comprise the fibrinopeptides, respectively. In fibrinogens, the fibrinopeptide regions include several glutamate and aspartate

residues that give away a high negative charge to this region and help in the solubility of fibrinogen in plasma. Active thrombin is a serine protease that hydrolyses fibrinogen at four arg-gly (R-G) bonds between the fibrinopeptide and the **a** and **b** portions of the protein.

Fibrin monomers with a subunit structure $(\alpha\beta\gamma)_2$ are created when thrombin-mediated release of the fibrinopeptides is done. These monomers spontaneously aggregate in a regular array, forming a somewhat weak fibrin clot. In addition to fibrin activation, thrombin converts factor XIII to factor XIIIa, which is a highly specific transglutaminase. This transglutaminase introduces cross-links made of covalent bonds between the amide nitrogen of glutamines and α-amino group of lysines in the fibrin monomers.

5.5.6 Tests and Interpretations Related to Blood Coagulation

In order to evaluate vascular and platelet responses associated with haemostasis, bleeding time assays are used. Bleeding time is a common assay that is done on preoperative patients to make sure there is ample response to vessel injury prior to surgery. Vessel constriction and platelet adhesion to the vessel wall are rapid responses to vascular injury (occurring within seconds).

The Ivy method is used to calculate the bleeding time. It involves using a sphygmomanometer (blood pressure cuff), which is placed on the forearm and inflated to 40 mm Hg. A superficial incision is made on the forearm and the time needed for bleeding to stop is noted. Bleeding can be ceased within 1 to 9 minutes using the Ivy method. Bleeding time more than 15 minutes indicates that there is a problem in the initial responses of vessels and platelets to vascular injury. Lancets or special needles can be used for less invasive incisions. A 3- to 4-mm deep prick is made on the fingertip or earlobe and the bleeding time assay is referred to as the Duke method. In this assay, bleeding should stop within 1 to 3 minutes. These assays determine that bleeding time can be prolonged because of defects in functioning of platelets or vascular disorders, if any.

Any kind of defects or problems related to pathways of blood coagulation factors can also be tested with specific assays. Prothrombin time (PT) assay detects defects in fibrinogen, prothrombin and factors V, VII and X. It evaluates functioning of the extrinsic pathway of coagulation. When there are any problems in these factors, the PT is affected. A normal PT lasts for 11.0–12.5 seconds. A PT that lasts for longer than 20 seconds indicates coagulation deficit. After the blood cells are removed, PT is measured using plasma. The process involves collection of a blood sample in a tube that contains citrate or EDTA to chelate calcium and inhibit coagulation. The cells are then removed by centrifugation. After this, excess calcium is added to the plasma to begin the process of coagulation. PT is most commonly measured by dividing the time of coagulation of a patient's blood with a known standard. The value derived is the international normalized ratio (INR). Normal INR values range from 0.8 to 1.2. The role of PT is to verify the correct dosage of

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warfarin drugs (Coumadin), to determine the presence of liver disease or damage and evaluate the status of vitamin K.

Partial thromboplastin time (PTT) is an assay used to check for defects in the intrinsic pathway of coagulation. Activators that lessen the normal clotting time have been used to modify the PTT assay, which is referred to as activated partial thromboplastin time (aPTT).

PTT is usually approved for patients who go through bleeding or clotting of unknown causes. This assay evaluates the function of fibrinogen; prothrombin and factors V, VIII, IX, X, XI and XII. Defects in these factors lead to an affected PTT (or aPTT). The duration of a normal PTT is 60–70 seconds, while that for an aPTT is 30–40 seconds. The PTT is a standard assay used to assess the efficacy of heparin anticoagulant therapy. Acquired or congenital bleeding disorders associated with coagulation factor deficiency, vitamin K related deficiencies and liver diseases are associated with affected PTTs.

Check Your Progress

4. What does the term serum refer to?
5. What is the opposite process of haemostasis?
6. What does the kallikrein-kinin system comprise?

5.6 RED BLOOD CELLS (RBCs): MORPHOLOGY, FUNCTIONS AND DEVELOPMENT

The role of red blood cells is to transport oxygen and nutrition to all the cells and tissues in the body. Any failure on their part would mean slow death for the body. These blood cells derive their red colour from a protein chemical called haemoglobin, which has a bright red colour. Haemoglobin contains iron, which makes it an appropriate vehicle to provide oxygen and take away carbon dioxide from the body. The oxygen molecules in the blood attach to the haemoglobin and are released into the cells as the blood passes through. Subsequently, the empty haemoglobin molecules bond with the carbon dioxide and other waste gases, in the tissues and take them away. Red blood cells eventually die; the average life cycle of a red blood cell is 120 days. These are gradually replenished with new red blood cells manufactured in the bone marrow.

Erythropoiesis refers to the production of red blood cells in the body. Mature red blood cells develop from haemocytoblasts. This process takes about 7 days and involves three to four mitotic cell divisions, such that each stem cell gives eight or sixteen cells. The various cell types have the characteristic gradual appearance of haemoglobin and disappearance of ribonucleic acid (RNA) in the cell; the progressive degeneration of the cell's nucleus, which is eventually extruded from

the cell; the gradual loss of cytoplasmic organelles, such as mitochondria; and the gradual reduction in cell size.

The blood circulating in our body is being continuously replenished and that is why it is absolutely safe for healthy adults to donate blood. This blood is stored by hospitals and blood banks under controlled environments to be used in emergency situations. Initially after donating blood, the donor may feel lightheaded momentarily. This is because of the loss of oxygen-rich red blood cells and blood sugar. However, this condition gets stabilized soon enough by administering liquids and sugar supplements.

Young red cells are known as reticulocytes because of a network of reticulum (RNA) in their cytoplasm. As these cells mature, the reticulum disappears. A newborn baby has between 2 and 6 per cent reticulocytes, which comes down to less than 2 per cent in a healthy adult. However, the reticulocyte count goes up substantially in cases of rapid erythropoiesis. For example, the reticulocyte count goes up following haemorrhage or acute haemolysis of red cells. Reticulocytes normally take about 4 days to mature into erythrocytes. Erythropoiesis is regulated in a healthy person such that the number of circulating erythrocytes is controlled within a narrow range. Usually, slightly less than 1 per cent of the body's total red blood cells are produced in a day and these replace the same number of cells that have/are going to die. This number still represents approximately 200,000,000,000 cells!

Hypoxia (lack of oxygen) stimulates the condition of erythropoiesis. But, hypoxia does not affect haemopoietic tissues directly but stimulates the production of erythropoietin, a hormone. Erythropoietin then stimulates haemopoietic tissues to produce red cells. Erythropoietin is a glycoprotein, which is inactivated by the liver and excreted through urine. Erythropoietin is produced in the kidneys by a renal erythropoietic factor called erythrogenin on erythropoietinogen, a plasma protein. The juxtaglomerular cells of the kidneys have erythrogenin, which is released into the blood when there is lack of oxygen in the renal arterial blood supply.

Following listed factors affect the erythropoiesis rate by manipulating erythropoietin production. These factors are discussed as follows:

- Thyroid hormones (TH), thyroid-stimulating hormone (TSH), adrenal cortical steroids, adrenocorticotrophic hormone (ACTH) and human growth hormone (HGH) all promote erythropoietin formation and so enhance red blood cell formation (erythropoiesis). In thyroid deficiency and anterior pituitary deficiency, anaemia may occur due to reduced erythropoiesis.
- Polycythaemia (excess red blood cell production) is often a feature of Cushing's syndrome. However, very high doses of steroid hormones seem to inhibit erythropoiesis.
- Androgens (male hormones) stimulate and oestrogens (female hormones) depress the erythropoietic response. In addition to the effects of menstrual

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blood loss, this effect may explain why women tend to have a lower haemoglobin concentration and red cell count than men.

- Plasma levels of erythropoietin are raised in hypoxic conditions (low oxygen levels). This produces erythrocytosis (increase in the number of circulating erythrocytes) and the condition is known as secondary polycythaemia.
- A physiological secondary polycythaemia is present in the foetus (and residually in the new-born) and in people living at high altitude because of the relatively low partial pressure of oxygen in their environment.
- Secondary polycythaemia occurs as a result of tissue hypoxia in diseases such as chronic bronchitis, emphysema and congestive cardiovascular abnormalities associated with right-to-left shunting of blood through the heart, for example Fallot's tetralogy.
- Erythropoietin is also produced by a variety of tumours of both renal and other tissues.
- The oxygen carrying capacity of the blood is increased in polycythaemia but so is the thickness (viscosity) of the blood. The increased viscosity produces circulatory problems such as raised blood pressure.
- There is a condition known as primary polycythaemia (polycythaemia rubra vera), in which there are increases in the numbers of all the blood cells, and plasma erythropoietin levels are normal. The cause of this condition is unknown.The underlying cause of secondary polycythaemia is treated with the aim of eliminating hypoxia. Venesection (blood letting) is sometimes employed to reduce red cell volume to normal levels. Blood is frequently removed, centrifuged to remove cells and the plasma returned to the patient (plasmapheresis).
- In anaemia, there is a reduction in blood haemoglobin concentration due to a decrease in the number of circulating erythrocytes and/or in the amount of haemoglobin they contain. Anaemia occurs when the erythropoietic tissues cannot supply enough normal erythrocytes to the circulation. In anaemias due to abnormal red cell production, increased destruction and when demand exceeds capacity, plasma erythropoietin levels are increased. However, anaemia can also be caused by defective production of erythropoietin as, for example, in renal disease. You will learn more about anaemia in the following section.

5.6.1 Erythrocyte (Red Blood Cell) Differentiation

In the process involving the formation of red blood cell, a cell undergoes a number of stages during differentiation and development. The development of red blood cells is completed in the following seven stages:

1. **Haemocytoblast stage**: A haemocytoblast refers to a pluripotent hematopoietic stem cell.

2. **Common myloid progenitor multipotent stem cell stage:** The hematopoietic tissue contains cells with long-term and short-term regeneration capacities and committed multipotent, oligopotent, and unipotent progenitors.
3. **Unipotent stem cell stage:** Unipotent stem cells arise from multipotent cells.
4. **Pronormoblast stage: A pronormoblast is** also usually referred to as a proerythroblast or rubriblast.
5. **Basophilic normoblast/early normoblast stage:** The_basophilic normoblast is also usually called erythroblast.
6. **Polychromatophilic normoblast/intermediate normoblast stage:** Polychromatophilic normoblasts are formed by extrusion of orthocromatic normoblast nuclei.
7. **Orthochromatic normoblast/late normoblast stage**: In this stage, the nucleus is expelled before becoming a reticulocyte.

The cell is released from the bone marrow after stage 7, and so of circulating red blood cells there are ~1 per cent reticulocytes. After 1–2 days these ultimately become 'erythrocytes' or mature red blood cells.

Figure 5.2 shows the lineage of blood cells during the differentiation of erythrocytes.

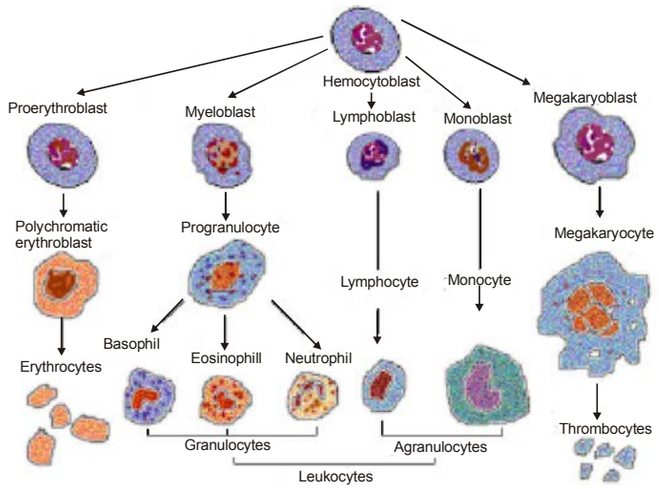

Fig. 5.2 *Blood Cell Lineage during Erythrocyte Differentiation*

Characteristics seen in red blood cells during erythropoiesis

The following characteristics can be seen changing in the red blood cells during their maturation:

- There is a reduction in the cell size.
- There is an increase in the amount of cytoplasmic matrix.

- There is a change in staining reaction of the cytoplasm from basophilic to acidophilic.

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5.7 HAEMOGLOBIN AND ANAEMIA

Haemoglobin is a metalloprotein that contains iron and transports oxygen to the cells and tissues. The term 'haemoglobin' is derived from the terms 'haeme' and 'globin'. This proves that each subunit of haemoglobin is a globular protein with an embedded haeme group. In adult humans, haemoglobin is a tetramer, which means it contains four subunit proteins called haemoglobin A. This consists of two subunits each, alpha and beta, bound non-covalently, denoted as $á_2â_2$. These subunits are similar structure wise and have about the same size. The haeme group has an iron atom in a heterocyclic ring, known as a porphyrin. The iron atom is the site where the oxygen binds and equally to all four nitrogens in the center of the ring. These four nitrogens are placed in one plane. Oxygen is then able to bind to the iron centre perpendicular to the plane of the porphyrin ring. Thus, a lowered level of haemoglobin, with or without the absolute decrease in red blood cells, leads to anemia. There are different causes of anemia, but deficiency of iron is the most common cause. Gene mutations for the haemoglobin protein result in haemoglobinopathies, a group of hereditary diseases.

Both the structures of tertiary and quaternary proteins are exhibited in the characteristics of haemoglobin. Mostly, amino acids present in the haemoglobin form alpha-helices. These are connected by short non-helical segments. Hydrogen bonds stabilize the helical sections inside this protein, causing attractions within the molecule. This folds each polypeptide chain into a specific shape. The quaternary structure of haemoglobin is derived from its four subunits in an approximate tetrahedral arrangement.

In most humans, haemoglobin molecules are an arrangement of four globular protein subunits, where each subunit is a chain of proteins tightly associated with a non-protein haeme group. Each protein chain arranges into a set of alpha helix structural segments. These are connected together in a globin-fold arrangement. This is so called because the arrangement is the same folding motif used in other haeme/globin proteins, such as myoglobins This folding pattern contains a pocket that strongly binds the haeme group.

In anaemia, the level of haemoglobin in the blood goes below a certain level. This leads to a decreased capacity to carry oxygen by red blood cells. This means, anaemia is a bodily condition in which the blood does not have adequate number of red blood cells to sustain the body's need for oxygen. Most cases of anaemia are caused by a lack of iron; other common causes of anaemia are malaria, schistosomiasis and genetic factors, which lead to thalassaemia and sickle cell disease. In its severe form, the symptoms of anaemia are fatigue, weakness, dizziness and drowsiness. Especially vulnerable are pregnant and lactating women and children. Anaemia has several types and classifications and understanding

these helps in identifying the symptoms and avoiding it in the first place. The various categories of anaemia are discussed as follows:

1. Iron deficiency anaemia

The most common type of anaemia is caused by deficiency of iron. It is also known as sideropenic anemia. This form of anaemia is common in adolescents and pre-menopausal women. Blood loss caused by heavy menstruation, internal bleeding due to disorders of the gastrointestinal tract or excessive donation of blood can lead to this disease. Other causes are poor dietary habits or chronic intestinal diseases.

Signs and symptoms

Iron deficiency anemia is characterized by pallor (reduction in oxygen-rich haemoglobin in skin or mucous membrane), fatigue and weakness. Dyspnea (trouble in breathing) can also occur in severe cases. Hair loss and lightheadedness are also associated with iron deficiency anemia. Other symptoms and signs of iron deficiency anemia include constipation; sleepiness; tinnitus; palpitations; hair loss; fainting spells; depression; breathlessness on exertion; twitching of muscles; tingling, numbness,or burning sensations; missed menstrual cycles, heavy menstrual flow; slow social development; glossitis (inflammation or infection of the tongue); angular cheilitis (inflammatory lesions at the mouth's corners); koilonychias; poor appetite; pruritus and dysphagia due to formation of esophageal webs (Plummer–Vinson syndrome).

2. Folic acid deficiency anaemia

Folic acid deficiency anaemia is caused by a lack of folic acid in the blood. Folic acid deficiency is caused by an inadequate consumption of folic acid, which is usually found in vegetables and destroyed when vegetables are overcooked. Excessive consumption of alcohol also leads to folic acid deficiency. During pregnancy, when the need for folic acid is increased, or in infancy, such anaemia can also be seen. Folic acid deficiency can also be caused as a side effect of blood disorders.

Signs and symptoms

Symptoms of the disorder include weakness, fatigue, memory lapses and irritability.

3. Pernicious anaemia

Pernicious anaemia usually affects people between 50 and 60 years. It is caused by a lack of vitamin B_{12}. This is a hereditary form of anaemia, but some forms of this condition can be autoimmune. This means those people who have autoimmune diseases can be prone to this type of anaemia.

Signs and symptoms

Symptoms of pernicious anaemia may include fatigue, dyspnea, heart palpitations and numbness or tingling in extremities.

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4. Aplastic anaemia

Aplastic anaemia is caused when there are no or less red blood cells in the body. This happens when there is some injury in the bone marrow, due to which the production of red blood cells is hampered. In aplastic anemia, the person is not able to fight infection and can bleed heavily in case of any injury.

Signs and symptoms

Symptoms include lethargy, paleness, purpura, bleeding, rapid heartbeat, infections and congestive heart failure. However, there are no definite known causes of this anaemia. It is considered to be caused by exposure to certain toxins and the hepatitis virus.

5. Sickle cell anaemia

Sickle cell anaemia is a hereditary disease and is caused by abnormal red blood cells. It is a life-threatening disease and the only solution is to go for regular blood transfusions.

Signs and symptoms

Symptoms of this condition include extreme pain in the arms, legs and stomach; jaundice; fever; chronic fatigue; rapid heartbeat and paleness. Also, this disease can cause leg ulcers, shocks, cerebral haemorrhages and orthopedic disorders.

6. Polycythemia vera

Polycythemia vera is common in middle-aged men and is characterized by an increase in the number of red blood cells, leucocytes and thrombocytes. The cells reproduce very quickly and intensely and the bone marrow cells mature more rapidly than required.

Signs and symptoms

The most common signs and symptoms of polycythemia vera are headache, dizziness, weakness, shortness of breath and problems breathing while lying down, feeling of pressure or fullness on the left side of the abdomen due to an enlarged spleen, blurred vision and blind spots, itching, bleeding from gums and heavy bleeding from small cuts, sudden and unexplained weight loss and fatigue. In rare cases, people who have polycythemia vera may also have pain in their bones.

Check Your Progress

7. Why are red blood cells red in colour?
8. What is anaemia?
9. List the various categories of anaemia.

5.8 WHITE BLOOD CELLS (WBCs): CLASSIFICATION, DEVELOPMENT AND FUNCTIONS

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The role of leukocytes is to take care of the defense mechanism of a body. They are much less in number than the red blood cells. Their density in the blood is 5000-7000/mm3. Leukocytes can be divided into two categories: granulocytes or agranulocytes (lymphoid cells). Granulocytes are so called because of the presence of granules in the cytoplasm of cells. These granules have different affinities for neutral, acidic or basic stains and give the cytoplasm its various colours. Granulocytes distinguish themselves in neutrophils, eosinophils (or acidophil) and basophils. The lymphoid cells, however, distinguish themselves in lymphocytes and monocytes.

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

- **Neutrophil:** 50–70percent
- **Eosinophil**: 2– 4percent
- **Basophil:** 0.5–1percent
- **Lymphocyte:** 20– 40percent
- **Monocyte:** 3–8 per cent

Let us discuss the various types of leukocytes in detail.

1. Neutrophils

Neutrophils are very active in phagocyting bacteria and are present in large amount in the pus of wounds. Unfortunately, these cells are not able to renew the lysosomes used in digesting microbes and dead after having phagocyted a few of them.

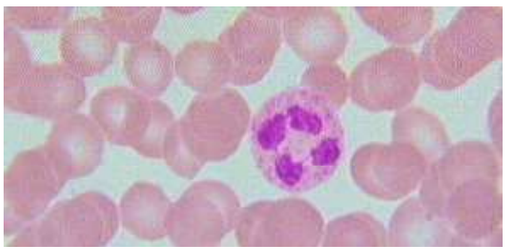

Fig. 5.3 *Neutrophil*

2. Eosinophils

Eosinophils attack parasites and phagocyte antigen–antibody complexes.

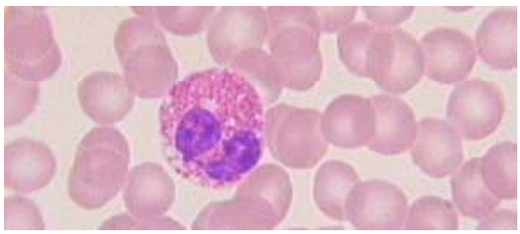

Fig. 5.4 *Eosinophil*

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3. Basophils

Basophils secrete anti-coagulant and vasodilatory substances as histamines and serotonin. Even if they have a phagocytory capability, their main function is secreting substances which mediate the hypersensitivity reaction.

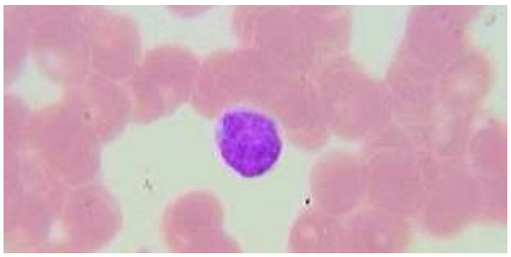

Fig. 5.5 *Basophil*

4. Lymphocytes

Lymphocytes are types of white blood cells that are found in the lymphoid tissues and organs and the lymph circulating in the lymphatic vessel. Lymphoid organs include the thymus, bone marrow, spleen, lymphoid nodules, palatine tonsils, Peyer's patches and lymphoid tissues of respiratory and gastrointestinal tracts. Most lymphocytes that are circulating in the blood lie in a dormant state. These are little cells with a compact, round nucleus, which occupies nearly the entire cellular volume. The lymphocytes present in the lymphoid tissues and organs can be activated in various amounts following antigenic stimulation. Lymphocytes comprise 20-40 per cent of all leukocytes and are slightly bigger than red blood cells.

Lymphocytes constitute the main part in the immune system in attacks against microorganisms such as viruses, bacteria and fungi. They produce antibodies, which are molecules able to bind themselves to antigens. As for all proteins, even the antibodies are coded according to genes. Every lymphocyte produces antibodies of a specific shape based on a recombination mechanism in some genes.

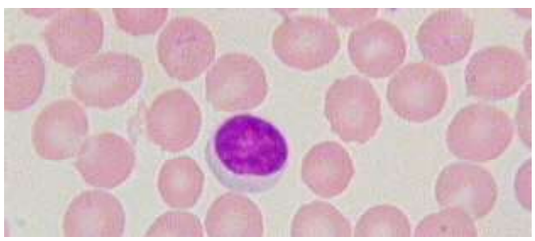

Fig. 5.6 *Lymphocyte*

Therefore, lymphocytes perform specific actions such that each of them recognizes only the complementary antigen. Every lymphocyte acts selectively and is able to recognize only one molecule, and the number of circulating lymphocytes is so high such that they are able to identify practically all substances in the organism. The cells of the immune system, mainly lymphocytes, act amongst themselves to

activate, boost or constitute a more precise immune response. To achieve this aim, different types of lymphocytes exist with different functions. The main types of lymphocytes are T and B lymphocytes. When the B cells are activated, they breed quickly (clonal selection) and become plasma cells that secrete several antibodies in the blood stream (humoral response). When free antibodies meet microorganisms with complementary shapes (epitopes), they bind to them and form complexes that immobilize the microorganisms.

Tc (cytotoxic), Th (helpers) and Ts (suppressors) are the three types of T cells. Cytotoxic lymphocytes breed quickly when they are activated and do not release antibodies in the blood stream. However, the antibodies are kept on their membrane and used to identify cells infected by viruses or tumours. Cytotoxic lymphocytes eliminate cells by releasing perforins, which are substances that produce lesions in the target cell's membrane and cause its death by osmotic lysis. Helper lymphocytes activate both B and Tc lymphocytes which, though are able to recognize extraneous agents, seldom get into direct action. Suppressor lymphocytes lessen the intensity of the immune response.

The immune system does not attack its own cells as the autoimmune reaction can damage and eliminate the organism. B and Tc lymphocytes have identified an antigen that does not get into action, but needs to be activated by a helper lymphocyte. Some of the new lymphocytes pass through the thymus where they become T lymphocytes. Here, they are compared with all auto-antigens (antigens of the organism). As the auto-reactive Th lymphocytes are eliminated, only B and Tc lymphocytes that have recognized extraneous antigens can be activated. The system of cellular cytotoxicity mediated by Th cells is evolved as a defense against their own infected, modified or aberrant cells. In fact, B and Tc lymphocytes can get activated against bacteria even without the cooperation of helpers.

Activated B and Tc lymphocytes not only produce antibodies and kill foreign cells, but also multiply quickly. During the process of division of cells, there are often rearrangements in the sequence of the genes that are codes for the antibody. This way the antibody of the new cell gets a somewhat different shape as compared with its 'mitotic parent'. If the shape of the new cell matches the antigen better, this cell will divide further. The subsequent generation of clones has thus increased efficiency and can bring on more selective varieties. This clonal selection makes the immune response more effective. Finally, the immune system produces memory cells, that is, deactivated lymphocytes are ready to be reactivated on the occasion of further meeting with the same antigen.

Apart from the Th and B cells, there is a third population of lymphocytes, which have a non-specific defense function not activated by Th lymphocytes, in the peripheral blood and lymphoid organs. These do not have receptors for antigens. These cells represent the older component of the immune system and are characterized by the cytotoxic activity. Hence, these cells are called natural killers

(NKs). Apart from killing viruses, bacteria, infected and neoplastic cells, these lymphocytes also control the production of erythrocytes and granulocytes.

5. Monocytes

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The precursors of macrophages are monocytes. Macrophages are larger blood cells that after becoming mature in the bone marrow enter the blood where they live for 24-36 hours. Monocytes become macrophages after they migrate into the connective tissue and move within the tissues. Monocytes quickly migrate from the blood vessel in the presence of an inflammation site and start an intense phagocytory activity. The role of monocytes is not solely confined to phagocytosis; they also have an intense secretory activity. Monocytes produce substances such as lysozime, interferons and other substances that alter the functionality of other cells. Macrophages also have a role to play in the defense of the immune system. Monocytes also expose molecules of digested bodies on the membrane and present them to B and Th lymphocytes.

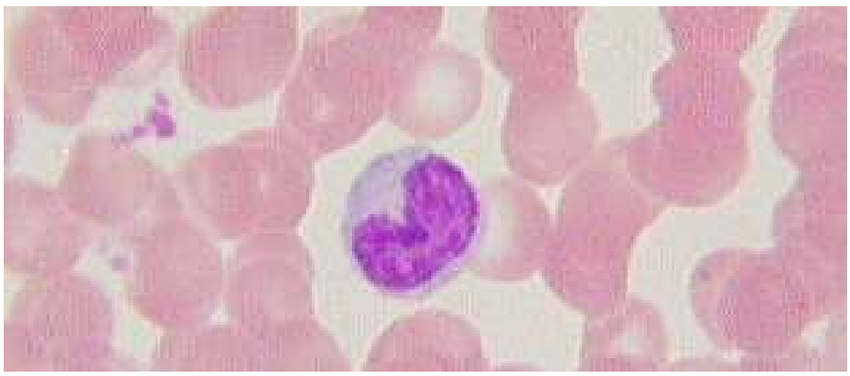

Fig. 5.7 *Monocyte*

The bone marrow is where monocytes are produced, where they develop from nucleated precursors, that is monoblasts and promonocytes. Mature monocytes have a lifespan of approximately 3–8 hours. Monocytes engulf other cells, that is, they are actively phagocytic. On migration into tissues, they mature into larger cells called macrophages (the term is derived from the Greek term, where *macro* means big and *phage* means eat), which can survive for long periods in the tissues. These cells form the mononuclear phagocytic cells of the reticuloendothelial system in the bone marrow, liver, spleen and lymph nodes. Tissue macrophages (also called histiocytes) have slower response than neutrophils to chemotactic stimuli. They eliminate bacteria, protozoa, dead cells and foreign matter from the body. They also modulate the immune response by processing the structure of antigens and facilitating antigen concentration at the lymphocyte's surface. This function is essential such that full antigenic stimulation of T and B lymphocytes can take place.

Figure 5.8 shows the process of macrophage formation.

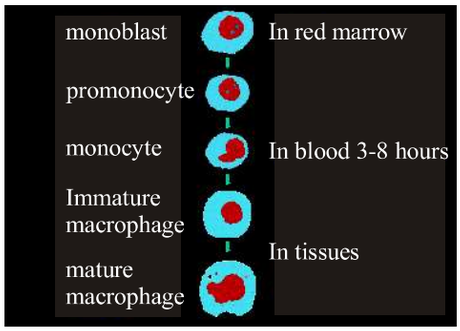

Fig. 5.8 *Process of Macrophage Formation*

Production of granulocytes

Neutrophils, basophils and eosinophils are the three types of white blood cells that make up the term 'granulocyte'. In terms of their formation through granulopoiesis, they all are derived from the same type of myeloblasts (committed stem cells). Granulopoiesis takes place in the red marrow after birth and through adulthood. The process of producing granulocytes is characterized by the progressive condensation and lobulation of the nucleus, loss of RNA and other cytoplasmic organelles and the development of cytoplasmic granules in the cells involved.

Developing of a polymorphonuclear leukocyte may take as much as 15 days, but this time can be reduced when there is an increased demand, for instance during bacterial infection. Mature cells pass actively through the endothelial lining of the marrow sinusoid into the circulation. In the circulation, about half the granulocytes adhere closely to the internal surface of the blood vessels. These are called marginating cells and are not normally included in the white cell count. The other half circulate in the blood and exchange with the marginating population.

Within 7 hours, half the granulocytes will be ready for action in response to certain requirements for these cells in the tissues. A granulocyte that has left the blood does not return and may survive in the tissues for 4–5 days or less, depending on the conditions it meets. Granulocytes, thus, have a very high turnover. Dead cells are eliminated from the body through urine, excreta and respiration and eliminated by tissue macrophages (monocytes). There are no precise mechanisms used to control granulocyte production so far. But, in a healthy body, the count stays more or less constant and that is why it is possible that homeostatic control mechanisms operate.

5.9 PLATELETS: MORPHOLOGY AND FUNCTIONS

Platelets (or thrombocytes) stop blood loss in wounds (haemostasis) by aggregating and releasing factors that facilitate the coagulation of blood. This includes use of serotonin, which brings down the diameter of vessels that have lesions and slows

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down the haematic flux, and fibrin, which traps cells and encourages blood to clot. Although the platelets appear round, they are not real cells. In the Giemsa smears, platelets have an intense purple colour. Their diameter is approximately 2–3 micrometer; thus making them much smaller than erythrocytes. Their density in the blood is 200000–300000 /mm3.

Thrombopoiesis is the process by which platelets are produced in the bone marrow. Platelets are formed in the cytoplasm of very large cells, also known as megakaryocytes. The cytoplasm of megakaryocytes fragments at the edge of the cell, known as platelet budding. Megakaryocytes mature from a large stem cell, in approximately 10 days, also known as megakaryoblasts.

The possibility exists that there are mechanisms of thrombopoietic feedback as the platelet count stays fairly steady in a healthy individual, whereas the platelet count reduces after platelets are infused and increased after platelets are removed. However, these mechanisms of feedback have not been discovered yet. At any given time, approximately two-thirds of the body's platelets circulate in the blood and one-third is pooled in the spleen. There is constant exchange between the two populations. The lifespan of platelets is between 8 and 12 days. Platelets are destroyed by macrophages, chiefly in the spleen and the liver.

Check Your Progress

10. Name the two categories of leukocytes.
11. What are lymphocytes?
12. What is the process of producing granulocytes characterized by?

5.10 BLOOD GROUPS, BLOOD TRANSFUSION AND TRANSFUSION REACTIONS

Blood can be classified as follows: There are two blood groups, namely, AB0 and Rh (rhesus). According to the AB0 group, there are four blood groups, namely, A, B, AB, O (null). Some people also have an Rh factor on the surface of red blood cells, also an antigen, and those who have it are called Rh-positive and those who do not are called Rh-negative.

While donating blood, one must keep in mind the blood group of the person and the type of blood that matches to it. Blood transfusion is successful if a person who is going to receive blood has a blood group that does not have antibodies against the donor blood's antigens. However, if a person who is going to receive blood has antibodies that match with the donor blood's antigens, it will lead to clumping of the red blood cells of the donated blood.

It must also be noted that people with blood group 0 Rh are considered 'universal donors' and people with blood group AB Rh-positive are known as 'universal receivers'. Rh-positive blood cannot be given to someone with Rh-negative blood, but it works the other way. 0 Rh-positive blood cannot be given to someone with the blood type AB Rh-negative.

5.10.1 Blood Groups

For several hundred years, experiments have been carried out with relation to blood transfusions and transfer of blood components, leading to the death of several patients. It was not until 1901, when Karl Landsteiner discovered blood groups in human beings and the process of blood transfusion became safe.

Blood clumping, or agglutination, takes place when blood from two individuals is unsuccessfully mixed. Clumped red cells can lead to toxic reactions and lead to lethal consequences. Landsteiner discovered that blood clumping is an immunological reaction that occured when, during a blood transfusion, the receiver's antibodies react against the donor's blood cells. His work made it possible to decide upon blood groups and led the way to blood transfusions being carried out safely. He was awarded the Nobel Prize in Physiology in 1930 for his work.

Types of blood groups

Differences in human blood exist due to the presence or absence of antigens and antibodies. Antigens are located on the surface of red blood cells and antibodies are present in blood plasma. Various individuals have different combinations and types of antigens and antibodies. The blood group of a person depends on what has been inherited from the parents and grandparents. More than twenty blood group systems are known today, but the AB0 and Rh systems are the ones to reckon with in terms of blood transfusions. It must be noted that not all blood groups are compatible with each other and mixing incompatible blood groups leads to agglutination.

ABO blood grouping system: There are four different kinds of blood groups: A, B, AB or 0 (null), according to the ABO blood group system.

- **Blood group A:** Those who have blood group A have group A antigens on the surface of their red blood cells and B antibodies in their blood plasma.
- **Blood group B:** Those who have blood group B have B antigens on the surface of their red blood cells and A antibodies in their blood plasma.
- **Blood group AB:** Those who have blood group AB have both A and B antigens on the surface of their red blood cells but do not have either A or B antibodies in their blood plasma.
- **Blood group O**: Those who have blood group O (null) have neither A or B antigens on the surface of their red blood cells but have both A and B antibodies in their blood plasma.

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Rh factor blood grouping system

Some people also have an Rh factor on the surface of red blood cells, also an antigen, and those who have it are called Rh-positive and those who do not are called Rh-negative. Those who have Rh-negative blood do not have Rh antibodies naturally in the blood plasma (since one can have A or B antibodies). But those with Rh-negative blood can develop Rh antibodies in the blood plasma if they receive Rh-positive blood, because their Rh antigens can trigger the production of Rh antibodies. Those with Rh-positive blood can receive Rh-negative blood without any problems.

Blood group notation

According to the ABO and Rh blood grouping systems, you can belong to either of following 8 blood groups:

A Rh+	B Rh+	AB Rh+	O Rh+
A Rh-	B Rh-	AB Rh-	O Rh-

Identification of blood groups

If you want to identify the blood group of an individual, you need to do the following:

- You mix the blood with three different reagents including either of the three different antibodies, A, B or Rh antibodies.
- Then you take a look at what has happened. In which mixtures has agglutination occurred? The agglutination indicates that the blood has reacted with a certain antibody and therefore is not compatible with blood containing that kind of antibody. If the blood does not agglutinate, it indicates that the blood does not have the antigens binding the special antibody in the reagent.
- If you know which antigens are in the person's blood, it's easy to figure out which blood group he or she belongs to.

A person with A+ blood receives B+ blood. The B antibodies (yellow) in the A+ blood attack the foreign red blood cells by binding to them. The B antibodies in the A+ blood bind the antigens in the B+ blood and agglutination occurs. This is dangerous because the agglutinated red blood cells break after a while and their contents leak out and become toxic.

5.10.2 Blood Transfusions

Blood with O Rh– group type can be donated to people with all other blood groups and individuals with this blood group are known as 'universal donors'. On the other hand, the AB Rh+ blood group can receive blood from all other groups and people with this blood group are known as 'universal receivers'. It is important to note that the Rh+ blood can never be given to someone with Rh – blood even though the opposite is possible.

However, it is always possible to give A blood to people with blood group A, B to a person with blood group B and so on. In certain cases, you can receive blood from another blood group or donate blood to a person with a different blood group.

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The transfusion works if the receiver has a blood group type that doesn't have any antibodies against the donor blood's antigens but if the receiver has antibodies that match the donor blood's antigens, the red blood cells present in the donated blood will form a cluster.

For a blood transfusion to be successful, ABO and Rh blood groups must be compatible between the donor blood and the patient blood. If they are not, the red blood cells from the donated blood will clump or agglutinate. The agglutinated red cells can clog blood vessels and stop the circulation of the blood to various parts of the body. The agglutinated red blood cells also crack and its contents leak out in the body. The red blood cells contain haemoglobin which becomes toxic when outside the cell. This can have fatal consequences for the patient.

The A antigen and the A antibodies can bind to each other in the same way that the B antigens can bind to the B antibodies. This is what would happen if, for instance, a B blood person receives blood from an A blood person. The red blood cells will be linked together, like bunches of grapes, by the antibodies. As mentioned earlier, this clumping could lead to death.

5.10.3 Blood Transfusion Reaction

In terms of medical sciences, a transfusion reaction is any adverse event that occurs due to a blood transfusion. These events can take the form of an allergic reaction, a transfusion-related infection, hemolysis related to an incompatible blood type or an alteration of the immune system related to the transfusion. The risk of a transfusion reaction must always be balanced against the anticipated benefit of a blood transfusion.

Table 5.3 *Types of Transfusion Reactions*

Name	Description
Febrile non-hemolytic transfusion reaction	Symptoms include fever and dyspnea. Such reactions are clinically benign, causing no lasting side effects or problems, but are unpleasant.
Bacterial infection	Blood products can provide an excellent medium for bacterial growth, and can become contaminated after collection while they are being stored. The risk is highest with platelet transfusion.
Viral infection	Hepatitis B, Hepatitis C, HIV
Acute hemolytic reaction	It results from rapid destruction (hemolysis) of the donor red blood cells by host antibodies, usually related to ABO blood group incompatibility.
Anaphylactic reactions	These reactions are most common in people with selective IgA deficiency (although IgA deficiency is often asymptomatic, and people may not know they have it until an anaphylactic reaction occurs).

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Transfusion-associated acute lung injury (TRALI)	TRALI is a syndrome of acute respiratory distress, often associated with fever, non-cardiogenic pulmonary edema, and hypotension. Symptoms can range from mild to life-threatening.
Volume overload	Patients with impaired cardiac function can become volume-overloaded as a result of blood transfusion, leading to edema, dyspnea and orthopnea. This is sometimes called TACO, or Transfusion associated circulatory overload.
Iron overload	Since elimination pathways for iron are limited, a person receiving numerous red blood cell transfusions can develop iron overload, which can in turn damage the liver, heart, kidneys, and pancreas.
Delayed hemolytic reaction	Varying from sub-clinical reaction, to severe life-threatening reaction. Features include fever, lower than expected blood haemoglobin concentration with associated jaundice and urobilinogenuria.
Transfusion-associated graft-vs-host disease (GVHD)	GVHD refers to an immune attack by transfused cells against the recipient. This is a common complication of stem cell transplantation, but an exceedingly rare complication of blood transfusion.

5.10.4 Erythrocyte Sedimentation Rate (ESR)

The rate at which the red blood cells sediment in an hour is called the erythrocyte sedimentation rate (ESR or sed rate). In 1897 the Polish pathologist Edmund Biernacki developed the test and for this reason in few countries it is still known as Biernacki's Reaction. Dr Robert Fahraeus observed in 1918 that ESR fluctuated simply in pregnancy. Consequently, he recommended the ESR may be also helpful in determining the starting of pregnancy. In 1921, Dr Alf Vilhelm Albertsson Westergren applied ESR to find out the results of tuberculosis.

It is a general test for hematology and provides the general extent of inflammation. In order to conduct the test the blood which is anticoagulated blood is usually kept in a vertical tube, the tube is referred to as a Westergren tube, and the speed of the falling red blood cells is counted and at the end of one hour it is recorded and the measure is presented in mm.

After the automatic analyzers were introduced in clinical laboratories the test can be performed automatically. The ESR is directed by the equilibrium concerning the factors of pro-sedimentation, essentially fibrinogen, and also the factors that resist sedimentation, specifically the erythrocytes with a negative charge (zeta potential). In case the process of inflammation is present in the blood then large quantity of fibrinogen in the blood, the red blood cells stick to one and other. They create lots together termed as 'rouleaux,' they settle very quickly as a result of their amplified concentration. Formation of Rouleaux may take place along with few lymphoproliferative sicknesses wherein the secretion of paraproteins takes

place in large quantities. Although in animals like horses, cats, and pigs Rouleaux formation is considered to be normal physiological findings.

The ESR increases during disorders like inflammation, pregnancy, anemia, rheumatoid arthritis and lupus, infections; it is seen to be increased in few kidney diseases and cancers such as lymphoma and multiple myeloma. The ESR decreases during disorders like polycythemia, hyperviscosity, sickle cell anemia, and leukemia, low plasma protein that could be caused as a result of liver or kidney infection and congestive heart failure. Though surges in immunoglobulins generally result in increased ESR, extremely high levels could lessen it once more as a result of hyperviscosity in the plasma. There is a strong likelihood with IgM-class paraproteins, and to some extent with IgA-class. The basal ESR is marginally on the upper side in females as compared to men.

Application of ESR

Measuring the ability of red blood cells (erythrocytes) falling in the blood plasma and accumulating at the bottom of the vessel in an hour is described as Erythrocyte sedimentation rate (ESR) is the measure of ability of erythrocytes (red blood cell) to fall through the blood plasma and accumulate together at the base of container in one hour.

The erythrocyte sedimentation has three phases: In the first phase the formation of Rouleaux takes place. The second phase is of sedimentation in this the settling of the erythrocyte takes place and the third phase is referred to as the packing stage, it lasts for ten minutes wherein the sedimentation decelerates and cells begin to accumulate at the base of the tube.

In condition of normalcy since the red blood cells have negative charge they do not stack on top of each other as they repel with each other. Moreover in case there is high viscosity of blood then the red blood cells would not fall quickly to the bottom of the tube and this will lower the ESR.

Both inflammatory and conditions with no inflammation have an impact on the rate of erythrocyte sedimentation. In former conditions, fibrinogen, additional clotting proteins, and alpha globulin are charged positively this result in increasing the ESR. In conditions where there is no inflammation, the concentration of plasma albumin, dimension, form, and quantity of red blood cells, and the concentration of immunoglobulin may have an impact on the ESR. Conditions where there is no inflammation and yet they lead to increase ESR are disorders like anemia, renal failure, fatness, old age, and in females. During this the amplified number of red blood cells (polycythemia) results in reducing ESR since there is an increase in the viscosity of blood. Low ESR is observed in disorders of Hemoglobinopathy which include the sickle-cell disease, the ESR is low because of the shape of the red blood cells is not proper and this has a direct impact on the stacking in the tube. During monthly periods and pregnancy the ESR is found to be high amongst females. The value of ESR remains same even if dialysis is performed or may not

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be performed. For this reason, ESR cannot be regarded to be a reliable source of measuring infection in cases of kidney disease since its value may be increased from the beginning.

The ESR starts rising one or two days after the infection has set in and reduces slowly back to normal after the infection has been treated, the level comes back to normal after several weeks and even months sometimes. In case the value of ESR is more than 100 mm/hour then there is an urgent need to investigate the cause as there is a high possibility of a serious ailment in the body.

5.10.5 Erythroblastosis Fetalis

Erythroblastosis fetalis is referred as the haemolytic disease of the newly born infants. There are several cases where the pregnant woman's blood type does not have compatibility with the blood type of the baby. This causes the condition termed as the erythroblastosis fetalis, in this the white blood cells (WBCs) of the mother invade the RBCs of the baby as they are not compatible. This causes a kind of anaemia as the red blood cells (erythrocytes) of the foetus are finished as a reaction of the maternal immunity. There are few factors in father's blood which are not present in mother, in cases where the foetus gets these factors the incompatibility occurs. This disorder occurs very rarely and only few cases have been noticed in western countries and in case it is diagnosed during early stages of the pregnancy it can be easily cured but if pregnancy progresses and the disease is not treated then it often leads to the death of the new-born. The symptoms of the babies suffering from the disease are immediately noticed by the doctors, they mostly seem to have swelling and pale coloured skin as it appears during jaundice. The size of the liver is also enlarged and the baby suffers from Anaemia as the RBC count is low. In few cases the new-born also experiences a condition termed as hydrops fetalis, in this fluid is accumulated in abdomen, lungs or heart and in normal cases there is no fluid present in these parts of the body and thus becomes life-threatening as the presence of fluid prevents the heart to pump efficiently.

There are two systems of blood group namely Rh and ABO that are essentially related with the disease. The symptoms are extremely severe in the first system, this happens once the mother is RH negative and she conceives a foetus with Rh positive. The immune system of the mother fights with the foetus's blood and destroy its RBCs. This sensitization mostly occurs during the second pregnancy of the female as in the first pregnancy with Rh-positivity the quantity of RH antgen of the entering the mother's bloodstream is not enough for the sensitization to take place. The sensitivity to the Rh factor develops when the female is experiencing labour therefore the occurrence of the disease during second pregnancy is much higher than in the first.

In case the pregnant mother receives Rh immunoglobulin injections during the pregnancy the risk will be considerably lessened. The injections help in destroying the baby's red blood cells present in her blood from her previous delivery. They provide protection to the fetus from the disease in case an ABO blood group

mismatch is present as well. The ABO antibodies provide the protection as they end the fetal blood cells present in the mother's blood flow in advance and prevent her from developing sensitivity to Rh group. The disease occurs more frequently due to the incompatibility of the mother and foetus due to the ABO blood group as compared to the first system. However the immunity is better and severe only in cases wherein the mother is O type and the foetus is A type.

In order to detect erythroblastosis fetalis, doctors prescribe blood test during routine check-ups of the expecting mother, the mother's blood type is tested and this helps in determining in case the mother has anti-Rh antibodies in the blood due to the first pregnancy. In very few rare cases the blood of the fetus is also tested, the process is very risky as well as difficult. In case the test result imply that the baby is at risk of suffering from the disease then the mother's blood is tested several times so that the levels of antibodies can be checked. The high levels of antibodies will require the doctors to test the cerebral artery blood flow of the fetal as well. The cases with positive results indicate that the blood flow of the baby is affected.

Babies suffering from erythroblastosis fetalis in the womb of the mother will require a transfusion of intrauterine blood so that the chances of anemia can be reduced. The doctor's often suggest a pre-mature delivery and this takes place as soon as the baby's heart and lungs have developed. The baby requires blood transfusion after birth also. In few cases the new-born will need to be put on a ventilator and intravenous feeding of fluids.

Check Your Progress

13. What is the main function of platelets?
14. What can mixing blood from two individuals lead to?
15. What is required for a blood transfusion to be successful?
16. What does transfusion reaction refer to in terms of medical science?

5.11 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. Plasma contains dissolved proteins, glucose, mineral ions, hormones, carbon dioxide, platelets and the blood cells.
2. Blood comprises the following three types of cells (occasionally called corpuscles)
   (i) Erythrocytes or red blood cells
   (ii) Leukocytes or white blood cells
   (iii) Thrombocytes or platelets

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3. White blood cells or leukocytes are produced in red bone marrow.
4. The term 'serum' refers to plasma from which the clotting proteins have been removed.
5. The opposite process of haemostasis is haemorrhage.
6. The kallikrein-kinin system comprises a complex of proteins that when activated lead to the release of vasoactive kinins.
7. Red blood cells are red in colour because they contain a protein chemical called haemoglobin which is bright red in colour.
8. Anaemia is a condition in which the haemoglobin concentration in the blood is below a defined level, resulting in a reduced oxygen-carrying capacity of red blood cells.
9. The various categories of anaemia are as follows:
   - Iron deficiency anaemia
   - Folic acid deficiency anaemia
   - Pernicious anaemia
   - Aplastic anaemia
   - Sickle cell anaemia
   - Polycythemia vera
10. The two categories that leukocytes are divided into are granulocytes and lymphoid cells or agranulocytes.
11. Lymphocytes are the cells which, besides being present in the blood, populate the lymphoid tissues and organs as well as the lymph circulating in the lymphatic vessel.
12. The process of producing granulocytes is characterized by the progressive condensation and lobulation of the nucleus, loss of ribonucleic acid (RNA) and other cytoplasmic organelles and the development of cytoplasmic granules in the cells involved.
13. The main function of platelets or thrombocytes, is to stop the loss of blood from wounds (haemostasis).
14. Mixing blood from two individuals can lead to blood clumping or agglutination.
15. For a blood transfusion to be successful, ABO and Rh blood groups must be compatible between the donor blood and the patient blood.
16. In terms of medical science, a transfusion reaction is any adverse event which occurs due to a blood transfusion.

5.12 SUMMARY

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- Blood refers to a specialized bodily fluid whose function is to deliver necessary substances to the body's cells, such as nutrients and oxygen and transport waste products away from those same cells.
- Blood performs several important functions within the body which include supplying oxygen to tissues, supplying nutrients such as glucose, amino acids and fatty acids, removing wastes, getting involved in the circulation of white blood cells and taking part in coagulation.
- Other functions of blood include facilitating the messenger functions, regulating the body pH and core body temperature and performing hydraulic functions.
- The three types of cells that blood comprises are erythrocytes or red blood cells, leukocytes or white blood cells and thrombocytes or platelets.
- Red blood cells or erythrocytes are the most common type of blood cell and the human body's principal means of delivering oxygen (O_2) to the body tissues through the circulatory system.
- White blood cells or leukocytes are mainly produced in red bone marrow. Some of them are produced in thymus, spleen and lymph nodes and are known as lymphocytes.
- Platelets or thrombocytes are oval and single-nucleus cells. They are produced in red bone marrow. In one millilitre of the human blood, there are 200–400 thousands of platelets. Thrombocytes start the process of blood clotting.
- Approximately 55 per cent of whole blood is blood plasma. Plasma refers to a fluid that is the blood's liquid medium. In an average human, the volume of blood plasma totals of 2.7–3.0 litres.
- Haemostasis is a complex process which causes the bleeding process to stop. It refers to the process of keeping blood within a damaged blood vessel. The opposite of haemostasis is haemorrhage.
- Red blood cells perform the most important blood duty. A single drop of blood contains millions of red blood cells, which are constantly travelling through the body delivering oxygen and removing waste.
- Haemoglobin is the iron-containing oxygen-transport metalloprotein in the red cells of the blood in mammals and other animals. Haemoglobin transports oxygen from the lungs to the rest of the body, such as to the muscles, where it releases the oxygen load.
- Anaemia is a condition in which the haemoglobin concentration in the blood is below a defined level, resulting in a reduced oxygen-carrying capacity of

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red blood cells. In other words, it is a condition in which the body lacks the amount of red blood cells to keep up with the body's demand for oxygen.

- The various categories of anaemia are iron deficiency anaemia, folic acid deficiency anaemia, pernicious anaemia, aplastic anaemia, sickle cell anaemia and polycythemia vera.
- Leukocytes, or white blood cells, are responsible for the defense of the organism. In the blood, they are much less numerous than red cells. The density of the leukocytes in the blood is 5000–7000 /mm^3. Leukocytes are divided in two categories, namely, granulocytes and lymphoid cells or agranulocytes.
- The differences in human blood are due to the presence or absence of certain protein molecules called antigens and antibodies. The antigens are located on the surface of the red blood cells and the antibodies are in the blood plasma.
- For a blood transfusion to be successful, ABO and Rh blood groups must be compatible between the donor blood and the patient blood. If they are not, the red blood cells from the donated blood will clump or agglutinate. The agglutinated red cells can clog blood vessels and stop the circulation of the blood to various parts of the body.
- In terms of medical sciences, a transfusion reaction is any adverse event which occurs due to a blood transfusion. These events can take the form of an allergic reaction, a transfusion-related infection, haemolysis related to an incompatible blood type, or an alteration of the immune system related to the transfusion.

5.13 KEY WORDS

- **Blood:** It is a special body fluid that delivers necessary substances, such as nutrients and oxygen, and transport waste products from the body's cells.
- **Platelets**: Also known as thrombocytes, these are oval, single-nucleus cells that initiate blood clotting.
- **Plasma:** It is a watery fluid in which blood cells remain suspended.
- **Haemostasis:** It is a process that contains the blood within a blood vessel, when it is damaged.
- **Erythropoiesis:** It is the production of red blood cells.
- **Haemoglobin:** It is a metalloprotein that contains iron and transports oxygen in the red cells of blood.
- **Anaemia:** It is a condition in which the haemoglobin concentration in the blood goes lesser than a set level and leads to reduced oxygen-carrying capacity of red blood cells.

5.14 SELF ASSESSMENT QUESTIONS AND EXERCISES

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Short-Answer Questions

1. List the important functions of blood.
2. What is the kallikrein-kinin system in coagulation.
3. Outline the stages of development of red blood cells.
4. What are the causes and symptoms of folic acid deficiency anaemia.
5. List the different types of leukocytes present in blood along with their proportions.

Long-Answer Questions

1. Explain the three types of cells present in blood.
2. Discuss blood clotting.
3. Describe the relation between haemoglobin and anaemia. Also, provide a description of the various types of anaemia.
4. Describe the morphology and functions of platelets.
5. Write a short note on blood groups.
6. Describe the various types of transfusion reactions.

5.15 FURTHER READINGS

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UNIT 6 THE CARDIOVASCULAR SYSTEM

NOTES

Structure

6.0 INTRODUCTION

The cardiovascular system can be thought of as the transport system of the body. This system has three main components: the heart, the blood vessel and the blood itself. The heart is the system's pump and the blood vessels are like the delivery routes. Blood can be thought of as a fluid which contains the oxygen and nutrients the body needs and carries the wastes which need to be removed.

While humans, as well as other vertebrates, have a closed cardiovascular system (meaning that the blood never leaves the network of arteries, veins and capillaries), some invertebrate groups have an open cardiovascular system. The lymphatic system, on the other hand, is an open system providing an accessory route for excess interstitial fluid to be returned to the blood. The more primitive, diploblastic animal phyla lack circulatory systems.

6.1 OBJECTIVES

After going through this unit, you will be able to:

- Describe the basic properties of the heart
- Discuss the concept of cardiac output
- Explain the definition and factors affecting blood pressure
- Analyse the meaning and causes of hypertension
- Describe the importance of nutrition and metabolism of the heart
- Discuss the techniques to identify cardiovascular disorders

6.2 BASIC PROPERTIES OF THE HEART

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The human heart is the life-providing, ever-beating muscle in one's chest. From inside the womb until death, the beat goes on. The heart for the average human will contract about 3 billion times; never resting, never stopping to take a break except for a fraction of a second between beats. At 80 years of age, a person's heart will continue to beat an average of 1,00,000 times a day. Many believe that the heart is the first organ to become functional. Within the weeks of conception, the heart starts its mission of supplying the body with nutrients even though the embryo is no bigger than a capital letter on this page. The primary function of the heart is to pump blood through the arteries, capillaries and veins. There is an estimated 60,000 miles of vessels throughout an adult body. Blood transports oxygen, nutrients, disease-causing viruses, bacteria, hormones and has other important functions as well. The heart is the pump that keeps blood circulating properly.

The human heart is a hollow, muscular organ about the size of a fist. It is responsible for pumping blood through the blood vessels by repeated, rhythmic contractions. The heart is composed of cardiac muscle, an involuntary muscle tissue that is found only within this organ. The term 'cardiac' (as in cardiology) means 'related to the heart' and comes from the Greek word *kardia*, for 'heart.' It has a four-chambered, double pump and is located in the thoracic cavity between the lungs. The cardiac muscle is self-exciting, i.e., it has its own conduction system. This is in contrast with skeletal muscle, which requires either conscious or reflex nervous stimuli. The heart's rhythmic contractions occur spontaneously, although the frequency or heart rate can be changed by nervous or hormonal influence such as exercise or the perception of danger.

Myocardium

The heart muscle or the myocardium is the muscular tissue of the heart. The myocardium is composed of specialized cardiac muscle cells with an ability not possessed by muscle tissue elsewhere in the body. Cardiac muscle, like other muscles, can contract, but it can also conduct electricity, like nerves. The blood to the myocardium is supplied by the coronary arteries. If these arteries are occluded by atherosclerosis and/or thrombosis, this can lead to angina pectoris or myocardial infarction due to ischemia (lack of oxygen).

The failure of the heart to contract properly (for various reasons) is termed as heart failure, generally leading to fluid retention, edema, pulmonary edema, renal insufficiency, hepatomegaly, a shortened life expectancy and decreased quality of life.

Pericardium

The pericardium is the thick, membranous sac that surrounds the heart. It protects and lubricates the heart. There are two layers to the pericardium: the fibrous

pericardium and the serous pericardium. The serous pericardium is divided into two layers; in between these two layers, there is a space called the pericardial cavity.

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Epicardium

The layer next to the heart is the visceral layer, also known as the epicardium. This is the innermost layer and consists of connective tissue.

Heart Chambers

The heart has four chambers, two atria and two ventricles. The atria are smaller with thin walls, while the ventricles are larger and much stronger.

Atrium: There are two atria on either side of the heart. On the right side is the atrium that contains blood, which is poor in oxygen. The left atrium contains blood, which has been oxygenated and is ready to be sent to the body. The right atrium receives de-oxygenated blood from the superior vena cava and inferior vena cava. The left atrium receives oxygenated blood from the left and right pulmonary veins.

Ventricles: The ventricle is a heart chamber, which collects blood from an atrium and pumps it out of the heart. There are two ventricles: the right ventricle pumps blood into the pulmonary circulation for the lungs and the left ventricle pumps blood into the systemic circulation for the rest of the body. Ventricles have thicker walls than the atria and thus can create the higher blood pressure. Comparing the left and right ventricle, the left ventricle has thicker walls because it needs to pump blood to the whole body. This leads to the common misconception that the heart lies on the left side of the body.

Septum: The interventricular septum (ventricular septum, or during development septum inferius) is the thick wall separating the lower chambers (the ventricles) of the heart from one another. The ventricular septum is directed backward and to the right and is curved toward the right ventricle. The greater portion of it is thick and muscular and constitutes the muscular ventricular septum. Its upper and posterior part, which separates the aortic vestibule from the lower part of the right atrium and upper part of the right ventricle, is thin and fibrous and is termed as the membranous ventricular septum.

Valves: The two atrioventricular (AV) valves are one-way valves that ensure that blood flows from the atria to the ventricles and not the other way. The two semilunar (SL) valves are present in the arteries leaving the heart; they prevent blood from flowing back into the ventricles. The sound heard in a heart beat is the heart valves shutting. The right AV valve is also called the tricuspid valve because it has three flaps. It is located between the right atrium and the right ventricle. The tricuspid valve allows blood to flow from the right atrium into the right ventricle when the heart is relaxed during diastole. When the heart begins to contract, the heart enters a phase called systole and the atrium pushes blood into the ventricle. Then the ventricle begins to contract and blood pressure inside the heart rises. When the ventricular pressure exceeds the pressure in the atrium, the tricuspid valve snaps

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shut. The left AV valve is also called the bicuspid valve because it has two flaps. It is also known as the mitral valve due to the resemblance to a bishop's mitre (liturgical headdress). This valve prevents blood in the left ventricle from flowing into the left atrium. As it is on the left side of the heart, it must withstand a great deal of strain and pressure; this is why it is made of only two cusps, as a simpler mechanism entails a reduced risk of malfunction. There are two remaining valves called the semilunar valves. They have flaps that resemble half moons. The pulmonary semilunar valve lies between the right ventricle and the pulmonary trunk. The aortic semilunar valve is located between the ventricle and the aorta.

Subvalvular Apparatus: The chordae tendineae are attached to papillary muscles that cause tension to better hold the valve. Together, the papillary muscles and the chordae tendineae are known as the subvalvular apparatus. The function of the subvalvular apparatus is to keep the valves from prolapsing into the atria when they close. The subvalvular apparatus have no effect on the opening and closing of the valves. This is caused entirely by the pressure gradient across the valve.

Complications of the heart

The most common congenital abnormality of the heart is the bicuspid aortic valve. In this condition, instead of three cusps, the aortic valve has two cusps. This condition is often undiagnosed until the person develops calcific aortic stenosis. Aortic stenosis occurs in this condition usually in patients in their 40s or 50s, an average of 10 years earlier than in people with normal aortic valves. Another common complication of rheumatic fever is thickening and stenosis (partial blocking) of the mitral valve. For patients who have had rheumatic fever, dentists are advised to prophylactally administer antibiotics prior to dental work to prevent bacterial endocarditis that occurs when bacteria from the teeth enter the circulation and attach to damaged heart valves.

The aortic valve is a semilunar valve, but it is called bicuspid because of its regular three 'cusps' or 'semilunar' valves and is not to be confused with the left atrioventricular valve, which is more commonly called the mitral valve and is one of the two-cuspidal valves.

Passage of blood through the heart

While it is convenient to describe the flow of the blood (Figure 6.1) through the right side of the heart and then through the left side, it is important to realize that both atria contract at the same time and that both ventricles contract at the same time. The heart works as two pumps, one on the right and one on the left that work simultaneously. The right pump pumps the blood to the lungs or the pulmonary circulation at the same time that the left pump pumps blood to the rest of the body or the systemic circulation. Venous blood from systemic circulation (de-oxygenated) enters the right atrium through the superior and inferior vena cava. The right atrium contracts and forces the blood through the tricuspid valve (right atrioventricular valve) and into the right ventricles. The right ventricles contract and force the

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blood through the pulmonary semilunar valve into the pulmonary trunk and out the pulmonary artery. This takes the blood to the lungs where the blood releases carbon dioxide and receives a new supply of oxygen. The new blood is carried in the pulmonary veins that take it to the left atrium. The left atrium then contracts and forces blood through the left atrioventricular, bicuspid, or mitral, valve into the left ventricle. The left ventricle contracts forcing blood through the aortic semilunar valve into the ascending aorta. It then branches to arteries carrying oxygen-rich blood to all parts of the body. The blood flows when it leaves the heart as follows:

Aorta→Arteries→Arterioles→Capillaries→Venules→Veins→Vena Cava

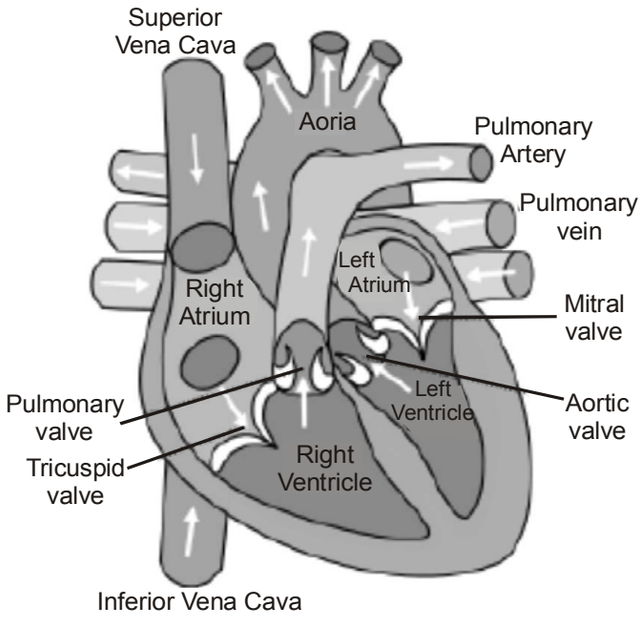

Fig. 6.1 *Passage of Blood Through the Heart*

Blood flow through capillaries

From the arterioles, the blood then enters one or more capillaries. The walls of capillaries are so thin and fragile that blood cells can only pass in single file. Inside the capillaries, exchange of oxygen and carbon dioxide takes place. Red blood cells inside the capillary release the oxygen that they carry, which passes through the wall and into the surrounding tissue. The tissue then releases waste, such as carbon dioxide, which then passes through the wall and into the red blood cells.

6.2.1 Cardiac Output

In physiology, the volume of blood that is pumped by the heart's ventricle either left or right per unit is referred to as the Cardiac output. In other words it is merely the quantity of blood pumped by the heart in 60 seconds. Essentially, the cardiac output is the produce of the heart rate and it refers to the quantity of beats in 60 seconds, and the stroke volume that refers to the quantity pumped on every beat. It is generally denoted with this formula- CO = HR X SV

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The cardiac output is typically communicated in litres per minute. If the weight of the individual is roughly 70 kg then while resting the cardiac output would be approximately 5 litres in every sixty seconds and in case the heart rate is 70 beats per sixty seconds; then the stroke volume may be around 70ml per beat or little more. It is necessary to keep in mind that these calculations are as per a rested body, they will drastically change once the individual begins to exercise. The cardiac output of an active and young individual can mount up to approximately 20 litres per minute during intensive workout. The maximum cardiac output of an international-level athlete could be approximately 35 litres per minute. Cardiac output's value is typically referred to as L/min.

Since cardiac output is correlated directly to the amount of blood supplied to several body parts therefore it acts as an indicator for exhibiting the efficiency of the heart in being able to meet the demands of perfusion of the body. As it is already understood that the need of oxygen becomes higher when the body is involved in a muscular activity as compared to when it is resting, when a heart attack occurs than it denotes that the cardiac output was so low that it was unable to support the basic routine activities of the body and it was not able to escalate marginally in order to keep up with the low level of exercise.

Cardiac output is a universal parameter in haemodynamics for measuring and studying the blood flow of the body. The factors which affect stroke volume and heart rate have a direct impact on cardiac output. The figure below clearly explains the relation of dependence and it also enumerates the factors respectively.

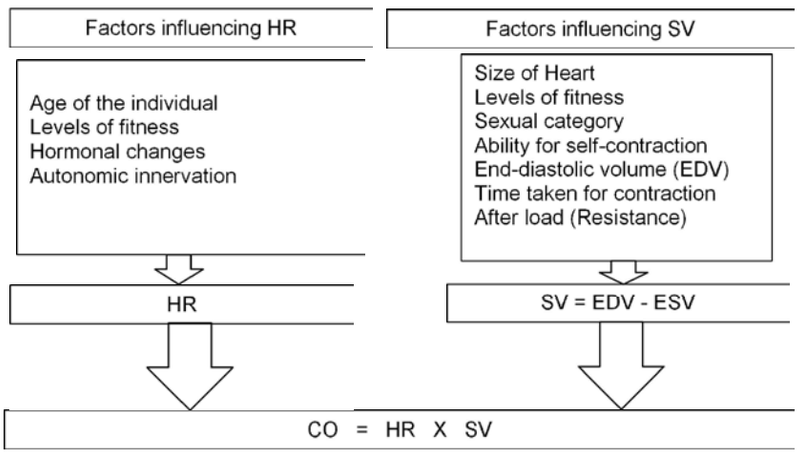

Fig. 6.2 *Relation of Dependence*

The heart functions in the circulatory system as a delivery agent for blood, through its cycle it delivers oxygen, nutrients and chemicals to the cells of the body and eliminates the waste of the cells. Since the heart pumps out all the blood that is received from the venous system therefore amount of blood coming back to the heart effectually decides the amount of blood pumped out of the heart; this denotes the cardiac output, Q. Cardiac output is typically defined along with the stroke volume (SV) and the heart rate (HR) in the following manner:

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CO (L/min) =SV (L/beat) XHR (beat/min)

Clinically there are many ways of measuring the cardiac output. This could be measured using the direct intracardiac catheterization or the non-invasive measurement of the arterial pulse. In the absence of a universally accepted standard measurement it becomes difficult to pin-point the most effective method of measuring cardiac output; all methods have their pros and cons. The phase of respiration – intra-thoracic pressure changes have a direct impact on the cardiac output as it influences the diastolic filling and that brings changes to the cardiac output. This is specifically essential in mechanical ventilation, during this the cardiac output varies tremendously, in some cases it can differ almost fifty per cent over a solo respiratory cycle. Therefore it is essential to measure Cardiac output at regular intervals during a particular cycle or else an average should be worked out after considering many cycles. In spite of the non-accuracy of the invasive method of measuring, cardiac output is used in most cases. In the meantime efforts are being made to develop a method which is universally accepted and accurate.

Check Your Progress

1. What is the most common congenital abnormality of the heart?
2. What is cardiac output?

6.3 BLOOD PRESSURE: DEFINITION AND FACTORS AFFECTING IT

Blood pressure can be referred to as the horizontal force applied on the wall of the blood vessel by column of blood flowing through it. Blood pressure is also known as end arterial pressure.

Systolic blood pressure denotes the extreme pressure which may be logged in arteries in the course of ventricular systole. The normal range could vary from 100 to 140mm Hg in an adult aged twenty years and 120 mm Hg id the mean pressure.

Diastolic blood pressure denoted the lowest pressure which may be logged in the arteries in the course of ventricular diastole. The normal range could vary from 60 to 90 mm Hg in an adult aged twenty years and 80 mm Hg is the mean pressure.

Mean pressure of the arteries in the course of the cardiac cycle denotes the mean arterial pressure. It constitutes basically of the diastolic pressure and an extra one-third of pulse pressure. Accordingly it would be roughly around 94 mm Hg the sum total of 80 + 40/3.

The difference between systolic and diastolic pressure is referred to as Pulse pressure. Accordingly it would be 40mmHg the difference of 120 – 80.

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The state of high blood pressure is referred as hypertension; high blood pressure is not good as it will make the heart to exert added labour while pumping blood from the body and this also affects the arteries as they become hard. Hardening of arteries leads to a stroke or atherosclerosis; it also can cause kidney disorders or heart failure.

The reading of the blood pressure is written as 120/80 and is read as "120 over 80." The first digits are referred to as the systolic and subsequent digits are referred as diastolic. It has following ranges:

Standard or normal: Less than 120 over 80 (120/80)

Raised or elevated: 120-129/less than 80

First stage of high blood pressure: 130-139/80-89

Second stage of high blood pressure: 140 and above/90 and beyond

Crisis of Hypertension occurs when it is higher than 180/higher than 120. The individual needs to visit a doctor urgently. In any case the doctor needs to be consulted if the blood pressure is more than the normal range.

Factors Influencing the Blood Pressure

The exact cause for high blood pressure is not known as there are many factors which are responsible for it, some of them are mentioned below:

- Smoking
- Being over-weight
- Inadequate physical activity
- High quantity of sodium (salt) in food
- High intake of alcohol
- Increased stress levels
- Individuals develop high blood-pressure in old age
- Hereditary
- Family history of high blood pressure in the family
- Prolonged kidney disease
- Adrenal and thyroid conditions
- Sleep apnea

There are few other factors like age, gender, lifestyle or even physic of the individual that have a direct impact on the level of the blood pressure in the body.

Elements that help in maintaining normal blood pressure are:

- **Cardiac output:** The cardiac output has a direct impact on the systolic blood pressure of the body, in case there is fluctuation in the cardiac output there will be a direct impact on the systolic pressure.
- **Peripheral resistance**: The diastolic pressure and peripheral resistance have a direct relation and it affects the diastolic pressure. The arterioles

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form the seat of resistance. Arterioles consist of many soft muscle fibres; these are provided due to the sensitive vasoconstrictor fibres. These fibres increase the resistance provided by the flow of blood and as a result there is an increase in the diastolic blood pressure.

- **Blood volume**: In case the volume of the blood is reduced the blood pressure also decreases. There is a decrease in the systemic filling pressure due to the decreased blood volume. The lessened venous pressure leads to lessening of the venous return as well as the cardiac output, thus directly affecting the blood pressure.
- **Blood pressure**: As stated above the normal blood pressure is 120/80 mm Hg, the first value denoting the systolic pressure of the blood and the second value denotes the diastolic pressure. The difference of the two provides the pulse pressure. There are two methods of measuring the blood pressure.

  The first is the direct measurement that is done by injecting a needle through the artery. The second is indirect measurement, done with the help of the Sphygmomanometer. There are again two methods; the first one is the Palpatory method, this is the most common method for measuring blood pressure; this method is used for measuring the systolic pressure. The palpatory method is widely used in OPDs, hospital wards and several places where the blood pressure needs to be measured frequently; it can be taken in places with loud noises and even in the absence of a stethoscope. This is a manual method of measuring the blood pressure. The second indirect method is the Auscultatory method; the method was described by the Russian physician "Korotkoff" in 1905. This method involves the cuff to be inflated till a level which is more than the arterial pressure. With the gradual deflation of the cuff the pressure is recorded with the reverberations created by the appearance and the disappearance of the arterial pulse waves. The waves appear and disappear once the flow in the artery restarts. The systolic pressure is recorded when the first sound of the korotkoff appears and this is also the highest pressure that is generated in every cardiac cycle. The diastolic pressure is recorded at the level when the reverberations no longer appear and stop completely. At this stage there is no compression in the artery and the blood flow is fully restored.

  The blood pressure may be measured by usage of direct as well as indirect methods. Although the indirect method is more common as it can be easily done in varied venues whereas the direct method would require a specific environment as the needle needs to be inserted in the artery in order to record the pressure of the blood. Even among the indirect methods the Auscultatory method is more preferred as it accurately measures both the systolic as well as the diastolic pressure. In the

Palpatory method only the systolic pressure can be measured and even that is sometimes not accurate.

- **Viscosity of the blood**: Another element which has an impact on the blood pressure. The blood pressure is bound to increase when there is an increase in the viscosity of blood's flow as it prevents the blood from flowing freely. This is frequently apparent in polycythemia vera cases.
- **Flexibility of the blood vessels:** With the advancement of age the elasticity of the fibres in the wall of the vessel lessens, the blood vessels begin to form into rigid tubes as a result there is a reduction in the extendibility of the vessel. This results in increasing the systolic blood pressure and decreasing the diastolic pressure. On the other hand, in some cases the diastolic pressure is known to increase as a result of the atherosclerotic changes, the diameter of the tube lessens and this hampers the flow of blood.

Ways of Controlling Blood Pressure

Let us analyse the different ways of controlling the blood pressure.

- **Losing the excess weight:** It is important to lose the extra weight for keeping a check on the blood pressure. The excessive weight prevents even breathing during sleep and causes sleep apnea as a result the blood pressures escalates. It is believed that with a decrease in every kilogram there is a decrease in the blood pressure; the decrease is around 1 mm Hg. Smaller waistline is essential for preventing high blood pressure. Men with a waist size of more than 40 inches are more prone to be suffering from blood pressure and in the same way women with a waist size over 35 inches.
- **Regular exercise**: It is important to exercise at least for 30 minutes every day in order to keep the blood pressure in check. Exercising on a daily basis does not allow the increased levels of blood pressure to turn into chronic state of hypertension. Exercising helps in maintaining the blood pressure levels.
- **Nutritious diet**: The diet of the individuals must include whole grains, green leafy vegetables, fruits, nuts and dairy products which are low in fat. High saturated fats and cholesterol need to be controlled. It is essential to monitor food intake and food rich in potassium should be included so that the effect of sodium on blood pressure can be reduced.
- **Low sodium diet:** A common cause for high blood pressure is increased levels of sodium in the body. In order to maintain healthy levels of blood pressure individuals must limit the amount of salt they consume. Reducing salt intake may help in reducing up to 5 to 6 mm Hg of blood pressure. Adults need to consume less than 1500 mg in a day in order to maintain their blood pressure. Processed foods should be completely avoided and

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addition of extra salt to salad and other snacking foods should be also avoided.

- **Restricted quantity of alcohol should be consumed:** Moderate quantity of alcohol consumption is not harmful for health; in fact it helps in lowering the blood pressure as well. It helps in lowering almost 4 mm Hg but the effect is completely opposite in case the consumption is high. High intake of alcohol reduces the efficiency of the medication taken for high blood pressure.
- **Smoking needs to be completely stopped**: In order to maintain healthy levels of blood pressure as smoking even a single cigarette increases the level of blood pressure for several minutes. Smoking frequently throughout the day leads to higher levels of blood pressure throughout the day. Smoking needs to be completely quit for maintaining a healthy heart and overall wellbeing.
- **Limiting the consumption of caffeine**: Another essential way of controlling high blood pressure is by cutting down on consumption of beverages with caffeine. It is frequently argued that caffeine has a negative impact on the blood pressure levels, though there is no clarity regarding its actual impact.
- **Reducing the stress levels is important:** Continuous stress leads to high blood pressure. Even short spans of stress can increase the blood pressure as most individuals develop unhealthy eating patterns during stress; more so some even begin to drink and smoke heavily. It is important to determine the cause of stress and efforts should be made to reduce and end it completely. Even though stress is an integral part of every person's routine it is essential to learn to cope with stress and not let it become a cause of ill-health.
- **Regular monitoring of blood pressure**: The blood pressure needs to be checked regularly so that it can be rectified in early stages. Regular monitoring will help in alerting and the doctor would be consulted in time.
- Having support of loved ones can help in maintaining healthy heart health. Being happy and cheerful helps in controlling the blood pressure naturally.

6.3.1 Hypertension

Hypertension (HTN or HT) is often referred as high blood pressure (HBP). It is a lasting medical condition wherein the pressure of the blood in the arteries is constantly high. There are no usual symptoms for high blood pressure though having high blood pressure for long periods may become a cause for several other health issues such as coronary disease of the arteries, stroke, failure of heart, atrial fibrillation, and peripheral vascular disease, loss of eye-sight, long-lasting kidney disease, and dementia.

State of high blood pressure is often mentioned as hypertension. As stated in the previous section that blood pressure is the horizontal force applied on the wall of the blood vessel by column of blood flowing through it. The pressure is

dependent on heart's capability and the level of blood vessel's resistance. According to the guidelines provided by the American Heart Association in November 2017, hypertension is prevailing in case the blood pressure is higher than 130 over 80 mm Hg. More than half of the world's population suffers from hypertension for this reason it has become a universal concern. The World Health Organization (WHO) has suggested that the increased consumption of processed food is one of the major causes for hypertension.

High blood pressure is mainly of two types, namely the primary and secondary high blood pressure. The first type i.e. the primary high blood pressure is common and it develops as people become older. The second type, i.e. the secondary blood pressure occurs due to a health condition or by usage of particular medicines. The condition is rectified as soon as the ailment is cured and the medication for it is stopped.

The constant high levels of blood pressure make the heart exert more effort while pumping blood and this could lead to several fatal health issues. There could be complete failure of heart or even a kidney failure. Therefore the condition cannot be ignored and besides taking medication people need to maintain a lifestyle which promotes healthy heart. In some cases just altering the lifestyle helps in controlling the blood pressure but others need to be put on medication along with the changes; the medication is effective only when eating habits are heart friendly, exercise regime is followed and several other precautions are taken.

Treating Hypertension

The levels of blood pressure need to be constantly monitored so that hypertension can be avoided. The best way of monitoring the blood pressure is by checking it frequently and incorporating healthy eating habits will help in regulating the blood pressure and evade the stage of hypertension. Changes in eating habits sometimes are not enough and people need to choose other options for curing hypertension.

The primary way of treating hypertension is to make few basic adjustments in the way of living.

Incorporating physical exercise in the daily routine, it is recommended by doctors that individuals suffering from hypertension need to indulge in activities such as walking, swimming, cycling or light jogging for at least half an hour per day.

Stress management is important for avoiding hypertension. Individuals need to learn to manage their stress levels as it will keep the blood pressure in control. People suffering from stress tend to develop wrong eating habits and resort to drinking as well, they need to curb from doing such things. Smoking can make the blood pressure shoot up and cause complications in existing levels thus it is advised by doctors to quit smoking.

Final resort for treating hypertension is through medicines. The medicines will only be effective if all the above mentioned precautions are adopted. Doctors

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prescribe medication for all those who have blood pressure levels above 130 over 80. The medicines usually do not have any side-effects. In most cases the doctors start with a low dosage and gradually put them on two anti-hypertension medications. There are many medicines available for lowering the level of the blood pressure some of them are listed below:

- Diuretics like thiazides, chlorthalidone, and indapamide may be prescribed for reducing the salt levels in the body
- Blocking agents, beta-adrenergic help in reducing the blood pressure.
- Calcium channel blockers have an impact on the cells and blood vessels calcium movement; they help in providing relaxation to the blood vessels by increasing the supply of oxygen as well as blood to the heart thus the workload of the heart reduces.
- Central alpha agonists help in lowering the blood pressure
- Peripheral adrenergic antagonists like reserpine.
- Vasodilators help in broadening the arteries thus help in improving the blood flow
- The frequently prescribed ACE inhibitors are benazepril or zofenopril
- Patients that show intolerance to ACE treatment need to be put on angiotensin II receptor blockers for treating hypertension.

Doctors prescribe medication as per the general health of the individuals. While taking medicine for hypertension intake of other medicines should be only done under the guidance of a medical practitioner after providing them with complete list of medicines being consumed. Most of the medication mentioned above may not interact well be few medicines.

Causes of Hypertension

The factors responsible for hypertension is mostly not identified, some of the factors which may contribute to this state are:

- The state very frequently develops as a reaction to an aliment or due to the medication prescribed for its treatment.
- Long lasting kidney disorders is another common factor for developing hypertension.
- Common Factors for Hypertension
- People tend to be hypertensive during their old-age as the blood pressure increases more frequently.
- Individuals belonging to a certain ethnic group have a tendency to develop the state
- The most common factor for being hypertensive is obesity
- Excessive drinking and smoking is another factor contributing to hypertension

- Wrong lifestyle and lack of regular exercise
- High sodium and fat diet
- Diet low on potassium
- Health issues
- Hereditary

Check Your Progress

3. What is systolic blood pressure?
4. State some of the factors that have a direct impact on the level of blood pressure in the body.
5. Define hypertension.

6.4 NUTRITION AND METABOLISM OF THE HEART

Nutritious diet is very essential for a healthy heart. Diets that are balanced help in keeping the blood pressure and cholesterol in check. They not only reduce the risk of developing heart diseases but also contribute towards overall wellbeing. Consumption of a diet full of nutrients is best way to avoid heart related problems. The heart gets its nutrition by including an assortment of foods along with controlling the consumption of specific items and beverages. In order to maintain good health of the heart it is essential to keep a check on the calories count.

The body functions effectively once it has been provided with adequate amount of carbohydrates, proteins, fats, vitamins, limited amount of salt and omega-3 fatty acids and minerals. Thus the nutrients for the body are dependent on the food consumption by the individuals.

The energy to function is provided by the carbohydrates to the body. It is essential to consume the required amount as the extra carbs would be stored in the body as fat. The nutrients to the heart are provided by consumption of complex carbohydrates as the simple carbs include the sugar and starches. The need for simple carbohydrates is not as much a complex carbohydrates which is got from foods like whole grains, potatoes, rice, etc. The carbs found in refined flour and sugar is not useful for the body. A fibre rich diet is helpful in reducing the levels of cholesterol and also safeguards the body against other disorders like cancer, heart diseases and digestive issues. Body needs soluble as well as insoluble fibre.

Proteins are very essential for the growth and development of the tissues and muscles in the body. They help in providing emergency fuel in the absence of carbs and fats. Protein from animal as well as vegetables is required by the body. The protein from animal sources are also rich in fat therefore their consumption should be restricted as it could lead to high levels of cholesterol. The best source of protein is found in sea-food as it helps in fulfilling the need for omega-3 fatty

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acids, EPA and DHA. Consumption of sea food helps in preventing heart related diseases.

Body needs a small quantity of dietary fats in order to maintain a balance in the system. Unsaturated fats are more beneficial than the saturated fats.

Vitamins help in regulating the metabolism of the body. They help in preventing coronary artery disease. Vitamins like A, C, and E stop the formation of plaque on the walls of the arteries. These anti-oxidant vitamins help in preventing the oxidation which forms due to the combining of oxygen and LDL.

The biological processes of the body are managed with the help of minerals found in the food. The body has a very small requirement of the minerals therefore an over-dose can cause a lot of harm. Salt is one of the essential minerals required by the body but a high dosage could lead to increased levels of blood pressure. The daily salt requirement of the body should not exceed 2300 mg for normal people and those prone to high blood pressure should restrict it to 1500 mg.

The diet of the individual is essential for the overall well-being and for the wellbeing of the heart. One of the most common causes of high blood pressure is obesity. The health of the heart is affected by not just the extra weight but also the shape of the body. In case excessive fat is stored in the upper part of the body, as found in most men the tendency to develop high blood pressure is very high. Such body shapes are often referred as "apple-shaped" bodies and they are at a high risk of having heart related ailments and even suffer from a heart attack.

Metabolism of the heart

Heart as compared to any other organ of the body has the highest metabolic demands. It requires normal cardiac metabolism in order to keep its functions going as per its capabilities. The demand for heart's energy depends on sufficient oxygenation and existing substrates so that enough quantity of adenosine triphosphate (ATP) can be generated. ATP is required mainly for contraction and to some extent for ionic homeostasis. In order to meet the myocardial requirements high rate of production of ATP needs to be maintained. This is much more than the overall quantity of ATP in the myocyte that is used up in less than sixty seconds; for that reason, the passageways used in the production of ATP are diligently related to the ones which are involved in the consumption of ATP utilization, this needs to be done so that the energy demands can be met swiftly.

Myocardial Energy Metabolites

The heart's chemical energy is mainly deposited in the metabolites which are the phosphoryl bonds like the ATP. This notion about phosphate bonds being the source of the chemical energy has been prevailing since many years. These high energy phosphate bonds due to their high energy have been frequently compared with the supply of domestic electricity that helps in functioning of several appliances. The ATP is the most important high-energy phosphate found in most of the cells,

even in myocytes. It is completely needed for the regular functions of myocardial contraction and viability.

All processes of the cells need ATP since it is their basic source of energy. The heart is no different; the membrane transport system of the heart needs ATP for performing its functions. It is also required for sarcomere contraction and relaxation; this involves myosin ATPase and ATP-dependent transport of calcium through the sarcoplasmic reticulum. Hence, the myocardial metabolism helps in escalating the heart's mechanical actions this in turn increases the heart rate and the rate of contractions.

ATP pools of the cells are directly dependent on the sense of balance concerning the utilisation of ATP and the production of ATP. The heart needs the ATP's aerobic production in order to sustain enough contractions of the ATP since the heart has a limited capacity for anaerobic. The ATP levels of the cells will reduce and it will not be able to produce ATP aerobically in the absence of sufficient availability of oxygen. The levels will get affected in case there is an increase in the utilisation of ATP levels and it does not correspond with increase in production of ATP.

The heart is able to use many types of substrates in order to oxidatively redevelop ATP dependent on obtainability. After a meal has been consumed the heart uses about sixty to seventy per cent of the fatty acids and thirty percent of the carbs. The heart is able to consume all the carbs after a meal which is rich in carbohydrates. Lactate is an alternative for glucose, and hence proves to be essential substrate while exercising. The heart is also able to use amino acids and ketones in place of fatty acids. Ketone bodies such as acetoacetate are on the whole essential during diabetic acidosis. During ischemia and hypoxia, the coronary circulation is not able to supply hearts' metabolic substrates during ischemia and hypoxia for enabling aerobic metabolism. During such circumstances the heart utilises the stored carbs in form of glycogen for enabling the substrate for anaerobic ATP production and creation of lactic acid. Even though during this pathway the heart's production of ATP is very low when compared to the production during aerobic metabolism. Moreover, as the supply of glycogen is inadequate with the heart and it gets further reduced at the time of acute hypoxic conditions.

6.5 EXERCISE AND HEART FUNCTION

During cardiovascular exercises large muscles are repeatedly used, the exercises activate the fibres that are pre-set for stamina and they utilise almost forty to eighty-five percent of the individual's heart rate. These activities may include running, jogging, swimming, biking, or skipping.

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Impact of Cardiovascular Activities on the Heart

While undertaking cardio exercises the flow of blood is concentrating on the muscles which are working and leaves those which are not involved, for instance the muscles in the arms are not in use while running or even the muscles of the digestive system are not in focus. The heart receives an increased volume of blood as the flow increases. As soon as the heart realises that the volume of blood has increased its left ventricle become accustomed and expands. This expanded cavity is able to hold larger quantity of blood, and emit extra blood on every beat, this continues in spite of being at rest.

In time with continuous cardio activities the heart rate reduces even while the heart is at rest as every beat supplies a larger quantity of blood as a result less beats are required. For this reason cardio exercises are suggested for healthy heart as reduces the load on the heart. On the other hand, cardiovascular exercises are known to develop stress in few cases. When individuals tend to exert more during training they land up harming themselves more as it results in gaining fat in waist area and face. Some people spend most of their day in a stressful state as a result they have weak digestive systems and they land up increasing their stress levels by extensive workout and training. It is very important to underline the goals of exercising and limit the workout as per the goals. Efforts should be made to reduce the stress levels.

Impact of Strength Training Exercises on the Heart

The heart is working in a different fashion during strength training exercises. During strength training only a specific muscle is contracting and depending mostly on muscle fibres of two types these also help in improving the body shape and improving overall strength. During the contraction the muscles curl and close the flow of the blood vessels in the process. This increases the blood pressure in other parts of the body and the heart needs to combat powerfully so that it is able to push the blood out. The heart copes by enhancing the viscosity of the ventricle wall from the left. The viscosity which results from long lasting weight training has a positive impact but in case the viscosity is an outcome of constant high blood pressure then sadly it is not a good sign.

The heart which is healthy is over worked only for a couple of hours in a day, but heart suffering from high blood pressure over worked every single minute. Strength training for healthy heart is beneficial as it makes it stronger by reducing the heart rate of the rested heart whereas the heart with high blood pressure is forced to be under extra stress and is exhausted even further.

Both cardiovascular and strength training exercises are beneficial for the heart. New blood vessels are produced while exercising; the former helps in increasing the number of vessels and the later helps in increasing the size of the blood vessels. Exercise helps in improving the blood circulation of the body thus resulting in a healthy heart.

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6.6 TECHNIQUES TO IDENTIFY CARDIOVASCULAR DISORDERS: ANGIOPLASTY AND ANGIOGRAM

The technique of Angioplasty is used in order to treat a cardiovascular disorder. The technique is used to reopen a blocked or a nearly closed coronary artery of the heart. The procedure does not involve a surgery though in some cases it is as effective as a bypass. The technique was used for the first time in 1977. It is occasionally referred as percutaneous transluminal coronary angioplasty (PTCA) or percutaneous coronary intervention (PCI). Here "angio" refers to blood vessel and "plasty" refers to its restoration. The technique is used in order to treat disease of peripheral artery in the body.

The Procedure of Angioplasty

After conducting a few preliminary blood tests the patient is ready for the procedure. The patient needs to stop smoking for a specified period before and after the procedure and also the doctor should be informed about allergies pertaining to iodine based dyes. The patient needs to be fasting at least six to seven hours before the procedure though clear liquids are allowed.

During the procedure the patient is fully in senses as only a local anaesthesia is administered. A tiny incision is made by the surgeon in the arm or the groin area in order to put the catheter (thin tube) in the artery. The catheter contains a tiny balloon and a stent (small wire tube). After the catheter is placed properly the dye is inserted then patient's X-rays are taken in order to identify and locate the blocked artery. This part of the procedure helps in guiding the doctor as it provides him with a map for conducting the procedure. The balloon is inflated and the stent is opened so that it can be pushed against the wall of the artery. After the completion of the procedure the cells around the lining of the blood vessel develop all over the stent and help in securing it. The procedure generally takes only thirty minutes but in few cases it may last for a couple of hours, depending on the area of blockage. Occasionally patients have to come back for the procedure for opening of other blockages which could occur. This procedure is referred as restenosis.

Other types of Angioplasties

Sometimes along with the balloon the doctors have to use other combinations for a successful angioplasty. These are:

- **Drug-eluting stents:** These are stents which are specially treated with medicine and the medicine is slowly released into the wall of the artery after insertion. This combination is helpful for those who might seem prone to redeveloping the narrowing of the artery. The latest stents are safe and have minimal side-effects.

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- **Directional Atherectomy**: In this procedure a small rotating blade is used in order to cut away the deposited fat.
- **Excimer laser angioplasty:** In this procedure the blockage of the artery is removed with the help of the laser. The balloon helps in making the space around the blockage bigger.
- **Rotational Atherectomy:** This involves using a drill bit which helps in pulverising hard blockages. A diamond-studded drill bit is used.
- **Intracoronary radiation:** In this procedure radioactivity is performed on the section of artery post balloon angioplasty so that reoccurrence can be prevented.

Angioplasty Vs Coronary Artery Bypass Surgery

There is no denying the fact that a Coronary artery bypass grafting (CABG) is an effective technique for repairing heart's blood flow. The heart is customarily at a standstill and made to chill while the heart-and-lung machine keeps the patient alive. In this shreds of veins are detached from the patient's legs and grafted. The surgery is performed in cases where angioplasty will not be effective.

The artery comes back to its original size in angioplasty even though the procedure is not surgical. One major drawback of angioplasty is that there are chances of re-blocking of the artery and the patients have to return for restenosis. Whereas CABG is more permanent. On the flip side at least patients have a chance of returning for the procedure after angioplasty but after a bypass in case there is blockage they may not be able to get another surgery as adequate quantity of veins are not there for grafting. Even if they are able to return the experience of a second surgery is much more traumatic than a second angioplasty. In some cases angioplasty is not an option and the patients have to go for surgery, people having multiple blockages or diabetic patients do not have the option of angioplasty. In case the patient is very old then they are not able to withstand the trauma of a bypass surgery; in such cases angioplasty is the only option.

Complications during Angioplasty

The procedure is considered to be safe and has no fatal consequences. Serious complication may occur in few rare cases anyhow the percentage of these complication is just about one to five percent.

These include:

- The lining of the artery might tear and result in complete blockage of the artery and may lead to a heart attack. However this is rectified with the help of the stent
- Chances of a stroke due to the displacement of a clot when the catheter is inserted in the body
- Punctured blood vessel may lead to bruising in few cases.

- Could lead to kidney disorder in people suffering from diabetes or kidney disease due to the iodine in the dye.

Coronary Angiogram

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The procedure of angioplasty can be performed only after the angiography of the patient has been done. It is a procedure which involves X-raying the blood vessels so that the doctors are able to see the blood vessels and the blockages in the artery. The procedure provides the doctors with a guide-map for angioplasty.

The technique is a part of common procedures referred as cardiac catheterizations. These procedures help in not only diagnosing the condition of the blood vessel but also in treatment of the heart. A coronary angiogram is one of the general procedures of the group which helps in diagnosing the condition of the heart.

In this procedure, a kind of dye is inserted into the blood vessel of the heart. This is clearly seen in the X-ray machine, the machine takes angiograms or images so that the doctors can clearly see the blood vessels. In few cases doctors are able to un-block the arteries during this procedure itself.

Need for Angiogram

The doctors conduct the procedure when following symptoms appear:

- In case the patient complains of chest pain
- Unaccounted pain in neck, arm or jaws.
- Unstable angina
- In case the patient is suffering from defective heart from birth
- Irregular outcomes on a non-invasive heart test for stress
- Additional issues related to the blood vessels or an injury in the chest
- Problem in the valve of the heart requiring surgery

The angiogram is recommended by the doctors in most cases only after the non-invasive heart tests such as ECG and other heart stress tests have been undertaken as the procedure does have slight complications. The patients are at a risk of suffering from a stroke, heart attack, damage to the catheterized artery, reaction to the dye, damage to the kidney or even there is a risk of catching an infection. The procedure could result in arrhythmias or bleeding.

Check Your Progress

6. When is the technique of angioplasty used?
7. What happens during cardiovascular exercises?
8. How are the biological processes of the body managed?

6.7 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

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1. The most common congenial abnormality of the heart is the bicuspid aortic.
2. In physiology, the volume of blood that is pumped by the heart's ventricle either left or right per unit is referred to as the Cardiac output.
3. Systolic blood pressure denotes the extreme pressure which may be logged in arteries in the course of ventricular systole.
4. There are few factors like age, gender, lifestyle or even physic of the individual that have a direct impact on the level of the blood pressure in the body.
5. Hypertension (HTN or HT) is often referred as high blood pressure (HBP). It is a lasting medical condition wherein the pressure of the blood in the arteries is constantly high.
6. The technique of Angioplasty is used in order to treat a cardiovascular disorder. The technique is used to reopen a blocked or a nearly closed coronary artery of the heart.
7. During cardiovascular exercises large muscles are repeatedly used, the exercises activate the fibres that are pre-set for stamina and they utilise almost forty to eighty-five percent of the individual's heart rate.
8. The biological processes of the body are managed with the help of minerals found in the food. The body has a very small requirement of the minerals therefore an over-dose can cause a lot of harm.

6.8 SUMMARY

- In physiology, the volume of blood that is pumped by the heart's ventricle either left or right per unit is referred to as the Cardiac output. In other words it is merely the quantity of blood pumped by the heart in 60 seconds.
- The cardiac output is typically communicated in litres per minute. If the weight of the individual is roughly 70 kg then while resting the cardiac output would be approximately 5 litres in every sixty seconds and in case the heart rate is 70 beats per sixty seconds then the stroke volume may be around 70ml per beat or little more.
- Since cardiac output is correlated directly to the amount of blood supplied to several body parts therefore it acts as an indicator for exhibiting the efficiency of the heart in being able to meet the demands of perfusion of the body.
- Clinically there are many ways of measuring the cardiac output. This could be measured using the direct intracardiac catheterization or the non-invasive measurement of the arterial pulse.

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- Blood pressure can be referred to as the horizontal force applied on the wall of the blood vessel by column of blood flowing through it, blood pressure is also known as end arterial pressure.
- The state of high blood pressure is referred as hypertension; high blood pressure is not good as it will make the heart to exert added labour while pumping blood from the body and this also affects the arteries as they become hard.
- The palpatory method is widely used in OPDs, hospital wards and several places where the blood pressure needs to be measured frequently; it can be taken in places with loud noises and even in the absence of a stethoscope. This is a manual method of measuring the blood pressure.
- Hypertension (HTN or HT) is often referred as high blood pressure (HBP). It is a lasting medical condition wherein the pressure of the blood in the arteries is constantly high.
- High blood pressure is mainly of two types, namely the primary and secondary high blood pressure. The first type i.e. the primary high blood pressure is common and it develops as people become older. The second type, i.e. the secondary blood pressure occurs due to a health condition or by usage of particular medicines.
- Nutritious diet is very essential for a healthy heart. Diets that are balanced help in keeping the blood pressure and cholesterol in check. They not only reduce the risk of developing heart diseases but also contribute towards overall wellbeing. Consumption of a diet full of nutrients is best way to avoid heart related problems.
- The heart's chemical energy is mainly deposited in the metabolites which are the phosphoryl bonds like the ATP. This notion about phosphate bonds being the source of the chemical energy has been prevailing since many years.
- During cardiovascular exercises large muscles are repeatedly used, the exercises activate the fibres that are pre-set for stamina and they utilise almost forty to eighty-five percent of the individual's heart rate.
- The procedure of angioplasty can be performed only after the angiography of the patient has been done. It is a procedure which involves X-raying the blood vessels so that the doctors are able to see the blood vessels and the blockages in the artery.

6.9 KEY WORDS

- **Angioplasty:** It is also known as balloon angioplasty and percutaneous transluminal angioplasty, is a minimally invasive, endovascular procedure to widen narrowed or obstructed arteries or veins, typically to treat arterial atherosclerosis.

- **Peripheral resistance**: It is the resistance of the arteries to blood flow. As the arteries constrict, the resistance increases and as they dilate, resistance decreases.

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6.10 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. State the factors influencing the blood pressure.
2. Write a short note on the treatment of hypertension.
3. Write a short note on myocardial energy metabolites.
4. State the impact of cardiovascular activities on the heart.

Long Answer Questions

1. Describe the meaning and significance of blood pressure.
2. Discuss the elements that help in maintaining normal blood pressure.
3. 'Cardiac output is a universal parameter in haemodynamics for measuring and studying the blood flow of the body.' Discuss.
4. Analyse the techniques to identify cardiovascular disorders: angioplasty and angiogram.

6.11 FURTHER READINGS

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UNIT 7 RESPIRATORY SYSTEM

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Structure

7.0 INTRODUCTION

Humans and other living organisms need oxygen in order to survive. There is an interrelationship between the act of breathing and cellular respiration. The respiratory system helps organisms to breathe (inhalation and exhalation) so that oxygen can be pumped through the blood to the entire body and carbon dioxide can be removed from the blood stream. Further, with the help of this molecular oxygen, the cells can store energy in the form of nutrients (like sugar and fats), which is released in times of need in the form of hydrolysis and converted to adenosine triphosphate (ATP). Thus, the energy generated during this process of cellular respiration helps organisms to perform day-to-day activities. Also, the carbon dioxide is released from the tissue to the blood, from where it goes to the lungs and is then exhaled into the air.

7.1 OBJECTIVES

After going through this unit, you will be able to:

- Explain the anatomy and physiology of the respiratory system
- Describe the mechanism of respiration
- Analyse the gaseous exchange in lungs and tissues

- Describe the meaning of resuscitation and analyse its methods
- Discuss the different respiratory disorders and their treatment

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7.2 ANATOMY AND PHYSIOLOGY OF RESPIRATORY ORGANS

The human respiratory system automatically carries air in and out of the lungs (passively), in a repeated cycle of about 12–16 times per minute, that is, about 23,000 times per day. This system removes carbon dioxide from the body, the accumulation of which could turn fatal. The respiratory system consists of various organs and tissues and it can be divided into the following two parts:

- Conducting portion
- Gas-exchange portion

The conducting portion of the respiratory system consists of an elaborate set of passage ways that carry air into and out of the gas-exchange area. The alveoli present in lungs, provide that space, where the exchange of gases occurs. They have high vasculature of blood capillaries and form the structural and functional unit of the lungs.

The lungs are two large, sac-like organs located in the chest, that is, the thoracic cavity. The conduction of air through the respiratory tract can be described as follows:

- Initially, the air enters through the nose or mouth and then passes through the nasal or oral cavity into a common chamber called the pharynx.
- From the pharynx, the air travels through the larynx (also called as 'voice box') into the trachea which is a flexible tube with semi-circular bands of stiff cartilage making up its wall.
- The trachea further splits into two large branches called bronchi with each entering the lungs individually.
- Inside the lungs, each bronchus branches repeatedly into much smaller tubes called bronchioles.
- Finally, these bronchioles give rise to microscopic alveoli, which are tiny air sacs where gaseous exchange occurs.

Figure 7.1 shows the different components of the respiratory system.

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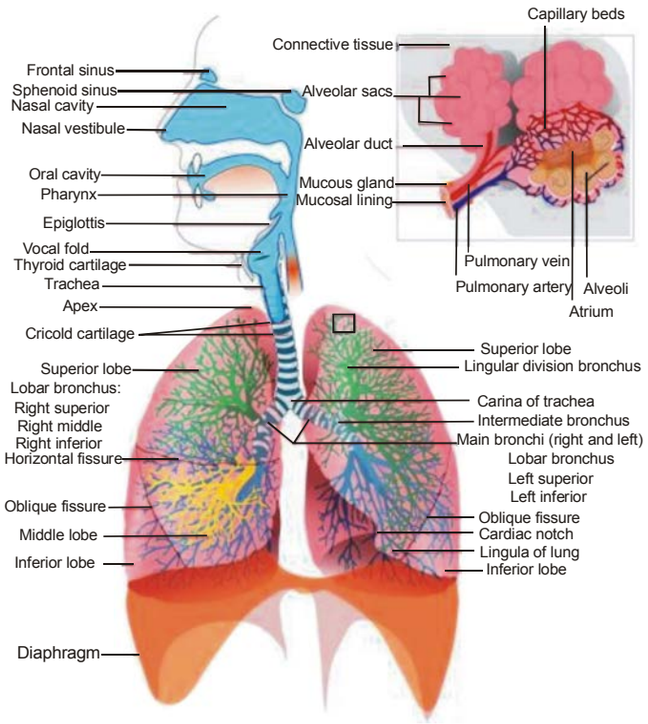

Fig. 7.1 *Respiratory System*

Functions of Respiratory System

The major functions of the human respiratory system are as follows:

- Its primary function is to regulate the exchange of gases. The gaseous exchange takes place in the lungs by diffusion, through the thin and moist alveolar surface which is covered with blood capillaries. Oxygen is passed from the alveoli into the bloodstream, which then distributes it to cells, where it is used for generation of adenosine triphosphate (ATP). The blood carries carbon dioxide (a waste product of food combusting with oxygen within cells) back to the capillaries, where it goes back to air through the walls of the alveoli and is breathed out during exhalation.
- The mucus in this system helps to protect it and carry debris out of the respiratory tract, which is assisted by the movements of little hair-like structures called cilia.
- Sound production is another secondary function of the respiratory system. Sounds are produced when the expired air passes through the vocal cords present in the larynx.
- It assists in abdominal compression during urination, defecation and parturition.
- It also assists during the processes of coughing and sneezing, which automatically clean the respiratory tract.

Anatomy of Human Respiratory System

Now you will learn about each part of the conducting portion of the respiratory system in detail.

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- **Nasal cavity:** The nose contains two nasal cavities, which are narrow canals separated from each other by a septum composed of bone and cartilage. The upper recesses of the nasal cavity contain ciliated cells that act as receptors. From these cells, the nerves travel to the brain, where the impulses are generated by the odour receptors. The function of the nasal cavity is to filter, warm and moisten the inhaled air and transport it to the pharynx. Figure 7.2 shows the nasal cavities.

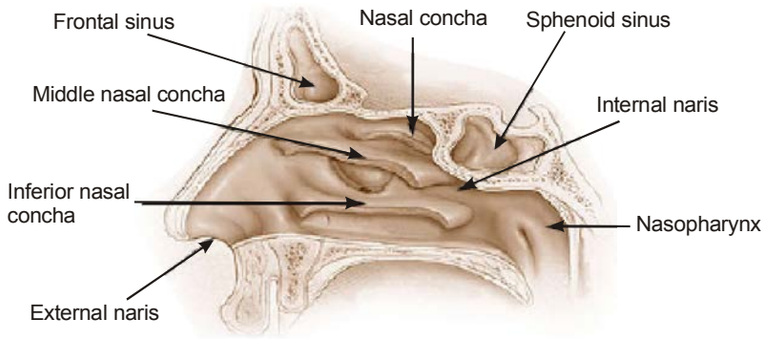

Fig. 7.2 *Different Parts of the Nasal Cavity*

  - **Oral cavity:** The air can be inhaled either through the nose or using the oral cavity. Air gets transported from the oral cavity to the pharynx.

- **Pharynx:** It is a funnel-shaped structure that opens into the nose and mouth anteriorly and joins with the larynx that lies below it. It has three parts—the nasopharynx (the nasal cavities open here), oropharynx (the oral cavity opens here) and the laryngopharynx (opening into the larynx). The function of the pharynx is to transport air to the larynx. It is in this region where the air and food passage cross, as the larynx is located ventrally to the oesophagus (which receives food). The larynx lies at the top of the trachea. During inhalation, the larynx and trachea are normally open but the oesophagus remains closed and opens only when the food is swallowed.
- **Larynx:** The larynx is a triangular, rigid, hollow structure which contains the vocal cords. The vocal cords are two folds of elastic ligamentous tissue that vibrate when we talk, sing or hum and so, it is also called a 'voice box'. The vocal cords contribute to the production of a range of sounds for communication in human beings through its own vibration when air is expelled from the lungs. The sounds thus generated can be modified with change in the shape of tongue and oral cavity. It is interesting to note that the vocal cord varies in length and thickness from one person to another. They also vary between males and females. Men have longer and thicker vocal cords than women and hence their voices are comparatively deeper than that of

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the latter. The vocal cords have often been compared to the strings of a guitar that can be tightened or loosened, thereby producing sounds of different pitch. The muscles that attach the vocal cord to the larynx help in tightening or loosening the vocal cord. Thus, relaxation of these muscles decreases the tension on the cords, thus dropping the tone and vice-versa. Besides this, the apex of the triangular larynx is called the Adam's apple which is situated in front of the neck. It is more prominent in men than in women. Figure 7.3 shows the anatomy of a larynx.

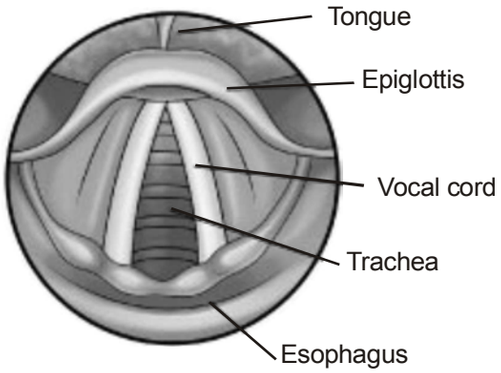

Fig. 7.3 *Anatomy of Larynx*

- **Epiglottis:** It is a flap of tissue supported by cartilage that guards the opening of the pharynx to the larynx. During normal breathing, the epiglottis gets tilted upwards thereby letting the air flow into the larynx. On swallowing food, this epiglottis is tilted downwards, thus covering the larynx and allowing the food to pass directly into the esophagus instead. Whenever an individual tries to inhale as well as swallow at the same time, this reflex fails and food gets lodged in the larynx. Hence, the air is blocked from entering the lungs and this also can lead to the death of an individual.
- **Trachea:** It is commonly called the windpipe and is a flexible tube connecting the larynx to the primary bronchi. The trachea lies ventral to the oesophagus and its walls are reinforced with semicircular bands of stiff cartilage. This allows the oesophagus to expand when swallowing. There is a lining of pseudostratified ciliated columnar epithelium on the inner side of the trachea where the cilia keep the lungs clean. These cilia clean up the mucus produced by goblet cells by a sweeping mechanism towards the pharynx. Smoking can result in destroying these cilia which can lead to further complications.

- **Bronchi:** The trachea further splits into two large branches called the right and left primary bronchi within the chest. Each bronchus enters each of the lungs on either side, followed by further repeated branching into even smaller tubes called bronchioles. These bronchioles finally lead to the microscopic alveoli (Figure 7.4).

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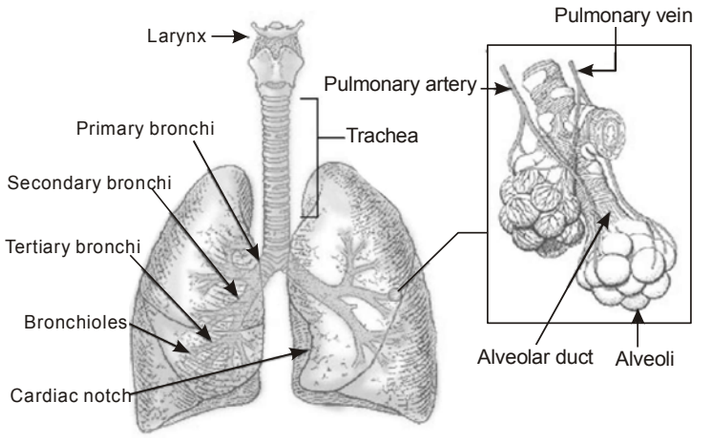

***Fig. 7.4** Bronchi*

- **Lungs:** A pair of lungs is present inside the thoracic cavity of human beings, which are large cone-shaped organs. Though similar in appearance, the two are not identical. The left lung has a cardiac notch on its medial surface which is a concave impression molded to accommodate the shape of the heart It is subdivided into two lobes by a single fissure and contains eight bronchial segments. The right lung does not have a notch but is subdivided into three lobes by two fissures and contains ten bronchial segments. Each lung presents four borders that match the contour of the thoracic cavity and a layer called mediastinum separates them from each other. The mediastinal surface which is concave has a vertical indenture (hilum) and pulmonary vessels, a primary bronchus and branches of the vagus nerve that pass through the hilum.

  Each lung is composed of lobes which in turn constitutes the lobules which contain alveoli. The environment of the lung is very moist making it hospitable for bacteria that result in bacterial or viral infections of the lungs. An inflammation in the lungs is known as pneumonia.

  The base of the lung has a diaphragmatic surface which lies in contact with the diaphragm, whereas the top surface of the lung is called the apex. There is also a broad and rounded surface (costal surface) which lies in contact with membranes covering the ribs.

  The lung is lined by double membranous structures called the pleurae, which are composed of simple squamous epithelium and fibrous connective tissues. The inner layer called the visceral pleura is attached to the surface of the lungs, while the outer layer called the parietal pleura is present outside the visceral pleura. The function of pleurae is to lubricate the lungs and also assist in the creation of respiratory pressure. There is also a damp pleural cavity between the visceral and parietal pleurae of each lung. The pleural cavity plays a role in the influx of air in the lungs as the air pressure in each cavity is a bit below the atmospheric pressure in the case of resting lungs

and it becomes even lower during inspiration, causing atmospheric air to inflate the lungs (Figure 7.5).

Inflammation of the pleurae is called pleurisy and it can be associated with some kind of respiratory disease or other, due to an autoimmune reaction associated with viral infections or autoimmune diseases. Pleurisy can be treated by anti-inflammatory drugs like aspirin, ibuprofen and corticosteroids etc.

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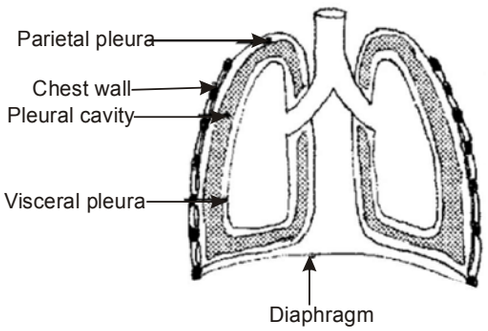

Fig. 7.5 *Parts of Lungs*

- **Alveoli:** These are tiny air sacs made up of simple squamous epithelium surrounded by blood capillaries where gaseous exchange takes place. It makes up the inner surface of the lungs and there are about 300 million alveoli in the two lungs (combined) along with a combined surface area of 143 square meters. This enormous surface area contributes to gaseous exchange for oxygen (O_2) inlet and carbon dioxide (CO_2) outlet, thus supplying oxygen to various cells in the body for many metabolic needs. These microscopic chambers (0.2 mm diameter) of the alveoli give the appearance of a pink sponge-like lung tissue. Type 1 and 2 pneumocytes form the major proportion of the surface of the alveoli. Type 2 pneumocytes are involved in producing surfactant and are the originator of type 1. Most of the alveolar surface (95 per cent) is covered by type I cells. These are flattened cells, which are unable to divide, contain just a few organelles and serve as a thin barrier between blood and air (Figure 7.6). Type 1 cells are mainly involved in gaseous exchange and defense mechanisms. Alveolar macrophages are also found in the alveolar wall which are phagocytic and whose function is to remove the dust particles or other debris from the pulmonary alveoli. These pulmonary alveoli help in the mechanism of gaseous exchange with the blood. The alveoli are covered with a network of capillaries that cover about 85 per cent of their surface. These alveoli are lined with a thin layer of fluid containing an oily secretion called surfactant. It reduces the surface tension and prevents a collapse of the alveoli during exhalation. Cigarette smoking can lead to a lung disease called emphysema where the harmful substances of cigarette smoke ruptures the alveoli, thereby reducing the surface area available for gaseous exchange to a great extent.

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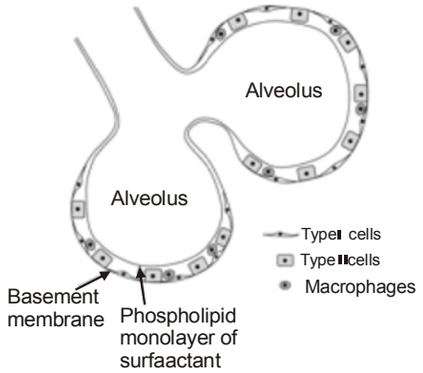

Fig. 7.6 *Alveoli and Cellular Components*

Check Your Progress

1. Define tidal volume.
2. What is a larynx?
3. What is the foremost requirement of the tissues?

7.3 MECHANISM OF RESPIRATION

The lungs are a pair of large lobes situated in the chest or the thoracic cavity. A thin sheet of epithelium (pleura) separates the inside of the chest cavity from the outer surface of the lungs. As you already know, the membrane covering the outside of the lungs is the visceral pleural membrane while that lining the inner wall of the thoracic cavity is called the parietal pleural membrane. The space between these two membranes is called the pleural cavity and is filled with pleural fluid. A muscular, dome-shaped diaphragm forms the bottom of the thoracic cavity. The process of breathing occurs in two stages, which are as follows:

1. **Inhalation:** It is the process of taking air into the lungs. This is in accordance with Boyle's Law which states that when the volume of a given quantity of gas increases, its pressure decreases. This is implemented when the thoracic cavity is enlarged to perform inhalation. During this, the muscles of the diaphragm contract, drawing the diaphragm downwards. Simultaneously, external intercostals muscles contract thereby lifting the ribs up and outward. The final outcome is the expansion of the lungs with the creation of a partial vacuum that draws air into the lungs. Each contraction involved in this process is stimulated by impulses from the nerves that originate in the respiratory center located in the medulla of the brain. The atmospheric pressure is 760 mmHg in normal conditions. Inside the lungs, there are two main regions where the pressure of the air is regulated for the inflow of the air. The two pleural layers are always at lower pressure than the atmosphere.

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2. **Exhalation:** It is a passive process in which air is thrown out of the lungs, back into the atmosphere. Due to inherent elasticity of the lung tissue, it recoils back to a lower volume. This occurs when the diaphragm and the external intercostal muscles get relaxed. As a result, the diaphragm projects upward with simultaneous falling back of the ribs downward and inward. In a forced exhalation, internal intercostal muscles also contract (in forced expiration). This causes a decrease in the size of the chest cavity and the air is forced out of the lungs. This form of passive relaxation of the respiratory muscles is also under the impact of impulses from the respiratory center. A pressure of 762 mmHg is created as the volume inside the lungs decreases and this causes air to flow out of the lungs.

Respiratory Air Volumes

The total capacity of the lungs can be expressed as the sum of four volumes—tidal volume, inspiratory reserve, expiratory reserve and residual volume. The volumes are associated with different phases of respiratory cycle and can be understood as follows:

- **Tidal volume:** Tidal volume (TV) can be defined as the amount of air which is breathed in or out during normal respiration and it varies depending on the person.
- **Inspiratory reserve volume (IRV):** The inspiratory reserve volume can be defined as the air that can be inhaled after a normal breath in, along with the tidal volume.
- **Expiratory reserve volume (ERV):** It is the volume of air that can be expirated out after all the air has been exhaled out tidally (normal breath).
- **Residual volume (RV):** At the end of a normal exhalation, the volume of air that the lungs contain consists of the residual volume and the expiratory reserve volume. If you forcefully exhale out the air further to a limit, the air which is exhaled is called the expiratory reserve volume and the air that remains inside the lungs is called the residual volume. This is the amount of air that always remains inside the lungs and it can never be exhaled out and can not be measured by spirometry.
- **Total lung capacity:** Total lung capacity is defined as the total volume of the lung which is none other than the volume of air present in the lung at the end of maximal inspiration. It can be calculated as follows:

  TLC = IRV + TV + ERV + RV (6000 ml)
- **Vital capacity:** It can be defined as the maximum amount of air that can be expelled out from the lungs after a maximum inspiration. It is equal to the inspiratory reserve volume and the tidal volume along with the expiratory reserve volume. It is calculated by the following formula:

  VC= IRV+TV+ERV (4800 ml)

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- **Forced vital capacity:** It is the amount of air that can be maximally forced out of the lungs after a maximal inspiration.
- **Functional residual capacity:** It can be defined as the amount of air left in the lungs after a normal breath out which is equal to the sum of residual volume and expiratory reserve volume.

  FRC = ERV + RV (2400 ml)
- **Inspiratory capacity:** It is defined as the maximal volume of air that can be inhaled after a normal expiration.

  IC = TV + IRV (3600 ml)

All these air volumes are measured by an instrument called a spirometer that records the rate and the amount of air which is breathed in and out over a specified period of time. It has extensive use in medicine in diseases such as asthma, bronchitis and emphysema which involves the use of pulmonary function tests (PFTs).

7.3.1 Gaseous Exchange in Lungs and Tissues

The law of gas states that single gases flow from areas of greater partial pressures towards lower partial pressure areas; the same rule applies to the gaseous exchange in the lungs and tissues.

Standard alveolar P_{O2} is around 100 mm Hg. The P_{O2} of systemic venous blood received by the lungs is 40 mm Hg. For this reason oxygen travels down the partial pressure gradient through the alveoli inside the capillaries. Diffusion reaches equilibrium, and the P_{O2} of arterial blood exiting the lungs is similar to the alveoli i.e. 100 mm Hg.

The gradient is completely reversed once the tissue capillaries receive the blood. Oxygen is constantly being used by the cells for oxidative phosphorylation. Averages intracellular P_{O2} in a person in rested state is 40 mm Hg in the cells. Arterial blood reaching the cells contains a P_{O2} of 100 mm Hg. Since the P_{O2} is lesser in the cells, diffusion of oxygen is downward from the partial pressure gradient through the plasma to the cells. One more time the diffusion reaches equilibrium, thus the venous blood to have similar P_{O2} as the cells through which it has travelled.

On the contrary the tissues have a higher P_{CO2} as compared to the blood in the systemic capillary as in the process of metabolism CO_2 is produced. Average P_{CO2} in the cells of a person in a rested state is around 46 mm Hg, whereas it is 40mmHg in the arterial plasma of a person in a rested state. The gradient makes the CO_2 to diffuse from the cells into the capillaries. Diffusion travels to equilibrium, and average P_{CO2} in systemic venous blood is 46 mm Hg.

The process is completely reversed in the pulmonary capillaries. Venous blood from the cells brings waste CO_2 with 46 mm Hg P_{CO2}. The P_{CO2} in Alveolar is 40 mm Hg. Since the plasma has more P_{CO2}, the CO_2 leaves the capillaries and moves into the alveoli. At this stage the P_{CO2} of alveoli is 40 mm Hg.

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A Reduction in Alveolar P_{O2} Drops Oxygen Delivery at the Lungs

The foremost requirement of the tissues is to have adequate supply of oxygen and this delivery of oxygen is dependent on the atmospheric intake. This is visible through the P_{O2} of the alveoli. A drop in alveolar P_{O2} has a direct impact on the levels of oxygen in the blood; there is a drop in oxygen levels coming into the blood. Low levels of P_{O2} in the alveolar could be because of two reasons firstly the air in the atmosphere has exceedingly low levels of oxygen. And secondly there is inadequate ventilation in the alveolar.

The primary reason for exceedingly low levels of oxygen in the atmospheric air could be due to the altitude. As the air travels higher and moves away from the sea-level there is a decrease in the partial pressure of oxygen in the atmosphere (atmospheric pressure is 760 mm Hg) to higher altitudes. For instance if a city is 1609 m above sea level then its atmospheric pressure will be around 628 mm Hg. The level of dry air, P_{O2} will be 132 mm Hg; there will be a drop from 160 mm Hg at sea level.

There is a change in the altitude only when the individual is travelling; at other times it continues to be stable. In case the composition of the atmospheric air is normal, still the P_{O2} is low in that case there is inadequate ventilation of the alveolar. Low alveolar ventilation is referred to as hypoventilation as well and this state happens when very less quantity of outside air enters the alveoli. Extreme factors which lead to alveolar hypoventilation is when the lungs are not complaint and have been subjected to an excessive dose of medicines or high intake of alcohol. These result in dropping the rate of ventilation and strain the nervous system generally.

7.4 RESUSCITATION AND ITS METHODS

The process of rectifying physiological conditions for a person who is severely unwell is referred to as resuscitation. The process is an essential element of the intensive care medicine, surgeries related to trauma and medication during emergencies. Cardiopulmonary resuscitation and mouth-to-mouth resuscitation are two of the most common examples of the process.

Cardiopulmonary resuscitation (CPR) is a technique which helps in saving lives. It tries to maintain the body's flow of blood and oxygen even once the individual's heart and breathing are not functioning. A person trained in CPR will be able to perform the technique efficiently as it requires administering compressing the chest externally and rescuing breathing.

In case the CPR is administered in time it can help in keeping the person alive till the time an ambulance arrives with medical aid. It needs to be administered within the initial five minutes from the time since the heart stops functioning.

Even during the eighteenth century breathing techniques were used in order to revive victims of drowning but it was only in the 1960s that the cardiac message

given externally came to be regarded as an effectual technique for reviving patients. A formal program for CPR has been developed by the AHA.

Methods of Resuscitation

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Cardiopulmonary resuscitation (CPR) can be referred to as a lifesaving process. It helps in preserving the functions of the brain by maintaining the blood flow and breathing till proper medical help can be arranged. The process is a combination of compressing the chest along with providing ventilation artificially to revive a person suffering from cardiac arrest. It may be administered on unresponsive individuals who have stopped breathing or breathing abnormally and with effort for instance it is used during agonal respirations.

In CPR for adults, the chest compressions are between 2.0 inches and 2.4 inches in depth and the rate has to be from 100 to 120 per sixty seconds. The provider of CPR may also need to give ventilation artificially by breathing into the victim's mouth or nose; this is referred as mouth-to-mouth resuscitation and performed manually sometimes if available then mechanical ventilation into the lungs of the victim with the help of a device is also provided. The process of CPR with chest compressions is preferred and recommended over the artificial ventilation in most conditions. The CPR through chest compressions can be provided by an untrained individual as well. In case of children just giving chest compression can worsen their condition. In adults the ratio of chest compression and breathing is established as 30 to 2.

As stated above the process needs to be administered in four to six minutes after the breathing stops so that damage to the brain can be prevented and the person's life can be saved. CPR entails two aspects firstly, rescue breathing; this helps in supplying oxygen to the lungs of the victim and secondly providing chest compressions externally so that the flow of blood continues to the heart and other parts of the body.

The technique of CPR is administered differently for new born, children, and teenagers. Both AHA and the American Red Cross have provided the guidelines for the same and they have also specified the categories with their limits. The new-born or infants include babies less than a month old up till they are one year old. In the second category are children and toddlers starting till the age of eight years and above eight years all fall under the adult category.

There is a difference in the way CPR is administered for children below the age of eight because their upper and lower airways are smaller and adults have a slower heart rate as compared to children below eight years. The body size of children of eight and above can cope with the technique and pressure used during CPR, hence there is no difference after the age of eight.

Precautions

The individual administering CPR should be completely aware of the steps and procedure involved in the technique. The process of rescue breathing should be

done wearing face mask and covers so that the chances of transmitting any disease is ruled out.

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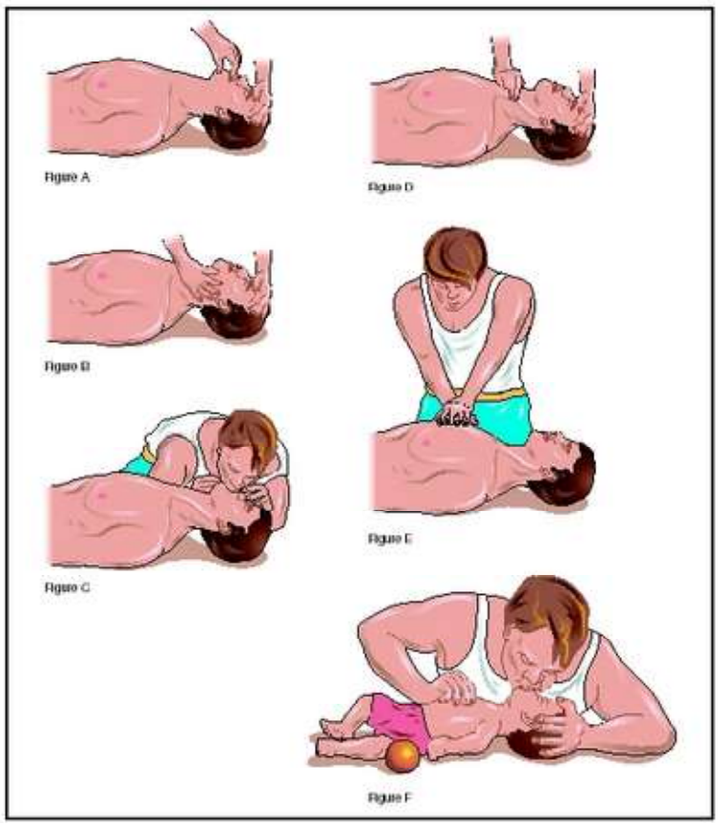

***Fig. 7.7** CPR as Primary Life Support*

Figure A shows that the victim needs to lie flat on his/her back and the mouth needs to be checked so that there are no fragments inside.

Figure B shows in state of unconsciousness the victim's head should be titled back, airway needs to be opened and neck should be lifted.

Figure C shows: In the absence of breath the victim should be given quick four breaths artificially.

Figure D shows that the carotid pulse needs to be checked

Figure E shows that in the absence of pulse, artificial circulation needs to be started with the help of depressing sternum.

Figure F shows administering of Mouth-to-mouth resuscitation to a new born.

Post-CRP Care: After administering CRP it is essential to provide medical care. Once the victim is stable he/she needs to be made to feel comfortable and motivated till the medical help arrives. They should not be left alone till they are under medical supervision.

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Risk Factor: The procedure does not involve any major risks and at the end a life is saved but in some cases there could be chances that the victim's ribs, may suffer an injury, this could cause chest pain in some cases.

Outcome of CPR: Most cases the individual regains consciousness and is able to function normally within a couple of hours. Sometimes when CPR is not completely successful the person might suffer from a damaged brain or loss of life.

The need for all individuals to be trained in giving CPR is strongly felt in present times especially for parents of young children so that the child can be saved in time from drowning, choking because of toys and other such traumas. There are many hospitals and organisations which offer CPR training completely free of cost.

7.5 RESPIRATORY DISORDERS: DYSPNOEA, ASPHYXIA, HYPERPNOEA, ORTHOPNOEA

Respiratory disease or disorder covers several pathogenic illnesses which have an impact on the living being's respiration process. In higher living beings respiration helps in exchange of gases. The exchanging of gases refers to inhaling oxygen and exhaling carbon dioxide. The disorder takes place in the respiratory tract; this consists of the alveoli, bronchi, bronchioles, pleura, cavity in the pleural, trachea and the nerves and muscles involved in breathing.

Respiratory disease is mainly of three kinds namely:

- **Airway diseases**: In these the tubes circulating the oxygen and other gases are affected, they are narrowed or blocked, hampering the flow.
- **Lung tissue diseases**: The arrangement of lung tissues is affected in these disorders. There is swelling and scarring of the tissues in the lungs and because of that the person is not able to breathe comfortably and there is difficulty.
- **Lung circulation diseases**: Occurs due to clotting, swelling or scarring of the lung's blood vessels. The disorder impacts the lungs ability to receive oxygen and production of carbon dioxide takes place. This disorder has an effect on the functions of heart as well.

The common factors for respiratory diseases include allergens, air pollution, smoking from cigarettes etc. In recent times more than 250 million people suffer from asthma all over the world.

7.5.1 Respiratory Disorder: Dyspnoea

Sometimes individuals are unable to breathe in presence of adequate air, they are mostly suffering from a medical condition termed as dyspnoea. Being short of breath should not be ignored as it can be an indication of disorders concerning the heart or lungs. However feeling breathless after a vigorous workout may be caused due to temporary dyspnoea and need not be a cause of worry.

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Symptoms

Having difficulty in breathing is one of the primary symptoms of dyspnoea. The difficulty in breathing could last for few minutes after exertion or it may be a long lasting issue. The individual in spite of adequate presence of air might feel that there is shortage of air in the lungs. Cases of advanced stage might feel suffocated due to difficulty in breathing. An attack of dyspnoea could lead to feeling tightness in the chest.

Breathlessness after a vigorous workout may be ignored but in case following symptoms persist then medical advice should be taken:

- Feeling of breathless soon after starting any physical exercise.
- Excessive breathless after usual workout.
- Experiencing dyspnoea in a rested state

Causes

It is very normal to feel short of breath after a run or a swim and as soon as the body cools down the breathing becomes normal. This state is referred to as temporary dyspnoea and is caused due to temporary lack of oxygen after any workout. A healthy body recoups from this state in a couple of minutes. Therefore exercising causes temporary dyspnoea, sometimes travelling in places at a high altitude causes this as the level of oxygen is low and body takes time to get acclimatised to the lower levels of oxygen. But people suffering from this disorder are not able to adjust to the lack of oxygen at very high altitude regions. It is important that before visiting such regions they consult with their doctor.

In case an individual is suffering from medical condition of dyspnoea and it is not temporary it may cause several health issues such as:

- Failure of heart
- Low levels of blood pressure
- Pneumonia
- Pulmonary embolism
- Poisoning due to excessive carbon monoxide
- Increases levels of stress or nervousness

Dyspnoea may be experienced in case a food particle gets stuck in the windpipe; there is a sudden feeling of choking. Breathlessness is felt due to excessive loss of blood resulting from an injury or strain on the lungs may also cause dyspnoea.

Chronic dyspnoea becomes a cause of many other disorder and malfunctions in the body, some of these include:

- Chronic obstructive pulmonary disease (COPD), this includes emphysema and chronic bronchitis
- Causes scaring in the tissues of the lungs resulting in interstitial lung disease

- Weak physical condition of the body
- Leads to obesity
- Becomes a cause for heart disease

NOTES

Asthma may be described as a chronic dyspnoea or temporary one. An individual suffering from asthma needs to carry their inhalers in order to treat unexpected attacks.

7.5.2 Respiratory Disorder: Asphyxia

An abnormal breathing condition wherein the body is unable to get sufficient supply of oxygen is referred to as Asphyxia or asphyxiation. This condition can cause choking as well. Generalised hypoxia is caused by asphyxia and that has a direct impact on the tissues and other parts of the body. Asphyxia could be caused due to a number of factors and in all of them the individual is unable to get adequate supply of oxygen for a long duration, this state could cause coma or even loss of life. Over the years many people have lost their life due to this disorder, in 2015, alone more than 35000 people lost their lives due to suffocation. The term has been derived from old Greek words, "á" means in the absence of and "sphyxis" means throbbing of the heart.

Causes of Asphyxia

Whenever this is an obstruction in the airways asphyxia is caused. This happens during an asthmatic attack, laryngospasm, or unpretentious blocking due to external particles. It can be caused by being in an environment where the levels of oxygen are generally low like high altitude, underwater or vacuumed surroundings. The symptoms can occur during high levels of air pollution as in spite of the supply of air it is not fit for breathing, areas with lots of smoke make it difficult to breathe.

The disorder can be caused due to,

- Severe respiratory discomfort syndrome
- Inhalation of Carbon monoxide rising out of motor exhaust
- Inhaling cigarette smoke

Presence of carbon monoxide in the respiratory system displaces the oxygen and prevents the blood from supplying oxygen to various parts of the body.

- Interaction with particular chemicals such as phosgene and such as hydrogen cyanide
- In the event of drowning
- Over-dosage of medicines
- Being exposed to areas with extremely extreme low pressure or vacuumed environment such as space
- Being suspended in the air

NOTES

- Holding of breath for long
- During hyperventilation
- Inactive gas asphyxiation
- Patients suffering from primary alveolar hypoventilation
- Respiratory disorders
- Sleep apnea
- An attack which hinders breathing action
- Choking
- Breach in the wind pipe.
- Continued contact with chlorine gas

7.5.3 Respiratory Disorder: Hyperpnoea

Hyperpnoea refers to augmented breathing. The rise in the amount of air inhaled in every sixty seconds is termed as hyperpnoea.

Causes of Hyperpnoea

- Voluntary
- Influx of emotions provides impulse from the cerebral cortex of the respiratory epicentres
- Compulsions from the hypothalamus
- Reflex due to the stimulus of general sensations of the nerves like feeling of pain, hot or cold
- Physical activity which increases the rate of metabolism, the demand for oxygen is increased and even there is an increase in the production of carbon dioxide.
- All the factors that cause dyspnoea will obviously result in hyperpnoea.

7.5.4 Respiratory Disorder: Orthopnea

Individuals suffering from lack of breath or experience difficulty in breathing at the time of lying down are said to be suffering from orthopnea. It has a Greek origin and has been derived from two words, "ortho," denotes vertical or straight and "pnea," denotes ability to breathe. People suffering from this disorder will have difficulty in breathing whenever they are positioned vertically, the condition is not visible while sitting or standing. Most people suffering from orthopnea are very prone to suffer from heart failure as well.

Orthopnea and dyspnoea are not same disorders as in the latter there is discomfort felt at all times but in orthopnea the discomfort is felt only while lying down and there is no discomfort in performing other activities.

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The disorder has many variations, these include:

- The difficulty in breathing felt during standing is referred to as Platypnea.
- The difficulty of breathing felt while lying on one side is referred to as Trepopnea.

Symptoms of Orthopnea

The symptom of the disorder are realised at the discomfort felt in breathing at the time of lying down. People try to ease their breathing by taking more number of pillows; in fact the number of pillows taken to relieve the discomfort also confirms the seriousness of the disorder. People taking more than three pillows are acutely suffering from orthopnea.

Causes of Orthopnea

When the pressure increases on the blood vessels of the lungs it causes orthopnea. In vertical position the blood flows back to the heart from the legs and reaches the lungs. People suffering from heart disorders experience discomfort during this transporting when they are in a lying down position. The heart lacks the strength to pump out the additional blood and therefore there is an increased pressure in the veins and capillaries of the lungs. This causes leaking of fluids into the lungs and this extra fluid become the cause of breathing discomfort.

In few instances people suffering from pulmonary disease develop orthopnea as there is excessive production of mucus in the lungs. The lungs are not able to clear mucus when the body is in a vertical position.

Additional causes of orthopnea are as follows:

- Presence of excessive fluids in the lungs
- Acute pneumonia
- Over-weight
- In cases of pleural effusion due to fluid accumulation around the lung
- In cases of ascites due to fluid accumulation inside the abdomen
- During diaphragm paralysis

Check Your Progress

4. What is resuscitation?
5. Define Cardiopulmonary resuscitation (CPR).
6. What cases call for serious medical advice in case of breathlessness?

7.6 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

NOTES

1. Tidal volume (TV) can be defined as the amount of air which is breathed in or out during normal respiration and it varies depending on that person.
2. The larynx is a triangular, rigid, hollow structure which contains the vocal chords.
3. The foremost requirement of the tissues is to have adequate supply of oxygen and this delivery of oxygen is dependent on the atmospheric intake.
4. The process of rectifying physiological conditions for a person who is severely unwell is referred to as resuscitation. The process is an essential element of the intensive care medicine, surgeries related to trauma and medication during emergencies.
5. Cardiopulmonary resuscitation (CPR) can be referred to as a lifesaving process. It helps in preserving the functions of the brain by maintaining the blood flow and breathing till proper medical help can be arranged.
6. Breathlessness after a vigorous workout may be ignored but in case following symptoms persist then medical advice should be taken:
   - Feeling of breathless soon after starting any physical exercise.
   - Excessive breathless after usual workout.
   - Experiencing dyspnoea in a rested state

7.7 SUMMARY

- The human respiratory system automatically carries air in and out of the lungs (passively), in a repeated cycle of about 12–16 times per minute, that is, about 23,000 times per day. This system removes carbon dioxide from the body, the accumulation of which could turn fatal.
- The conducting portion of the respiratory system consists of an elaborate set of passage ways that carry air into and out of the gas-exchange area. The alveoli present in lungs, provide that space, where the exchange of gases occurs.
- The nose contains two nasal cavities, which are narrow canals separated from each other by a septum composed of bone and cartilage. The upper recesses of the nasal cavity contain ciliated cells that act as receptors.
- The larynx is a triangular, rigid, hollow structure which contains the vocal cords. The vocal cords are two folds of elastic ligamentous tissue that vibrate when we talk, sing or hum and so, it is also called a 'voice box'.

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- The trachea further splits into two large branches called the right and left primary bronchi within the chest. Each bronchus enters each of the lungs on either side, followed by further repeated branching into even smaller tubes called bronchioles.
- The lungs are a pair of large lobes situated in the chest or the thoracic cavity. A thin sheet of epithelium (pleura) separates the inside of the chest cavity from the outer surface of the lungs.
- The law of gas states that single gases flow from areas of greater partial pressures towards lower partial pressure areas; the same rule applies to the gaseous exchange in the lungs and tissues.
- The primary reason for exceedingly low levels of oxygen in the atmospheric air could be due to the altitude. As the air travels higher and moves away from the sea-level there is a decrease in the partial pressure of oxygen in the atmosphere (atmospheric pressure is 760 mm Hg) to higher altitudes.
- The process of rectifying physiological conditions for a person who is severely unwell is referred to as resuscitation. The process is an essential element of the intensive care medicine, surgeries related to trauma and medication during emergencies.
- Even during the eighteenth century breathing techniques were used in order to revive victims of drowning but it was only in the 1960s that the cardiac message given externally came to be regarded as an effectual technique for reviving patients.
- Respiratory disease or disorder covers several pathogenic illnesses which have an impact on the living being's respiration process. In higher living beings respiration helps in exchange of gases. The exchanging of gases refers to inhaling oxygen and exhaling carbon dioxide.
- Sometimes individuals are unable to breathe in presence of adequate air, they are mostly suffering from a medical condition termed as dyspnoea. Being short of breath should not be ignored as it can be an indication of disorders concerning the heart or lungs.
- When the pressure increases on the blood vessels of the lungs it causes orthopnea. In vertical position the blood flows back to the heart from the legs and reaches the lungs. People suffering from heart disorders experience discomfort during this transporting when they are in a lying down position.

7.8 KEY WORDS

- **Orthopnea**: It is shortness of breath (dyspnea) that occurs when lying flat, causing the person to have to sleep propped up in bed or sitting in a chair.
- **Asphyxia:** It is a condition arising when the body is deprived of oxygen, causing unconsciousness or death; suffocation.

- **Cardiopulmonary resuscitation (CPR):** It is an emergency procedure that combines chest compressions often with artificial ventilation in an effort to manually preserve intact brain function until further measures are taken to restore spontaneous blood circulation and breathing in a person who is in cardiac arrest.

7.9 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. State the functions of respiratory system.
2. Comment on the gaseous exchange in lungs and tissues.
3. What are the three kinds of respiratory diseases?
4. State the causes of Hyperpnoea.

Long Answer Questions

1. With the help of relevant diagram, explain the anatomy of human respiratory system.
2. Describe the role of respiratory air volumes.
3. 'The technique of CPR is administered differently for new born, children, and teenagers.' Discuss.
4. Differentiate between the respiratory diseases Dyspnoea and Asphyxia.

7.10 FURTHER READINGS

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UNIT 8 DIGESTIVE SYSTEM

NOTES

Structure

8.0 INTRODUCTION

The digestive system involves a series of hollow organs, which are linked to one another. These organs take active part in the process of digestion. The process of digestion can be defined as 'a process in which larger and bigger food particles are broken down into smaller fragments so that the nutrients can become accessible for absorption by the system.' The absorbed nutrients are used for the process of 'cell respiration', which releases energy or are utilized for various anabolic processes. Often, digestive system is also termed as gastrointestinal (GI) system, which starts from mouth and ends at anus. All the organs associated in the process of digestion form a gastrointestinal system as a whole. These organs are – mouth, pharynx, oesophagus, stomach, small intestine, large intestine, rectum, liver and

pancreas. Various secretory organs are – salivary glands, liver and pancreas. These organs drain their juices into the gastrointestinal tract (GIT). These secretions contain various digestive enzymes, which are responsible to break the complex molecules into the simpler molecules.

This unit describes the structural and functional aspects of the digestive system.

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8.1 OBJECTIVES

After going through this unit, you will be able to:

- Understand the basic physiology and anatomy of the organs of oral cavity
- Understand the physiology and anatomy of stomach, small intestine and large intestine
- Explain the internal structure of GIT and associated organs
- Identify the basic composition of the secretions from liver and pancreas
- Discuss the process of digestion, absorption and excretion of food
- Describe the function of liver, including description of liver tree and gall bladder

8.2 PHYSIOLOGY AND ANATOMY OF ORGANS OF ORAL CAVITY

The organs included in the digestive system start from mouth, followed by pharynx, oesophagus, stomach, small intestine, large intestine, rectum and anus, in the last. These main components of the GIT are connected to a series of ducts, which are salivary gland, liver, pancreas and gall bladder. Scientists often divide gastrointestinal tract on the bases of their location in the GIT, which is as follows:

Upper gastrointestinal tract: The upper GIT can be divided into mouth cavity, pharynx, oesophagus, stomach and duodenum.

Lower gastrointestinal tract: The lower GIT can be divided into small intestine and large intestine. Small intestine can further be divided in to duodenum, jejunum and ileum; whereas, large intestine can be divided into caecum, colon and rectum.

All organs play a specific, important and vital role in the digestive system. In brief, the role of every organ is as follows:

- Mouth is an entrance for the food particles where they are chewed mechanically and their sizes are reduced to ease the 'swallowing process.' The process of ingestion, i.e., intake of food occurs here. Salivary glands located in the mouth release saliva for lubrication during the process.
- Oesophagus is a channel that connects the mouth to stomach.

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- Stomach is the place where the actual chemical digestion of food material takes place in acidic environment. Here, partially digested, semi-solid materials are converted to semi-liquid phase.
- Liver plays a very essential role as it discharges bile salts, which act in the process of the digestion and absorption of fats.
- Pancreas can be considered as a mixture of exocrine and endocrine organ. It has the work of pouring its potent mixture of digestive enzymes into small intestine, which act in the process of the digestion of carbohydrate, fats and proteins at alkaline pH.
- Small intestine is a place where the final step of the chemical decomposition of food completes. After this step, all the nutrients are absorbed in small intestine and transported to blood and lymph capillaries for circulation throughout the body.
- Electrolytes are reabsorbed from the digested food in the large intestine. Bacterial fermentation takes place and converts the undigested food into stool, which moves towards the rectum till it leaves the body through the anus due to bowel movement.

The activity in the digestive tract can be grouped under the following four main categories:

- **Ingestion:** It involves the intake of food into the alimentary tract.
- **Digestion**: It is the process of breaking down the complex food particles into simplest form that is best suitable for absorption, and final intake into the cells for energy or storage purpose. It can be divided into the mechanical breakdown of food by chewing and chemical breakdown by salivary enzymes and other enzymes present in secretions produced by the glands of digestive tract. These secretions include the following:
  - o Saliva – salivary gland (three pairs)
  - o Gastric juice – stomach
  - o Intestinal juice – small intestine
  - o Pancreatic juice – pancreas
  - o Bile – liver
- **Absorption**: In this process, the useful end products of digestion are absorbed into the lymph and blood capillaries for transmission within the body.
- **Elimination:** The non-digestible residue of food is egested out as faeces through anus.

Figure 8.1 shows the organs of the digestive system.

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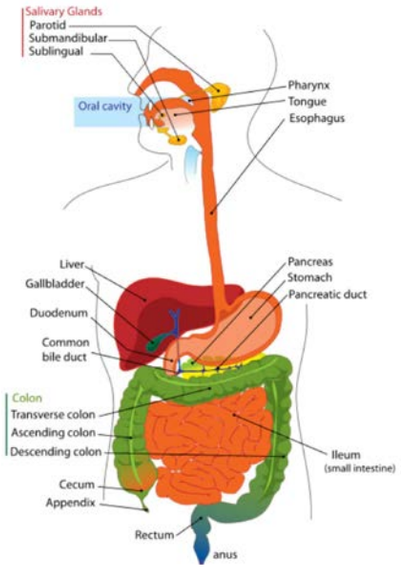

Fig. 8.1 *Digestive System*

Anatomy and physiology of GIT

The GIT is about 6–9 meters long in an adult when fully stretched. All the organs of GIT are connected via long and flexible twisting tube like structure. The inner side of organs is a lining called mucosa, composed of mucousal epithelium and lamina propria. Glandular secretions maintain them in the moist conditions. Submucosal region is composed of a layer of dense irregular connective tissue. Externally, smooth muscles are arranged in circular and longitudinal layers, which are mostly covered by serous membrane. Figure 8.2 shows the basic components of the GIT.

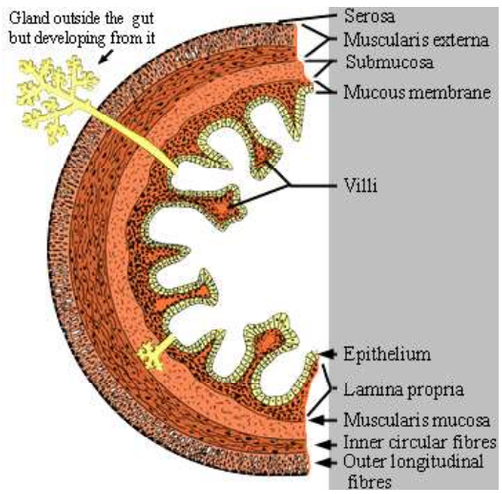

Fig. 8.2 *Basic Components of the Layer of the GIT*

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8.2.1 Mouth

The mouth cavity is positioned at the beginning of the digestive tube. It is almost oval-shaped cavity, which comprises two parts – a small portion outside the gums and teeth, or the vestibule**,** and an inner, bigger part, or the mouth cavity proper. The mouth or oral cavity is enclosed by quite a few muscles and bone. It consists of the lips anteriorly, pharynx at the posterior end, muscles of cheeks laterally, bony hard palate forming the superior roof and a muscular soft palate. At the inferior end, it has the muscular tongue and the soft tissue of the floor of the mouth. Figure 8.3 shows the mouth or oral cavity and its mucus linings.

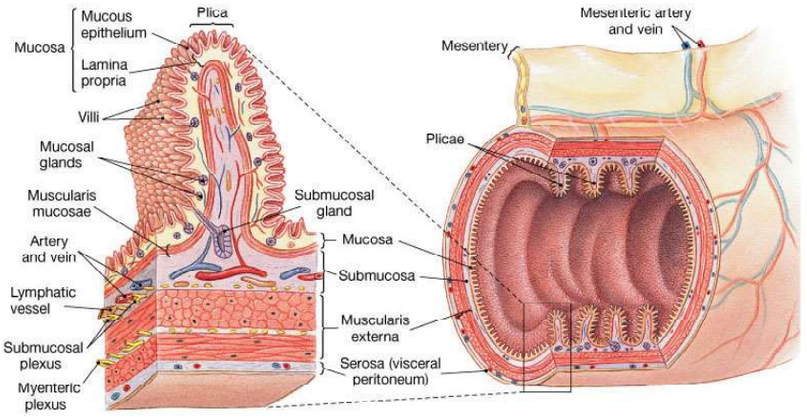

Fig. 8.3 *Oral Cavity and its Mucus Linings*

The oral cavity is lined throughout with mucus membrane. This membrane consists of stratified squamous epithelium containing minute mucus-secreting glands. The lining of mucus membrane of the cheeks and the lips is reflected on to the gums or alveolar ridges.

The roof of oral cavity is called palate. The palate is separated into two parts – the anterior hard palate and the posterior soft palate. The bones forming hard palate are the maxilla and the palantine bones. The alveolar arches and gums bint the palate in front and at the sides; in the rear, it is a continuous structure with the soft palate. It is covered by a thick structure, formed by the mucous membrane of the mouth and periosteum, which are very close. The linear raphe, which ends anteriorly in a small papilla parallel to the incisive canal, is located along the middle line. On each side and in front of the raphe, the mucous membrane is pale in colour, thick and corrugated; in the rear, it is of a deeper colour, thin and smooth; it is coated with stratified squamous epithelium and furnished with numerous palatal glands, which are positioned between the surface of the bone and the mucous membrane.

Soft palate is muscular and bends downwards from the posterior end of the hard palate. It shapes a partial septum between mouth and pharynx. It comprises a fold of mucus membrane enclosing nerves, adenoid tissue, muscular fibre and

mucus gland. Its lower border is open, its lower portion, which suspends like a curtain between the mouth and pharynx, is identified as palatine velum.

Hanging from centre of its lower border is a minute conical pendulous process, called the palatine uvula. It is a curved fold of muscle found. Originating from the upper end of uvula, there are four folds of mucous membrane, two passing downward at each side to form membranous arches. The posterior folds are present one on each side called as palatopharyngeal arches and the two anterior folds are the palatoglossal arches. Palatine tonsil (collection of lymphoid tissue) is found in between and both sides of arches.

8.2.2 Tongue

Tongue is an extremely mobile, muscular structure. It is very important for the digestive functions of chewing, tasting and swallowing and occupies the floor of the mouth. Another important function of the tongue is its role in speech. The tongue consists of striated muscle. The dorsal mucosal surface consists of stratified squamous epithelium, with numerous papillae and taste buds. The tongue, a voluntary muscular structure, is attached by a mucous membrane fold, called the frenulum, to the floor of the mouth. There are three varieties of papillae (little projections on the superior surface of tongue), which are as follows:

- **Vallate papillae**: These are typically between 8 and 12. The circumvallate papillae are arranged in an inverted V-shape towards the base of the tongue. They are the largest of the papillae and are most easily seen.
- **Fungiform papillae***:* These are located mostly at the tip and the edges of the tongue. These are more numerous in number when compared to than the vallate papillae.
- **Filiform papillae:** These are the smallest and most numerous among the three papillae. They become visible on the surface of the anterior two-thirds of the tongue.

The lingual division of the external carotid artery supplies arterial blood to the tongue. Tongue is very sensitive. It is kept moist by saliva and has plenty of nerves and blood vessels. The nerves involved for taste sensation are as follows:

- The hypoglossal nerves (12 cranial nerves), which supply the voluntary muscle tissue.
- The lingual branch of the mandibular nerves; these are the nerves of somatic sensation like temperature, touch and pain.
- The facial and glossopharyngeal nerves (7^{th} and 9^{th} cranial nerve), which are the nerves responsible for special sensation of taste.

Figure 8.4 shows the structure of the tongue.

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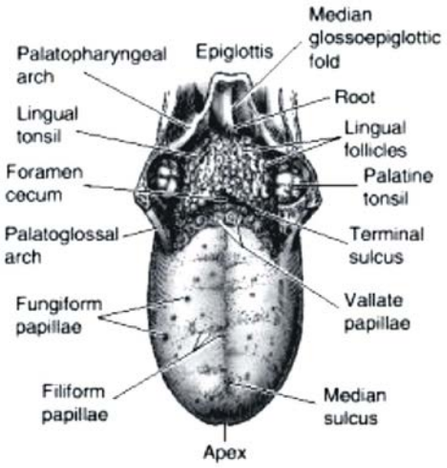

Fig. 8.4 *Structure of Tongue*

Functions of the tongue

Tongue consists of lots of clusters of muscles, which run in diverse directions so that it can move in a number of different directions. It also plays a significant role in deglutition (swallowing), mastication and speech. The tongue can deal with all its different jobs. Figure 8.5 shows the structure of oral cavity.

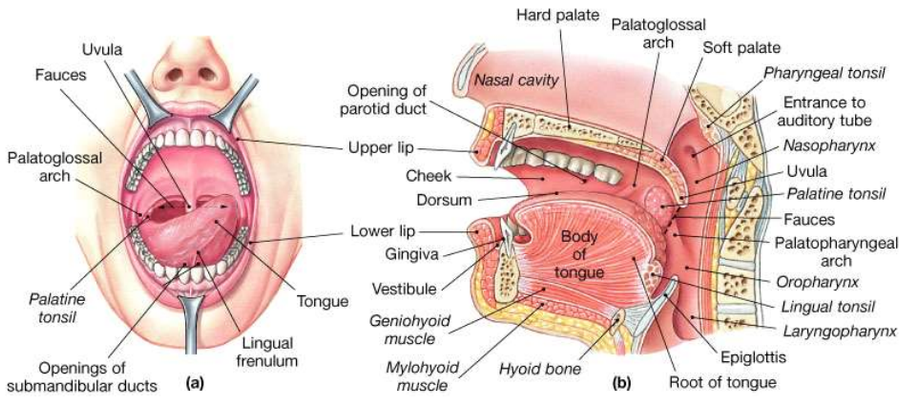

Fig. 8.5 *Structure of Oral Cavity*

Uvula: It is the conic projection from the posterior edge of the middle of the soft palate, composed of connective tissue containing a number of racemose glands and some muscular fibers.

Fauces: It is the passage that extends from the back of the mouth to the pharynx. It is bounded by the soft palate, the base of the tongue and the palatine arches.

Palatoglossal arch: It is an arch that runs downward, laterally, and forward to the side of the base of the tongue (on either side). It is formed by the projection of the glossopalatine muscle with a covering of mucous membrane. It forms the border between the mouth and the pharynx.

Palatine tonsil: Also called the **faucial tonsils**, these are found on the right and left sides at the back of the throat. Inflammation of these tonsils results in a condition called tonsillitis.

Tongue: It is a muscular hydrostat on the floor of the mouth which helps manipulate food for mastication. It senses taste, is sensitive and is moistened by saliva. It has a rich supply of nerves and blood vessels. In humans, a secondary function of the tongue is phonetic articulation. It also serves as a natural means of cleaning the teeth.

Oropharynx: It is a part of the pharynx (which is a part of the throat situated immediately posterior to the mouth and nasal cavity; and forms an important part of the digestive and respiratory system). It lies behind the oral cavity and extends from the uvula to the level of the hyoid bone. It is lined by non-keratinised squamous stratified epithelium.

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8.2.3 Teeth

Teeth are amongst the most characteristic and lifelong marks of mammal species.

A tooth is a hard structure, placed in the upper or lower jaw and is employed for chewing food. Teeth also give shape to the face and help in the course of speaking unmistakably. The enamel covers the crown (the part above the gum) in every tooth and can be broken down by acids created by the mouth for digestive functions. This process is called 'decay'. To stop decay, good oral cleanliness, consisting of daily brushing and flossing, is essential. The hardest substance in the human body is one of the four kinds of tissues, which form the tooth. The enamel covers the crown (area above the gum line) of the tooth. A bony matter called 'cementu' coats the root, which fits into the jaw socket and is united to it with membranes. 'Dentin' or 'ivory' is found under the tooth enamel and the cementum (Figure 8.6), and this matter shapes the largest part of the tooth. The dentin comprises a number of microfibres embedded in a thick homogenous matrix of collagenous proteins. At the heart of every tooth a soft, living centre called 'pulp,' is located, which contains nerves, blood vessels, connective tissues and lymphatics. In case of a toothache, the pulp is area that hurts.

The teeth are embedded in the alveoli or sockets of the alveolar ridges of the mendible and the maxilla. Every person has two sets of teeth, the temporary or baby milk or deciduous teeth, which normally start to appear at about six months of age and the permanent teeth. At birth, both of dentition is found in immature form in the mandible and maxilla.

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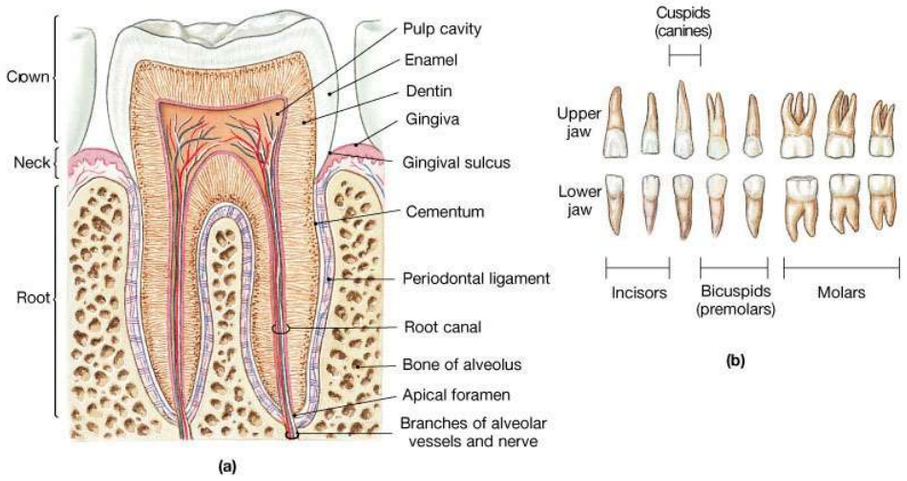

Fig. 8.6 *Structure and Types of Teeth*

Deciduous teeth

Deciduous or temporary teeth are twenty in number; ten are found in each jaw.

Jaw	Molar	Canine	Incisors	Incisors	Canine	Molar
Upper	2	1	2	2	1	2
Lower	2	1	2	2	1	2

At the age of six months, the deciduous teeth begin to develop, and should be present by the end of 24 months.

Permanent teeth

Permanent teeth begin to replace the deciduous teeth in the 6 years of age and this dentition consists of 32 teeth.

Jaw	Molar	Premolars	Canine	Incisors	Incisors	Canine	Premolars	Molar
Upper	3	2	1	2	2	1	2	3
Lower	3	2	1	2	2	1	2	3

There are four types of teeth, which have distinct roles: the incisors and canine teeth are used for cutting and biting off pieces of food, as they have sharp ends; the premolar and molar teeth are used for grinding and chewing purposes because their surfaces are flat and broad.

Structure of a tooth (external)

Though the figure of different teeth varies; their basic structure is same and consists of the following:

- **The crown**: It is that part of the tooth which can be seen and protrudes from gum.

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- **The root**: It is that part of tooth which lies under the gums and inside the alveolar bone; it keeps the tooth in tact.
- **Neck (Gum margin):** It is the somewhat constricted part where the crown joins the root.

Structure of a tooth (internal)

The internal structure of tooth consists of the following components:

- **Tooth enamel**: It is the hardest of all the tissues found in the human body. It is the hardest part of tooth as well. It is a defensive structure and coats the exposed part of tooth and the crown.
- **Dentin or ivory**: It makes up the major mass of tooth and emerges below the tooth enamel. Dentine bears the tooth enamel and absorbs the load of eating. The dentine comprises a number of microfibres imbedded in a thick homogeneous matrix of collagenous proteins.
- **Dental pulp:** It is produced in the soft centre of the tooth, within the pulp chamber and the root canal. It is a soft connective tissue having nerves and blood vessels, which feed the tooth. It is the most interior structure of a tooth, surrounded by the dentine.
- **Cementum:** It is as hard as a bone but not as hard as the tooth enamel. Anatomically, it covers the dentine outside of the root (under the gum line) and it is joined to the bone of the jaw with minute elastic fibres.

Gingiva: These are part of the soft tissue lining of the mouth. They surround and seal the teeth. Most of the gingiva are tightly bound to the underlying bone. This resists the friction of food passing over them. Healthy gingiva is usually coral pink, but may contain physiologic pigmentation. Due to increased accumulation of bacterial plaque, there may be inflammation, increased redness in the gums and tendency to bleed.

Gingival sulcus: It is the area of potential space between the tooth and the surrounding gingival tissue. It is lined by sulcular epithelium. The depth of the sulcus or groove is bounded apically by the gingival fibres of the connective tissue attachment and coronally by the free gingival margin.

Root canal: It is the space within the root of a tooth and forms part of a natural space within a tooth. This space comprises the pulp chamber (within the coronal part of the tooth), the main canal(s) and more intricate anatomical branches that may connect the root canals to each other or to the surface of the root. The smaller branches are called **accessory canals** and are most frequently found near the root end (apex) but may be encountered anywhere along the root length. There may be one or two main canals in each root.

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Bone of alveoli: These are the thickened ridges of bones containing the tooth sockets on bones bearing teeth. They comprise the mineral hydroxyapatite (also found in enamel). It contains a region of compact bone adjacent to the periodontal ligament called lamina dura. The periodontal ligament attaches it to the cementum of the roots.

Apical foramen: It is the opening at the apex of the tooth through which the nerve and blood vessels that supply the dental pulp pass. It represents the junction of the pulp and the periodontal tissue.

8.2.4 Salivary Glands

In humans, salivary glands are one of the exocrine glands, which are positioned under the tongue and near lower jaw. It has three different pairs of glands which are parotid, sublingual and submandibular.

The parotid gland is the major salivary gland and is covered around the mandibular ramus. It discharges saliva through Stensen's duct into the oral cavity. It helps in the progress of chewing and swallowing of the food materials. The top of the parotid gland is directed downwards. The gland possesses four surfaces that can be divided as follows:

- Superior
- Superficial
- Antero-medial
- Postero-medial

All four surfaces are divided by three borders at anterior, posterior and medial axis. Parotid gland generates serous fluid. The secretion of serous fluid by the parotid gland is managed largely by pre-synaptic parasympathetic fibres starting off in the inferior salivatory nucleus. These nerves depart the brain via the tympanic nerve branch of glossopharyngeal nerve and pass through the tympanic plexus, and then structured the lesser petrosal nerve till they reach the otic ganglion. After synapsing in the otic ganglion, the postganglionic fibres pass as part of the auriculotemporal nerve to arrive at the parotid gland. Parasympathetic stimulation produces water rich, serous saliva. At the time of sympathetic stimulation, vasoconstriction causes reduced blood supply to the parotid gland and this reduces water collection, thereby leading to the generation of a low volume, enzyme-rich saliva. There is no inhibitory nerve supply to the gland. The parotid gland discharges alpha-amylase enzyme, which is the first step in the digestion of starches throughout mastication. It breaks down amylose (straight chain starch) and amylopectin (branched starch) by hydrolyzing alpha 1, 4 bonds. Figure 8.7 shows the location and structure of salivary glands.

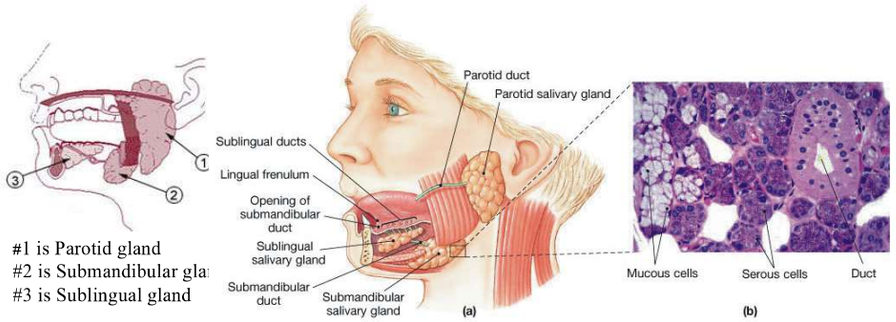

Fig. 8.7 *Location and Structure of Salivary Glands*

The paired submandibular glands are salivary glands that are located under the floor of the mouth. In humans, they reported for almost 70 per cent of the salivary volume and weigh about 15 grams. The secretion comes into the oral cavity via Wharton's ducts. Secretion is a combination of both serous fluid and mucus. Each submandibular gland is divided into two parts – superficial and deep lobes, which are split by the mylohyoid muscle. The superficial portion is larger as compared to deep lobes and the mylohyoid muscle runs underneath. Parasympathetic innervation to the submandibular glands is given by the superior salivatory nucleus through the chorda tympani, a branch of the facial nerve that synapses in the submandibular ganglion after which it follows the lingual nerve, leaving this nerve as it moves towards the gland. Increased parasympathetic activity supports the secretion of saliva. Submandibular secretions are controlled through the sympathetic nervous system because of arterial vasoconstriction. As the sympathetic activity increases, it decreases glandular blood flow, and thus decreases salivary secretions and produces enzyme-rich mucous saliva.

The sublingual glands are a pair of glands positioned beneath the tongue to the submandibular glands. Even though these are categorized as mixed glands, they mainly produce discharge, which is mucous in nature. The sublingual glands do not have striated ducts, as other two gland systems have. Just about 5 per cent of saliva entering the oral cavity arrives from these glands. They are drained by 8–20 excretory ducts called the ducts of Rivinus. The biggest duct, the sublingual duct (of Bartholin) joins the submandibular duct to drain via the sublingual caruncle. The sublingual gland consists mostly of Mucous acini capped with serous demilunes and is therefore called a mixed gland.

8.2.5 Pharynx

The pharynx is the part of the neck and throat positioned directly behind the mouth and nasal cavity, and superior, to the oesophagus, larynx and trachea. The pharynx is the part of both: the digestive and respiratory systems. Because food, liquid and air travel through the pharynx, a flap of connective tissue called the epiglottis closes over the trachea when food is swallowed to avoid choking or aspiration. The stratified squamous epithelium lines pharynx.

NOTES

The process of swallowing inside oral cavity

The following steps are involved in the process of swallowing:

Step 1: A mass of chewed, moistened food, or a bolus, is moved to the backside of the mouth by the tongue. In the pharynx, the bolus activates a spontaneous swallowing reflex that avoids food from entering the lungs, and directs the bolus into the oesophagus.

Step 2: Muscles in the oesophagus press the bolus forward by the waves of spontaneous muscular contractions (peristalsis) of smooth muscle lining the oesophagus.

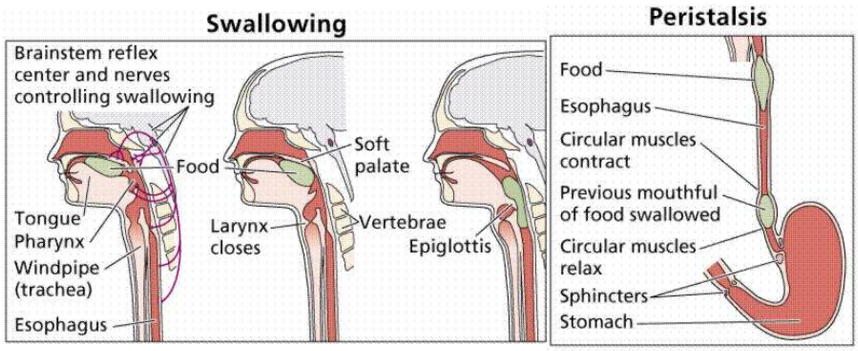

Fig. 8.8 *Process of Swallowing*

Functions of oral cavity

The oral cavity has following functions:

- Sensory receptors on the tongue are responsible for the sensation analysis like taste, touch and temperature of the food materials before swallowing.
- Teeth and tongue are responsible for mechanical processing such as chewing and swallowing of the food stuff.
- Chewing allows food to be mashed into a spongy mass, which is easier to swallow and digest later.
- Secretions containing bicarbonate ions in saliva neutralize the acids in foods.
- Salivary glands secrete salivary amylase, an enzyme that starts the breakdown of starch into glucose.
- Mucus moistens food and lubricates the oesophagus.
- Swallowing moves food from the mouth through the pharynx into the oesophagus and then to the stomach.

8.2.6 Oesophagus

The oesophagus, which is located in between trachea and the spine, is considered as a vital organ in digestive system as it plays major and important role in transporting food saliva and liquids to the stomach. Hence, it is also termed as 'ingestion tube.'

Structure and composition

NOTES

The length of the oesophagus in a normal adult is about 25 cm. It opens in the mouth and travels through the neck until the diaphragm, joining the upper end of the stomach. There are a number of glands that are present in the linings of the inner side of wall. Glands help in keeping the inner passage moist and also smooth the progress of swallowing. The wall of the oesophagus is made up of three layers – mucosal, submucosal and muscularis. Mucosa layer that is often termed as 'mucus layer' is non-keratinized and comprises stratified squamous epithelium cells. It serves a purpose of defensive effect owing to the high volume transit of food, saliva and mucus. The submucosal layer contains connective structures called as 'papillae' and also mucous secreting glands termed as oesophageal glands. To maintain the control over swallowing and autonomic in the upper and lower portions respectively, the composition of muscularis externa differs in various parts of the oesophagus. The upper or superior part is made up of striated muscles, middle portion is made up of smooth muscles and striated muscles both and lower portion is made up primarily of smooth muscles. In the oesophagus, smooth muscles contract to generate a peristaltic wave, which forces a mass of food or bolus. In the humans, peristalsis is the process in which smooth muscles are contracted and force the bolus contents through the digestive tract. Figure 8.9 shows the histology of oesophagus.

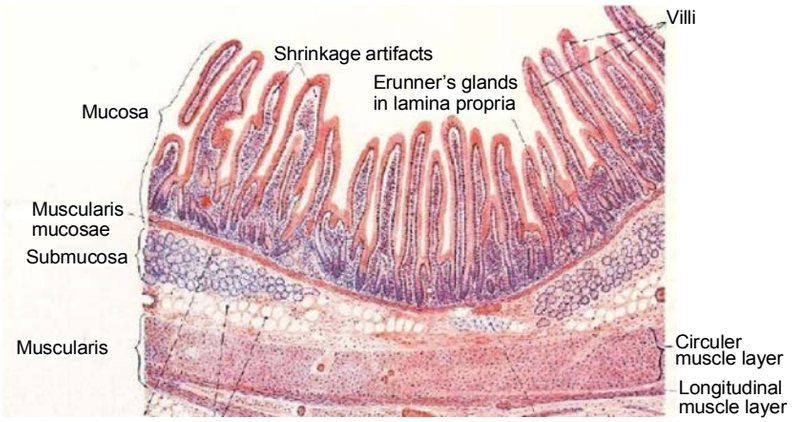

Fig. 8.9 *Histology of Oesophagus*

Function of oesophagus

As discussed previously, the oesophagus is actively involved in transportation of food from mouth to stomach. Layers of muscles, throughout the lining wall of the oesophagus, termed as 'sphincters' help the oesophagus in carrying out the function. The oesophageal sphincters can be portioned in two different sections, the upper oesophageal sphincter and lower oesophageal sphincter. The upper sphincter remains usually closed, but opens when food or liquid is swallowed. In order to prevent food or liquid from entering the lungs, the passage to the lungs is blocked when the upper sphincter is open. The oesophagus is connected to the stomach

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by the lower oesophageal sphincter. The lower sphincter of oesophagus remains closed even at rest; thus preventing the contents from flowing back into the oesophagus. When food is swallowed, upper oesophageal sphincter relaxes to push the food into the upper oesophagus. Food is further pushed into the lower oesophagus by peristalsis as shown in Figure 8.10.

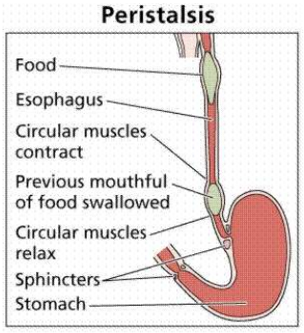

Fig. 8.10 *Peristalsis Movement of Food*

When food reaches the bottom of the oesophagus, lower oesophageal sphincter loosens up to transport food into the stomach. This process of transportation of foods can be divided in two steps, i.e., from mouth to oesophagus due to peristaltic movements and from oesophagus to stomach due to sphincters' movements. Peristaltic movement is the process in which muscles contract to push the food through the oesophagus. The food is transported to the stomach by a series of contractions (Figure 8.11) caused by sphincters in the oesophagus. During the transportation of food from oesophagus to stomach, the muscles or sphincters automatically close in order to stop food from returning to the mouth or oesophagus. Enzymes liberated by sphincters also help in the semi digestion of food in the oesophagus.

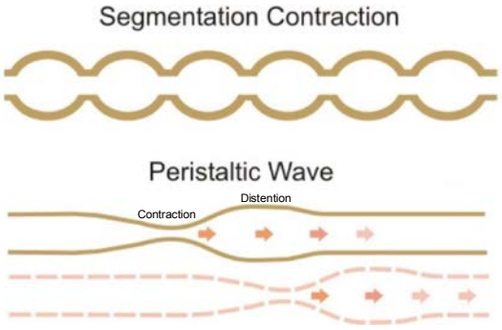

Fig. 8.11 *Intestinal Motility*

Check Your Progress

1. What is the name of roof of oral cavity?
2. Which organ is part of both the digestive and respiratory systems?

8.3 PHYSIOLOGY AND ANATOMY OF STOMACH, SMALL INTESTINE AND LARGE INTESTINE

NOTES

Stomach, small intestine and large intestine form the main organs where actual digestion takes place.

8.3.1 Stomach

The stomach is a big J-shaped, empty organ and is located between the oesophagus in the upper side and the upper portion of small intestine termed as duodenum in the lower side. The stomach is situated on the left upper part of the abdominal cavity. The apex of the stomach is positioned against the diaphragm. Inferior to the stomach is the pancreas and the greater omentum that suspends from the greater curvature.

The stomach is the most enlarged and expandable organ in the digestive system. It is a sac-like structure, having an empty volume of around 45 to 50 ml in humans. However, in normal adult humans, it can get enlarged, so as to hold 1 to 3 litres of food. It is also considered as storage compartment as average adult stomach widens to hold from two to three times and creates approximately the same amount of gastric juices every 24 hours. The stomach comprises layers of muscle and nerves that helps and continue the breakdown of food, which begins in the mouth. The oesophageal sphincter regulates the movement of food coming from the oesophagus to the stomach and the pyloric sphincter is responsible for regulating the motion of somewhat digested food from the stomach to the duodenum. Figure 8.12 shows parts of stomach.

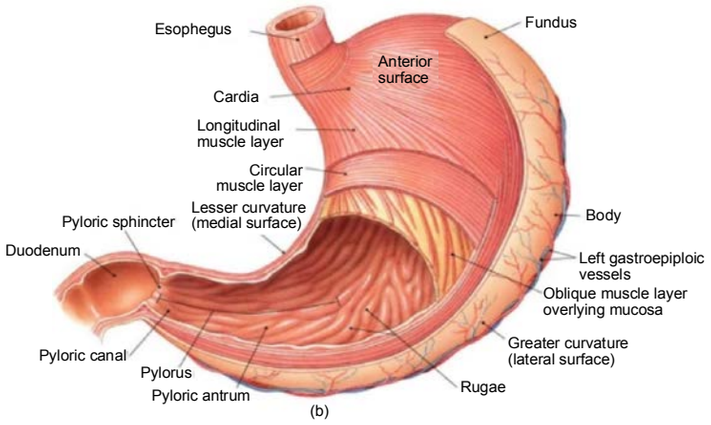

Fig. 8.12 *Parts of Stomach*

Organs in relation to the stomach are as follows:

- Anteriorly: Left lobe of liver and anterior abdominal wall
- Posteriorly: Abdominal aorta, pancreas, spleen, left kidney and adrenal gland
- Superiorly: Diaphragm, oesophagus and left lobe of liver

- Inferiorly*:* Transverse colon and small intestine
- To the left: Diaphragm and spleen
- To the right: Liver and duodenum

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Functions

The stomach has several functions, which are as follows:

- The digestive juices produced by the stomach, split and crack the chemicals in food, and therefore, the stomach can be considered as a digestive container.
- The stomach is considered as a storage bin. It can store a meal in the upper portion and release it a little at a time into the lower portion for processing.
- The stomach can act as a food mixer. The strong muscles of the stomach contract and mash the meal into a sticky, slushy mass.
- The cells in the stomach produce juices, which are acidic in nature and help in killing germs in the food, and hence, act as disinfecting agents.
- Absorption takes place in the stomach to a limited extent. Water, some drugs and alcohol are all absorbed through the wall of the stomach into venous circulation.
- Absorption of iron occurs in small intestine but is dissolved out of food most effectively in the presence of hydrochloric acid in the stomach.

Only a few substances, such as alcohol and water, can be absorbed directly from the stomach. Any other food substance must endure the digestive processes of the stomach. The food is processed into a semi-liquid form called chyme. About 2–4 hours or so after having a meal, the chyme is gradually discharged a little at a time through the pyloric sphincter.

The stomach is found in connection with oesophagus at the cardiac orifice, and with the duodenum at the pyloric orifice. It is divided into four sections, each of which has different functions and cells. The sections are as follows:

- Place where the contents of the oesophagus drain into the stomach is called as cardia**.**
- Fundus is formed by the upper curvature of the organ.
- Main or the central region is called as body or corpus.
- The lower section of the organ, which eases draining the contents into the small intestine, is termed pylorus**.**

The cardia is the section, which is closest to the heart and is where the oesophagus is joined with the stomach. The fundus is the region that bends above the rest of the stomach (with respects to a person who is standing upward). It is the main part is the body and the lower part is pyloric antrum. The body of the stomach is the biggest region located in the centre. This part of stomach bends upwards just before the pyloric sphincter to complete the J shape. Two sphincters, keep the contents of the stomach contained. They are the oesophageal sphincter (found in the cardiac region) dividing the tract above, and the pyloric spincter

dividing the stomach from the small intestine. When the stomach is dormant, the pyloric sphincter is relaxed and open up. In humans, the stomach has a relaxed, near empty volume of about 45 ml. It normally expands to hold about 1 litre of food.

NOTES

Histology

From inside to outside, the walls of stomach comprise the following layers:

- **Mucosa:** Mucosa is the major layer and first layer of stomach wall. It comprises an epithelium, consisting of loose connective tissues, and a thin layer of smooth muscle called the muscularis mucosa. It has gastric glands under that, which produce chemicals (enzymes and acid) that make the gastric juices.
- **Submucosa:** This layer lies on top of the mucosa and comprises fibrous connective tissues. It divides the mucosa from the next layer by Meissner's plexus.
- **Muscularis externa:** The layer is on the top of the submucosal layer. In the stomach, the muscularis externa is different from that of other gastrointestinal organs as it has three layers of smooth muscle in place of two.
- **Serosa:** This is the external layer of the stomach and is a strong membrane.

The parasympathetic (stimulant) nerves surround the stomach; whereas, supply is from vagus nerves and sympathetic (inhibitor) is mainly from coeliac plexuses. The sympathatic nerves decrease the motility of the stomach and the secretion of gastric juice. Figure 8.13 shows the histology of stomach wall.

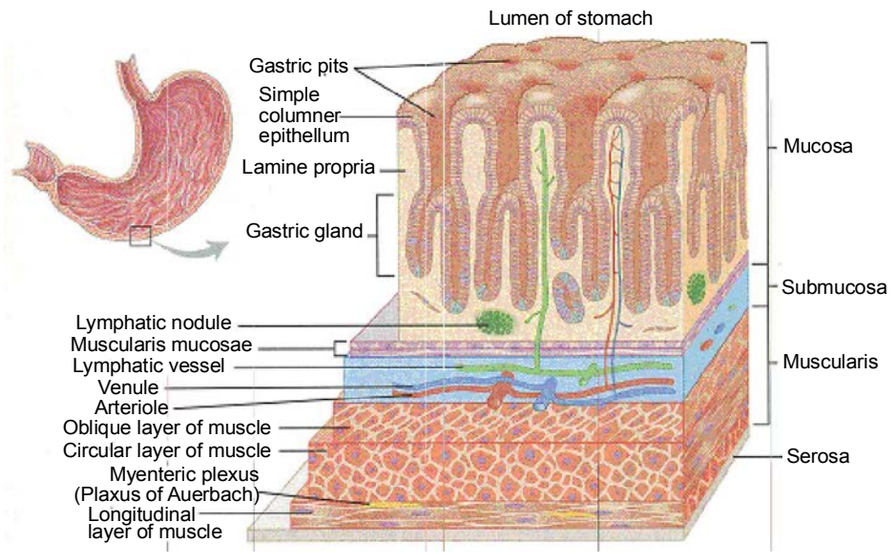

Fig. 8.13 *Histology of Stomach Wall*

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8.3.2 Gastric Glands

The glands are named on the basis of their subsequent locations in the stomach; glands in the cardia are called as cardiac glands, in the pylorus region are called pyloric glands, and at fundus region are called as fundic glands. The various types of cells are found at the various layers of these glands; cells in the isthmus of fundic, cardiac and pyloric glands are called as mucus neck cells and form mucous gel layer. Cells in the body of fundic, cardiac and pyloric glands are called as parietal cells, which are also called as oxyntic **c**ells. These cells are responsible for the secretion of gastric acid and intrinsic factor, which are acidic in nature. Cells in the base of fundic glands are called as chief zymogenic cells and responsible for the secretion of pepsinogen, which is basic in nature. Cells in the base of cardiac and pyloric glands are called as entero endocrine cells and are responsible for the secretion of hormones like gastrin, histamine, endorphins, serotonin, cholecystokinin and somatostatin.

Gastric secretion

When a meal has been eaten and the food accumulates in stomach in layers then the mixing of this food with the gastric juice takes place gradually.

Gastric secretion includes hydrochloric acid (HCL) and enzymes from the gastric glands. Undue secretion of gastric acid is the most important problem in human as it results in gastritis, gastric ulcers and peptic acid disease. Such diseases inspire scientists and doctors to find out the root cause and basic mechanism of gastric secretion and its regulation. The pH in the region of stomach, especially in the lumen, is 1 – 2, which is highly acidic. The stomach secretes about 2 – 2.5 litres of gastric juice everyday. Out of juices, major exocrine secretions are prorennin and pepsinogen secreted by the chief or peptic cells and HCl and intrinsic factor**,** secreted by the parietal or oxyntic cells. Mucus secreting cells bound around the surface cells in gastric mucosa where bicarbonate ions are trapped; hence, form a gel-like preventive layer, maintaining the pH of mucosal surface to 6 – 7. Bile secreted from liver and ingestion of ethanol can break this preventive layer. Disturbance in such secretory and protective mechanisms are often considered as major reason in the pathogenesis of peptic ulcer.

Gastric juice is secreted by the special secretory glands in mucosa comprises f the following components:

- Water and mineral salts secreted by gastric gland
- Mucus secreted by cells in the gland and on the stomach surface
- Hydrochloric acid and intrinsic factor secreted by parietal cells in the gastric gland
- Enzymes; pepsinogen secreted by chief (peptic or zymogen) cells in the glands

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The proton pump (H^+), potassium (K^+) and chloride (Cl^-) conductance channels at first reside on intracellular membranes and are transported to and fused into the cannalicular membrane just before the acid secretion. Parietal cells, when stimulated, secrete HCl in to large cannaliculi at a concentration of approximately 150–160 mm that is equivalent to a pH of 0.8. Main stimuli acting on the parietal cells are acetylcholine (a stimulatory neurotransmitter), histamine (a stimulatory local hormone), gastrin (a stimulatory hormone), prostaglandins E2 and I2 (local hormones that inhibit acid secretion). The epithelium of the stomach is anti to the damaging effects of gastric acid. There is an alteration in the morphology of the membranes of the parietal cell, when acid secretion is activated. Cytoplasmic tubulo-vesicular membranes, which are affluent in the resting cell virtually, disappear with increase in the cannalicular membrane. The regulation of gastric acid secretion by parietal cells is highly important in the pathogenesis of peptic ulcer and can help in the particular targeting of a drug action.

The parietal cells, which have a pH value less than 1, discharge HCl (Figure 8.14) and have higher concentration of hydrogen ions than the plasma. Therefore, Cl^- is actively transported into cannaliculi in the lumen of the gastric glands and thus with the stomach. This Cl^- secretion is accompanied by K^+, which is then exchanged for H^+ from within the cell by a K^+/H^+ ATPase and bicarbonate ions.

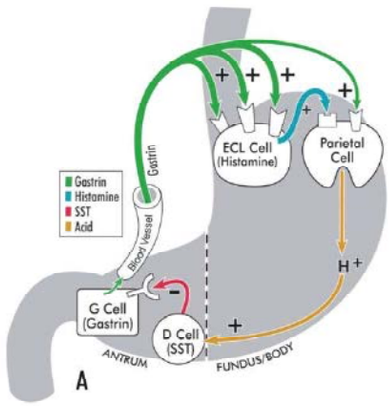

Fig. 8.14 *Secretion of HCL*

In short, the steps involved in the acid secretion are as follows:

- In the parietal cells, hydrogen ions are produced because of the dissociation of water.
- The hydroxyl ions created by this procedure join with carbon dioxide and forms bicarbonate ion. The whole reaction is catalyzed by carbonic anhydrase.
- Then, bicarbonate ion is transported out of the membrane in replacement for chloride.

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- The escape of bicarbonate into blood results in a slight rise of blood pH towards basic scale. This procedure helps in maintaining intracellular pH in the parietal cell.
- Potassium and chloride ions are transported into the lumen of the cannaliculus by conductance channels, and are essential for the secretion of acid.
- Hydrogen ions are pumped out of the cell, into the lumen, in substitute for potassium through the action of the proton pump.
- Build up of osmotically-active hydrogen ion in the cannaliculus produces an osmotic gradient across the membrane, which eventually results in the external diffusion of water.
- The resulting gastric juice is 150–160 mm HCl and with KCl and NaCl in relatively minute quantity.

Regulation of gastric secretion

Secretion and movements of various chemicals into the stomach are regulated by various hormones like gastrin, cholecystokinin and secretin, which are secreted by digestive system and also by the autonomic nervous system.

Gastrin is a peptide hormone, discharged by G–cells in the stomach in reaction to the expansion of the antrum. Digestive products, particularly large quantities of partly digested proteins, are also responsible for the discharge of gastrin. The discharge of gastrin is inhibited when pH goes below 4 (high acid), and as well as the hormone somatostatin**.** The secretion of gastrin results in an increase in the secretion of HCl from the parietal and pepsinogen cells in the stomach. Gastrin is also liable for increased motility in the stomach. Cholecystokinin (CCK) has major consequence on the gall bladder. Under the effect of CCK, gall bladder contracts, and this decreases the amount of gastric emptying and increases the discharge of pancreatic juice, which is basic and neutralizes the chyme. Secretin, generated in the small intestine, has major effects on the pancreas, but in addition decreases acid secretion in the stomach. Enteroglucagon decreases gastric acid secretion and motility.

Other than gastrin, rest of the hormones are equally responsible for minimizing and/or regulating the stomach acid secretion. This is just because of unabsorbed food products in the gall bladder and liver. When the intestine is stationary, the stomach pushes food into the small intestine but when the intestine is full and still digesting food, the stomach acts as storeroom for food.

8.3.3 Small Intestine

The end of stomach has the pyloric sphincter, which is attached with small intestine and connected with the large intestine through ileocaecal valve. The intestine consists of two parts –small intestine and large intestine. The large intestine is mostly responsible for the absorption of water and excretion of solid wastes, thus, it functions more towards coping with the bulk and its removal from the body. As

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the large intestine deals with bulk, it is wider and shorter, while the small intestine's thin width corresponds to the digestion and absorption process. Food ingested via mouth enters the stomach and is permitted to enter the duodenum through a muscle called pyloric sphincter. The ingested food is then pushed through the small intestine by a muscular-wavelike process called peristalsis. The contents of stomach empty into the small intestine in 1–2 hours, which is based on the contents of the food. Food having low fat diet acquires less emptying time as compared to diet having high fat content. Figure 8.15 shows internal and external structure of small intestine.

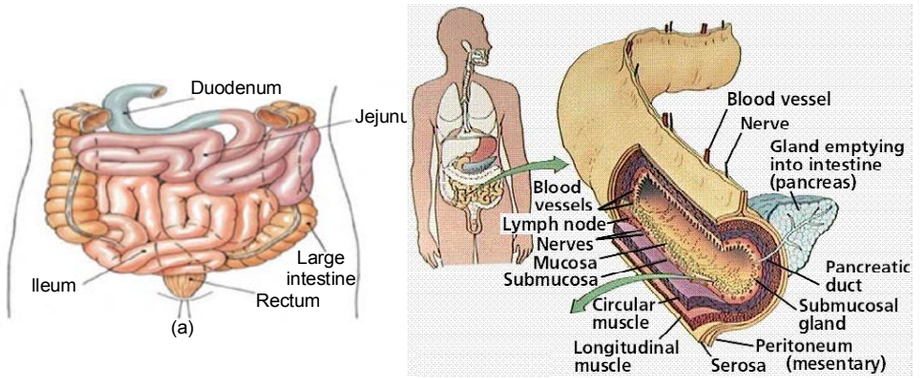

Fig. 8.15 *Internal and External Structure of Small Intestine*

Small intestine is that organ in the digestive system where the last phase of digestion and absorption takes place. It is a twisting tube over 5 meters long and 2–3 cm broad but when untwisted give this 5 meters tube the surface area of a 500–600 square meters long tube. In spite of its span, the small intestine's surface area is not sufficient to absorb all body nutrients needed by the body. Thus, the small intestine features myriads of microscopic folds, which add to the surface area accessible for absorption. The inner walls of the small intestine consist of two kinds of folds called plicae circulares and rugae. The rugae allow tissues to inflate and contract when needed. The plicae circulares are permanent structures, on the intestinal wall. They comprise two structures called villi and microvilli. These two work together to maximize the surface area available for absorption. Moreover, the 6 m long small intestine is separated into three distinct zones: duodenum about 25 cm long, jejunum approximately 2.5 m long and ileum on an average 3.5 m long.

The duodenum, or the upper part of small intestine, is the most dynamic in digestion of food. Secretions from a variety of accessory glands like liver and pancreas are employed for digestion of food in the duodenum. Watery mucus is discharged by epithelial cells of the duodenum. The pancreas secretes digestive enzymes and stomach acid-neutralizing bicarbonate. The liver generates bile, which is stored in the gall bladder prior to entering the bile duct into the duodenum. Bile emulsifies fats, facilitating their breakdown into increasingly smaller fat globules till they can be acted upon by lipases. Bile has cholesterol, bilirubin, phospholipids

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and a mix of salts. Fats are totally digested in the small intestine, unlike proteins and carbohydrates. Digestion of proteins, carbohydrates and fats continues in the small intestine. Glycogen and starch are broken down into maltose by small intestinal enzymes. Proteases are enzymes discharged by the pancreas responsible for the breakdown of protein into amino acids and small peptide fragments. Absorption is an active transport, needing cellular energy.

Peritonium

Mesentery, a double layered peritoneum, attaches the jejunum and ileum to the posterior abdominal wall. This attachment is quite short in comparison to the length of the small intestine. Therefore, it is fan shaped. Blood vessels and nerves lie on the posterior abdominal wall and its branches pass through mesentery.

Structure

The wall of small intestine is composed of the following four layers of tissues:

- Adventitia or outer covering
- Muscle layer
- Submucosa layer
- Mucous membrane lining

Mucous membrane

Several circular folds and villi (Figure 8.16) increase the surface area of small intestinal mucosa. The villi are small finger-like projections into the intestinal lumen measuring about 0.5 mm to 1 mm in length. Their wall is made up of columner epithelium and also microvilli (1μm long) on their free border. Virtually all nutrients, together with sugars and all amino acids, enter the body across the epithelium covering small intestinal villi. Each villus contains a capillary bed and a blunt-ended lymphatic vessel referred to as the 'central lacteal.' They are termed so because they absorb fat that gives the lymph a milky appearance.

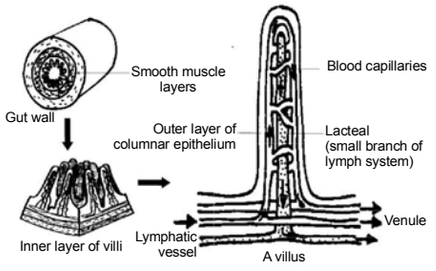

Fig. 8.16 *Structure of Villi and Absorption of Food*

Absorption and digestion of nutrient material takes place in the villi and microvilli. Some tubular glands are situated below the surface between the villi. The cells of gland form digestive enzyme that lodge in microvilli and together with intestinal juice complete the chemical digestion of carbohydrates, proteins and

fats. After crossing the epithelium, most of these molecules disperse into a capillary network inside the villus, and hence into systemic blood. Some molecules, fats in particular, are passed not into capillaries, but into the lymphatic vessel, which drains from the intestine and quickly flows into blood via the thoracic duct.

NOTES

There are numerous lymph nodes found in the mucous membrane all through the length of small intestine and towards the distal end of ileum and are called *peyer's patches.* Figure 8.17 shows the histology of small intestine.

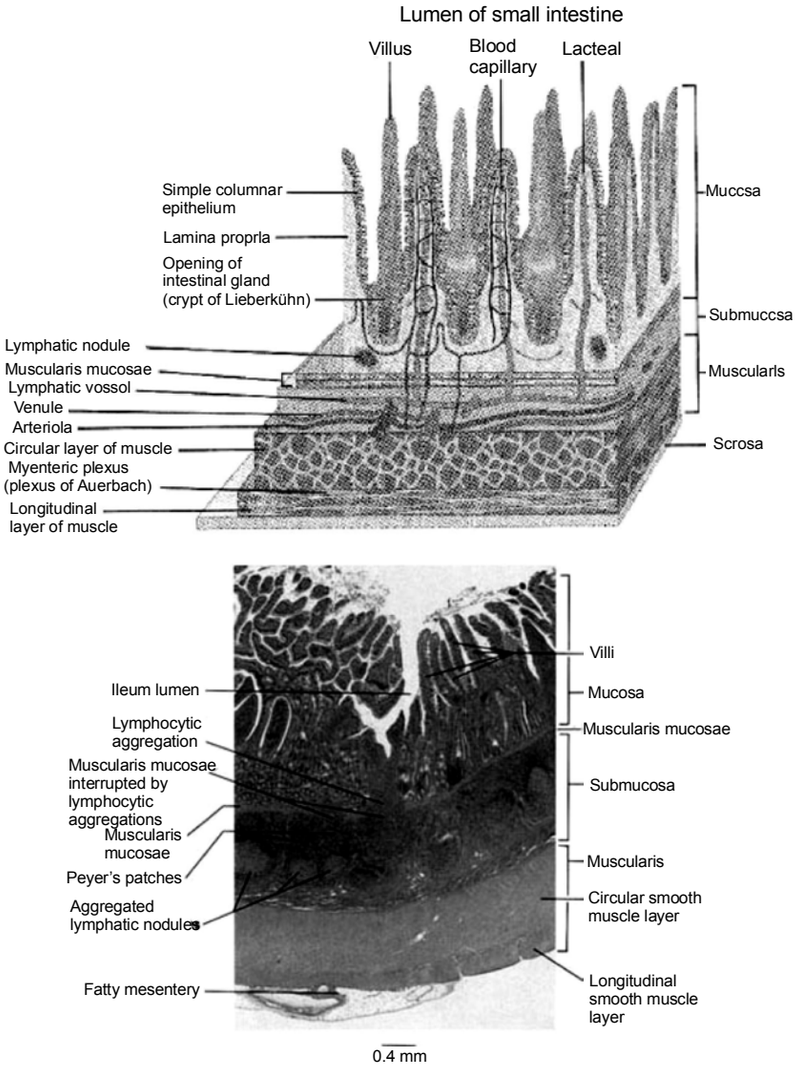

Fig. 8.17 *Histology of Small Intestine*

Most absorption takes place in the duodenum and jejeunum. The internal surface of the intestine has circular folds that more than triple the surface area for absorption. Villi covered with epithelial cells add to the surface area. The epithelial cells are lined with microvilli that further enlarge the surface area. Each villus has a capillary network supplied by a small arteriole.

NOTES

Intestinal juices (succus entericus) and intestinal secretions

Intestinal juice (succus entericus) refers to a pale yellow watery secretion from the glands lining the walls of small intestine. Secretion is activated by the mechanical pressure of partly digested food in the intestine. It consists of the following:

- Water
- Mucus
- Enzymes such as enteropeptidase (enterokinase), peptidase, lipase, sucrase, maltase, lactase

The traces of other enzymes found in succus entericus are released through the breakdown of cells of villi. The digestion of carbohydrate, fat and protein is completed in microvilli of the cells of the walls of villi. The enzymes involved in completing the digestion of food in cells of villi are as follows:

- Peptidases: It activates pancreatic peptidase, which converts polypeptides to amino acid and some to smaller peptides. The breakdown of amino acid occurs inside the wall of villi.
- Lipase: It does the digestion of fats to fatty acid and glycerol, which occurs partly in intestine and partly in villi.
- Sucrase, maltase and lactase: These complete the digestion of carbohydrates by converting the disaccharide to monosaccharide, in the cells of villi.

Function of small intestine

Small intestine has following functions:

- Secretion of intestinal juice
- Completion of digestion of fat, carbohydrate and protein in the cells of villi
- Protection of stomach wall against infection by microbes, through the secretion of HCL and lymph follicles
- Secretion of hormones cholecystokinin/pancreozymin and secretin
- Absorption of nutrient material

Digestion in small intestine

As acidic chyme enters into the small intestine, it is mixed first with pancreatic juice and bile then with intestinal juice. Although the intestinal juice is secreted throughout the length of the small intestine, its action is very limited to the duodenum.

Pancreatic juice enters the duodenum at the ampulla of the bile duct and consists of the following:

- Water
- Mineral salt
- Enzymes such as amylase, lipase, peptidases, trypsinogen and chymotrypsinogen. Pancreatic juice is strongly alkaline (pH 8).

- Trypsinogen and chymotrypsinogen are inactive enzyme and become active in presence of enterokinase enzyme of intestinal juice, which converts into trypsin and chymotrypsin. These enzymes convert some polypeptide to amino acid and some to dipeptide and tripeptide.
- Pancreatic amylase converts all digestible polysaccharides to disaccharide.
- Lipase converts fats to fatty acid and glycerol. Pancreatic lipase converts triglycerides into free fatty acids and monoglycerides. Pancreatic lipase functions with the help of the salts from the bile secreted by the liver and the gall bladder.

Most of the digestive enzymes, which are present in the small intestine, are discharged by the pancreas and enter the small intestine with pancreatic juice. The enzymes go into the small intestine in response to the hormone cholecystokinin, secretin, which is produced in the small intestine in response to the presence of nutrients. The hormone secretin also causes bicarbonates to be released into the small intestine from the pancreas to neutralize the potentially dangerous acid coming from the stomach.

Pancreatic juices may not arrive at duodenum, if the papilla of vater is blocked, or if the pancreas is so injured by disease that it is not capable to generate adequate enzymes and bicarbonate. This results in insufficient digestion of food. Clinically, the symptoms are the passage of large bowel movements with a strong odour and are too complicated to be flushed down the toilet due to high fat content. Too much fat in the stools is called as steatorrhoea. This results in the loss of weight in the patients. In addition to this, sometimes the bile is generated adequately by the liver but is not capable to get to the duodenum due to obstruction of the main bile duct, or papilla. In this situation, the bile spills backwards into the blood stream resulting in yellowish discolouration of the body and is called as jaundice. As the bile does not enter the duodenum, the bowel's colour turns out to be pale putty. On obstacle of the bile ducts, the bile salts are retained in the blood and leads to itching (pruritis).

8.3.4 Role of Bile in Digestion and Excretion

Bile or gall is a bitter-tasting, dark green to yellowish brown liquid, generated by the liver of most vertebrates. It helps in the process of digestion of lipids in the small intestine. If sphincter of oddi is closed, it is not capable to enter in the duodenum; thus, it travels through hepatic duct together with the cystic duct to the gall bladder where it is stored. On ingestion of a meal, the gall bladder contracts, the sphincter of oddi relaxes and bile travels through the cystic duct and the common bile duct into the duodenum along with pancreatic juice. The hormone cholecystokinin- pancreozymin (CCK-PZ), which is generated by the wall of duodenum, excites its activity. The human liver can generate close to 1 litre of bile per day (depending on body size). About 95 per cent of the salts discharged in bile are re-absorbed in the terminal ileum and are re-used. Blood from the ileum runs straight to the hepatic portal vein and returns to the liver where the hepatocytes

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re-absorb the salts and return them to the bile ducts to be re-used, at times two to three times with every meal.

There is slight difference between the composition of bile produced by the liver and that entering into duodenum. In gall bladder, the water is absorbed and mucus is added by the goblet cells in the mucus membrane lining; thus, bile becomes more concentrated and viscous.

Function of bile

Bile has following functions:

- The bile salts, sodium glycocholate and sodium taurocholate, increase the absorption of fats. It is a significant part of the absorption of the fat-soluble substances such as vitamin D, K, E and A.
- In addition to its digestive function, bile also serves as the route of excretion for bilirubin, a by-product of red blood cells recycled by the liver. Bilirubin derives from haemoglobin by glucuronidation.
- It colours and deodorise the faeces.
- Bilirubin is altered by microbes in the intestine. The formed urobilin is reabsorbed and excreted in urine.
- Bile salts also act as bactericides, annihilating many of the microbes that may be there in the food.

Absorption of nutrients

Absorbed substances travel through the brush border into the capillary, generally by passive transport. Sucrose, maltose and lactose are the main carbohydrates present in the small intestine; they are absorbed by the microvilli. Starch is converted into two-glucose units (maltose) elsewhere. Enzymes in the cells break down these disaccharides into monosaccharide that then leave the cell and enter the capillary. Lactose intolerance results from the genetic want for the enzyme lactase, which is usually produced by the intestinal cells. Amino acids and peptide fragments cross the epithelial cell membranes by active transport. Within the cell, they are broken into amino acids that then enter the capillary. Gluten enteropathy is the incapability to absorb gluten, a protein found in wheat. Digested fats are not very soluble. Bile salts surround fats to form micelles that can travel into the epithelial cells. The bile salts return to the lumen in order to repeat the process.

Fat digestion is normally completed by the time the food reaches the ileum. Bile salts are consecutively absorbed in the ileum and are recycled by the gall bladder and liver. Fats travel from the epithelial cells to the small lymph vessel, which also runs through the villus.

Once the food is digested, it is ready to pass into the blood stream via the blood vessels located in the intestinal walls, by using the combinations of processes, such as active, passive and facilitated diffusion. Furthermore, the mucosal lining in

the intestinal walls featuring plicae circulares and rugae absorb maximum nutrients as possible from the food, which is passed through the small intestine. The absorbed nutrients are then taken to different organs of the body, via blood vessels in which they are used to build proteins and other substances needed by the body. This process is called assimilation. Most of the nutrients are absorbed by the jejunum and the nutrients not absorbed by the jejunum are absorbed by the ileum. The residual undigested food is passed to the next part of the digestive system, i.e., to the large intestine.

8.3.5 Large Intestine (Colon)

Small intestine is followed by the large intestine.

Structure and location

Large intestine begins at the end of small intestine. It is the second to last part of the digestive system. Large intestine comprises the caecum at its starting point and anal canal at the last point. It starts in the right iliac region of the pelvis, just at or below the right waist, where it is joined to the bottom end of the small intestine. From here, it continues up the abdomen, across the size of the abdominal cavity, and then it turns down, continuing to its endpoint at the anus. Figure 8.18 shows large intestine.

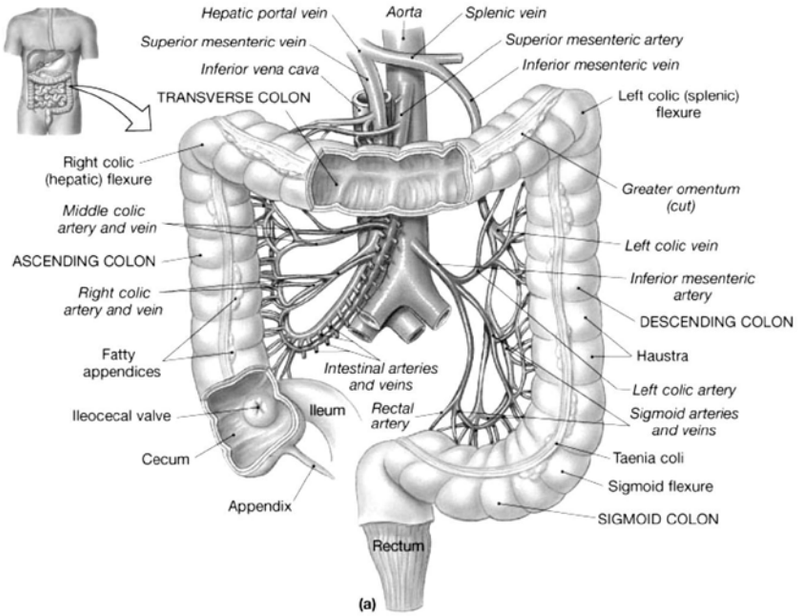

Fig. 8.18 *Large Intestine*

The large intestine forms an upside down 'U' shape over the small intestine. It starts at the lower right abdominal cavity in the body and terminates on the lower left side of abdominal cavity. The large intestine is about 5–6 feet long. The large intestine can be divided in to three parts – the cecum, colon and rectum.

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Cecum is the organ that links colon to the ileum. Ascending colon is the cecum, which rises up through the right side of the abdominal cavity. When this ascending colon runs horizontally through the abdominal cavity, it is known as the transverse colon. The transverse colon, when descends down the left side of the abdominal cavity, is called the descending colon. The descending colon finishes in the rectum and sequentially in the anus which are the last organs of the digestive tract. Just below the junction of two colons, the ileocaecal valve opens from the ileum. The vermiform appendix is a tube closed at one end, which leads from the caecum. It is 13 cm long and has the same structure as the wall of the colon but contains more lymphoid tissue.

Pelvic colon is an S-shaped curve in the pelvis that continues downwards to become the rectum.

The rectum is a slightly dilated part of the colon, which is about 13 cm long. It leads from pelvis colon and terminates in anal canal. Figure 8.19 shows the histology of large intestine.

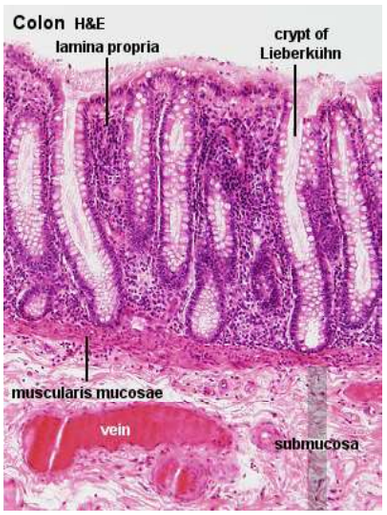

Fig. 8.19 *Histology of Large Intestine*

Functions of large intestine

1. Absorption

Large and small intestine are the two parts of intestine but functionally, both are totally different. Majority of the breakdown completes in the small intestine; more breakdown of food happens in the large intestine. The main function of the large intestine is to remove salts, water and electrolytes from undigested material, and it turns the food material into solid waste, which can be excreted. This helps in maintaining the fluid balance of blood. Bacteria present in the large intestine help in the process of breakdown of undigested material. The caecum is a pocket at the beginning of the large intestine, which serves as a passage for the food materials and permits food to travel from the small intestine to the large intestine. The colon

is the region in large intestine where fluids and salts are absorbed and it extends from the caecum to the rectum. The last part of the large intestine is the rectum, where faeces are stored prior to leaving the body through the anus.

NOTES

Undigested and digested materials, which reach from the small intestine to the large intestine, are in the solid faecal form as majority of digestion, breakdown and absorption of nutrients had been completed and absorption of water and salts from the faecal matter in the large intestine makes it more compact.

2. Production of vitamins

Another major function of the large intestine is absorption of certain vitamins. Many bacteria, useful for in vivo synthesis of vitamin K, reside in the colon. Vitamin K plays a major role in blood clotting process. The presence of such bacteria is very much dependent on the type and amount of food and any antibiotic medicines consumed by the patients. Any infection in this region due to lack of the bacteria or any other such useful bacteria, alters and reduces the absorption of water from the stool and results in diarrhoea. In addition to this, the flora in the intestine is responsible for generation of gases that results in peristaltic movement or number of contractions of the muscle of the digestive tract.

The large intestine also serves as the storeroom for solid faecal matter until it has to be excreted from the body through the anus.

3. Microbial activity

The large intestine possesses over 700 species of bacteria, which carry out several functions. Some of them are involved in vitamin production they are mainly: *Escherichia coli, Enterobacter aerogens, Streptococus fecalis* and *Clostridiu*. These microbes synthesize vitamin k and folic acid and Biotin (B vitamin), for absorption into the blood. The amount provided by them is really less although it is a significant contribution. People who are dependent upon antibiotics for longer periods encounter the problem of affected production of vitamins.

Some bacteria break down the complex undigested polysaccharide into small molecules and then get absorbed by passive diffusion. The environment becomes acidic by this activity, which is then neutralized by the production of bicarbonates produced by large intestine only.

Other bacterial products include gas, which is a combination of carbon dioxide and nitrogen, with small amounts of the gases hydrogen sulphide, hydrogen and methane. Bacterial fermentation of undigested polysaccharide generates these. The normal flora is also necessary in the development of certain tissues, including the lymphatics and cecum.

Some bacteria are also involved in the generation of cross-reactive antibodies. These are antibodies generated by the immune system against the normal flora, which are also effectual against related pathogens, thereby preventing invasion or infection.

NOTES

The most common bacteria are the bacteroides, which have been implicated in the beginning of colon cancer and colitis. Bifidobacteria are also profuse, and are often described as 'friendly bacteria.'

4. Defaecation

Peristaltic movements are not prominent in large intestine, as they occur only at fairly long intervals. A wave of strong peristalsis sweep along the transverse colon forces its contents into descending and pelvic colon. Mostly the rectum remains empty but whenever a mass is moved into rectum, the stretch reflex is induced into the nerves endings. This defaecation involves involuntary contraction of muscles of the rectum and rest of the internal anal sphincter and voluntary relaxation of external anal sphincter. Defaecation has been discussed in detail in Section 8.5.3.

Check Your Progress

3. What is bile or gall?
4. What is cecum?

8.4 ABSORPTION OF FOOD AND ITS EXCRETION

Digestion includes all the chemical changes, which occur while the food is being prepared for use by the body. Another process called absorption embraces the transfer of digested food to the blood stream and excretion refers to the process by which waste products of metabolism and other non-useful materials are eliminated from an organism.

8.4.1 Gastrointestinal Absorption

Absorption is the process whereby a cell, tissue or organ takes up a substance. In a man, about 8–9 litres of fluid, is absorbed from the gastrointestinal tract every day. Of this, about 1.5 litres is digested nutrients and the rest is water, salt and nutrients. All about 1.5 litres is absorbed in small intestine, leaving only 1.5 litres to go through the ileocaecal valve in colon. Stomach has poor absorptive area of the gastrointestinal tract as it does not have typical villi type absorptive membrane. Only some lipid-soluble substances like alcohol, aspirin can be absorbed in very less quantity.

8.4.2 Absorptive Surface of the Intestinal Mucosa

The absorptive surface of internal mucosa has many concentric folds called plicae circularis, also known as valves of Kerckring, which increases the surface area to three fold. These folds are well developed in the duodenum and jejunum, where they protrude as much as 8 millimeter into the lumen. In small intestine, the region where the common bile duct empties into duodenum has millions of small villi

(Figure 8.20), which projects few millimeter from the surface of mucosa. The presence of villi on the mucosal surface enhances the absorptive area ten fold. Each intestinal epithelial cell is has brush border, consisting of 600 microvilli. Thus, the combination of the folds of Kerckring, the villi and the microvilli increases the absorptive area of mucosa about 600 folds, totalling to about 250 square meters. The absorptive cells of internal mucosa are specialized for this function. The chime stays for a considerable time in the small intestine and regularly comes in contact with the internal mucous membrane due to the mixing contractions of small intestine.

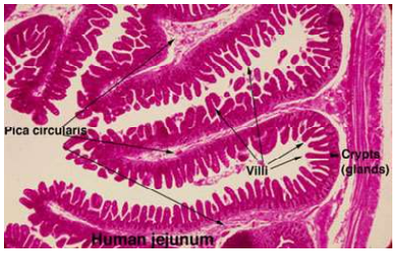

Fig. 8.20 *Structure of Villi*

8.4.3 Absorption in the Small Intestine

Water gets transported with the help of intestinal membrane. When chyme is diluted, water gets absorbed through the intestinal mucosa into the blood of villi by osmosis. On the other hand, water can be transported in the other direction from the plasma in the chyme. This happens when the hyper osmotic solutions get discharged from the stomach in the duodenum.

Absorption of ions

20–30 grams of sodium are secreted in the intestinal secretions every day. A normal person eats 5–8 grams of sodium every day. By combining these two, the small intestine must absorb 25–30 gram of sodium every day. Whenever the intestinal secretions are lost due to exteriors, as in extreme diarrhoea, the sodium reserves of the body can be depleted to a lethal level within hours. The sodium plays an important role in the absorption of sugars and amino acids. Some absorption of digested nutrients into absorptive cell is by simple diffusion (passive transport) and pinocytosis, but most of it is by active transport through carrier protein and a considerable amount of ATP is spent by the absorptive cell. The absorption of glucose is actively participated by sodium ions therefore it is called Na^+ co-transport mechanism.

When a person becomes dehydrated, large amounts of aldosterone are secreted by adrenal gland. Within one to three hours the excess aldosterone enhances all the enzymes and transports the mechanism for sodium absorption by the intestinal epithelial cells. This effect of aldostrone is particularly important in the colon as it allows no loss of sodium chloride in the faeces and quite less water loss.

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Absorption of chloride ion in the duodenum

In the upper section of the small intestine, chloride absorption is quite fast and mainly due to passive diffusion.

Absorption of bicarbonate ion in the duodenum and jejunum

When the sodium ions are absorbed, moderate amounts of hydrogen ions get secreted into the lumen of gut. These hydrogen ions then merge with the bicarbonate ions leading to the formation of carbonic acid (H_2CO_3) that then dissociates for forming water and CO_2. Water remains as a part of the chyme in the intestine, but the carbon dioxide gets readily absorbed in the blood and then gets expired through the lungs. This is the active transport of bicarbonate ion.

Absorption of nutrients

Carbohydrates are absorbed in the form of monosaccharide. As disaccharide, carbohydrates are actively transported into microvilli where the digestion gets completed to monosaccharide before it gets transferred to the capillaries in the villi.

Absorption of fructose is different from monosaccharide. It is transported by facilitated diffusion rather than active transport.

Absorption of fat

Fats get converted into fatty acid and glycerol. These digestive products get dissolved in the central lipid portion of the bile acid. They the get soluble in the chyme, and in this manner they get carried towards the surface of microvilli in the brush border. Here, both the monoglyceride and fatty acid diffuse first in local fluid then immediately in chyme. The procedure of the absorption of monoglyceride and fatty acid through the brush border is based on the fact that these substances are lipid soluble. They get dissolved in the membrane and just diffuse to the cell interior.

Protein absorption

Most of the proteins get absorbed through the luminal membranes of the epithelial cells in form of dipeptides, tripeptides and some amino acids. Energy for most of this transport is supplied through sodium-co transport mechanism as transport of glucose occurs. Most peptide or amino acid molecule bind with a specific transport protein that also require sodium binding before transport can occur. The sodium ions then move down its electrochemical gradient to the interior of the cell and pulls amino acid or peptide along with it. It is co- transport or secondary active transport of the amino acids or peptide.

8.4.4 Absorption in the Large Intestine

Approximately 100 ml of chyme passes through ileocaecal valve in the large intestine every day. Both water and electrolytes get absorbed in the colon, leaving less than 100 ml of fluid to be excreted in the faeces. All the essential ions get absorbed,

which leaves only 1–5 ml sodium and chloride ions to be lost in the form of faeces. Maximum absorption in the large intestine happens in the proximal half of the colon, whereas the distal colon functions principally for storage and is therefore called as the storage colon.

Large intestine can soak up about 5–7 litres of fluid and electrolytes every day. But then the total quantity exceeds the amount. The excess appears in the faeces as diarrhoea. When toxin from cholera or other bacteria often causes the crypts of Lieberkuhn in the end of ileum and in large intestine, which secrete which secrete as much as 12 litres of fluid each day, it leads to lethal diarrhoea.

Various bacteria especially C*olon bacilli* exist in the absorbing colon. Other substances that are formed as a result of bacterial captivity are vitamin K, vitamin B12, thiamine, riboflavin and various gases, such as carbon dioxide, hydrogen gas and methane. It contributes to the flatus in colon.

Normally, faeces are three-fourth water and one fourth solid matter, which consists of about 30 percent dead bacteria, 10–20 per cent fat and inorganic matter, 2–3 per cent protein and 30 per cent undigested roughage of the food and even the dried constituent of the digestive juice like bile pigment. The brown colour of faeces is due to the presence of urobilin and stercobilin, which is the derivative of bilirubin. The odour is due to the bacterial action.

8.4.5 Accessories of Digestive Tract (Pancreas)

Digestive tract consists of many organs. Some of them are being discussed in the following sections.

Pancreas

Pancreas is located in the abdominal cavity, and it extends up to the back of abdomen and is attached towards the first section of the intestine that is known as duodenum. It is spongy and yellowish in colour. The shape of the pancreas is just like a fish. It is about 15 cm in length and 3.8 cm in width and it shows both the endocrine and exocrine functions.

After food ingestion, glucose concentration in blood might increase, which leads to the release of insulin. It causes the uptake of glucose by liver and skeletal muscle cells to form the glycogen that is carbohydrate. As the levels of glucose in the blood fall, further insulin production gets inhibited. Glucagon that causes the breakdown of glycogen in glucose, released in the blood for maintaining glucose levels within a specific range. Glucagon production is encouraged whenever blood glucose levels fall, and gets inhibited when it rises.

Diabetes is the disease that is caused due to the lack of insulin production by the islets of pancreas. Lack of insulin (Figure 8.21) leads to increase in the blood sugar level, which in turn leads to the establishment of two types of diabetes, namely, type I and type II. Diabetes might lead to impairment in the functioning of the eyes, circulatory system, nervous system, delayed wound healing and failure of the kidneys. Daily intake of insulin injection assists the patient in keeping the

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sugar concentration in blood at a normal level. Oral medications like metformin, monitoring of blood glucose levels and a controlled diet contributes to the management of diabetes.

Pancreatic cancer is nearly always fatal. It is also a severe disorder, which may be responsible for leading cause of cancer death. Till now, no standard treatments are established that have proved to be that much effective, though advances in molecular biology, cellular biology and genomics show some promising milestones in treatment of cancerous cells.

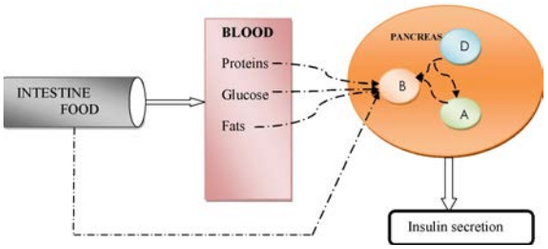

Fig. 8.21 *Secretion of Insulin*

Pancreas function

Pancreas shows the function as both the endocrine and the exocrine gland and hence, is considered to be a dual functioning gland. Pancreatic function plays a vital role in the body's activities. Regular functioning of the pancreas is quite important as the pancreatic problems lead to disorders like pancreatitis and diabetes.

Endocrine part of pancreas that is responsible for the endocrine function is made by millions of cell clusters. The endocrine glands are mismatched through a thick chain of capillaries. These capillaries get lined up in the layers of endocrine cells that are in direct contact with the blood vessels. Some of the endocrine cells are in direct contact whereas the rest are connected via the cytoplasmic processes.

Exocrine parts of pancreas make the alkaline fluid with the help of digestive enzymes. Both these secretions get secreted in the small intestine through the exocrine ducts. This secretion function gets performed in response to the small intestinal hormones known as cholecystokinin and secretin. Digestive enzymes produced by the exocrine glands comprises of chymotrypsin, trypsin, pancreatic lipase and pancreatic amylase. Digestive enzymes are made by the acinar cells that are present in the exocrine pancreas. Cells lining the pancreatic ducts are termed as the centroacinar cells and they secrete a solution that is rich in salt and bicarbonate contents in the intestine.

So, pancreatic problems should be avoided for ensuring a proper function of pancreas.

Check Your Progress

5. Define excretion.
6. How are carbohydrates absorbed?

8.5 LIVER: ANATOMY, PHYSIOLOGY AND IMPORTANCE

NOTES

Liver is the largest organ in the human body. It is located in upper right part of abdominal cavity. It is the responsible for the production and secretion of bile, which is accumulated in gall bladder. Bilirubin is result of the breakdown of haemoglobin. It also has bile salts, derived from cholesterol that emulsifies fat in small intestine. Figure 8.22 shows liver.

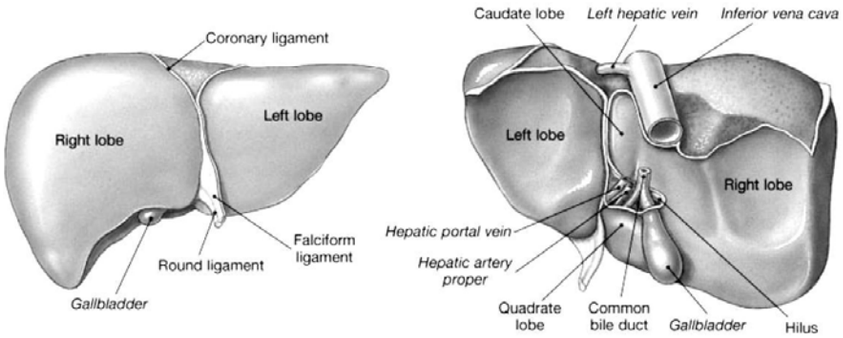

Fig. 8.22 *Liver*

The liver generates and sends bile to the small intestine via the hepatic duct. Bile contains bile salts, which emulsify fats, making them susceptible to enzymatic breakdown. Bile is generated in almost all mammals by the liver. This fluid has emulsification properties, which help in binding two substances together and therefore it is helpful in breaking down fats present in food. A significant function of bile is that it helps in absorption of a variety of vitamins from foodstuffs and helps the body make use of them. In addition to digestive functions, the liver plays several important roles such as synthesis of blood proteins, detoxification of blood, production of bile, destruction of old erythrocytes and conversion of haemoglobin into a component of bile, storage of glucose as glycogen, and its release when blood sugar levels drop and production of urea from ammonia and amino groups.

The liver in humans is an indispensable organ. It is the largest gland in the body. It has so many functions that one cannot live without it. Its smooth and curved upper and anterior surfaces are to fit under surface of diaphragm and anterior to the stomach; its posterior surface is irregular in outline.

Organs connected with the liver

- Superiorly and anteriorly: Diaphragm and anterior abdominal wall
- Inferiorly*:* Stomach, bile ducts, duodenum, right colic flexure of the colon, right kidney and adrenal gland
- Posteriorly*:* Oesophagus, inferior vena cava, aorta, gall bladder, vertebral column and diaphragm

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Microstructure

The liver is essentially an epithelial-mesenchymal outgrowth of the caudal part of the foregut, and the biliary tree helps in retaining its connection with it. The surface of the liver facing the peritoneal cavity is covered by a typical serosa, the visceral peritoneum. Beneath this, and enclosing the whole structure, is a thin (50–100 μm) layer of connective tissue from which extensions pass into the liver as connective tissue septa and trabeculae. Branches of the hepatic artery and hepatic portal vein, together with bile ductules and ducts, run within these connective tissue trabeculae, which are termed portal tracts (portal canals). The combination of the two types of vessel and a bile duct is termed a portal triad. These structures are usually accompanied by one or more lymphatic vessels. The liver parenchyma consists of a complex network of epithelial cells, supported by connective tissue and perfused by a rich blood supply from the hepatic portal vein.

The liver is surrounded by a thin capsule and incompletely covered by a layer of peritonium. The attachment of the liver to the inferior surface of diaphragm is through the formation of supporting ligament formed by the folds of peritonium. It is held in position partly by these ligaments and partly by the pressure of the organs in the abdominal cavity. The coronary ligaments symbolize reflections of the visceral peritoneum covering the liver onto the diaphragm. In isolation, between the two layers of the coronary ligament, there is a big triangular surface of the liver devoid of peritoneal covering; this is named the bare area of the liver, and is attached to the diaphragm by the areolar tissue.

The bare area of the liver is covered by Glisson's capsule, which is the fibrous capsule that sheathes the whole liver. The bare area of the liver is clinically significant as it represents a site where infection can increase from the abdominal cavity to the thoracic cavity.

The liver has four lobes. Two are the large right lobe and the smaller wedge-shaped, left lobe. The other two caudate and quadrate lobes are found on the posterior surface. The right lobe of the liver is bigger than the left lobe. Each lobe is further separated into many small lobules, each being about the size of a pin-head, and consisting of many liver cells, with blood channels and bile channels among them. Permeating the entire liver structure is an organization of bile capillaries, blood capillaries and lymph capillaries.

Portal fissure

It is the part of posterior surface of the liver where various structures enter and leave the gland**.** The hepatic portal vein enters; it carries blood from stomach, pancreas, spleen and the small and large intestine.

The hepatic artery enters; it carries arterial blood. It is a branch from the coeliac artery, which is a branch from the abdominal aorta. The right and left hepatic ducts leave; they carry bile from the liver to the gall bladder.

Lymph vessels leave the liver, pouring some lymph to the abdominal and some to thoracic nodes.

Structure

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The lobes of liver are made up of tiny lobules. These lobules are hexagonal in outline and made up of cubical-shaped cells called hepatocytes. These hepatocytes are arranged in pairs of columns, radiating from central vein and are separated from each other by corresponding, radiating venous sinusoids (cells with incomplete walls) containing a mixture of blood from the tiny branches of the portal vein and portal artery. This arrangement allows the venous blood and arterial blood to mix and come into close contact with the liver cell. The endothelial cells lining the sinusoids are hepatic macrophages or kuffer cells. The sinusoids arise as branches of the portal vein and open into the central vein of lobule, which in turn join to form many sub lobular veins. All these veins join to form the two hepatic veins, which carry the blood from the liver and empty blood into inferior vena cave just below the diaphragm.

Within hepatic lobules, bile canaliculi or capillaries form profuse networks of polygonal meshes, each mesh surrounding individual liver cell. All bile capillaries of a lobule open into an interlobular bile ductule of portal triad. All interlobular bile ductules of a hepatic lobe merge together in order to make a single hepatic duct. All hepatic ducts from right and left liver lobes merge to form a single right, left hepatic duct. Right and left hepatic ducts join to form common hepatic duct, which joins the duct of gall bladder. The gall bladder lies inside the liver, and is the storeroom for bile, which is made by the liver cells.

Functions of liver

Liver performs the following functions:

1. **Glycogenesis, glycogenolysis, gluconeogenesis and regulation of blood sugar**: The hepatic portal vein, which takes away most of the end products of digestion from intestine, enters in the liver and breaks into capillaries. Therefore, before absorption, it reaches into the liver. In liver, the level of blood sugar stays at around 0.1 per cent, and surplus sugars are withdrawn from the portal blood by liver cells and are converted into glycogen granules for storage. The hormone called insulin – excreted by the pancreas – causes the excess glucose to turn into glycogen. When usual amount of sugar in blood is declined, liver cells convert their stored glycogen into glucose. In the same way liver cells also generate glucose from fatty acids, amino acids, glycerol called gluconeogenesis.
2. **Regulation of lipids**: Lipids are extorted from the blood and converted into carbohydrates, etc. as needed, or are sent to fat storage sites if not required straight away.

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3. **Regulation of amino acids**: A supply of amino acids in the blood is kept at a regular level. Any spare which has not been absorbed cannot be stored but is changed into the waste products, called urea when at the liver, and is then transported to the kidneys to be taken out from the body as urine. The rest of the amino acid molecule is not wasted; it is changed into a carbohydrate that can be useful.
4. **Production of heat**: The liver is one of the hardest working regions of the body and generates a lot of waste heat. This is carried round the body in the blood and warms less energetic regions.
5. **Formation of bile**: The bile is an intricate greenish and alkaline fluid containing, among other substances, bile pigment, bile salt, lecithin and cholesterol. It is significant to speed up the digestion of lipids.
6. **Forms cholesterol**: This fatty matter is used in the cells. Surplus amounts in the blood can cause the blood vessels to become choked-up, leading to heart attacks, etc.
7. **Removals of hormones, toxins**: The liver removes many harmful matters from the blood and excretes them in the bile or from the kidneys.
8. **Formation of red blood cells:** It happens in the young embryo while it is developing within the womb.
9. **Secretion of heparin**: Liver cells exude this substance, which prevents the blood from clotting as it passes through the blood system.
10. **Removal of haemoglobin molecules**: When red blood cells die, the haemoglobin is changed into bile pigments and the iron atoms are saved for future use.
11. **Storage of blood**: The liver can enlarge to hold huge amounts of blood, which can be released into the transmission if the body suddenly needs more, e.g., if it is wounded.
12. **Synthesis of blood proteins**: The plasma proteins are employed in blood clotting and in keeping the blood plasma stable. The main blood proteins comprise prothrombin, fibrinogen, albumins and globulins.
13. **Synthesis and storage of vitamins:** These vitamins are vitamin A and D. Vitamin A is also prepared in the liver from carotene, the orange-red pigment in plants. Vitamin B12 is also stored in the liver.
14. **Lymph formation:** Liver plays an important role in lymph formation.
15. **Destruction of bacteria*:*** Kuffer cells of liver perform their phagocytic action in blood and destroy not only inactive and dead RBCs but also harmful bacteria.
16. **Storage of inorganic substances*:*** Just like the iron of haemoglobin, the liver cells also store other metal ions like copper.

8.5.1 Gall Bladder

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Gall bladder is a pear-shaped, muscular sac situated in a depression on the inferior surface of the liver. Several people do not have knowledge about the exact location of the gall bladder. This is due to the gall bladder having a small sac-like structure that is hidden somewhere at the back of the liver. It plays a relatively minor role in the entire digestion process. The gall bladder is located in the body on the right hand side of the rib cage, right behind the liver and it is known to touch the liver at the base. A canal or duct that joins the liver and the small intestine connects with a duct to and from the gall bladder. This duct is responsible for the entrance and exit of the bile. The duct is also a carrier of bile and the enzymes that the pancreas secretes that aid in the process of digestion. However, one cannot ignore the value and significance of the gall bladder in the human body and the digestive system.

The excess bile that the liver produces is stored by the gall bladder which turns it into a thick, mucous-like material by reabsorbing water. Any bile that the liver makes in the body is made to pass through small canals or ducts to the small intestine, and then on to the gall bladder. Bile exits the gall bladder through cystic duct. Cystic duct and common hepatic duct combine for forming a common bile duct that gets into the duodenum. On consumption of a small meal by an individual, the gall bladder secretes the bile stored in it and uses it for digestion. On consumption of food by an individual, the fat in the food facilitates the release of the hormone cholecystokinin **(**CCK). This hormone gives an indication to the gall bladder for ejecting the bile contained in it to the small intestine, where it enables fats to be dissolved which is there in the food to be consumed.

Role of bile in digestion and excretion

One of the primary functions of liver is the secretion of bile, usually between 600 and 1200 ml/day. Bile has two main functions: First, it actively participates in digesting and absorbing fat, not due to the presence of enzymes in bile causing fat digestion. Rather it is due to two functions that the bile performs which are as follows:

(1) They aid the emulsification of the bigger fat particles of the food into several tiny food particles that the lipases secreted in pancreatic juice attack.

(2) They enable the transportation and absorption of digested fat through the intestinal mucosal membrane.

Second, bile is a way for excretion of many significant waste products from the blood. Particularly, bilirubin is a final product of haemoglobin destruction, and excess of cholesterol that the liver cells synthesize.

Storage of bile in the gall bladder

The bile that the liver cells continuously secrete is generally stored in the gall bladder till required in the duodenum. Bile is generally concentrated about 5 fold which also includes bile salts, cholesterol , lecithin and bilirubin.

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Composition of bile differs from the time of its first secretion by the liver and post concentration in the gall bladder. The most profuse material secreted in the bile is bile salt. However, the secretion or excretion of those in big concentration is bilirubin, cholesterol, lecithin and usual electrolytes of plasma.

	Liver Bile	Gall bladder Bile
Water	97.5 gm/	92 gm/dl
Bile Salts	1.1 gm/dl	6gm/dl
Bilirubin	0.04 gm/dl	0.3 gm/dl
Cholesterol	0.1 gm/dl	0.3- 0.9 gm/dl
Fatty Acid	0.12 gm/dl	0.3-1.2 gm/dl
Lecithin	0.04 gm/dl	0.3 gm/dl
Na+	145 mEq/ltr	130 mEq/ltr
K+	5 mEq/ltr	12 mEq/ltr
Ca+	5 mEq/ltr	23 mEq/ltr
Cl-	100 mEq/ltr	25 mEq/ltr
HCO3-	28 mEq/ltr	10 mEq/ltr

Role of Bile

Though bile contains no digestive enzymes, yet it takes an active part in fat getting digested and absorbed and benefits the body in several other ways:

1. It intensifies the "mixing contractions" of intestinal wall
2. Its inorganic bile salts neutralize the HCl, imparting alkalinity to the chyme and inactivating gastric pepsin. This condition is essential for intestinal digestion, because enzymes of both pancreatic and intestinal juices act upon food only in an alkaline medium.
3. The organic salts of bile have a detergent action on the fat particles in the food, that reduces the surface tension of the particles. It permits the demonstration in the intestinal tract for breaking the fat globules in tiny sizes. This is known as the *emulsifying or detergent function* of bile salt.
4. The bile salts even aid fatty acids, monoglycerides, cholesterol and other lipids to be absorbed from the intestinal tract. This is done by the formation of tiny complexes with these lipids, known as *micelles* that help in transporting all end products of fat digestion from intestinal lumen to absorptive cell.
5. Facilitation of fat absorption is associated with absorption fat soluble vitamins A,D,E & K.
6. Removal of waste products from blood such as toxins, metal ions, excessive cholesterol, bilurubin through faeces.

8.5.2 Biliary System or Tree

The biliary tree is the general anatomic name for the path by which the liver secretes the bile when it is on its way to the second part of the duodenum, or small intestine

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of a majority of the members of the mammal family. It is known as a tree since it starts with several small branches ending in the common bile duct, certain times known as the trunk of the biliary tree. It is divided into intra hepatic and extra hepatic biliary trees. The intra hepatic duct is formed from the larger bile canaliculi and fuse close to the porta hepatis into right and left hepatic ducts. The extra hepatic biliary tree contains the right and left hepatic ducts, the common hepatic duct, the cystic duct and gall bladder, and lastly the common bile duct.

The biliary system supplies the channels through which transportation of the bile from liver to the duodenum through the papilla of vater (it remains closed at rest) takes place. The liver can be seen in the right upper corner of the abdomen, right under the diaphragm. In a normal individual, its weight is approximately 2 – 3 pounds. It is categorized into the right and left lobes, and is made up of the ducts. The biliary system that takes place in the liver further combines with the gall bladder and its duct besides the common bile duct. Starting in the liver, the right and left hepatic duct combines for forming the common hepatic duct right external to the hepatic portal. Hepatic duct moreover goes on downwards for approximately 3 cm for joining with the cystic duct. The gall bladder is the gathering or storage sac for bile with the latter entering and leaving this organ through a narrow tube known as cystic duct.

Bile is transported in the following manner:

1. As the secretion of bile takes places by the liver cells, system of ducts that flow from the liver through the right and left hepatic ducts collect the latter.
2. These ducts then drain into the common hepatic duct.
3. The common hepatic duct then combines with the cystic duct from the gall bladder for forming the common bile duct, running from the liver to the duodenum (the first section of the small intestine).
4. Nevertheless, approximately 50 percent of the bile that the liver produces is initially stored in the gall bladder.
5. Lastly, on consumption of food, the contraction of the gall bladder enables the release of the stored bile into the duodenum to enable the breaking down of fats. Bile salt is the real constituent that enables the breaking down and absorption of fats. Bile, the excretion of which takes places from the body through faeces, is responsible for the dark brown colour of the faeces.

Cystic duct

The cystic duct measures 3–4 cm in length and travels posteriorly to the left from the neck of the gall bladder, and in last joins the common hepatic duct to form the common bile duct. The cystic duct empties the gall bladder into the common bile duct. The intersection where the cystic duct joins the common bile duct takes place near the porta hepatis. Infrequently, it has been found that the cystic duct empties into the right hepatic duct. In this situation, it may be stretched out in size.

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Biliary stones

Gallstones or biliary stones are formed in the gall bladder, and they move towards the cystic duct when the gall bladder empties. If the stone is small and enters the cystic duct, it can cause irritation of the columnar mucosa. This leads to spasm of the smooth muscle in the cystic duct wall and further generates pain known as biliary colic, which is often very severe. Stones that occlude the neck of the gall bladder cause the distension of the latter. Stones that lodge in the distal cystic duct might cause swelling in the tissues around the duct.

Hepatic bile ducts

The right and left hepatic ducts come out from the liver and bond near the right end of the porta hepatis forming the common hepatic duct. The extrahepatic right duct is short and almost vertical; whereas, the left one is more horizontal. The common hepatic duct descends about 3 cm before joining the cystic duct to make the common bile duct. The common hepatic duct is located to the right of the hepatic artery and anterior to the portal vein.

Biliary drainage

A distended and obstructed gall bladder drains into the proximity of the fundus of the gall bladder to the anterior abdominal wall. It can be accessed below the costal margin and is usually performed under ultrasound guidance. Due to the spiral conformation of the cystic duct, drainage of the gall bladder is rarely adequate to decompress the biliary tree if it is blocked, and this must be done endoscopically, surgically or by a percutaneous, transhepatic approach. Percutaneous access is obtained via segment III in the left lobe of the liver and via segments V and VI in the right lobe of the liver. Figure 8.23 shows pancreas and biliary tree.

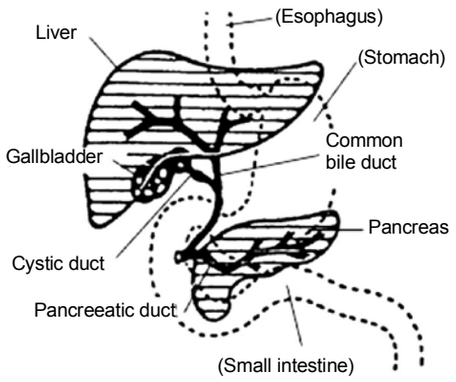

Fig. 8.23 *Pancreas and Biliary Tree*

8.5.3 Defecation

The act of removing feces (solid as well as semisolid waste) through the digestive tract is referred to as defecation or bowel movement. The frequency of removing

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waste from the body is not same for all human beings, some remove it once or twice daily and some have defecation two three times in a week. Both are considered normal state of health. The waste material moves to the rectum with help of the muscular contractions that take place in the walls of the colon. The movement takes place through the digestive tract.

The distensible muscular tube shape of the rectum acts as a storage area for holding waste of the body. Once the walls of the rectum get stretched due to the waste filling the stretch receptors of the nervous system situated inside the walls of the rectum signal the need to defecate. The urge to defecate is felt only for a couple of minutes and in case the action is not completed then the waste material returns to the colon and extra water is absorbed from it. In cases, where the defecation is repeatedly postponed there are chances that feces will become hard and this will result in constipation. Once the rectum is full, the pressure inside increases, the internal pressure of the rectum compel the walls of the anal canal to open and allow the waste materials entry into the canal; once the material enters the canal the pelvic floor muscles open the walls of the canal. As soon as the material enters the anal canal the rectum shortens and the muscular contractions makes the feces leave the rectum. There are two muscular constrictors in the anus, the inner and outer sphincters, these permit the passage or retention of the feces. Once the feces leaves, the pelvic muscles of the pelvic diaphragm help the anus to draw up above the exiting mass, the prolapse of the anal canal can be prevented.

Excretion of urine generally takes place along with the action of defecation. Pressure is exerted on the digestive tract by chest muscles, diaphragm, abdominal-wall muscles, and pelvic diaphragm. There is a temporary halt on the respiration as well since the packed lungs thrust the diaphragm down so that pressure can be exerted. The pumping of blood by the heart decreases and this raises the blood pressure.

The act of defecation may be completely spontaneous, or it occurs under deliberate control. As the people age, they tend to lose control over the process of defecation. The loss of control may be an outcome of a surgery or injuries in spine and other neurological disorders as a result of diabetes, stroke, or multiple sclerosis. Defecation can be affected due to factors like ache, terror, fever and psychological or neurological problems. Diarrhea, or unusually recurrent defecation, is a typical symptom of several ailments and disorders especially during cholera and dysentery.

Check Your Progress

7. What is the main role of liver?
8. Where do the right and left hepatic ducts combine with each other?

8.6 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

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1. The roof of oral cavity is called palate.
2. The pharynx is the part of both the digestive and respiratory systems.
3. Bile or gall is a bitter-tasting, dark green to yellowish brown liquid, generated by the liver of most vertebrates.
4. Cecum is the organ that links colon to the ileum.
5. Excretion refers to the process by which waste products of metabolism and other non-useful materials are eliminated from an organism.
6. Carbohydrates are absorbed in the form of monosaccharide.
7. The main role of liver is to discharge the bile.
8. The right and left hepatic ducts come out from the liver and bond near the right end of the porta hepatis.

8.7 SUMMARY

- All the organs associated in the process of digestion form a gastrointestinal system as a whole. These organs are mouth, pharynx, oesophagus, stomach, small intestine, large intestine, rectum, liver and pancreas.
- Stomach is the place where the actual chemical digestion of food material takes place in acidic environment. Here, partially digested and semi-solid materials are converted to semi-liquid phase.
- Liver plays a very essential role as it discharges bile salts, which act in the process of the digestion and absorption of fats.
- Tongue is very sensitive. It is kept moist by saliva and has plenty of nerves and blood vessels.
- The parotid gland is the major salivary gland and is covered around the mandibular ramus.
- Oesophagus is actively involved in the transportation of food from mouth to stomach.
- Gastric secretion includes hydrochloric acid (HCL) and enzymes from the gastric glands.
- Intestinal juice (succus entericus) refers to a pale yellow watery secretion from the glands lining the walls of small intestine.
- Vitamin K plays a major role in blood clotting process.
- Carbohydrates are absorbed in the form of monosaccharides.

- The bare area of the liver is covered by Glisson's capsule, which is the fibrous capsule that sheathes the whole liver.
- The biliary tree is the ordinary anatomic term used for the path by which bile is secreted by the liver on its way to the duodenum. It is called a tree as it starts with various small branches which end in the common bile duct, at times called the trunk of the biliary tree.

8.8 KEY WORDS

- **Oesophagus:** It is a channel that connects the mouth to stomach.
- **Stomach**: It is a big J-shaped, empty organ and is located between the oesophagus in the upper side and the upper portion of small intestine termed as duodenum in the lower side.
- **Villi**: These are minute finger-like projections that come out of the wall of small intestine.
- **Diabetes:** It is the disease that is caused due to the lack of insulin production by the islets of pancreas.
- **Gall bladder:** It is a pear-shaped, muscular sac situated in a depression on the inferior surface of the liver.

8.9 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. How is the blood sugar level maintained once the glucose gets absorbed from the intestine after digestion?
2. Compare the structure of small and large intestines in terms of the process of absorption of the nutrients.
3. Differentiate between the digestive juice secreted by pancreas and liver.
4. How can one sense the taste of food?
5. How does the inner lining of GIT tract protect itself in the presence of various digestive enzymes secreted during digestion?
6. What is the function of acid in stomach and bicarboanate in intestine?
7. What is the special structure present in the small and large intestines for absorption?
8. Give the location and function of salivary glands.

Long Answer Questions

1. Explain the harmful consequences of the high blood glucose level.

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2. Explain the structure of a typical tooth and discuss different types of teeth.
3. Explain the differences between the histology of different parts of the GIT (stomach, small intestine and large intestine).
4. Describe the structure of liver and explain the function of liver and bile in the process of food digestion.
5. Analyse the process of food digestion in stomach and intestine. Differentiate the two in terms of the enzyme used and the pH of the environment.
6. What are the special structures available in the GIT for absorption? Explain the absorption of the nutrients from the digested food in the GIT.
7. Name the accessory organs associated with the GIT. Explain their functions and importance.
8. Explain the structure and function of biliary tree.
9. Review how the secretion of pancreatic juice, bile secretion and juice from the gastric glands is regulated.
10. Discuss the role of liver in the process of digestion.

8.10 FURTHER READINGS

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BLOCK - III
EXCRETORY AND REPRODUCTIVE SYSTEM, SENSE ORGANS

NOTES

UNIT 9 EXCRETORY SYSTEM

Structure

9.0 INTRODUCTION

The body produces waste material due to the production of energy and various other metabolic processes. This waste is removed by the urinary system from the body. The main parts of the urinary system consist of the kidneys, ureters, urinary bladder, nephrons and urethra. After the urine is collected in the urinary bladder, it is passed out of the body through the urethra. The main waste material is urea, generated after protein metabolism, along with several other components that get dissolved in the blood plasma. The kidneys act as filters to separate the toxic waste and chemicals from the blood plasma.

In this unit, you will study about the role of kidneys, mechanism of urine formation, the need for conducting renal function tests, the kinds of dialysis and the procedure for conducting renal transplantation.

9.1 OBJECTIVES

After going through this unit, you will be able to:

- Analyse the role of kidneys
- Discuss the mechanism of urine formation

- Identify the need for conducting renal function tests
- Explain the kinds of dialysis
- Describe the procedure for conducting renal transplantation

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9.2 ROLE OF KIDNEYS

Kidneys are bean-shaped organs that measure approximately 11 cm in length, 6 cm in width and 3 cm in thickness. They are located on the posterior abdominal wall, one on each side of the vertebral column behind the peritoneum and below the diaphragm. The position of the right kidney is usually slightly lower than the left, probably because of the considerable space occupied by the liver.

Gross structure of the kidney

The kidneys are surrounded by a fibrous capsule, known as the renal capsule. The individual capsule of each kidney helps to maintain the shape of the kidney and protects it from damage. If we look at the longitudinal section (LS) of the kidney, we can divide the kidney into two regions:

(i) Cortex (towards outside)

(ii) Medulla (the inner portion)

Figure 9.1 shows the longitudinal section of the human kidney.

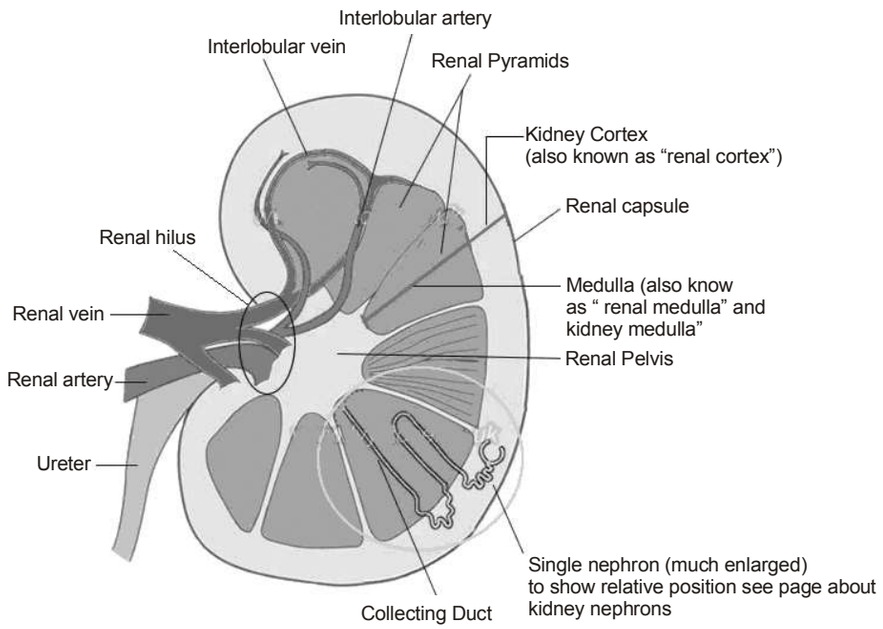

Fig. 9.1 *Longitudinal Section of Human Kidney*

The cortex is the reddish brown layer of tissue that lies under the capsule and between the pyramids. There is a depression found in the cortex tissue, known

as the renal hilus, where the renal blood and lymph vessels and nerves enter into the kidneys. The renal hilus is the concave medial border of the kidney. The other important components of the kidneys are as follows:

- **Renal medulla:** It is the innermost layer that consists of pale conical-shaped striations known as the renal pyramids.
- **Renal pelvis:** It is a funnel-shaped structure that acts as a receptacle for the urine formed by the kidney.
- **Renal vein and artery:** The renal arteries originate from the abdominal aorta and transport blood to the kidneys. From these arteries, the segmental arteries bifurcate and they again divide into interlobular arteries. These then supply blood to arcuate arteries that supply blood to the glomerular capsules for filtration. The renal veins get de-oxygenated blood from the peritubular veins that merge into interlobular, arcuate, interlobar and segmental veins in the kidneys. The de-oxygenated blood is subsequently returned to the blood circulation system.

Nephrons

Nephrons are the basic structural and functional units of kidneys. There are more or less a million nephrons present in each kidney that filter blood to remove urea, extra salts and other waste material from the blood. Nephrons are structured in the form of tubule closed at one end and open at the other end into a collecting medium. The collecting medium is a cup-shaped glomerular capsule, known as the Bowman's capsule, which surrounds a cluster of arterial capillaries, known as the glomeruli (Figure 9.2).

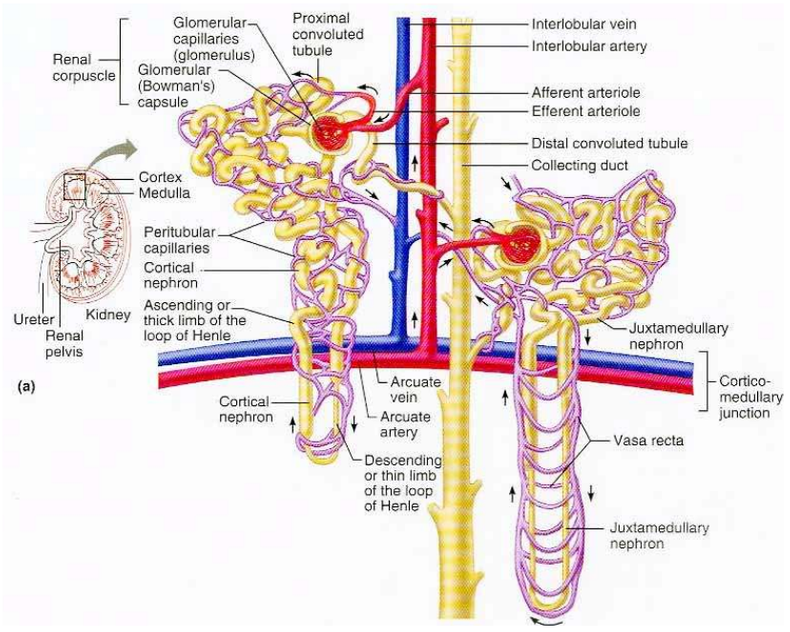

Fig. 9.2 *Structure and Location of Nephrons in Kidney*

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The structure of nephrons consists of the following main parts:

- Proximal convoluted tubule
- Loop of Henle
- Distal convoluted tubule that leads into the collecting tubule

The renal artery enters the kidney at the hilus where it divides into further arteries and arterioles. An afferent arteriole enters in the cortex into each glomerular capsule that then divides into a network of capillaries forming the glomerulus. The blood vessels that exit from the glomerulus are efferent arterioles that divide into a capillary network. This network provides oxygen and nutrition to the nephrons. The pressure of blood in the glomerulus is higher than in other capillaries because the afferent arteriole has higher functional capability than the efferent arteriole.

9.3 MECHANISM OF URINE FORMATION

The process of urine formation takes place in several steps. First, a portion of blood plasma is filtered through the capillaries in the Bowman's capsule and then nutrients and other chemical constituents get reabsorbed according to their requirement in the body. The steps of urine formation are discussed in the subsequent sections.

Filtration

The first step in urine formation is filtration. Filtration occurs through the semi-permeable walls of the glomerulus and glomerular capsule. The glomerulus lining is such that it only allows water and a large number of small molecules, like glucose, plasma, sodium and potassium ions and urea, to filter through. Blood cells, plasma proteins and other large molecules cannot filter through the glomerulus and remain in capillaries. The key factor that facilitates filtration is the variance in blood pressure of the filtrate between the glomerulus and the filtrate between the glomerular capsule. Since the capacity of the efferent arteriole is less than that of the afferent arteriole, a capillary hydrostatic pressure of about 70 mm Hg builds up in the glomerulus. This pressure is opposed by the osmotic pressure of blood (about 30 mm Hg) and by filtrate hydrostatic pressure (about 5 mm Hg) in the glomerular capsule. Therefore, the net filtration pressure is as follows:

$$70 - (30 + 5) = 35 \text{ mm Hg}$$

Approximately, 100–150 L of dilute filtrate is formed each day by the two kidneys and 1.0–1.5 L are excreted as urine. The volume of glomerular filtrate made every minute in the nephrons can be defined as the glomerular filtration rate (GFR). In an adult human, the glomerular filtration pressure of 1 mm Hg leads to filtration of approximately 12.5 mL plasma fluid from glomerular capillaries every minute. Therefore, the GFR in an adult is 125 mL of plasma fluid per minute or 180 l/day. Only about 1.45 L (about 0.8 per cent part) of the total glomerular

filtrate is excreted out as urine per day and the rest is reabsorbed into the blood from the nephrons.

Selective Reabsorption

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The chemical composition of glomerular filtrate is like blood plasma minus blood protein. Thus, it is mostly water with all soluble and diffusible solutes of plasma that include the following:

- Nutrients (glucose, amino acids)
- Electrolytes of salts (sodium, potassium, chlorine, hydrogen)
- Waste of protein metabolism (urea, uric acid and creatinine)

Conversely, urine extracted from the filtrate in nephrons contains water, urea, uric acid, creatinine and useless electrolytes in considerably higher concentration and nutrients are almost absent in it. This proves that while the filtrate flows through a uriniferous tubule, not only its volume is reduced, but its composition is also considerably changed. Changes are due to exchange of materials between the filtrate and blood of peritubular capillaries. This selective reabsorption process helps to reabsorb those filtrate constituents needed by the body to maintain fluid and electrolyte balance and blood alkalinity.

The blood flows rapidly in peritubular capillaries and with very low pressure (about 13 mm Hg). Consequently, fluid can diffuse into capillaries from surrounding tissue fluid but cannot filter out of them. Re-absorption involves both passive transports by diffusion and osmosis and active transport across the tubular epithelium. Glomerular filtrates have been analysed from different parts of uriniferous tubules to ascertain the changes occurring stepwise in the filtrate while it flows through the tubule.

Active Transport through the Tubular Membrane

Primary active transport and secondary active transport are the two mechanisms of active transport of sodium ions though the tubular membrane.

Primary active transport

The transport of sodium ions through the tubular membrane always occurs in the direction from the tubular lumen to the interstitium. On the basal and lateral surfaces of the tubular epithelial cell, the cell membrane contains an extensive Na^+, K^+ - ATPase system that is capable of cleaving adenosine triphosphate and using the released energy to transport sodium ions out of the cells to the interstitium, and at the same time transporting potassium ions from the interstitium to the interior of the cell. The ATPase system pumps three sodium ions for every two potassium ions pumped. Tubular epithelial sides are so permeable to potassium that virtually the entire potassium diffuses out of the cell into the interstitium. A net effect of the sodium pumped outside leads to the reduction of sodium inside the cell to a very low concentration. Also, because three positive electrical charges are pumped out

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of the cells along with the sodium ions, the interior of the cells are left with a negative potential of about –70 mV. Therefore, the two factors responsible for the diffusion of sodium ions from the tubular lumen to the interior of the cell are as follows:

(i) The very large sodium concentration gradient across the membrane, with high sodium concentration inside the cell

(ii) The attraction of the positive sodium ions in the tubular lumen to the interior of the cell by the –70 mV intracellular potential

The internal surface of the epithelium inside the tubule is increased 20 times by the brush-border of microvilli of columnar epithelium cells. In the membrane of this brush border, sodium carrier proteins are present. Those with the sodium ions on the membrane surface release them inside the cell, thus providing facilitated diffusion of sodium to the interior of the cell. This ensures rapid diffusion of sodium through the luminal border of the epithelial cell at the same time the sodium ion is being actively transported out of the cell at the basolateral border. Thus, sodium pumped from the tubule is eventually absorbed into the peritubular capillary and carried away by the blood.

Secondary active absorption

In secondary active transport, no energy is directly used from adenosine triphosphate (ATP). Instead, the movement of sodium ions from the tubular lumen to the interior of the cells energizes most secondary transport of other substances. This is achieved by multiple, different types of sodium carrier proteins in the epithelial cell brush border. For instance, the uppermost cell illustrates secondary active transport of glucose and the second cell illustrates secondary active transport of amino acid and ions. In each case, the carrier protein in the brush border membrane combines with both the substances to be transported and a sodium ion at the same time. As the sodium moves downward, its electrochemical gradient inside the cell pulls glucose or amino acid ions along with it, known as co-transport.

Glucose, amino acid and several other organic compounds are strongly co-transported in proximal tubules. Chloride ions are co-transported in the thick segment of the ascending limb of the loop of Henle. Other substances also co-transported at some point in the tubular system are calcium, magnesium, phosphate and hydrogen ions.

Passive Absorption of Water

When the different solutes are transported out of the tubule by either primary or secondary active transport, their total concentration decreases inside the tubular lumen and increases in the interstitium. This creates a concentration difference that causes osmosis of water in the same direction in which the solutes have been transported. A large share of this osmosis occurs through so-called tight junctions between the epithelial cells rather than through the cells themselves.

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These junctions are not as tight as their name would imply but instead allow rapid diffusion of water and many other small ions. As solutes are absorbed through the proximal tubular epithelial cells, this increases the osmolality in the interstitium and almost instantaneous osmosis of a proportionate volume of water to go along with the solutes. Therefore, the fluid absorbed from the proximal tubule is almost exactly iso-osmotic.

The loop of Henle is composed of three parts:

(i) The thin descending limb

(ii) The thin segment of ascending limb

(iii) The thick segment of ascending limb

There is a gradual increase in the osmolality of interstitial fluid in the renal medulla and cortex. The thin wall of the descending limb of the loop of Henle is permeable to water but not to sodium and other solutes. As the filtrate flows forward in this limb, more of its water is gradually reabsorbed due to increasing osmolality of interstitial fluid. Now, filtrates become four times hyper-osmotic to blood plasma.

The thin segment of the ascending limb of loop of Henle is structurally similar to the descending limb, but its permeability is different. It is poorly permeable to water, but quite permeable to sodium chloride and partially permeable to urea. Here, the filtrate loses sodium and chloride ions by diffusion due to decreased osmolality of interstitial fluid towards cortex but gains in urea concentration as it ascends in the thin portion of ascending limb. As a result of this exchange, filtrate becomes diluted and almost iso-osmotic to plasma without changing its volume.

In distal convoluted tubule, the permeability of tubular wall to both urea and water is completely lost and reduced to sodium chloride. Epithelial cells takes up chloride ions from the filtrate and leave them in the interstitial fluid by active transport. Sodium ions automatically force their way along with chloride ions. This is controlled by aldosterone, a hormone, and by several other factors. Now, the filtrate is hypo-osmotic to plasma without change in its volume.

Collection of Urine

The hypo-osmotic filtrate now flows into a collecting duct, and this entire duct is permeable to water. Its permeability to water is controlled by the level of anti-diuretic hormones in the circulating blood. Its distal part, situated in the medullary pyramid, is also permeable to urea. When an excessive amount of anti-diuretic hormones are available, water is reabsorbed into the medullary interstitium with great avidity, thus reducing the volume of urine and concentrating most of dissolved substances in the urine. Therefore, some urea is reabsorbed into the medullary interstitium. Most of it then diffuses into the loop of Henle and is returned through the distal tubule to the collecting duct and is finally excreted.

The most important characteristic of the collecting duct epithelium is it is also capable of secreting hydrogen ions against a very high hydrogen ion gradient.

Therefore, collecting duct epithelium plays an important role in controlling the acid–base balance of the body fluid.

Hormones Regulating Volume of Urine

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In order to maintain homeostasis, re-absorption is regulated by certain hormones in some cases.

- Parathormone is formed in the parathyroid gland and *calcitonin* is formed in the thyroid gland. Both these hormones regulate the reabsorption of calcium and phosphates.
- Antidiuretic hormone (ADH) is formed in the posterior lobe of the pituitary and is responsible for the permeability of the distal convoluted tubule and collecting tubule, thus regulating water reabsorption.
- Aldosterone is secreted by the cortex of adrenal gland (suprarenal gland). This hormone influences the concentration of major electrolytes (sodium and potassium) by controlling the reabsorption of sodium and excretion of potassium.

Tubular Secretion

Tubular secretion is the ultimate step in urine formation. In this step, urine is produced in a concentrated form by increasing the percentage of waste elements like creatinine and potassium. Thus, in addition to its role in selective reabsorption of materials from glomerular filtrate back into the blood of peritubular capillaries, the proximal tubule also alters the composition of filtrate by a process of secretion in its distal part. In this stage, substances are transported into the distal and collecting tubules from blood in the capillaries around these tubules. These substances are secreted by active transport and include hydrogen and potassium ions, ammonia and certain drugs or metabolic end products. Kidney tubules have an important part to play in sustaining the acid–base balance and the electrolyte balance in the body. The urine is drained by the distal convoluted tubules into the collecting tubules. Several collecting tubules are put together to drain the contents into the collecting duct, which after urine is formed, flows into the ducts of Bellini. The contents are sent to the renal pelvis, from where the urine is transported to the ureter that reaches the urinary bladder.

Composition of Urine

Normal urine contains the following:

- Water (96 per cent)
- Electrolytes (chlorides, sulphates, oxalates and bicarbonates of ammonia, sodium, potassium; 2 per cent)
- Urea (2 per cent)
- Uric acid (0.3 per cent)
- Creatinine, ammonia and some pigment and hormones (trace amounts)

Presence of urobilin, a bile pigment altered in the intestines, is reabsorbed and excreted by the kidneys which makes the urine transparent, but pale yellow in colour. Normal urine is slightly acidic with a pH of 6.0 and the specific gravity is between 1.015 and 1.020. A healthy adult passes 1,000–1,500 mL/day. Both the amount secreted and the specific gravity varies with the fluid intake and the amount of solutes excreted. Urine production is decreased during sleep and muscular exercise.

Figure 9.3 shows the process of formation of urine.

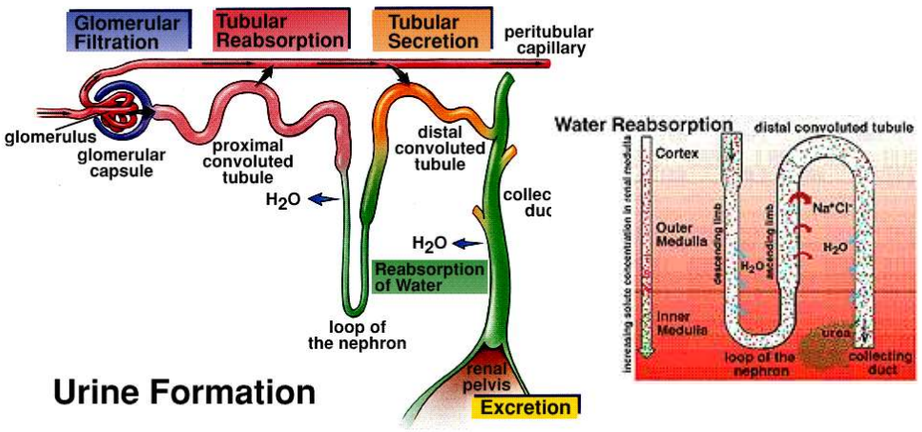

Fig. 9.3 *Formation of Urine*

9.4 RENAL FUNCTION TESTS

It is important to regularly evaluate the samples of blood and urine in order to assess the efficiency of the kidney functions. The human body has two kidneys. These are located on the sides of the spine and they are roughly as big as a closed fist of the hand. They are close to the abdomen and under the rib cage.

The kidneys have an essential role in the maintenance of a healthy body. The primary function of the kidneys is to remove the waste material present in the blood and help in its expulsion in form of urination. They also assist in controlling the body's fluid level and fulfilling the vital mineral requirements of the body. Furthermore, the kidneys help in production of RBCs, vitamin and essential hormones needed for regulating the blood pressure in the body.

In case, the doctors feel that kidneys of an individual are not functioning efficiently they will advise the individual to undergo kidney function tests. These are basic tests of blood and urine and they would help in identifying the complications. Kidney function tests are advised for people suffering from diabetes or high blood pressure as well, as these disorders have a direct impact on the kidneys.

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Kidney function tests are recommended in case the individual exhibits the following symptoms:

- High levels of blood pressure
- Traces of blood in the urine
- Frequent need to pass urine
- Feeling of discomfort as urination starts
- Feeling pain through the process of urination
- Water-retention in body causing hands and feet to swell up

Having one or more of the above mentioned symptoms would directly indicate towards kidney issues. The kidney function tests are performed after these symptoms persist.

9.4.1 Types of Renal Function Tests

The presence of the above mentioned symptoms in the body would compel the doctor to order further examination; these will help in estimating the Glomerular Filtration Rate (GFR) of the body. From the person's GFR, the doctor will be able to find out the speed at which the kidneys are able to clear the waste from the individual's body.

Urinalysis: This test is done in order to screen the existence of blood and protein in the urine. The presence of protein in the urine may not always indicate towards a kidney disorder. The protein levels in urine get high even after vigorous physical activity. In order to find out the cause the doctors would repeat the test again after a couple of weeks. Finding similar results would confirm the infection in the blood. The patient would be asked to provide urine samples of an entire day so that the doctor is able to check the rate of clearance of creatinine from the body.

Serum Creatinine Test: The blood test helps in examining the build-up of creatinine in the body. Efficiently functioning kidneys are able to filter creatinine from the blood completely, thus, in case the level is high then without doubt the individual would be suffering from kidney disorder. As per the guidelines of the National Kidney Foundation (NKF), women should not have a creatinine level higher than 1.2 mg/dL and in case of males it is not supposed to be higher than 1.4 mg/dL. Higher levels in either case indicate a kidney disorder.

Blood Urea Nitrogen (BUN): Another test that helps in checking the level of waste in the blood is Blood Urea Nitrogen (BUN). The test identifies the quantity of nitrogen in the blood. Urea nitrogen is nothing but a by-product of protein. Anyhow an increased level of BUN would not always indicate a kidney malfunction; the levels often become high in case the person has been under high dosage of medicines like aspirin and certain antibiotics. The doctor needs to be informed in case these are consumed prior to the testing. 7 to 20 mg/dL is the

standard level of BUN; escalated levels could be indication of many health related issues.

The estimated GFR of the body is affected by a number of factors. Results of testing done for levels of creatinine; the person's age, sex, weight, height, race and other factors also matter. Test results which are less than 60 milliliters/minute/ 1.73m2 should be considered as indication of a kidney disorder.

9.4.2 Need for the Renal Function Tests

They are essential because of following reasons:

(i) In order to assess the functioning of the kidney and help in diagnosing kidney disorders.

(ii) To keep a check on the extent of kidney malfunctioning

(iii) The tested ratios of BUN and creatinine help in assessing the fluid levels of the body.

All test related to the kidney functions should be performed by qualified laboratory assistants and nurses under the supervision of a doctor. The doctor needs to be informed in case the patient's diet is rich in non-vegetarian food as this may increase the levels serum creatinine and clearing of creatinine from the body. The levels of BUN may be increased in cases where diet is rich in protein or the patient is dehydrated. Intense workout elevates the creatinine clearance. Consumption of certain medicines also impacts the test results. For these reasons the patients must inform the doctors about their food habits, lifestyle, and medications and so forth prior to the testing. The person should limit his workout, protein and non-vegetarian food intake twenty-four hours prior to the test.

9.5 ARTIFICIAL KIDNEY, DIALYSIS AND RENAL TRANSPLANTATION

Scientists all over the world are trying to develop an artificial kidney which is able to imitate all the functions of the actual organ and effectively do away with the necessity of dialysis. Artificial kidney at one time was the same as hemodialysis, but in recent times its reference is in context bioengineered kidneys or bio-artificial kidneys. These are produced with the help of renal cell lines and renal tissue.

During the 1940s the first successful attempt of developing artificial kidney was made by Willem Kolff from Netherlands. In 1943 he also became the first person to build a functioning dialyzer. There is an urgent need for developing artificial kidneys as there is a long wait for those waiting for a kidney transplant, most lose their life before they are able to get a human kidney. Hemodialysis is not helpful for those who are at the last stage of kidney disease. The project is being undertaken by nephrologist William H. Fissell IV, MD, along with Professor Shuvo Roy from the University of California. The project has been going on for several

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years and it has been provided with regular funds as well. The aim of the project is to develop bio-hybrid equipment which will be able to replicate all functions of a real kidney and the patients would no longer need dialysis. The project will hopefully be effective as the equipment will be developed using silicon nanotechnology with a microchip that will be exquisite and will function as a natural filter. The microchip will hold live cells of a kidney; these will subsequently grow and begin to function as a real kidney. The artificial device will not be influenced by the immune system of the body; hence, it will be adaptable for all patients.

9.5.1 Dialysis

The kidneys help in filtering the waste out of the blood and also remove the extra fluids from the body. The waste is removed from the body after it is sent to the bladder and exited in form of urine.

When the kidneys fail to perform their functions, dialysis is used for this purpose. As per the National Kidney Foundation, the last stage of kidney failure takes place once the kidneys are unable to perform ninety per cent of their regular functions. The treatment of dialysis involves filtration and purification of blood with the help of a machine. Hence, the process helps in maintaining a balance for the body fluids and electrolytes. The treatment has been in practice since the 1940s.

Need for Dialysis

Kidneys help in cleansing the body as they filter and remove all the waste in the form of urine from the body. Their effective functioning helps in keeping a check on the level of the body's blood pressure and the chemical levels of the body remain in check. Kidneys help in production of vitamin D which helps in absorbing calcium in the body, hence, maintaining the health of the bones. In case, the kidneys are unable to perform their regular functions, the body will not be able to cope with the toxins that get accumulated in the blood and excess fluids. Other parts of the body will also suffer and get harmed.

Dialysis is only a treatment and not a cure for kidney disorders. Dialysis can be performed in three ways:

1. **Hemodialysis:** This is the most frequently used dialysis. An artificial kidney helps in removing the waste and surplus liquids from the blood. The blood is taken out of the body and filtered through the artificial kidney and this is then put back into the body. The entire process is performed with the help of a dialysis machine. The doctor performs a surgery for the blood to circulate into the hemodializer. He also has to generate a point for entering the blood vessels. There are three types of entry points, namely:
   (i) Arteriovenous (AV) fistula: This is the most common option. In this method, the artery and a vein is connected.
   (ii) Arteriovenous graft: In this method, a looped tube is used.

(iii) Vascular access catheter: The large vein in the neck is inserted with the catheter.

The first two are meant for dialysis treatment which is going to be performed for a longer period of time. Patients treated with AV fistulas recover in two to three months and are able to undergo hemodialysis again. Patients treated with AV grafts can be fit for a repeat in a couple of weeks. The third type of dialysis is meant for temporary usage.

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This process of dialysis normally takes three to five hours and can be done thrice in a week. If required, it can be done more frequently and in lesser duration as well. The actual duration of the treatment is dependent upon the extent of waste in the body and severity of the disorder. The physical structure of the patient also plays a role in determining the duration of the process. Patients needing hemodialysis for long-term may be provided with the treatment at the comfort of their homes though initially the patient has to come to the venue of the doctor.

2. **Peritoneal Dialysis:** A surgery is performed for the implantation of peritoneal dialysis (PD) catheter into the patient's abdomen. Blood is filtered due to the catheter with the help of the membrane in the abdomen, the peritoneum. A special liquid known as the dialysate passes into the peritoneum at the time of the treatment and, thus, helping in the absorption of the waste. The absorbed waste by the dialysate is pumped out from the abdomen.

   The procedure lasts for a couple of hours and the patient has to undergo it twice every day, the patient need not be awake throughout the treatment. There are many kinds of peritoneal dialysis. Some of them are listed below:

   - Continuous ambulatory peritoneal dialysis (CAPD): In this treatment, multiple times the abdomen is filled and drained. The patient needs to be awake during this process. This does not require any machine.
   - Continuous cycling peritoneal dialysis (CCPD): A machine is used for removing and filling fluids into the patient's abdomen. The patient may be sleeping while the process is being performed.
   - Intermittent peritoneal dialysis (IPD): The treatment is longer than the above two treatments and it is mostly performed in a hospital, the same machine is used as in CCPD.

3. **Continuous Renal Replacement Therapy (CRRT):** This third type of dialysis is mostly meant for patients severely suffering from kidney disorders. In fact, it is for patients admitted into the ICU. The dialysis is also referred to as hemofiltration. A tube is used to pass the blood into the machine, the filter in the machine cleanses the blood and also fluids are removed. The blood is supplied back into the body along with the replaced fluids. The procedure can last for half a day or take up the entire day and it has to be performed daily.

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9.5.2 Renal Transplantation

Kidney transplantation is performed on patients at the last stage of kidney disease, when their kidneys have failed up to ninety percent. The organ being transplanted can belong to a living donor or a brain-dead donor. The patient and the donor could be genetically related or not related.

Compatibility

The receiver and the donor should preferably belong to blood group ABO and cross match companionable. The donor and the receiver need to be compatible with each other. In order to lessen the chances of refutation in incompatible transplantation, ABO-incompatible and desensitization protocols using intravenous immunoglobulin (IVIG) are advanced; the purpose is to lessen ABO and HLA antibodies which the receiver might have with the donor.

Procedure of Kidney transplant

The non-functioning or diseased kidneys are not removed in most of the cases as removal leads to unnecessary complications. The new kidney is generally placed at a new location, thus, requiring a new channel for supply of blood. In most cases, the new kidney is placed in the iliac fossa.

The new kidney's renal artery is connected from outside to the iliac artery of the receiver. The new kidney's renal artery, earlier draining through donor's inner vena cava is now linked with the outer iliac vein of the receiver. The donor ureter is anastomosed with the bladder of the receiver.

Check Your Progress

1. What are the main parts of a nephron?
2. State the final step in urine formation.
3. What is the need for conducting renal kidney tests?
4. Name the most frequently used method of dialysis.

9.6 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. The main parts of the structure of a nephron are the following:
   - Proximal convoluted tubule
   - Loop of Henle
   - Distal convoluted tubule that leads in toe the collecting tubule
2. Tubular secretion is final step in urine formation.

3. They are essential because of following reasons:
   (i) In order to assess the functioning of the kidney and help in diagnosing kidney disorders.
   (ii) To keep a check on the extent of kidney malfunctioning
   (iii) The tested ratios of BUN and creatinine help in assessing the fluid levels of the body.
4. Hemodialysis is the most frequently used method of dialysis.

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9.7 SUMMARY

- The body produces waste material due to the production of energy and various other metabolic processes. This waste is removed by the urinary system from the body. The main parts of the urinary system consist of the kidneys, ureters, urinary bladder, nephrons and urethra.
- Kidneys are bean-shaped organs that measure approximately 11 cm in length, 6 cm in width and 3 cm in thickness.
- If we look at the longitudinal section (LS) of the kidney, we can divide the kidney into two regions:
  (i) Cortex (towards outside)
  (ii) Medulla (the inner portion)
- Nephrons are the basic structural and functional units of kidneys. There are more or less a million nephrons present in each kidney that filter blood to remove urea, extra salts and other waste material from the blood.
- The process of urine formation takes place in several steps. First, a portion of blood plasma is filtered through the capillaries in the Bowman's capsule and then nutrients and other chemical constituents get reabsorbed according to their requirement in the body.
- The first step in urine formation is filtration. Filtration occurs through the semi-permeable walls of the glomerulus and glomerular capsule.
- Primary active transport and secondary active transport are the two mechanisms of active transport of sodium ions though the tubular membrane.
- The hypo-osmotic filtrate now flows into a collecting duct, and this entire duct is permeable to water. Its permeability to water is controlled by the level of anti-diuretic hormones in the circulating blood.
- Tubular secretion is the ultimate step in urine formation. In this step, urine is produced in a concentrated form by increasing the percentage of waste elements like creatinine and potassium.
- The kidneys help in production of RBCs, vitamin and essential hormones needed for regulating the blood pressure in the body.

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- Urinalysis test is done in order to screen the existence of blood and protein in the urine. The presence of protein in the urine may not always indicate towards a kidney disorder.
- Another test that helps in checking the level of waste in the blood is Blood Urea Nitrogen (BUN). The test identifies the quantity of nitrogen in the blood. Urea nitrogen is nothing but a by-product of protein.
- During the 1940s the first successful attempt of developing artificial kidney was made by Willem Kolff from Netherlands.
- When the kidneys fail to perform their functions, dialysis is used for this purpose. As per the National Kidney Foundation, the last stage of kidney failure takes place once the kidneys are unable to perform ninety per cent of their regular functions.
- Hemodialysis is the most frequently used dialysis. An artificial kidney helps in removing the waste and surplus liquids from the blood.
- Kidney transplantation is performed on patients at the last stage of kidney disease, when their kidneys have failed up to ninety percent. The organ being transplanted can belong to a living donor or a brain-dead donor. The patient and the donor could be genetically related or not related.

9.8 KEY WORDS

- **Cortex:** It is the reddish brown layer of tissue that lies under the capsule and between the pyraminds.
- **Glomerular Filtration Rate:** It is a test used to check how well the kidneys are working. Particularly, it estimates how much blood passes through the ***glomeruli*** each minute.
- **Dialysis:** It is a procedure that that removes water and toxins from the body. It is typically applied to patients with acute or chronic kidney failure.

9.9 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. Write a short note on the role of kidneys in human body.
2. Mention the composition of urine.
3. Why are renal function tests conducted?
4. What do you understand by the term ‘artificial kidney’?

Long Answer Questions

1. Discuss the mechanism of urine formation.
2. Explain the types of dialysis.
3. Describe the procedure for renal transplantation.

NOTES

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UNIT 10 REPRODUCTIVE SYSTEM

NOTES

Structure

10.0 INTRODUCTION

The reproductive system or genital system is a system of organs within an organism, working together for the purpose of reproduction. Male and female reproductive systems have significant differences. These differences allow for a combination of genetic material between two individuals and enhance the possibility of greater genetic fitness of the offspring.

The major organs of the human reproductive system include the external genitalia as well as a number of internal organs including the gonads. In this unit, you will study about the structure and functions of male and female reproductive systems, male and female contraception and the various factors responsible for infertility among men and women.

10.1 OBJECTIVES

After going through this unit, you will be able to:

- Discuss the structure and functions of the male reproductive organs
- Explain the structure and functions of the female reproductive organs
- Analyse the factors responsible for infertility among men and women

10.2 MALE REPRODUCTIVE ORGANS: STRUCTURE AND FUNCTIONS

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The male reproductive system comprises the following organs:

- A pair of testes
- A pair of epididymides
- A pair of vasa deferentia
- A pair of spermatic cords
- A pair of seminal vesicles
- A pair of ejaculatory ducts
- One prostate gland
- One penis
- One urethra

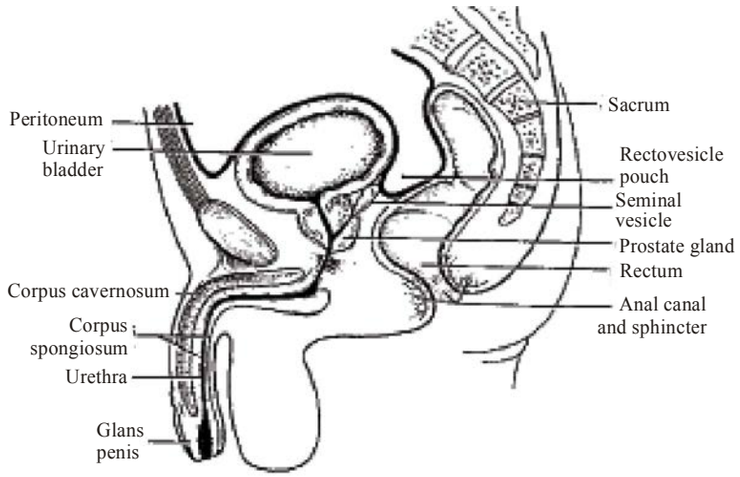

Fig. 10.1 *The Male Reproductive Organs and Their Associated Structures*

The testes and the epididymides are located in the scrotum, which is a pouch located behind the penis, anterior to the upper thighs below the pubic symphysis.

1. **Testes, epididymides and vasa deferentia**

   The main features of these organs are:

   - Each of these organs is paired.
   - Each has

     Length - 4.5 cm

     Width - 2.5 cm

     Thickness - 3.0 cm

NOTES

- There are three layers which surround the testes:

  (i) **Tunica vaginalis:** It is the outermost layer and is the downward continuation of the abdominal and pelvic peritoneum formation.

  In foetus testes , it develops in the lumbar region below the kidneys. By the eighth month of foetal life they descend into the scrotum and during descent carry with them:

  - Abdominal and pelvis peritoneum
  - Blood vessels
  - Lymph vessels
  - Nerves
  - Deferens duct

  Later on, the peritoneum surrounds the testes and gets detached from the abdominal peritoneum and the same peritoneum around the testes becomes tunica vaginalis.

  (ii) **Tunica albuginea:** It is a fibrous layer located below the tunica vaginalis. From this layer, ingrowths enter into the testes at various sites. These ingrowths are called septae. Septae divide (gland) the testes into various lobules (discussed ahead).

  (iii) **Tunica vascular:** This layer has a network of capillaries supported by delicate connective tissue.

Each of the testes has 200 to 300 lobules. Each lobule has:

Seminiferous tubules: Seminiferous tubules are one-to-four in number and are convoluted loops. They have germinal epithelial cells. All tubules unite at the upper pole of the testes and form tortuous tubule called epididymis.

The epididymis leaves the scrotum as the vas deferens or deferens duct which runs in the spermatic cord. Spermatic cord also has blood and lymph vessels to the testes . Between tubules, there are groups of interstitial cells of Leydig. They produce the hormone called testosterone.

2. **Spermatic cords**

Spermatic cords are two in number, one with each of the testes and each cord suspends its testes in the scrotum.

Each spermatic cord has the following structures:

- Testicular artery, one branch from the abdominal aorta.
- Testicular veins from testicular venous plexus, one right vein opens into the inferior vena cava.
- Lymph vessels

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- Vas deferens, one runs upward from the testes and via the inguinal canal it runs towards the posterior wall of the bladder and joins the duct from the seminal vesicle to form the ejaculatory duct.
- Nerves from the branches of the tenth and eleventh thoracic nerves.

3. **Seminal vesicles**

   Seminal vesicles are two fibromuscular pouches with columnar epithelial lining and are located on the posterior aspect of the bladder. They have a duct at its inferior end. This duct joins the vasa deferentia and forms ejaculatory duct. They produce and expel viscous fluid which is helpful for the survival of sperms.

4. **Ejaculatory ducts**

   Ejaculatory ducts are two in number. Each is 2 cm long and is formed by the union of vasa deferentia with duct of seminal vesicles and each is lined by the columnar epithelium. It runs through the prostate and opens in the prostatic urethra. It carries sperms and seminal fluid.

5. **Prostate gland**

   The prostrate gland is located in the pelvic cavity anterior to rectum and is posterior to the pubic symphysis. It lies around the first part of the urethra.

   It has the following structures:

   - Fibrous covering
   - Smooth muscle layer
   - Columnar epithelial cells

   The prostate gland produces fluid which reaches the urethra by its numerous ducts. The urethra is the 19- to 20-cm-long common pathway for urine and semen.

6. **Penis**

   The features of the penis are as follows:

   - It acts as an organ of copulation.
   - Its shape varies and is:
     - o Cylindrical when the organ is flaccid
     - o Triangular when the organs is erect
   - Surfaces are two:
     - o Ventral is directed backward and downward.
     - o Dorsal is directed forward and upward.
   - Penis has two parts:

     (i) **Root:** It has the following features:

     - It is a fixed part and is located in the superficial perineal power.

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- It has three names made of erectile tissue
  - o **Two crura:** Each is attached to the margin of the pubic arch and the ischiocavernosus covers it.
  - o **One bulb:** It is attached to the perineal membrane and lies in between two crura. Bulbospongiosus covers it. It has the urethra running through it to reach the corpus spongiosus of the body of the penis. The floor of this part of urethra is dilated and this dilated part is called the infrabulbar fossa.

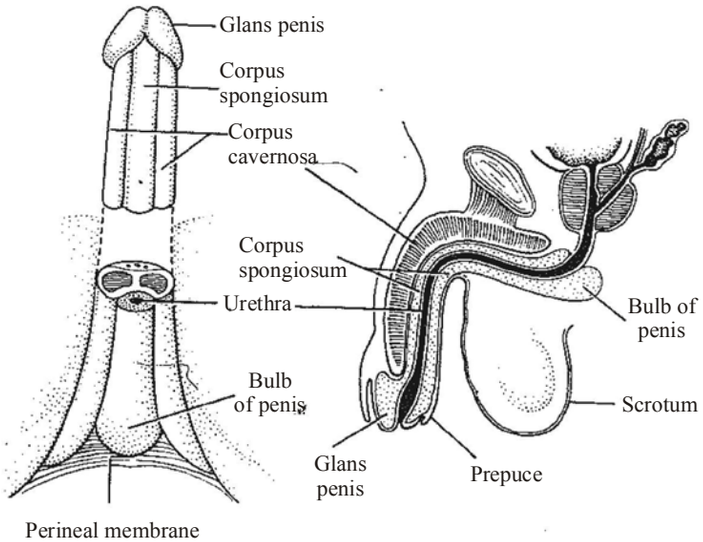

Fig. 10.2 *(a) Penis Seen from Below and (b) Penis Seen from Side*

(ii) **Body:** It is the free part as compared to the root which is fixed. The body and root are in close continuity in front of the lower part of the pubic symphysis. It has three masses of erectile tissue.

- **Two corpora cavernosa:** They are the forward continuation of the two crura of the root of the penis. They terminate and blunt externally under cover of glans. The penis corpora are surrounded by fibrous envelope of tunica albuginea. Turnica albuginea has two layers:
  - (a) Superficial layer of longitudinal fibres enclosing both corpora.
  - (b) Deep of circular fibres enclosing each corpus and forming the septum of the penis in the median plane.
- **One corpus spongiosum:** It is the forward continuation of the bulb of penis. It is covered by a fibrous sheath, tunica albuginea, and contains urethra in its entire length. The corpus spongiosum terminates into the conical structure called glans penis. Glans penis has the urethra in it. There is a dilated region in the urethra called the nevicular fossa.

  The base of the glans penis has a projected margin called the coronary gland which overhangs a constricted area called the neck of the penis.

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- The skin of the penis is thin and dark in colour and has a loose attachment with the fascial covering of the penis.

  Skin forms:

  (i) Prepuce or foreskin at the neck of the penis is a fold of skin. It covers glans to variable extent and is retractable to the back.

  (ii) Frenulum of prepuce on under surface of glans. Frenulum is a skin fold in the median plane.

  Between gland and prepuce, potential space called preputial sac exists, which contains sebaceous material of sebaceous glands. The sebaceous material in preputial sac is called smega.

- The penis has a layer, called superfacial fascia having tissue, few muscle fibres and superficial dorsal vein. It is continuous (above) with the fascial layer of the abdomen and is continuous below with the superficial layer of the perineum.

  The deepest layer of the superficial fascia has the following features:

  - It is membranous and is called the fascia of the penis.
  - It surrounds the erectile tissue.
  - It has: deep dorsal vein, dorsal arteries and dorsal nerves of the penis.

- The body of the penis has the following supports:
  - **Fundiform ligament:** It is superficial to the suspensory ligament. It starts above as an extension of the linea alba and below, it splits to surround penis.
  - **Suspensory ligament:** It extends from the pubic symphysis above and blends below with the fascia of the penis on each side.

Blood Supply

The following arteries supply blood to the penis:

1. Three branches of the internal pudendal artery are as follows:

   (i) Deep artery of the penis supplies corpus cavernosum

   (ii) Dorsal artery of the penis supplies blood to:
   - Glans
   - Distal part of corpus spongiosum
   - Prepuce
   - Ferenulum

   (iii) Artery of the bulb of the penis supplies blood to:
   - Bulb
   - Half of corpus spongiosun

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2. Superficial external pudendal branch of the femoral artery supplies blood to:
   - Skin of penis
   - Fascial of penis

The following veins drain impure blood from the penis:

- Superficial dorsal vein opens into superficial external pudendal veins.
- Deep dorsal vein opens into prostatic plexuses of veins.

Nerve supply

1. Skin at the root of the penis is supplied by:
   - Dorsal nerve
   - Ilioinguinal nerve
2. Muscles are supplied by:
   - Perineal branch of pudendal nerve
3. Autonomic fibres run along the branch of the pudendal nerve and supplies to the penis.

How penis erects

The penis becomes erect through a complex interaction of physiologic and psychologic factors. Contractions during ejaculation impel the semen into the urethra and out of the penis.

7. **Urethra**

The urethra has three parts:

(i) **Prostatic urethra:** Urethra starts at the urethral opening, urinary bladder and inside the prostate.

(ii) **Membranous urethra:** It starts from the prostate gland and passes through the perineal membrane and ends at the bulb of the penis.

(iii) **Spongiose urethra:** It is present in the corpus spongiosum of the penis. It ends at the external urethral openings in glans penis.

Urethra has two sphincters:

(i) **Internal sphincter:** It is located at the neck of the bladder above the prostate and has smooth muscle fibres, and so it is involuntary in action.

(ii) **External sphincter:** It is located around the membranous urethra and has striated muscle fibres.

10.3 FEMALE REPRODUCTIVE ORGANS

The female reproductive system comprises many reproductive organs also called genitalia. Female genitalia are divided into two groups: external genitalia and internal genitalia.

The group of external genitalia is called vulva. It consists of the following structures:

- Labia majora
- Labia minora
- Clitoris
- Vestibule
- Hymen
- Greater vestibular glands

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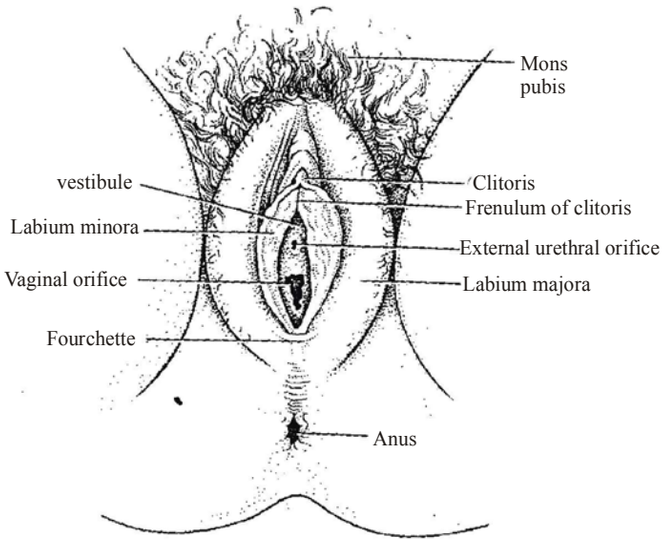

Fig. 10.3 *Female External Genitals*

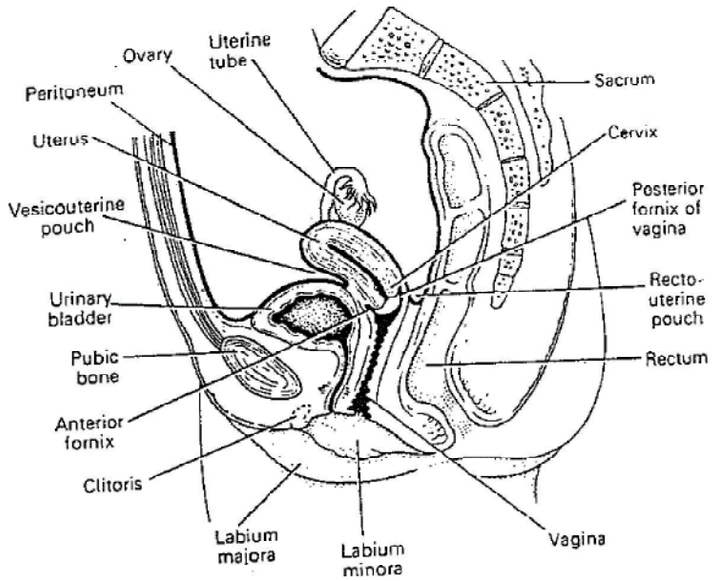

Fig. 10.4 *Lateral View of the Reproductive Organs in the Female Pelvis*

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Internal female genitalia are as follows:

- Vagina
- Uterus
- Uterine tubes
- Ovary

External Genitalia

Labia majora

Labia majoras are analogus to the scrotum in males. They are skin folds and contain fats in variable amount. They form lateral boundaries of vulva. They start anteriorly at mons pubis and end posteriorly in the skin over perineal body. Labia majora are:

- Best developed in child-bearing age.
- Relatively small-sized before puberty and after menopausal age due to decreased subcutaneous fat.

Each labium majus has two surfaces: an outer pigmented surface covered with strong, crisp hair and an inner, smooth section beset with large sebaceous follicles.

The following important components are enclosed in the labia majora:

- Sebaceous glands
- Sweat glands
- Hair follicles
- Special sweat glands called apocrine glands, which produce typical aroma

These components make them more susceptible to the following diseases:

- Folliculitis
- Boils
- Sebaceous cyst

Labia minora

Labia minora are two small skin folds located between the labia majora. Posteriorly, they unite with each other and form an area called fourchette. Between the folds a cleft called vestibule is present. The vestibule has the following structures:

- Opening of vagina
- Opening of urethra
- Opening of ducts of greater vestibular glands

Clitoris

It is like the penis in a male reproductive system. It has erectile tissue but has no role in reproduction.

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Hymen

It is the mucous membrane partially enveloping the vagina.

Greater vestibular gland

It is also called Bartholin's gland. One of these pea-sized glands lies on each side of the vaginal opening. Its ducts open into the vestibule. It produces secretion called mucus to moisten the vulva.

Blood supply of external genitalia

Arteries: Branches from the external pudendal artery and branches from the internal pudendal artery supply blood to the external genitalia.

Veins: Pudendal veins drain impure blood from external genitalia.

Lymph drainage and nerve supply of external genetalia: The lymph is drained into the superficial inguinal node. Nerve supply is by pudendal nerves.

Perineum

Perineum is a triangular area between the fourchette and the dual canal. It has connective tissue, muscle and fat. It provides an attachment to the pelvic floor muscles.

Internal Female Genitalia

Vagina, uterus, uterine tube and ovary are known as internal female genitalia.

Vagina

The vagina is a fibromuscular canal starting from the vulva and ending at the uterus. It is posterior to the bladder and the urethra.

The length of the anterior wall of the vagina is 8 cm and that of the posterial wall is 10 cm; diameter is 5 cm at the upper end and 2.5 cm at the lower end. The vagina is a distensible organ and its size increases during sexual intercourse. During delivery, it is partially closed with a fold of mucous membrane called the hymen.

Interior of the upper end is like a circular groove. It is divided into four parts, called the vaginal fornices.

Arterial supply: The following arteries supply blood to the vagina:

- Vaginal branch of internal iliac artery
- Additional supply by a branch of uterine artery
- Middle rectal and internal pudendal arteries

Venous drainage: Vaginal veins drain into the internal iliac vein.

Lymphatic drainage: It involves the following:

- Upper one-third drains into the external iliac nodes.

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- Middle one-third drains into the internal iliac nodes.
- Lower one-third drains into the medial group of the superficial inguinal nodes.

Nerve supply: The pain sensitive areas are the:

- Lower (pain sensitive area) one-third by inferior rectal branch of perineal nerve
- Upper (pain insensitive area) one-third by inferior hypogastric plexuses

Uterus

The uterus is a pear-shaped, hollow pelvic organ lying between the urinary bladder and the rectum in antiverted, antiflexed position. Antiversion means the leaning forward of the uterus. Antiflexion means the uterus is bent forward at a right angle to the vaginal anterior surface. It has the following three parts:

(i) Fundus

(ii) Body

(iii) Cervix

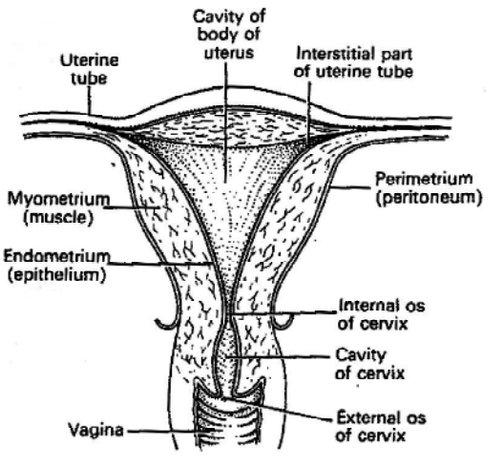

Fig. 10.5 *Uterus in Section*

It has the following three layers:

(i) Perimetrium

(ii) Myometrium

(iii) Endometrium

Blood is supplied to the uterus by the uterine arteries (branches of internal iliac arteries). Veins drain into the internal iliac veins. Lymph is drained into the aortic lymph nodes. The nerve supply is from sacral parasympathetic nerves and sympathetic fibres from lumbar nerves.

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Functions

Functions of the uterus are as follows:

- After puberty, it maintains the regular cycle called the menstrual cycle. It prepares the uterus to receive, nourish and protect fertilized ovum.
- It permits the growth of foetus for 40 weeks.
- It helps the delivery of foetus at the end of 40 weeks by contraction of uterine muscles and relaxation and dilation of the cervix.
- It promotes menstruation cycle if pregnancy does not occur.

Uterine tubes

There are two uterine tubes, one on each side of the uterus. Each tube has 10-cm length. It comprises four parts:

(i) Infundibulum

(ii) Ampulla

(iii) Isthmus

(iv) Intramural

Ovary

An ovary lies below and behind the ampullary part of the uterine tube on each side of the uterus. Ovary is attached to the posterior or upper layer of the broad ligament of the uterus. Its shape resembles almond. Its length is 3 cm, breadth 1.5 cm and thickness 1 cm. The function of the ovary is to provide ova during reproductive age. Before ovulation, the colour is grayish pink. The ovary is covered by the peritoneum. After puberty, the colour turns from pink to grey. It has two:

- Poles
- Borders
- Surfaces

Arterial Supply: Arterial supply to the ovary takes place by:

- Ovarian artery from the abdominal aorta
- Uterine artery

Venous drainage: Venous drainage takes place by:

- Ovarian vein which drains on the right side into the inferior vena cava
- Ovarian vein which drains on the left side into the left renal vein

Nerve supply: Nerve supply takes place by ovarian plexuses (a combination of sympathetic and parasympathetic nerves) derived from:

- Renal plexuses

- Aortic plexuses
- Hypogastric plexuses

Menstrual Cycles (Menstruation)

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Menstrual cycle means cycles of series of events regularly occurring in a female every 28 days (between 26 to 30 days) during the reproductive age. It has two phases: proliferation phase and secretary phase.

Proliferation phase

Ovarian follicle undergoes maturation by follicle stimulating hormone (FSH) of anterior pituitary. Mature ovarian follicle produces oestrogen. Oestrogen stimulates proliferation of uterine endometrium. During endometrial proliferation, there is an increase in the:

- Number of cells
- Mucus secreting glands
- Blood capillaries
- Thickness of endometrium

The aim of endometrial proliferation is to receive fertilized ovum. On the fourteenth day, ovulation occurs, ending the oestrogen production as well as proliferation phase.

Secretary phase

After ovulation, the luteinizing hormone of antipituitary acts on cells of the ovarian follicle. Cells proliferate and form corpus luteum. Corpus luteum produces the hormone progesterone. Progesterone acts on endometrium and uterine tubes and produces the following changes:

- Increased watery mucus secretion of seretory glands in endometrium, fallopian tubes and cervix.
- Swelling and oedema of endometrium

These changes facilitate:

- Movement of sperms to uterus via uterine tubes providing the site of fertilization of ovum
- Lubrication of vagina

Now, if the ovum is not fertilized, menstruation begins on the twenty-eighth day. The endometrium breaks, menstruation begins and the new cycle starts.

If the ovum is fertilized, the endometrium does not break, menstruation does not start. The fertilized ovum travels to the uterus and gets embedded in the uterine wall. This is the beginning of pregnancy.

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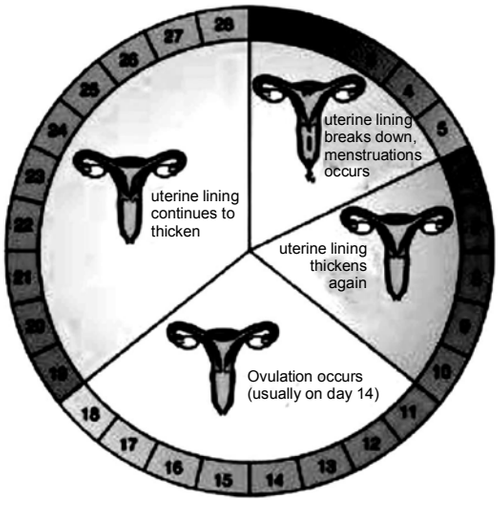
Gametogenesis

Gametogenesis means formation of gametes in both males and females.

- **Formation of male gametes:** The process of the formation of male gametes is called spermatogenesis. The process occurs best at 3°Celsius less than the body temperature. It occurs in seminiferous tubules of the testes. Each cycle of spermatogenesis takes 16 days to complete and approximately five cycles or two-and-a-half months are needed to produce one mature sperm.
- **Ovum production in females:** During child bearing age, the follicle in ovary mature, and a developed ovum is released during each menstrual cycle. This process is called ovulation Follicle stimulating hormones help in ovulation.

Menopause

At age 40–50 years, the menstrual cycle usually becomes irregular and ovulation fails to occur during many cycles. This is caused by the change in the concentration of sex hormone; the ovaries gradually become less responsive to the FSH and LH and ovulation and the menstrual cycle become irregular. After a few months to a year, the cycle ceases altogether. The period during which the cycle ceases and female sex hormone diminish rapidly to almost none is called menopause. Figure 10.6 shows the menstrual cycle and changes in endometrium and hormonal level.



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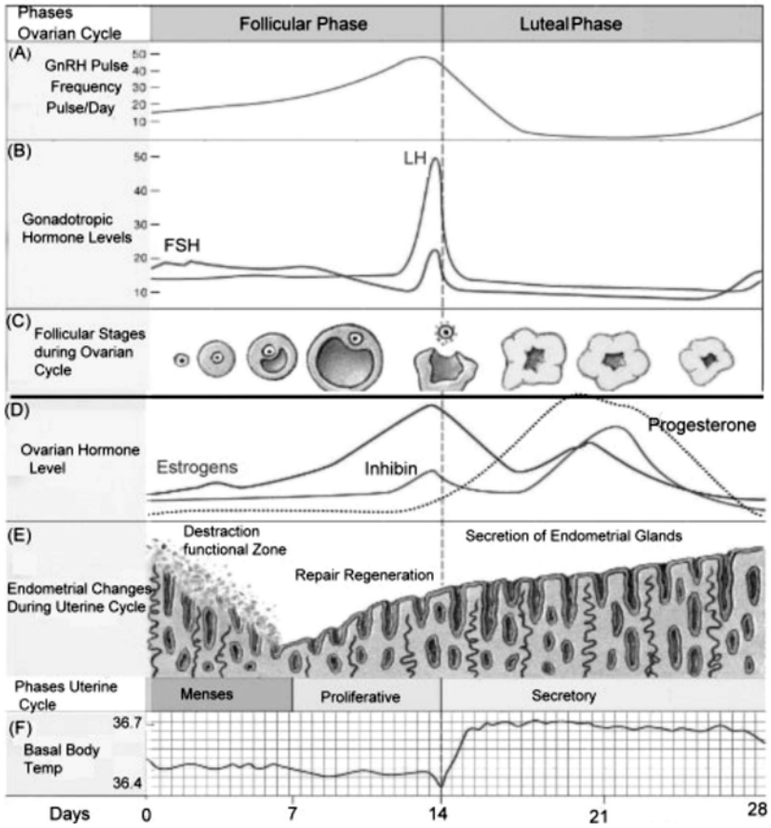

Fig. 10.6 *Menstruation Cycle and Changes in Endometrium and Hormonal Level*

10.3.1 Puberty and Menarche

Let us study the concept of puberty and menarche.

Puberty

The period of human physical and sexual development is referred to as puberty. Puberty starts with changes in hormones that are started by a segment of the brain known as the hypothalamus. The pituitary glands are stimulated and these further activate the extra glands. The changes take about a year before they can be noticed. The balance of male and female reproductive hormones changes during this stage; the females begin to produce reasonably extra estrogen and boys produce extra testosterone.

In girls puberty generally starts at the age of eight and for boys it starts when they are around ten years old. The hypothalamus initiates the hormonal changes and pituitary is stimulated, this leads to the releasing of hormones known as gonadotrophins; these trigger the gonads and adrenals. With the triggering of these glands, the male child has an overflow of sexual hormones, androgen and testosterone. On the other hand, the females have an overflow of estrogen and progestin. These control the development and functions of the sex organs. An

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interesting fact is that both males and females have same gonadotrophins; however, the different sex hormones are induced.

The process occurs in stages and over a period of time. The pace is not same for all, females of same age develop differently, and the time it starts is also dependent on factors like genes, weight, physical health and mental state.

The breast of the girls begin to form once they are ten or eleven years old, the menstrual cycle on an average starts at the age of thirteen or fourteen years. In the same way, testicles of boys start to develop by the time they are generally twelve years old. However, for some boys the stage of puberty starts only after they are sixteen years old and continues till roughly four odd years.

Puberty and adolescences are often regarded as same; the latter is considered to be a social term and could be referred to as the years between childhood and adult years. As the beginning of puberty is different for all children; in the same way, the duration also varies for all.

Causes for early or delayed puberty are many and different for all children. In either of the cases, the parents begin to worry.

- Increase in the levels of hormones can cause early puberty. Similarly, lack of stimulation of hormones can delay the stage.
- Many congenital disorders known as polyglandular deficiency syndromes could result in generation of hormones responsible for puberty. In such cases, hormones are orally induced into the body.
- Production of male hormones in females and visa-versa could lead to abnormal puberty in either of the cases.

The causes of both stages have to be carefully measured so that adequate treatment can be recommended. In case, there is chance of a tumour then X-ray, MRI and scans have to be undertaken. There is lot of emotional as well as physical stress during puberty. Untimely puberty can escalate these stresses not only for the child but for the parents as well. Moreover, children experience psychological changes and they need full support of their elders and friends. Children experiencing early or delayed puberty often become a subject of ridicule amongst their friends circle.

Menarche

The starting of menstrual cycle among teenage females is referred to as menarche. The periodic blood that flows as a discharge from the uterus is called menstruation. This happens when ovulation is not supported by fertilization. It ranges from twenty one to forty-five days. The starting age on an average is twelve to thirteen years. The periods continue for a duration of three to five days. In some cases, they last up to seven days as well but above that period are not considered normal. The starting of menstrual cycle indicates stage of maturing among girls as with this they develop the ability to reproduce and ovulation, though it is not necessary. Starting

of menarche by the age of nine years is mostly regarded as early and delayed if they do not begin by the age of fifteen years.

10.3.2 Fertilization, Conception and Implantation

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The following steps are essential for women to become pregnant:

- **Transporting of sperm:** The sperm has to be placed and conveyed till the fertilization location.
- **Transportation of egg:** Ovulation has to take place and the egg has to be taken into the tube.
- **Fertilization and development of the embryo:** Combining of the sperm and the egg will result in fertilization.
- **Implantation:** The embryo has to be implanted for it to develop in the uterus.

Understanding the Steps

Transportation of the sperm is dependent on many factors:

- The sperm needs to be proficient enough to propel itself in the location of the vagina and cervix.
- The location in spite of all hormonal cycles should be favourable for admitting the sperm without harming.
- The sperm needs to be capable of taking a shape so that it is allowed entry into the membrane of the egg.

After ejaculation, the gel in the semen protects it from the vagina's environment which is acidic. The prostate gland helps in liquefying the gel in half an hour or less. This liquid state enables the transportation of the sperm. The sperms that survive pass through the layers of cervical mucus guarding the entry into the uterus. At the time of ovulation, this fence turns diluent and no longer remains acidic providing a cordial atmosphere for the sperm. The cervical mucus becomes a saviour of the surviving sperm. After entering the uterus due to the contractions the sperm is propelled towards the fallopian tubes. Minutes after the ejaculation the sperm is able to enter the tubes, although the initial ones are not fertile enough for reproduction, they remain in the tract for a period of five days or less.

Transportation of egg starts during ovulation and finishes only when the egg has reached the uterus. Soon after ovulation, the finger shaped fallopian tube swishes above the ovary. Sticky surface on the cilia help in picking up of the egg and passing it through the tube. The egg is able to move forward because of the cilia inside the tube and the contractions of the muscles, this transportation is done within thirty hours. The fimbriae will be damaged in case there is infection in the pelvic and endometriosis. It will perpetually impair the functioning of the fallopian tube.

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Fertilization and Development of the Embryo

After ovulation, the egg has the capacity to be fertile only for a period of twelve to twenty four hours. Egg and sperm contact with each other randomly. The eggs arrive at the ampullar-isthmic junction and stays there for extra thirty hours. The fertilization takes place during this time inside the tube. The egg after fertilization begins to go down to the uterus. There is a danger of tubal pregnancy if there are imperfections in the fallopian tube. This is termed as ectopic pregnancy.

The membrane covering the egg is known as the zona pellucida. It plays two important functions during fertilization. Firstly, the zona pellucida encompasses the receptors of the sperm pertaining to humans. Secondly, after penetration takes place the membrane does not permit any other sperm.

After penetration, a number of activities arrange the setting up of the initial division of the cell. The single-cell embryo is known as zygote. In the following seven days the embryo undergoes many divisions of the cell and the process is known as mitosis. By the end of this phase the embryo gets formed into organized cells termed as blastocyst.

Implantation

Soon after the embryo arrives at the stage of blastocyst, this is roughly five to six days post fertilization, it breaks out of its zona pellucida and the process of implantation gets started for entering into the uterus.

10.4 MALE AND FEMALE CONTRACEPTION

Prevention of pregnancy is defined as contraception or birth control. It is meant to interfere with the regular course of ovulation, fertilization and implantation. Many different ways of controlling birth or preventing pregnancy are available and they are able to prevent pregnancy during any of the above mentioned stages.

A woman's body initiates the process of being pregnant in every thirty days as explained in the above section. In case, a women wants to avoid getting pregnant then proper birth controlling methods should be used. The main purpose of contraception is to obstruct the regular process and avoid pregnancy that could be an outcome. There are many types of birth controlling techniques; these provide help at various stages starting from ovulation to fertilization till implantation. None of them is full proof and all have their respective after effects and variable reliability.

The various methods of birth control are segregated into a number of groups depending on their functions, the groups are mentioned below:

- **Birth control with the help of hormones:** This includes medication for preventing ovulation. In this cateogy, all pills of oral contraceptives and injections are included.

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- **Birth control with the help of barricade:** The sperm is prevented to come in contact with the egg. This category includes male-female condoms, diaphragm, and cervical cap. The use of condoms no only prevents unwanted pregnancy but it also provides protection against HIV, AIDS and other diseases transmitted during sex.
- **Birth control with the help of spermicides:** These are medicines that help in killing the sperm as soon as it comes in contact. The spermicides mostly consist of nonoxynyl-9. These are available in several forms like gel, foam, pills, as a clear film. They have to be placed inside the vagina. These are most effective when used in combination with the barricade methods.
- **Birth control with the help of intrauterine devices (IUDs):** The uterus is injected with the device and remains effective for a period of up to five years.
- **Birth control with the help of tubal ligation:** This is a permanent method of contraception for women. It is a medical procedure in which the fallopian tube can be tied or burnt so that it closes, the sperm will not be able to get to the egg and, thus, egg will not travel till the uterus.
- **Birth control with the help of vasectomy:** Male contraception that permanently disables the man from fathering a child.

All the methods mentioned above are effective as well as ineffective in their own way. There is no full proof method of preventing pregnancy. Each individual has to choose the method which suits his lifestyle. They all will be effective if they are diligently followed. For instance, birth control pills are effective only when they are taken religiously every single day at the same time.

Risk Factors of Contraception

All forms of birth controlling technique involve certain levels of risks. Some of them are mentioned as the following:

- Pills for contraception contain a hormone that may increase the chances of suffering from heart attack in women over forty years of age, especially, those addicted to smoking.
- Devices such as IUD are prone to causing infection in the pelvic region. They sometimes even cause an injury inside the uterus. In few cases, the injury has to be surgically repaired.
- The condoms are prone to be punctured during the sexual act.

10.4.1 Etiology of Male and Female Infertility

It is not easy to identify the causes for infertility. The main cause could be lack of adequate hormonal levels in either of the partners or problem of ovulation in the female. The main symptom is not being able to become pregnant. In several cases, this is the only symptom with all other aspects being normal.

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In recent times, several treatments have been developed that help in improving the chances of pregnancy. There are several hormonal cures, medicines for fertility and surgery. Further, many supportive reproduction techniques in medicine help in fertilization of the egg.

Factors Responsible for Infertility in Men

There are several factors that cause male infertility. These are the following:

- **Irregular production and functioning of sperm:** This could be as a result of undescended testicles, defects in genes, infections or health issues such as diabetes. Infections like chlamydia, gonorrhea, mumps or HIV could be causing infertility and in cases where there is enlargement of testicles veins (varicocele) there could be issues of infertility.
- **Issues faced in supplying enough sperm as a result of untimely ejaculation:** In this case, infertility could be associated with genetic disorders like cystic fibrosis wherein the testicles could be blocked. In few cases, reproductive organs are not able to function properly due to an injury or impairment.
- **Few environmental exposures like pesticides, chemicals or radiation are known to cause infertility in few cases:** Personal habits like smoking, drinking or consuming drugs also cause infertility in men. Few medicines like antibiotics, anti-hypertensives, steroids may have an impact as well. The production of sperm is affected by exposure to extreme heat.
- Men affected by cancer are prone to infertility as the chemotherapy given during the treatment impairs the production of the sperm.

Factors Responsible for Infertility in Women

There are several factors for infertility among women. These are the following:

- Disordered ovulation can have an impact on the eggs being released from the ovaries: The ovulation disorder could be due to a polycystic ovary syndrome. Condition of Hyperprolactinemia may also be responsible for interfering with ovulation. Both hyperthyroidism and hypothyroidism causes infertility as it has an impact on the cycle of female's menstruation. Females indulging in vigorous physical exercises or workouts may have trouble in conceiving. The infertility among women could be due to tumour in the reproductive organs or it could be due to an injury of the organ.
- Abnormality in the uterus or cervix could affect fertility among women. Presence of fibroids affects the fertilised egg as they interfere with the implantation. In few cases, benign tumours could be the cause of infertility.
- Damaged or blocked fallopian tube leads to swelling in the tube as a result the female could suffer from pelvic inflammatory diseases, thus, becoming a cause for infertility.

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- Growth of endometrial tissues in the outer part of the uterus affects the functions of not only the uterus but also the ovaries and the fallopian tube. This disorder is known as endometriosis.
- Females experiencing an early menopause are no longer capable of getting pregnant: There are few genetic conditions like Turner syndrome or carriers of Fragile X syndrome, cancer treatments and excessive smoking and consumption of alcohol contributing to female infertility.
- Surgery in the pelvic region or infections in the region could hamper fertility.

In few cases, infertility is caused due to several other factors such as delayed puberty, cancer treatments, nonappearance of menstruation, celiac disease, uncontrolled sugar levels, autoimmune diseases-lupus and also abnormality in the genes.

General Precautions for Men and Women

- The fertility is sometimes related to the age of the women. It is advised to women to conceive by their early thirties. In the same way, men after crossing the age of forty tend to be less fertile.
- Avoiding the usage of drugs, cigarettes and tobacco as these increase the chances of miscarriage among women. Smoking for men can have an impact on their sperm count.
- Use of alcohol often contributes to infertility in both men and women.
- Obesity is another factor contributing to infertility. Being underweight is yet another factor. People of both the categories suffer from eating disorders and the body is deprived of essential nutrients.
- Over extortion and lack of physical activity both contribute to infertility in either of the cases.

Check Your Progress

1. List the various organs of the male reproductive system.
2. State the parts of the urethra.
3. Mention the parts of the internal female genitalia.
4. What are the functions of the uterus?

10.5 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. The male reproductive system comprises the following organs:
   - A pair of testes
   - A pair of epididymides

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- A pair of vasa deferentia
- A pair of spermatic cords
- A pair of seminal vesicles
- A pair of ejaculatory ducts
- One prostate gland
- One penis
- One urethra

2. The urethra has three parts:
   (i) **Prostatic urethra:** Urethra starts at the urethral opening, urinary bladder and inside the prostate.
   (ii) **Membranous urethra:** It starts from the prostate gland and passes through the perineal membrane and ends at the bulb of the penis.
   (iii) **Spongiose urethra:** It is present in the corpus spongiosum of the penis. It ends at the external urethral openings in glans penis.
3. Internal female genitalia are as follows:
   - Vagina
   - Uterus
   - Uterine tubes
   - Ovary
4. Functions of the uterus are as follows:
   - After puberty, it maintains the regular cycle called the menstrual cycle. It prepares the uterus to receive, nourish and protect fertilized ovum.
   - It permits the growth of foetus for 40 weeks.
   - It helps the delivery of foetus at the end of 40 weeks by contraction of uterine muscles and relaxation and dilation of the cervix.
   - It promotes menstruation cycle if pregnancy does not occur.

10.6 SUMMARY

- The male reproductive system comprises the following organs:
  - o A pair of testes
  - o A pair of epididymides
  - o A pair of vasa deferentia
  - o A pair of spermatic cords
  - o A pair of seminal vesicles
  - o A pair of ejaculatory ducts

- One prostate gland
- One penis
- One urethra

NOTES

- Seminiferous tubules are one-to-four in number and are convoluted loops. They have germinal epithelial cells. All tubules unite at the upper pole of the testes and form tortuous tubule called epididymis.
- Seminal vesicles are two fibromuscular pouches with columnar epithelial lining and are located on the posterior aspect of the bladder. They have a duct at its inferior end.
- The penis has a layer, called superfacial fascia having tissue, few muscle fibres and superficial dorsal vein. It is continuous (above) with the fascial layer of the abdomen and is continuous below with the superficial layer of the perineum.
- The female reproductive system comprises many reproductive organs also called genitalia. Female genitalia are divided into two groups: external genitalia and internal genitalia.
- Labia minora are two small skin folds located between the labia majora. Posteriorly, they unite with each other and form an area called fourchette.
- The vagina is a fibromuscular canal starting from the vulva and ending at the uterus. It is posterior to the bladder and the urethra.
- The uterus is a pear-shaped, hollow pelvic organ lying between the urinary bladder and the rectum in antiverted, antiflexed position.
- An ovary lies below and behind the ampullary part of the uterine tube on each side of the uterus. Ovary is attached to the posterior or upper layer of the broad ligament of the uterus.
- At age 40–50 years, the menstrual cycle usually becomes irregular and ovulation fails to occur during many cycles.
- In girls puberty generally starts at the age of eight and for boys it starts when they are around ten years old.
- Puberty and adolescences are often regarded as same; the latter is considered to be a social term and could be referred to as the years between childhood and adult years.
- The starting of menstrual cycle among teenage females is referred to as menarche. The periodic blood that flows as a discharge from the uterus is called menstruation.
- After ovulation, the egg has the capacity to be fertile only for a period of twelve to twenty four hours. Egg and sperm contact with each other randomly.

- Soon after the embryo arrives at the stage of blastocyst, this is roughly five to six days post fertilization, it breaks out of its zona pellucida and the process of implantation gets started for entering into the uterus.
- Prevention of pregnancy is defined as contraception or birth control. It is meant to interfere with the regular course of ovulation, fertilization and implantation.
- It is not easy to identify the causes for infertility. The main cause could be lack of adequate hormonal levels in either of the partners or problem of ovulation in the female. The main symptom is not being able to become pregnant. In several cases, this is the only symptom with all other aspects being normal.

10.7 KEY WORDS

- **Seminal vesicles:** These are two fibromuscular pouches with columnar epithelial lining and are located on the posterior aspect of the bladder.
- **Vagina:** It is a fibromuscular canal starting from the vulva and ending at the uterus. It is posterior to the bladder and the urethra.
- **Gametogenesis:** It means formation of gametes in both males and females.

10.8 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. Briefly mention the structure and functions of the male reproductive organs.
2. Write short notes on the following:
   (a) Puberty (b) Menarche
3. List the steps involved in fertilization.
4. Identify the risk factors of contraception.
5. What is ectopic pregnancy?

Long Answer Questions

1. Explain the structure of female reproductive organs with the help of diagrams.
2. Discuss the various methods of contraception.
3. Explain the factors responsible for infertility among men and women.

10.9 FURTHER READINGS

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UNIT 11 SENSE ORGANS

NOTES

Structure

11.0 INTRODUCTION

Human body has five main senses, and each of these contain organs with specific structures of cells with well outlined functions and receivers meant for stimulation. The cells of all the sense organs are connected with the brain through the nervous system of the body. The nervous system helps in integrating the sensations picked up by the cells of the sense organs. The most developed sense of the body is the sight, with hearing at the second level followed by taste, smell and touch. The senses help in interacting with the world. Each sense is attached with the corresponding organ in the body; eyes are for sight, ears for hearing, mouth for tasting, nose for smelling and lastly, skin for touching.

In this unit, you will study about the physiology of vision, hearing, taste and smell along with the concept of cutaneous sensation.

11.1 OBJECTIVES

After going through this unit, you will be able to:

- Identify the sense organs of human body
- Discuss the physiology of vision, hearing, taste and smell
- Prepare an overview of cutaneous sensation

11.2 PHYSIOLOGY OF VISION, HEARING, TASTE AND SMELL

The sight has the responsibility of perceiving the visual incitements. The eyes help in identifying the shapes, colour, expanses and making other observations. The

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two eyes, together help in providing a binocularly vision of the object, the object can be perceived three dimensionally from a reasonable distance.

The hearing has the responsibility to receive sounds form external sources and relay them to the brain with the help of the ears through the nervous system. The sounds are transmitted with the help of an intricate mechanism that is instigated at the tower of the headset, and, hence, forwarding it to the specific portion of the brain to accept them and decipher them.

The taste has the responsibility to supply input regarding the flavour of edible objects consumed by the body. The sense of tasting allows the body to differentiate between flavours such as bitter, sweet, sour or salty. The mouth is equipped with highly sensitive receivers. There structure helps humans to identify, appreciate or dislike certain flavours. These sensory receivers are known as glasses, buttons and taste buds; they are located on the tongue, palate, pharynx and larynx. Amalgamations of the basic tastes are initiated with the help of intricate sensation of tasting.

The sense of smell helps in perceiving the fragrances of the objects. The nasal mucosa and olfactory mucosa are equipped with special cells known as the chemoreceptors which are able to react to the chemical features of the odours found in the substances. These neurons are extremely specialized by means of a tuft of cilia and their bases are extended in the fibres of the nerves with the help of the ethmoid bone (bone at the top of the nasal cavity) getting to the olfactory bulbs, from this point remaining neurons arrive at the brain, thus, generating the sensitivity of definite odours.

The sense of touch helps the humans to identify the characteristics of objects contacted. They are able to feel the shape and texture of its surface whether it is hard or soft by touching the object. The sense felt from the external surface of the body is relayed to the brain with the help of an intricate mechanism because of the specialized cells present in the receptors of the touch.

11.2.1 Functions of the Sense Organs

It is already understood that the five sense organs help individuals to communicate with the world around them at different levels. These are very important for existence of human race. Aristotle (384 BC – 322 BC) was the first thinker who had provided a traditional classification for the same. The experience of reality is only possible for people because of their sense organs. Physiological perception of external objects is done through the senses. The topic of senses is studied in various fields and several neurologists often argue about the number of senses that are part of the human body. They have split the senses of human body into two groups, the exteroceptors and the interoceptors. Under the first group are the external stimulations received by the body—the exteroceptors which include smell, taste and equilibrium. Under the second group are those senses which are received from inside the body—the interoceptors; these include dropping of blood pressure, changing pH levels or fluctuations in the levels of glucose and pH levels. Traditionally,

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the children are made to study the five senses mentioned above but it is frequently established that humans have additional two senses and other living organisms have around nine senses. It is often observed that senses differ from one individual to the other, for instance, sour taste to one person may not be the same for all consuming the same food item. This difference arises due to the brain's interpretation of the taste experienced.

The primary function of the eyes is to allow living beings to see. But in reality they are performing several more functions, for instance, they help in identification of shape, colour and depth of the object. The eyes help in observing every detail about the environment.

Smelling the fragrance is the primary task of the nose. The nose helps in identifying harmful chemicals in the air. Noses are used to smell scents. They remind the brain about smells which could have been forgotten.

The primary function of the ear is to hear sounds, to sense the atmospheric vibrations. The inner part of the ear helps in maintaining a balance and regulates sinus pressure. This function helps people to adjust to pressures during air travel and in high altitudes.

The primary function of the tongue is to identify the taste of the edible items. The tongue helps in differentiating between good and bad taste.

The primary function of the skin is to protect the internal parts of the body and for this reason it is regarded as one of the most essential sense organs. Skin supports the sense of touch. The skin has many functions besides helping the body to feel physically, these are the following:

- The skin sweats and helps the body to cool down.
- It protects the body from external elements by sensing the object coming in contact of the body
- The living beings are able to communicate with other beings with the help of touch.
- Helps in storing fluids and keeps the body hydrated.
- The skin absorbs vitamin D when exposed to the rays of the Sun.

11.2.2 Cutaneous Sensation

The term cutaneous sensation refers to the sensory quality of the skin. The two main layers of the skin are epidermis and dermis. Sensory receptors located beneath the skin are are peripheral nerve-fibre endings that respond differently to different forms of energy. The sensory endings can be divided three morphological types: sensory endings, Ruffini endings and bare nerve endings. There is an interesting relationship between the specific responses of cutaneous receptors and the five intrinsic qualities of cutaneous sensation. These qualities are touch-pressure (mechano receptors), cold and warmth (thermoreceptors), pain and itch. Each quality is assisted by a specific set of cutaneous peripheral nerve fibres. It is to be noted that more complicated

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sensations arise from integration with the central nervous system of information from these sets of nerve fibres. When the surface of the skin is explored with a round metal point, it discloses local sensory spots on the skin, stimulation of which brings out any one of the five qualities of the sensation. In other words, there might be plotted maps of pressure, warm, cold, pain or itch spots.

Check Your Progress

1. What is the primary function of the tongue?
2. What is the main function of eyes?
3. Name the two layers of the skin.

11.3 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. The primary function of the tongue is to identify the taste of the edible items. The tongue helps in differentiating between good and bad taste.
2. The eyes help in identifying the shapes, colour, expanses and making other observations. The two eyes, together help in providing a binocularly vision of the object, the object can be perceived three dimensionally from a reasonable distance.
3. The two layers of the skin are epidermis and dermis.

11.4 SUMMARY

- Human body has five main senses, and each of these contain organs with specific structures of cells with well outlined functions and receivers meant for stimulation.
- The sight has the responsibility of perceiving the visual incitements. The eyes help in identifying the shapes, colour, expanses and making other observations.
- The taste has the responsibility to supply input regarding the flavour of edible objects consumed by the body. The sense of tasting allows the body to differentiate between flavours such as bitter, sweet, sour or salty.
- The sense of smell helps in perceiving the fragrances of the objects. The nasal mucosa and olfactory mucosa are equipped with special cells known as the chemoreceptors which are able to react to the chemical features of the odours found in the substances
- Physiological perception of external objects is done through the senses. The topic of senses is studied in various fields and several neurologists often argue about the number of senses that are part of the human body.

- Smelling the fragrance is the primary task of the nose. The nose helps in identifying harmful chemicals in the air. Noses are used to smell scents. They remind the brain about smells which could have been forgotten.
- The term cutaneous sensation refers to the sensory quality of the skin. The two main layers of the skin are epidermis and dermis.
- The sensory endings can be divided three morphological types: sensory endings, Ruffini endings and bare nerve endings.

11.5 KEY WORDS

- **Chemoreceptors:** It is a sensory receptor in a biological cell membrane to which an external molecule binds to generate a smell or taste sensation.
- **Exteroceptors:** It is any receptor that detects external stimuli.
- **Ethmoid bone:** It is a light spongy cubical ***bone*** of the skull that is made up of thin plates and forms much of the walls of the nasal cavity and part of those of the orbits.

11.6 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. What are the sense organs of the human body?
2. Write a short note on the functions of the sense organs.

Long Answer Questions

1. 'Physiological perception of external objects is done through the senses.' Explain the statement.
2. Discuss the significance of the sensory quality of the skin.

11.7 FURTHER READINGS

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BLOCK - IV
ENDOCRINE, EXOCRINE AND NERVOUS SYSTEM

NOTES

UNIT 12 ENDOCRINE SYSTEMS

Structure

12.0 INTRODUCTION

Glands are a group of epithelial cells producing secretions and these secretions are utilized in other parts of the body. Glands are of two types: exocrine glands and endocrine glands. Secretions produced by the exocrine glands travel through the ducts to reach the target sites to execute their functions.

Endocrine glands are glands of the endocrine system that secrete their products, that is, hormones, directly into the blood rather than through a duct. The main constituents of the endocrine system are the pancreas and the pituitary thyroid, parathyroid adrenal and pineal glands. Thus, endocrine glands are the glands without ducts. Their secretions, known as hormones, enter the blood capillaries around respective glands for circulation in the blood and lymph and ultimately for generating the desired effect at the destined targets.

In this unit, you will study about the major endocrine organs namely, pituitary gland, thyroid gland, parathyroid gland, adrenal gland, pancreas and pineal gland. Moreover, you will also get to study the mechanism of action of hormones and hormonal imbalance syndromes.

12.1 OBJECTIVES

NOTES

After going through this unit, you will be able to:

- Differentiate between exocrine glands and endocrine glands
- List the major endocrine organs
- State the mechanism of action of hormones
- Identify the hormonal imbalance syndrome

12.2 DIFFERENT ENDOCRINE GLANDS

A gland is an organ in a human or animal body that synthesizes a substance for release, such as hormones or breast milk, often into the bloodstream (endocrine gland) or into cavities inside the body or its outer surface (exocrine gland). Thus, glands are of two types: exocrine glands and endocrine glands.

Exocrine Glands

Exocrine glands are glands that secrete their products, excluding hormones, into ducts (duct glands) which lead directly into the external environment. They are the counterparts to endocrine glands, which secrete their products (hormones) directly into the bloodstream or ductless glands or release hormones that affect only target cells nearby the release site.

Exocrine glands are also known as apocrine gland, holocrine gland, or merocrine gland based on how their product is secreted.

- **Apocrine glands:** A portion of the plasma membrane buds off the cell, containing the secretion.
- **Holocrine glands:** The entire cell disintegrates to secrete its substance.
- **Merocrine glands:** Cells secrete their substances by exocytosis.

Endocrine Glands

Endocrine glands are different from exocrine glands because they secrete their hormones, directly into the blood rather than through a duct. The main as stated earlier endocrine system, include the pituitary gland, components of the pancreas, ovaries, testes, thyroid gland and adrenal glands. The hypothalamus is a neuroendocrine organ.

In this unit, we will concentrate on the endocrine glands.

12.2.1 Major Endocrine Organs

In this section, we will discuss the major organs and glands associated with the endocrine system.

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The various endocrine organs are as follows:

1. Pituitary gland (hypophysis)
2. Thyroid gland
3. Parathyroid gland
4. Adrenal gland
5. Islets of Langerhans (pancreas)
6. Pineal gland

Figure 12.1 shows the various types of endocrine glands.

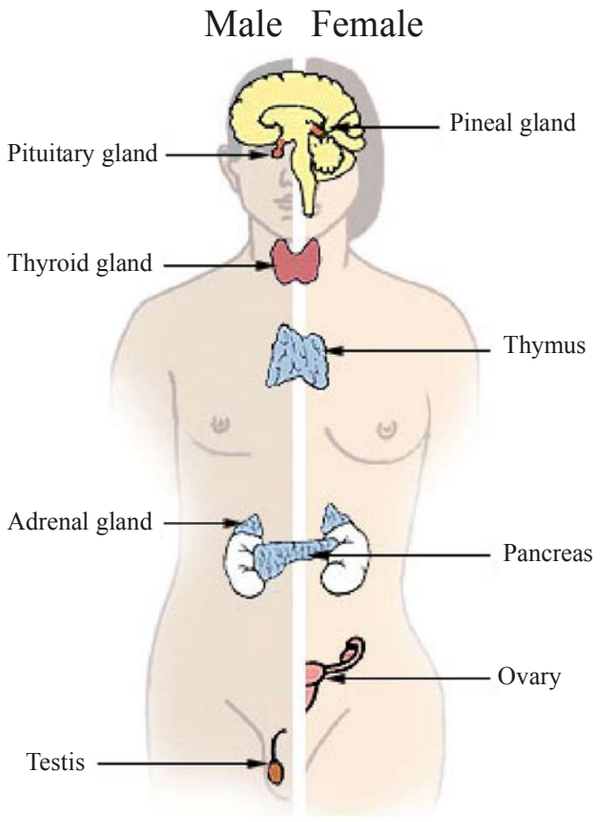

Fig. 12.1 *Major Endocrine Glands*

Pituitary Gland (Hypophysis)

The pituitary gland hangs from the base of the brain by a stalk and is enclosed by bone. It comprises a hormone-releasing glandular portion (known as anterior pituitary) and a neural portion (known as posterior pituitary), which is an extension of the hypothalamus. The function of the hypothalamus is to regulate the hormonal output of the anterior pituitary. Hypothalamus synthesizes two hormones that it exports to the posterior pituitary of storage and later release.

There are six adenohypophyseal hormones. Four of them are tropic hormones whose function is to regulate the function of other endocrine organs. Most of the anterior pituitary hormones exhibit a diurnal rhythm of release, which is subject to modification by stimuli influencing the hypothalamus.

NOTES

Parts

It has three parts:

(i) Anterior pituitary: It is called *adenohypophysis*.

(ii) Intermediate pituitary: It is a thin strip of tissue between ant and post pituitary.

(iii) Posterior pituitary: It is called *neurohypophysis*.

Blood Supply

Anterior lobe: It gets blood from capillary bed in hypothalamus formed by branches of internal carotid artery. This arrangement of blood is called pituitary portal system of blood.

Posterior lobe: It gets blood directly from internal carotid artery.

Venous: Short veins from both lobes take venous blood. These veins enter into venous sinuses between layers of dura matter.

Hormones of Anterior Pituitary (also known as adenohypophysis)

Hormones of anterior pituitary are as follows:

1. Growth hormone
2. Thyroid stimulating hormone (TSH)
3. Andrenocorticotrophic hormone (ACTH)
4. Prolactin (PRL) or luteotrophic hormone (LTH)
5. Gonadotrophic hormone (also called sex hormones)

1. Growth hormone

It is released by the effect of somatotrophin of hypothalamus. Its release is inhibited by the effect of somatostatin of hypothalamus.

Functions

It promotes the growth of:

- Bones
- Muscles
- Connective tissue
- Organs like:
  - o Kidney
  - o Liver

- o Intestine
- o Pancreases
- o Adrenals

NOTES

2. Thyroid stimulating hormone (TSH)

- TSH is produced by anterior pituitary only when thyroid releasing factor from hypothalamus acts on it. Its releases maximum between 9 p.m and 6 a.m and minimum between 4 p.m and 7 p.m.
- Regulation of secretion is by negative feed mechanism, i.e., if thyroid hormone is more, TSH secretion will be decreased.

Function

TSH helps in the growth of thyroid. TSH secretions lead to active growth of thyroid.

3. Adrenocorticotrophic hormone (ACTH)

The release of corticotrophin releasing factor (CRF) from hypothalamus promotes synthesis and release of ACTH from anterior pituitary.

The production of CRF depends upon the following factors:

- Nerve impulses from higher centres
- Decreased blood level of cortisol
- Physical stress, especially exercise
- Emotional stress
- Hypoglycemia
- Negative feedback mechanism, i.e., if cortisol is more, CRF will be less. If CRF is less, ACTH production will be less. If cortisol is less, ACTH will be more.

Function

ACTH increases the production of steroid hormones, mainly cortisol, from adrenal cortex by increasing the flow of blood and steroids to adrenal cortex.

4. Prolactin

Function: It directly acts on breasts after the birth of a child. Prolacien initiates and maintains lactation when it acts in the presence of estrogen, corticosteroid, insulin and thyroxine.

Its secretion is increased during:

- Sleeping hours
- Emotional stress
- Suckling of baby

5. Gonadotrophic hormones (GTH)

There are two types of gonadotrophic hormones:

(i) Follicle stimulating hormone (FSH)

(ii) Lutcinizing hormone (LH)

NOTES

FSH and LH are found both in males and females.

(i) FSH

In female

FSH ripens ovarian follicles. Mature ovarian follicles produce oestrogen. High levels of estrogen suppress the secretion of FSH.

In male

FSH stimulates the epithelial tissue of semini-ferous tubules of testes which stimulates the production of sperms.

(ii) LH

In females

- It finally matures ovarian follicle leading to ovulation. Ovulation means discharge of ovum.
- It promotes the formation of corpus luteum after ovulation. Corpus luteum produces second ovarian hormone, progesterone. A persistently high LH level indicates a situation in which the normal restricting feedback from the gonad is absent.

In males

It stimulates the interstitial cells of testes, setting in the production of testosterone.

Hormones of Posterior Lobe (also called neurohypophysis)

Posterior lobe has secretary cells called pituicytes and has nerve fibres which have their cells located in hypothalamus.

Posterior lobe produces the following two hormones in the hypothalamus:

1. Oxytocin

Oxytocin performs the following functions:

- It stimulates the contracting of uterine muscle in late pregnancy.
- It stimulates the epithelial cells of lactating breast
- Milk is stored into large ducts behind nipple. Its amount is increased during:
  - o Sucking of baby
  - o During labour
  - o Before labour

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2. Antidiuretic hormone (ADH) or vasopressin

They are produced by the cells of hypothalamus which travel to posterior pituitary via nerve fibres. They are stored in nerve endings. The functions of ADH are as follows:

(i) It increases the permeability to water of the collecting duct cells in the kidney and allowing water reabsorption and excretion of a smaller volume of concentrated urine.

(ii) It increases the permeability of the inner medullary portion of the collecting duct to urea by allowing increased reabsorption of urea into the medullary interstitium.

(iii) It stimulates sodium and chloride reabsorption in the thick ascending limb of the loop of Henle.

Regulation of ADH secretion: The secretion of ADH is regulated by osmotic pressure of blood circulating to osmoreceptor in hypothalamus.

Thyroid Gland

Structure

The structure of thyroid gland may be discussed as follows:

- It is located in neck anterior to C_5, C_6, C_7 and T_1. It is present anterior to larynx and trachea.
- It has two lobes joined by narrow isthmus.
- It is richly vascular and is surrounded by fibrous capsule.
- Each lobe is cone like, 5 cm length and 3 cm in width, and has two parathyroid glands at its posterior surface. There is a recurrent laryngeal nerve close to each lobe.
- Gland has epithelial cells arranged as closed spherical follicles.
- Between follicles, there are C-cells which produce calcitonin hormone.
- Inside follicles, there is semi-fluid, sticky thick structure containing protein called colloid. The thyroid hormone is stored in colloid.

Hormone-producing functions

Thyroid gland produces thyroxine (T_4), triiodothyronine (T_3) and calcitonine. These hormones are stored in follicles as thyroglobuline. They contain colloid and iodine taken from food.

Thyroid releasing factor (TRF) acts on ant pituitary of hypothalamus. Thyroid stimulating hormone (TSH) is produced by anterior pituitary. TSH acts on thyroid T_3 and T_4 and are released from thyroid gland. If T_3 and T_4 are increased, TSH starts decreasing and vice versa because $T_3 + T_4$ affect the sensitivity of anterior

pituitary to thyroid releasing hormone of hypothalamus. When the levels of T_3 and T_4 are low, the production of TSH increases and vice versa.

Poor iodine in food: Inadequate quantity of iodine leads to increased production of TSH.

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Functions of $T_3 + T_4$

- $T_3 + T_4$ control growth and development of tissues, especially nervous system.
- They regulate metabolism.

Calcitonin

- It decreases blood calcium by acting on bones and kidneys.
- It decreases blood calcium.
- It inhibits calcium absorption by renal tubules.

More ionized calcium in blood stimulates increased release of calcitonin.

Parathyroid Gland

The parathyroid glands refer to four or more small glands on the posterior surface of the thyroid gland.

- Length of each gland is approximately 6 mm approx.
- Width of each gland is approximately 3 mm approx.
- Thickness of each gland is approximately 2 mm approx.

When seen with the naked eye, these glands resemble dark brown fat. They are very difficult to locate.

Other possible locations of parathyroid glands are:

- Anterior mediastinum
- Posterior mediastinum

As parathyroid's location is not exact, a surgeon operating on parathyroid must look into its different possible locations.

Microscopically, a parathyroid gland has:

- Chief cells mainly producing parathyroid hormone.
- Oxyphil cells, which are rarely present, may produce even parathyroid hormone.

Parathyroid hormone is protein in nature.

It is very important to note that parathyroid gland has good ability to fight with hypertrophy.

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Functions

It produces hormone called parathyroid hormone (PTH). The functions of PTH are as follows:

Function of PTH

- It takes part in the control of calcium and phosphate homeostatis, as well as bone physiology.
- It controls:
  - o Calcium absorption from small intestine
  - o Calcium reabsorption from renewal tubules

If renal and intestinal sources provide less calcium, paratharmone stimulates osteoblasts and osteocyts to reasorb calcium from bones.

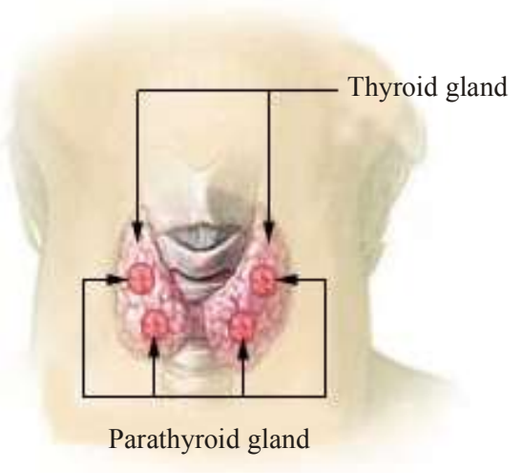

Fig. 12.2 *Thyroid and Parathyroid Glands*

Adrenal Glands

Various adrenal glands lie over upper layer of each kidney behind the peritoneum and on the posterior wall. Each gland comprises two parts:

(i) Outer cortex which secretes steroid hormones

(ii) Inner medulla which secretes adrenalin and non-adrenalin.

Each gland is present in epigastrium and abdominal compartment. It lies at the upper pole of each kidney in front of crus of diaphragm opposite vertebral end of the fourth inter-costal space.

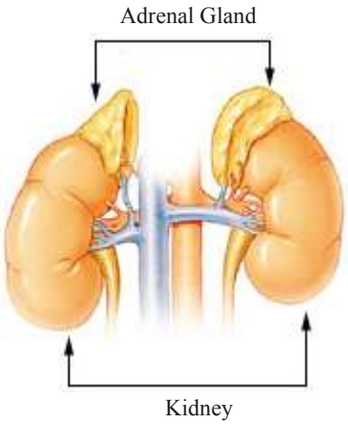

Fig. 12.3 *Adrenal Gland*

Anatomy of adrenal gland

Right gland is of triangular or pyramidal shape, whereas left gland is semi-lunar in shape.

- Height is 50 mm
- Breadth is 30 mm
- Thickness is 10 mm
- Weight is 5 gm

Septum intervens between kidney and suprarenal gland.

Right gland comprises:

- An apex
- A base
- Two surfaces:
  - (i) Anterior
  - (ii) Posterior
- Three borders:
  - (i) Anterior
  - (ii) Medial
  - (iii) Lateral

Left gland comprises:

- Two ends:
  - (i) Upper narrow
  - (ii) Lower rounded
- Two borders:
  - (i) Medial convex
  - (ii) Lateral concave

NOTES

- Two surfaces:
  (i) Anterior
  (ii) Posterior

Right gland has structures:

- Anterior to it, which are:
  Inferior vena cava, medially
  Liver, laterally
  Occasionally, duodenum
- Posterior to it, which is right crus of diaphragm.
- Near to its anterior border, which is hilum (a little below apex)
- Near to its medial border, which are:
  - Right celiac gangtion
  - Right inferior phrenic artery

Base of right glands is lying over the upper pole of right kidney.

Left gland has the following structures:

- Anterior to it, which are:
  - Cardiac end of stomach
  - Splenic artery
  - Pancreas
  - Hilum near the lower end left supra. Renal vein comes out of its
- Posterior to it, which are:
  - Kidney laterally
  - Left crus of diaphragm medially
- Medial to it, which are:
  - Left celiac ganglion
  - Left inferior phrenic artery
  - Left gastric artery

Microscopically, the adrenal gland has:

- Outer cortex
- Inner medulla

Cortex has three zones:

(i) Zona glomerulosa which produces mineralocorticoids
(ii) Fasciculata which produces glucocorticoids
(iii) Reticularis which produces sex hormones, e.g., progesterone, estrogen, androgen, etc.

Medulla has chromaffin cells called **phaeochromocytes** which produce adrenalin and non-adrenalin.

Arterial supply

Arterial suply is by:

- Superior supra renal artery branch of inferior phrenic artery.
- Middle supra renal artery branch of abdominal aorta.
- Inferior supra renal artery branch of renal artery.

Venous drainage

Venous drainage is by:

- Right supra renal vein of end into inferior vena cava
- Left supra renal vein of end into left renal vein

Lymphatic drainage

Lymphatic drains into aortic nodes.

Nerve supply

Nerve supply has the following features:

- Nerve supply of supra renal medulla is through pre-ganglion sympathetic fibres.
- Adrenal cortex is controlled by ACTH of anterior pituitary.

Adrenal glands are also called suprarenal glands. They are two in number, located at upper lobe of each kidney, each with approximately 4 cm length and 3 cm width.

Blood supply

Arteries: Branches from abdominal aorta and renal arteries.

Venous return: By suprarenal view

- Right suprarenal drains into inferior vena cava.
- Left suprarenal vein into left renal vein.

Hormones of adrenal cortex

It produces three hormones:

(i) Glucocorticoids

(ii) Mineralocorticoids

(iii) Androgens (Sex hormones)

(i) Glucocorticoids: They are mainly two: cortisone (hydrocortisone) and corticosterone.

Functions of glucocorticoids are as follows:

- It regulates carbohydrate metabolism.
- It promotes formation and storage of glycogen.

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- It promotes gluconeogenesis from protein.
- It promotes sodium and water reabsorption from renal tubules.

(ii) Mineralocorticoids (aldosterone): It maintains electrolyte balance in the body. It allows the retention of sodium ions and the excretion of potassium ions.

The production of aldosterone is regulated by the sodium level in blood. If sodium is less, aldosterone production is increased, so sodium reabsorption is enhanced.

Renin-angiotensin system (RAS)

- Renin enzyme is produced by kidney that constricts arteries and thus raises blood pressure.
- Renin converts **angiotensinogen** of liver to angioteusin.
- Angioteusin acts on adrenal cortex to stimulate the production of aldosterone.
- Aldosterone acts on renal tubules to increase sodium reabsorption and H_2O reabsorption but increases potassium excretion.
- Now blood volume increases and this leads reduction in the production of rennin by kidneys, thereby decresing the secretion of aldosterone.

(iii) Androgens

Androgen is a type of hormone that is associated with the development of male characteristics. It performs the two functions:

(i) It deposits proteins in muscles.

(ii) It retains nitrogen in males.

Hormones of adrenal medulla

Adrenal medulla is the inner part of adrenal gland. It produces the following two types of hormones:

(i) Adrenaline

(ii) Nor-adrenaline

(i) Adrenaline hormone: This hormone is secreted at some nerve endings of the sympathetic nervous.

The functions of adrenaline are as follows:

- It constricts skin blood vessels.
- It dilates blood vessels of muscles, heart and brain.
- It converts glycogen to glucose.
- It increases metabolic rate.
- It dilates pupil.
- It dilates bronchioles promoting increased excretion.

(ii) Nor-adrenaline hormone: This hormone is secreted by to regulate cardiac muscle, glandular muscle and smooth muscle. It is also a neurotransmitter in the sympathetic nervous system, where it acts as a powerful vasoconstrictor on the vascular smooth muscle.

Its main function is to maintain blood pressure by producing general vasoconstriction, except of coronary arteries.

Islets of Langerhans (Pancreas)

Structure

The islets of Langerhans are the regions of the pancreas that contain its endocrine (i.e., hormone-producing) cells. Hormones produced in the islets of Langerhans are secreted directly into the blood flow. Cells are of three types:

(i) α cells which produce glucagon

(ii) β cells which produce insulin

(iii) γ cells which produce somatostatin

Functions of glucagons and insulin

- Glucagon raises the blood glucose level by converting stored glycogen in liver to glucose.
- Insulin performs the following functions
  - (a) It tries to maintain homeostasis.
  - (b) It stimulates uptake of glucose, amino acid and fats.
  - (c) It converts glucose to glycogen in liver and muscles.
  - (d) It synthesis RNA and DNA.
  - (e) It stores fat in adipose tissue.
  - (f) It prevents glucone genesis.
  - (g) It prevents breakdown of protein and fat.

Regulation of insulin secretion

Secretion is stimulated by:

- Increased glucose level
- Increased amino acid level
- Glucose tolerance test (GTT) hormones, such as gastrin secretion and pancraeozymin.

Secretion is inhibited by:

- Sympathetic stimulation
- Adrenaline
- Somatoetatin

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Pineal Gland of Body

The pineal gland is considered an endocrine gland, but it does not clinically perform any specific hormonal function. Also known as the pineal body, epiphysis cerebri, epiphysis or the 'third eye', the pineal gland is a small endocrine gland in the vertebrate brain. It produces melatonin a hormone which influences the modulation of wake/sleep patterns and photoperiodic (seasonal) functions. Melatonin also inhibits the growth and development of sex organs before puberty.

12.2.2 Mechanism of Action of Hormones

Hormones are the chemical messengers/information molecules formed by cells of endocrine gland/cells of a mixed gland/organ, produced in one part of the body and translocated by circulatory system to another part for stimulating or inhibiting one or more physiological process for the welfare of the body. The various types of hormones are as follows:

- **Local hormones:** They refer to the hormones that are effective in low concentration (e.g. 0.003 ppm adrenaline).
- **Trophic hormones:** They are the hormones that control the growth and/or activity of other endocrine glands. This includes TSH, ACTH, FSH and GH.
- **Neuroendocrine hormone:** They refer to the hormones that are secreted by neurosensory neurons as, releasing hormones of hypothalamus. Releasing hormone is one that controls the production (stimulation or inhibition) of tropic hormones.

Chemical nature of hormones

Chemical nature of hormones has the following qualities:

- Amines
- Modified amino acids
- Peptides
- Proteins
- Steroids

Characteristics of hormones

Hormones have the following characteristics:

- They are the regulatory chemicals that control and coordinate functions of different body organs.
- They are formed by ductless or endocrine glands functioning away from area of formation in very low concentrations (e.g. testosterone 30–100 ìg/mL).
- They are poured into circulatory system in which they are soluble and carried to the target cells.

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- They do not catalyse reactions but function by stimulating or inhibiting the target cells.
- They can be proteins, peptides, amino acids derivatives and attach to target cell membrane at specific points having receptors for inward passage or reaction (Table 12.1).

Table 12.1 *Endocrine Glands and Their Source and Targets*

Endocrine gland	Hormone released	Chemical class	Target tissue/organs	Chief function(s)
Hypothalamus	Hypothalamus releasing and -inhibiting hormones	Peptide	Anterior pituitary	Regulates anterior pituitary hormones
Posterior pituitary	Anti-diuretic (ADH)	Peptide	Kidneys	Stimulates water reabsorption by kidneys
				Stimulates uterine muscle contraction, glands release of milk by mammary
	Oxytocin	Peptide	Uterus, mammary glands	
Anterior pituitary	Thyroid-stimulating (TSH)	Glycoprotein	Thyroid	Stimulates thyroid
	Adrenocorticotropic (ACTH)	Peptide	Adrenal cortex	Stimulates adrenal cortex
	Gonadotropic (FSH and LH)	Glycoprotein	Gonads	Egg and sperm production, sex hormone production
	Prolactin	Protein	Mammary glands	Milk production
	Growth	Protein	Soft tissues and bones	Cell division, protein synthesis and bone growth
	Melanocyte-stimulating	Peptide	Melanocytes in skin	Unknown function in humans, regulates skin colour in lower vertebrates
Thyroid	Thyroxine (T4) and triiodothyronine (T3)	Iodinated amino acid	All tissues	Increases metabolic rate, regulates growth and development
	Calcitonin	Peptide	Bones, kidneys and intestine	Lowers blood calcium level
Parathyroid	Parathyroid (PTH)	Peptide	Bones, kidneys and intestine	Raises blood calcium level
Adrenal cortex	Glucocorticoids (cortisol)	Steroid	All tissues	Raise blood glucose level, stimulate breakdown of protein
	Mineralocorticoids (aldosterone)	Steroid	Kidneys	Reabsorb sodium and excrete potassium

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	Sex hormones	Steroid	Gonads, skin muscles and bones	Stimulate reproductive organs and bring about sex characteristics
Adrenal medulla	Epinephrine and nor epinephrine	Modified amino acid	Cardiac and other muscles	Emergency situations raises blood glucose levels
Pancreas	Insulin	Protein	Liver, muscles and adipose tissue	Lowers blood glucose level and promotes formation of glycogen
	Glucagon	Protein	Liver, muscles and adipose tissue	Lowers blood glucose level
Gonads	Androgens (testosterone)	Steroid	Gonads, skin muscles and bones	Stimulate male secondary sex characters
Testes and ovaries	Estrogens and progesterone	Steroid	Gonads, skin, Muscles and bones	Stimulate female sex characteristics
Thymus	Thymosins	Peptide	T-lymphocytes	Production and maturation of T-lymphocytes
Pineal gland	Melatonin	Modified amino acids	Brain	Circadian and circannual rhythms, possibly involved in maturation of sex organs

12.3 HORMONAL IMBALANCE SYNDROMES

Hormones may be called as the chemical couriers of the body. Their production takes place in the endocrine glands of the body and they circulate in the body's blood. Hormones guide several organs and tissues in the performance of their functions. They are responsible for controlling major processes of the body such as reproduction and metabolism. Having deficiency or abundance of a hormone leads to hormonal imbalance in the body and this results in serious effects on the individual. The fluctuations in the hormones make some of the body parts to function inefficiently and abnormally.

12.3.1 Indications of a Hormonal Imbalance

The overall well-being of living beings is dependent on the hormones. An imbalance of the hormones is indicated through various signs and conditions, few conditions

are common in both the sexes but there are few which pertain to either sex. Listed below are common signs and conditions found as symptoms of hormonal imbalance:

- Excessive gain or loss of weight
- High levels of fatigue
- Enhanced feeling of cold or high temperature
- Constipation or extra recurrent bowel movements
- Excessive dryness of skin
- Swelling on face and other parts of the body
- Fluctuating heart rate
- Unexplained weakening of muscles
- Frequent urge to pass urine
- Feeling thirsty frequently
- Pain, swelling or stiffness of muscles and joints
- Excessive hair loss, roughness or thinning
- Hunger pangs
- Feeling of depression
- Low sexual urge
- Increase in levels of anxiety, edginess or frequent bouts of temper
- Blurry eyesight
- Excessive sweating
- Infertility
- Formation of stretch marks
- Frequent appearance of rashes or redness on the skin

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Symptoms of Hormonal Imbalance in Women

PCOS is the hormonal imbalance found in most women and this result in affecting various stages of their life. The polycystic ovary syndrome influences natural cycle of puberty, pregnancy and also menopause.

Women suffering from hormonal imbalance have the following symptoms:

- Irregularity in the menstrual cycle accompanied by heavy bleeding and frequent missing of periods
- Hair growths on various parts of the body especially face and breast
- Problem of acne not only on face but also on chest and back
- Excessive loss and thinning of hair
- Trouble in losing extra weight gained

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- Pigmentation and dark patches appear on various parts of the body
- Tanning of skin
- Dryness in vagina
- Unusual sweating
- Pain while having sex

Symptoms of Hormonal Imbalance in Men

Development in men is largely dependent on the levels of testosterone, in case they are not sufficiently produced, men will suffer from imbalance of hormones.

Men suffering from hormonal imbalance have the following symptoms:

- Breast tissues develop
- Swelling or pain in the breast
- Erectile dysfunction
- Muscle mass is lost
- Low sexual urges
- Infertility
- Lack of facial and body hair
- Suffer from osteoporosis
- Inability to concentrate
- Frequent flashes of sweat

Symptoms in Children

The hormones in children develop during puberty. Children who do not experience normal puberty suffer from hormonal imbalance termed as hypogonadism.

Boys suffering from hormonal imbalance experience the following symptoms:

- Lack of muscular mass
- Baby voice does not mature
- Sparing hair growth on body
- Lack of development of the penis and testicles
- Lack of proportion in the body structure
- Development of chest

Girls suffering from hormonal imbalance experience the following symptoms:

- Menstrual cycle does not start or is delayed
- Breasts do not develop
- Do not gain adequate height

12.3.2 Causes of Hormonal Imbalance

The causes of hormonal imbalance in the body could be due to a number of conditions. They are different for every individual:

- Diabetes
- Hypothyroidism or hyperthyroidism
- Hypogonadism
- Cushing Syndrome
- Tumour of any sort
- Congenital adrenal hyperplasia
- Disorders related to eating habits
- Consumption of specific medicines
- High level of stress
- Adrenal inadequacy
- Tumour in the pituitary gland
- Injury or experience of trauma, physical or emotional
- Treatment during cancer

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12.3.3 Hyperactivity and Hypoactivity

The word hyperactivity denotes increased level of action and movement. Individuals falling in this category are highly restless and tend to have a very short span of attention. They get bored and distracted frequently. Hyperactively behaving individual would be involved in some activity constantly; they would be easily distracted and will not be able to focus on a specific thing for long. Such individuals would be prone to aggressive and impulsive behaviour.

The characteristics of an hyperactive person are the following:

- Twitching or constantly moving
- Nomadic
- Tendency to be talkative
- Inability to take part in stationary activities like reading, writing and other such activities
- Exhibiting aggression if attempts are made to settle them at one place

It is not easy to define hyperactivity as each observer has a different perception. The extent of hyperness varies amongst all observers. The difference is obvious when behaviour of two children of the same age is compared. Hyperactive children are unable to perform their school work properly and they are often causing disturbance during classroom activities. Parents of such children

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often have to face embarrassment by the complaints of the teachers and other parents. It is not easy to handle children suffering from hyperactivity. In some cases, they are subjected to bullying and are unable to make friends. This can lead to depression and further aggravate the problem. Hyperkinetic behaviour mostly ends by the time the child reaches the teenage stage. Very rarely the condition persists in adulthood of life.

Complete reverse of hyperactivity is hypoactivity. In this condition, the individual is completely reluctant to move. This is a state of locomotive inactivity. Hypoactivity is caused in most cases due to side effects of certain medicines or it could be due the after effect of sedatives or even anaesthesia. Hypoactivity may be caused due to drugs like antipsychotics and mCPP. It could be an indication of the absent-minded type of ADHD (ADHD-PI) and inactive cognitive tempo.

Check Your Progress

1. Name the two kinds of glands found in human body.
2. List the various endocrine organs.
3. List two characteristics of hormones.

12.4 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. The two kinds of glands found in human body are exocrine glands and endocrine glands.
2. The various endocrine organs are the following:
   (i) Pituitary gland (hypophysis)
   (ii) Thyroid gland
   (iii) Parathyroid gland
   (iv) Adrenal gland –cortex and adrenal medulla
   (v) Islets of Langerhans (pancreas)
   (vi) Pineal gland
3. Two characteristics of hormones are the following:
   - They are the regulatory chemicals that control and coordinate functions of different body organs.
   - They are formed by ductless or endocrine glands functioning away from area of formation in very low concentrations (e.g. testosterone 30–100 ìg/mL).

12.5 SUMMARY

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- A gland is an organ in an animal's body that synthesizes a substance for release, such as hormones or breast milk, often into the bloodstream (endocrine gland) or into cavities inside the body or its outer surface (exocrine gland).
- Exocrine glands are glands that secrete their products, excluding hormones, into ducts (duct glands) which lead directly into the external environment.
- Endocrine glands are different from exocrine glands because they secrete their hormones, directly into the blood rather than through a duct.
- The various endocrine organs are as follows**:**
  - o Pituitary gland (hypophysis)
  - o Thyroid gland
  - o Parathyroid gland
  - o Adrenal gland
  - o Islets of Langerhans (pancreas)
  - o Pineal gland
- The pituitary gland hangs from the base of the brain by a stalk and is enclosed by bone.
- The parathyroid glands refer to four or more small glands on the posterior surface of the thyroid gland.
- Various adrenal glands lie over upper layer of each kidney behind the peritoneum and on the posterior wall. Each gland comprises two parts:
  - (i) Outer cortex which secretes steroid hormones
  - (ii) Inner medulla which secretes adrenalin and non-adrenalin
- Adrenal medulla is the inner part of adrenal gland. It produces the following two types of hormones:
  - (i) Adrenaline
  - (ii) Nor-adrenaline
- The pineal gland is considered an endocrine gland, but it does not clinically perform any specific hormonal function.
- Chemical nature of hormones has the following qualities:
  - o Amines
  - o Modified amino acids
  - o Peptides
  - o Proteins
  - o Steroids

NOTES

- Hormones may be called as the chemical couriers of the body. Their production takes place in the endocrine glands of the body and they circulate in the body's blood. Hormones guide several organs and tissues in the performance of their functions.
- The overall well-being of living beings is dependent on the hormones. An imbalance of the hormones is indicated through various signs and conditions, few conditions are common in both the sexes but there are few which pertain to either sex.
- PCOS is the hormonal imbalance found in most women and this result in affecting various stages of their life.
- The causes of hormonal imbalance in the body could be due to a number of conditions.
- The word hyperactivity denotes increased level of action and movement. Individuals falling in this category are highly restless and tend to have a very short span of attention.
- Complete reverse of hyperactivity is hypoactivity. In this condition, the individual is completely reluctant to move. This is a state of locomotive inactivity.

12.6 KEY WORDS

- **Gland:** It is an organ in a human or animal body that synthesizes a substance for release, such as hormones or breast milk, often into the bloodstream (endocrine gland) or into cavities inside the body or its outer surface (exocrine gland).
- **Parathyroid gland:** It refers to four or more small glands on the posterior surface of the thyroid gland.
- **Hormones:** These are the chemical messengers/information molecules formed by cells of endocrine gland/cells of a mixed gland/organ, produced in one part of the body and translocated by circulatory system to another part for stimulating or inhibiting one or more physiological process for the welfare of the body.

12.7 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. State the difference between exocrine gland and endocrine gland.
2. Write a short note on the hormones released by anterior pituitary.
3. What are the possible locations of the parathyroid gland in the human body?

Long Answer Questions

1. Discuss the structure of the thyroid gland.
2. Explain the anatomy of the adrenal gland.
3. Aanlyse the significance of hormones in human body.

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12.8 FURTHER READINGS

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UNIT 13 EXOCRINE SYSTEMS

NOTES

Structure

13.0 INTRODUCTION

The body is able to secrete substances out of the body because of the cellular sub-structures present in the organs known as the exocrine glands. These glands form a system which enables secretion of substances. They are not the same as the endocrine glands because their secretions are out of body while secretions of endocrine are going into the blood within the body. The secretion is done with a help of a system of ducts.

13.1 OBJECTIVES

After going through this unit, you will be able to:

- State the main functions of exocrine glands
- Discuss the structure of exocrine glands

13.2 FUNCTIONS AND STRUCTURE OF EXOCRINE GLANDS

There are different types of exocrine glands in the human body and all together they are able to perform a number of functions such as the following:

- They help in regulating the temperature of the body
- Help in lubrication of parts of body
- Help in lactation of new-born
- Assist in the digestion of food
- Assist in reproduction

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The structure of the exocrine gland is fragmented into the ductal portion and the portion with the glands. The portion of the glands is in a round shape or an elongated cluster. The round structure is known as the acinus or acini. The elongated cluster is made of cells which create the substance helping in secretion. The cells found in the gland are dependent on the nature of substance which has to be secreted. Serous cells for protein excretion and mucous cells for excretion of mucus and other liquids are two common types of cells found in the gland.

The ductal portion is in shape of a tube. It is mostly a single, cuboidal cell like a thick wall as it needs to enable movement during secretion. The tube like duct can be with multiple branches or a single tube shaped. Some of them are in a coiled shape as well.

13.2.1 Types of Exocrine Glands

There are various types of exocrine glands. Let us now study about them briefly.

Holocrine glands discharge complete fragmented open cells into the ductal system. The cells hold the stored substances that have to be discharged by the gland. In this secretion method, frequent cell turnover and substitution is required.

Merocrine or Eccrine glands directly discharge the substances into the duct with the help of the channels in the cells or through their pores. In this, the cell structure or membrane is not lost. This type of exocrine gland is very common.

Apocrine glands discharge the secretion by budding off their partial cellular cytoplasm and membrane. The bud has the substance that needs to be discharged in the ductal system.

Examples of Exocrine Glands along with their Secreted Product

- Lacrimal gland: These are ducts for tears and they are present near both the eyes.
- Mammary gland is responsible for the secretion of milk from the breast.
- Eccrine sweat glands release sweat and are present at the armpits and under the skin where excessive sweating takes place.
- Salivary glands are present in the mouth and consist of saliva which has fluids necessary for digestive enzymes.
- Pancreas secretes digestive juices through the pancreatic duct into the duodenum.
- Primarily the liver secretes bile juice. It also secretes enzymes which assist in metabolism of protein, fats and carbohydrates.

Some of the glands present in human body are the following:

Salivary gland: The human body has three pairs of salivary glands namely, the parotid, submandibular and sublingual. They help in secretion of saliva in the mouth which aids in the process of digestion. The parotid glands are positioned under

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and somewhat near both the ears. They are the biggest salivary glands. Just besides them are the submandibular glands. The sublingual glands are positioned in the frontal part of the surface of the mouth in between the tongue and mandible. The secretions are poured directly in the mouth by them. The secretion of digestive juices by these glands is known as the saliva. There is ninety per cent water in the fluid and remaining ten per cent is the digestive enzyme ptyalin known as the salivary amylase. Partial digestion of carbohydrates happens due to the saliva in the mouth. Saliva has mucin and calcium salts in small amount. The saliva helps in performing following functions:

- Keeps the mouth and tongue moistened
- Lubrication of the food for easy swallowing
- Ptyalin provides the starch and helps in breaking them into dextrins and maltose.
- Provided stimulation of the taste buds
- Acts as a cleaner in the mouth

Mammary gland: The gland positioned in the female's breast is referred to as the mammary gland. The gland helps during lactation and milk production. They are present in both the sexes but it develops only in females during puberty. After the baby is born the mother's mammary gland is able to produce milk as at the time of pregnancy; consequently, progesterone and prolactin are discharged. The progesterone restricts the prolactin and, thus, prevents the mammary glands from lactating. During pregnancy substances like milk known as colostrum are formed. This fluid full of antibodies helps in sustaining the new-born for a couple of days after birth. As soon as the baby is born, the levels of progesterone lessen and prolactin signals the gland to secrete milk.

Ceruminous gland: These are special glands for secreting sweat positioned intravenously in the outer one-third portion of the auditory canal. These are simple, twisted, tube shaped glands formed from the internal secretory layer of cells and an outward myoepithelial cover of cells. They are assigned as apocrineglands. The glands channel in bigger ducts. These are then channelled into the guard hairs that are present in the outer auditory canal. At this place cerumen is produced. Cerumen or earwax helps in keeping the eardrum supple, greases and cleanses the outer auditory canal, keeps the canal dry, helps in destroying the bacteria, and protects the ear from entry of foreign particles. The cerumen coats the guard hair and makes them sticky.

Sebaceous gland: These are minuscule exocrine glands present in the skin; they secrete sebum, a greasy or waxy substance. This helps in lubrication and waterproofing the hair and skin of all mammals. They are mostly present on face and scalp of humans. They are present in small amount in most parts of the body. However, they are completely absent from sole of feet and palm of hands. Substance secreted by this gland is known as holocrine. Meibomian glands, also known as

tarsal glands, are a type of sebaceous gland found in the eyelids; they secrete a distinct type of sebum in the tears. Fordyce's spots are ectopic sebaceous glands mostly found on the lips, gums and inside the cheeks and genitals. Areolar glands are found around the nipple of the females.

Mucous gland: They are referred to as muciparous glands and are in found in many parts of the body. These glands are mostly multicellular; however, goblet cells are glands with a single-cell.

The mucous salivary glands have the same structure as the buccal and labial glands. These are located particularly in the rare part of the vallate papillae, sometimes; they exist in the top and bordering parts.

The anterior lingual glands are located below the surface of the top part of the tongue, each on either side of the frenulum. Here, they are surrounded by a fascicle of muscular fibres resulting from the styloglossus and inferior longitudinal muscles. Glycoprotein is produced by them along with mucin which helps in absorbing moisture to create pasty secretion known as mucus.

The Weber's glands are illustrations of muciparous glands found besides the tongue. It comprises of the gastric glands.

13.2.2 Gland Secretion Syndromes

Let us briefly study the gland secretion syndromes.

Cystic fibrosis (CF), a genetic disease characterized by abnormalities of exocrine gland and mucociliary function.

Sjogren's syndrome: This is a chronic autoimmune disease where salivary glands are often attacked by certain cells which lead to dry mouth and dry eyes. Painless enlargement of the salivary glands has also been reported by certain patients in some cases.

Benign Prostatic Hyperplasia (BPH) is a pathologic disorder that develops in response to the action of dihydrotestostrene on the aging prostate and to changes in stromal and epithelial cells in this exocrine gland.

Check Your Progress

1. What are the main functions of exocrine glands?
2. Name the types of exocrine glands.

13.3 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. The main functions of exocrine glands are the following:
   - They help in regulating the temperature of the body
   - Help in lubrication of parts of body

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- Help in lactation of new-born
- Assist in the digestion of food
- Assist in reproduction

2. The types of exocrine glands are the following:
   - Holocrine glands
   - Merocrine or Eccrine glands
   - Apocrine glands

13.4 SUMMARY

- There are different types of exocrine glands in the human body and all together they are able to perform a number of functions functions such as the following:
  - o They help in regulating the temperature of the body
  - o Help in lubrication of parts of body
  - o Help in lactation of new-born
  - o Assist in the digestion of food
  - o Assist in reproduction
- Holocrine glands discharge complete fragmented open cells into the ductal system. The cells hold the stored substances that have to be discharged by the gland.
- Apocrine glands discharge the secretion by budding off their partial cellular cytoplasm and membrane. The bud has the substance that needs to be discharged in the ductal system.
- The human body has three pairs of salivary glands namely, the parotid, submandibular and sublingual. They help in secretion of saliva in the mouth which aids in the process of digestion. The parotid glands are positioned under and somewhat near both the ears.
- The gland positioned in the female's breast is referred to as the mammary gland. The gland helps during lactation and milk production.
- Mucus glands are referred to as muciparous glands and are in found in many parts of the body. These glands are mostly multicellular; however, goblet cells are glands with a single-cell.
- The Weber's glands are illustrations of muciparous glands found besides the tongue. It comprises of the gastric glands.

13.5 KEY WORDS

- **Sebaceous gland:** These are minuscule exocrine glands present in the skin; they secrete sebum, a greasy or waxy substance.
- **Mammary gland:** It is responsible for the secretion of milk from the breast.

NOTES

13.6 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. Give examples of exocrine glands along with their secreted products.
2. Write a short note on gland secretion syndromes.

Long Answer Questions

1. Explain the structure and functioning of the salivary gland and mammary gland.
2. What is the significance of ceruminous gland?

13.7 FURTHER READINGS

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UNIT 14 NERVOUS SYSTEM

NOTES

Structure

14.0 INTRODUCTION

Although every system in your body is equally important, the nervous system holds special significance as it controls all the body systems. The nervous system has two main components—the central nervous system (comprising of brain and the spinal cord) and peripheral nervous system (comprising spinal and cranial nerves). In this unit, you will learn about the general anatomy of the nervous system, functions of different parts, reflexes, autonomic nervous system, and the common tests conducted to diagnose neurological disorders.

14.1 OBJECTIVES

After going through this unit, you will be able to:

- Prepare an introduction to the nervous system
- Explain the functions of the different parts of the nervous system
- Name the various tests conducted to diagnose neurological disorders

14.2 INTRODUCTION TO THE NERVOUS SYSTEM

Nervous system is the system that controls all the other body systems. It consists of nervous tissues. These nervous tissue are neurons. Neurons are tissues that cannot be repaired once damaged. Nervous system has two main components, namely, central nervous system and peripheral nervous system.

The central nervous system, in turn, has two parts:

(i) Brain

(ii) Spinal cord

Peripheral nervous system also consists of two parts:

(i) Spinal nerves: 31 pairs

(ii) Cranial nerves: 12 pairs

NOTES

14.2.1 General Anatomy of the Nervous System

Central nervous system is comprised of the following:

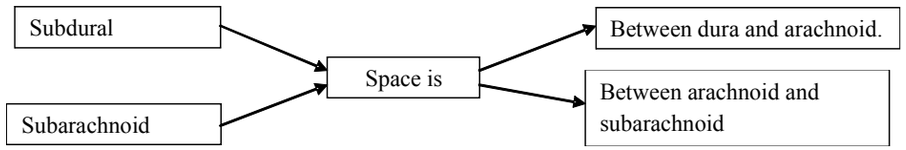
(a) Brain located in cranial cavity

(b) Spinal cord located in spinal cavity

There are three coverings around the central nervous system, i.e., around brain and spinal cord. These three coverings (also called meninges) are present between bony skull and brain and between vertebrae and spinal cord. The various coverings are:

- Dura
- Arachnoid
- Pia

These three coverings enclose two spaces, illustrated as follows:



Dura

Dura has the following two parts:

(i) **Cerebral dura:** It surrounds brain. It is made up of fibrous tissue and has two layers:

- Outer layer: This layer lines the inner surface of skull bones.
- Inner layer: This layer covers the brain.

(ii) **Spinal dura:** It surrounds spinal cord. It is a loose sheath round the spinal cord and is an extension of the inner layer of cesetral dura. It extends from the foremen magnum to the second sacral vertebra and ultimately gets fused with the periosteum of coccyx.

Epidural space: Epidural space is the space present between the spinal dura and the periosteum of vertebrae within the neural canal. Epidural space is very important for anaesthetists as:

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- Diagnostic dyes are injected in it.
- Anaesthetic drugs are injected in it.

The important structures present in epidural space are as follows:

- Blood vessels
- Areolar tissue
- Nerves entering spinal cord
- Nerves leaving spinal cord

Arachnoid

It is serous membrane present between dura and pia. It extends down and around spinal cord, ultimately merging with dura.

Pia

It is located next to arachnoid and is in close contact with brain and spinal cord. It has connective tissues and blood vessels. Pia ultimately fuses with the periosteum of coccyx.

Subarachnoid space: It is the space between arachnoid and pia. It also contains a fluid, called **cerebrospinal fluid**. The source of cerebrospinal fluid is the cells present in chroid plexus. The cerebrospinal fluid is characterized as follows:

- It is a transparent fluid.
- It is slightly alkaline.
- It has a specific gravity of 1005.
- It contains water.
- It has mineral salts.
- It has glucose.
- It has plasma proteins, both albimin and globulin.
- It has creatinine and urea in small amounts.

Cerebrospinal fluid also performs several important functions. It supports and protects brain and spinal cord. It maintains uniform pressure on brain and spinal cord. It absorbs shock between pons and brain. It keeps brain and spinal cord moist. It permits the exchange of substances, both nutrients and waste products, in the system.

14.3 FUNCTIONS OF DIFFERENT PARTS OF THE NERVOUS SYSTEM

Brain is the most important part of the nervous system. It is located in the cranial cavity and consists of the following parts:

- Cerebrum
- Midbrain
- Pons varoli
- Medulla oblongata
- Cerebellum or hind brain

Cerebrum

It is largest part of the brain; it is located in the anterior and middle cranial fosse. Cerebral hemisphere is made up of two parts, namely, right cerebral hemisphere and left cerebral hemisphere. Both are connected by a mass of white matter, called corpus callosum (refer Figure 14.1). Corpus callosum is located deep within the brain. Two hemispheres are separated by falx cerebri. Falx cerebri penetrates between two cerebral hemispheres to reach the level of corpus callosum.

Cerebrum has:

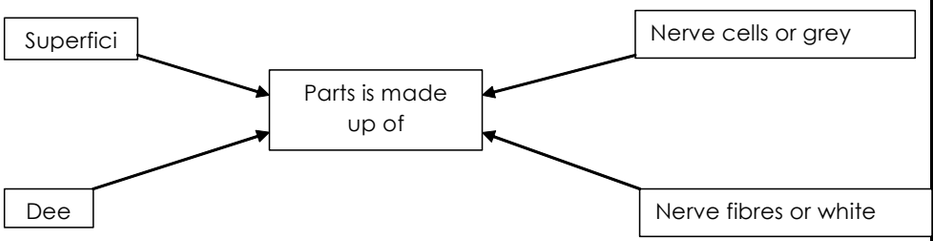

Fig. 14.1 *Connecting Nerve Fibres in Cerebrum*

Cerebrum is made up of two parts, namely, superfici and dee. Superfici is made up of nerve cells or grey matter, while dee is made up of nerve fibres or white matter.

Cerebral cortex has many furrows; the exposed areas of these furrows are called gyri, also known as convolutions. These gyri are separated by sulce or fissures. Each cerebral hemisphere has four lobes. These lobes are:

- Frontal
- Parietal
- Temporal
- Occipital

The deep fissures or sulce separating these lobes are:

- Central
- Lateral
- Parietal-occipital

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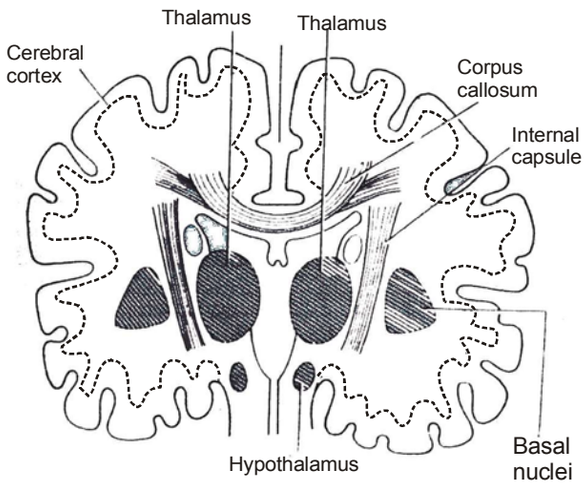

Fig. 14.2 *Connective Nerve Fibres Seen in Section of Cerebrum*

These lobes are connected by masses of nerve fibres or tracts. These tracts form white matter of the brain. Different parts of brain and spinal cord are connected by various afferent and efferent fibres. These fibres are as follows:

- Arcuate fibres (also known as association fibres)
- Commissural fibres
- Projection fibres

Arcuate fibres: These fibres connect one gyrus with another seyrus, which may be adjacent to each other or distant from each other. Likewise, different parts of cerebral cortex are connected by arcuate fibres.

Commissural fibres: These fibres connect the two cerebral hemispheres together. An example of commissural fibres is corpus callosum.

Projection fibres: These fibres connect cerebral cortex with grey matter of the lower parts of brain and spinal cord. For example, internal capsule consists of projection fibres. The fibres going to cerebral cortex and coming from cerebral cortex form internal capsule, located deep in the brain.

Functions of cerebrum

Cerebrum of the brain performs three main functions:

(i) It is responsible for various mental activities like memory, intelligence, sense of responsibility, thinking, reasoning, moral sense, learning and so on. These activities are controlled by the higher centres located in cerebrum.

(i) It is responsible for the sensory perception. For instance, it permits you to register perceptions of pain, temperature, touch, sight, hearing, taste, smell and so on.

(iii) It helps in the initiation and control of voluntary muscle contraction.

Functional areas of contraction

The functional areas of contraction control the sensory perception and voluntary motor activities. There are eleven such areas:

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(i) **Precentral area:** It is located in the frontal lobe and is anterior to central sulcus. This area has pyramid-shaped nerve cells, called BETZ cells. These cells help in initiating contraction of voluntary muscles. Betz cells have nerve fibres, that run downwards through internal capsules and reach medulla oblongata. In medulla, this fibre crosses to the opposite side and moves downwards with the spinal cord.

(ii) **Motor area:** The motor area of right hemisphere controls voluntary muscle movement of the left side of the body and vice-versa. Neurons are of two types:

(a) Upper motor neuron: These neuron cells lie in the cerebrum.

(b) Lower motor neuron: These neuron cells lie in the spinal cord.

Damage to either of the two leads to paralysis.

As far as representation of the human body in relation to the motor area is concerned, feet are represented by cells at the vertex of cerebral hemisphere (motor area), while head, neck, face and fingers are represented by cells located at the base of cerebral hemisphere (motor area).

Size of cortical area: The size of the cortical area is directly proportional to the movement of the represented part. In other words, if the represented part involves complex movement, the size of area representing such a part in the cerebral cortex motor area will be bigger than the size of the area representing parts with less complex movements. For example, trunks involve less complex movements and hence are represented by small area as compared to hand, tongue and lips which involve more complex movements and are represented by a comparatively larger area in motor area.

(iii) **Premotor area:** It is located in the frontal lobe and is interior to motor area. This area controls and orders the series of movements. For example, when you tie your shoelaces, muscular contraction of different groups of muscles is required but in proper sequence or what is called in proper pattern. Thus, the management of proper sequences in contraction of different group of muscles is done by cells in premotor area. Manual dexterity is the phenomenon by which a pattern of movement in proper sequence is established by premotor area.

(iv) **Motor speech area (brocals area):** It is located in the lower part of premotor area just above the lateral sulcus. It controls movements necessary for speech. In right-handed individuals, it dominates the left cerebral hemisphere, while in left-handed individuals, it dominates the right cerebral hemisphere.

Fronial area or pole: It is the area in the frontal lobe exterior to premotor area. Its main function is to coordinate with other areas in cerebrum to control the behaviour, character and emotional states in human beings.

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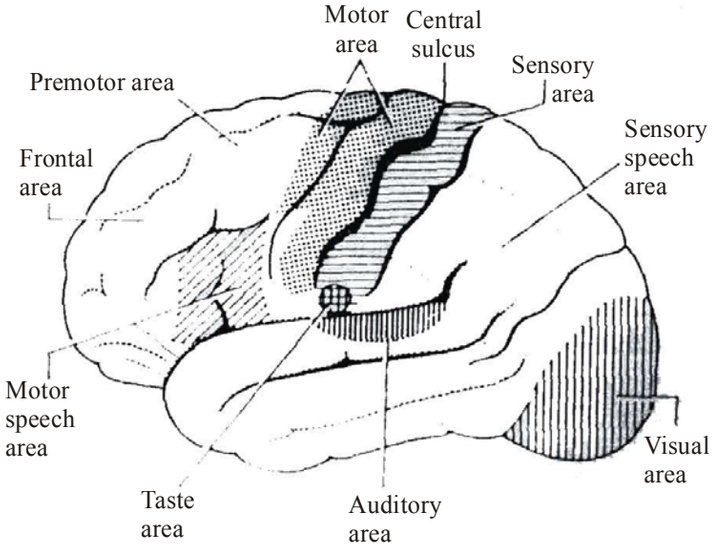

Fig. 14.3 *Functional Areas of Cerebrum*

(v) **Post central area:** It is the area behind the central sulcus. It is the sensory area that permits perception of the following:

(a) Sensation of

- Pain
- Temperature
- Pressure
- Touch

(b) Knowledge of muscular movements

(c) Portion of joints

Note: The right hemisphere receives impulses from the left side of the body and vice-versa. Size of the area is directly proportional to the richness of sensory nerve innervations in that area. For example, face is represented by a large area in post central sensory area as face has three branches of trigeminal (5^{th} cranial nerve).

(vi) **Parietal area:** It is located behind the post central area, occupying a major part of the parietal lobe of the cerebral hemisphere. It helps in retaining actual knowledge of subjects.

(vii) **Sensory speech area:** It is located in the lower part of the parietal lobe with a little extension into temporal lobe. The left area is active in right-handed individuals and vice-versa. Its main function is to perceive the spoken words.

(viii) **Auditory (heavy area):** It is located within the temporal lobe; it lies below the lateral status. It receives and interprets impulses from inner by vestibular nerves.

(ix) **Olfactory area (smell):** It is located deep within the temporal lobe. It receives and interprets impulses received from nose with the help of olfactory nerves.

(x) **Taste area:** It is located above the lateral sulcus deep within a part of the sensory area. Impulses are registered via special nerve endings present in the taste buds present on the tongue. These taste buds are rich in the following areas:

- Lining of cheeks
- Palate and pharynx

(xi) **Visual area:** It is located behind the parieto-occipital sulcus and occupies greater part of the occipital lobe. Optic nerves from the eye reach this area, receiving and interpreting impulses and visual impressions.

Nerve or gaglia

They are groups of nerve cells located deep within the cerebral hemispheres. They act as relay stations for impulses; impulses are received here from neurones and simultaneously relayed to meet the next neurone in chain. Nerves of important masses of grey matter are:

- Basal nuclei
- Thalamus
- Hypothalamus

Basal nuclei: They are grey matter located deep within the cerebral hemisphere. They regulate the tone of skeletal muscle if its control is poor or in case of jerky, clumsy and uncoordinated movements.

Thalamus: It is made up of two masses of nerve cells on each side of the third ventricle, below the corpus callosum. It receives sensations from skin, viscera and other special sense organs.

The received sensations are sent by thalamus to various areas of cerebrum.

Hypothalamus: It is made up of groups of nerve cells; it is located below thalamus, above pituitary and anterior to thalamus. Anterior pituitary is connected to hypothalamus by a complex system of blood vessels while post pituitary is connected to hypothalamus by nerve fibres. These connections facilitate the control of hypothalamus over the hormonal output from pituitary. It also controls autonomic nervous system, e.g., it controls hunger, thirst, body, temperature, heart, blood vessels and so on. Also, it registers different reactions linked with fear and rage.

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Midbrain

Midbrain is located around cerebral aqueduct, below cerebrum and above pons varolli. It consists of groups of nerve cells and nerve fibres, which connect cerebrum with the lower parts of brain and spinal cord. Nerve cells act as relay stations for ascending and descending fibres.

Pons Varolii

It is a structure found on the brain stem.

It is located:

- Anterior to cerebellum
- Inferior to midbrain
- Superior to medulla

It has the following important constituents:

- **Nerve fibres:** These are situated superficially and form a bridge between the two hemispheres of the cerebellum.
- **Groups of cells:** These are situated deeply and function as relay stations. Some of these are associated with cranial nerves.

Medulla

It is a 2.5 cm long, pyramid-shaped structure with its base upward. It is present between pons and spinal cord, enclosed within the cranial cavity above the foramen magnum. It contains the white matter at the periphery and grey matter at the centre.

Medulla also contains vital centres. *Vital centres* are groups of cells associated with automatic reflex activities. They are explained in Table 14.1.

Table 14.1 *Vital Centres and Corresponding Reflex Activities*

1. Cardiac	Acts as the centre of	Vomiting
2. Respiratory		Coughing
3. Vasomotor		Sneezing
4. Reflex centers		Swallowing

Medulla is characterized by the following six features:

(i) Decussation of pyramids: The fibres from the motor area of the cerebrum reach the medulla and cross from one side of the medulla to its other side, at the same time, running downwards to reach the spinal cord. Thus, the left cerebral hemisphere controls the right side of the body and the left cerebral hemisphere controls the left side of the body. This change, i.e., crossing over of fibres in the medulla is called *decussation of pyramids*. This is also called motor decussation of fibres.

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(ii) **Sensory decussation:** Some of the sensory fibres from the spinal cord too reach the medulla, cross to its opposite side and then run upwards to reach the sensory areas in the cerebrum. This crossing over of sensory fibres is called *sensory decussation* in medulla. Other sets of sensory fibres cross to the opposite side at lower levels, i.e., in the spinal cord.

(iii) **Cardiac centre:** It gives out sympathetic fibres and parasympathetic fibres. Both these groups of fibres reach the heart. The stimulation of sympathetic fibres increases the heart rate as well as the force of the heart. On the other hand, the stimulation of parasympathetic fibres decreases the heart rate and the force of the heart.

(iv) **Respiratory centre:** It controls the rate of respiration as well as the depth of respiration. The main stimulation factors, in this case, are:

- Excess CO_2 in blood
- Less O_2 in blood

Nerve impulses from chemoreceptor, located in carotid bodies, reach the respiratory centre. The nerves impulses from the respiratory centre then pass to the phrenic and intercostals nerves, resulting in the contraction of diaphragm.

(v) **Vasomotor centre:** It controls the diameter of blood vessels, especially small arteries and arteries with smoother muscles in their walls. Vasomotor impulses are carried to blood vessels by the automatic nervous system. The factors that stimulate the vasomotor centre are:

- Arterial baroreceptors
- Body temperature
- Emotions such as sexual excitement and anger

As a result of stimulation of the vasomotor centre, blood vessels may show dilution or contraction at different sites in the body.

(vi) **Reflex centres:** In case of the presence of certain irritants in the stomach or in the respiratory tract, nerve impulses from the respective sites reach reflex centres and reflex actions like vomiting, coughing and sneezing are initiated.

Cerebellum

The cerebellum is located posterior to the pons and inferior to the posterior part of the cerebrum. It occupies the posterior cranial fossa. It is oval in shape and has two hemispheres, which are separated by a narrow median strip called vermis. It has a superficial layer of grey matter and a deep layer of white matter. It is effective in controlling the following:

- Coordination of voluntary muscular movement

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- Posture of the body
- Balance of the body

All cerebellar activities are carried out below the level of consciousness. Hence, these activities are not under voluntary control. As a result, drainage to the cerebellum results in:

- Clumsy uncoordinated muscular movement
- Staggering gait
- Inability to carryout smooth, precise movement

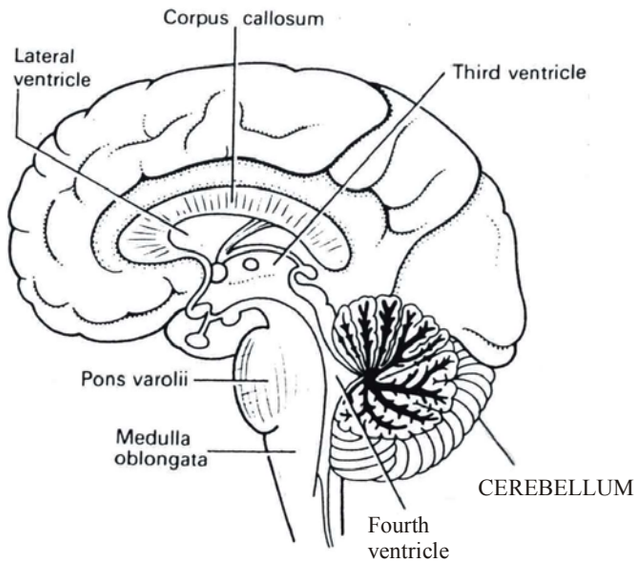

Fig. 14.4 *Cerebellum and Related Structures*

Spinal Cord

The spinal cord is a cylinder-shaped structure, located in the vertebral canal covered by meninges and cerebrospinal fluid. It starts at the upper border and extends till the power border of the Ist lumber vertebra. Its length is approximately 45 cm. Its thickness corresponds to the thickness of your little finger. It acts as a link between the brain and the rest of the body. Descending nerve fibres from the brain run into the spinal cord also. At an appropriate level, they leave or enter the cord, supplying respective organs and reaching specific sensory centres in the brain.

Spinal reflexes: These are activities that do not involve the brain. Spinal activities are performed with the help of extensive connections between sensory and motor neurons at the same or different levels in the cord. It has two equal halves and is divided incompletely by anterior and posterior partitions. The anterior partition is short and hollow median fissure while the posterior partition is a deep and narrow septum called the posterior median septum. Its grey matter is centrally situated while the white matter is peripherally situated.

Grey Matter

Grey matter is H-shaped and has two posterior columns, anterior columns and lateral columns. It also has transverse commissure in addition to these columns. It is transversely located and has a canal at its centre. This canal is called the *central canal*, which confirms the presence of four ventricles in the brain.

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Grey matter has the following types of nerve cells:

- **Sensory cells:** They receive impulses from the periphery of the body.
- **Cells of lower motor neurons:** They transmit impulses to skeletal muscles.
- **Cells of connector neurons:** They connect sensory and motor neurons at the same or different levels.

Apart from these, the synaptic cleft is an important site, which spreads nerve impulses from one neuron to the other.

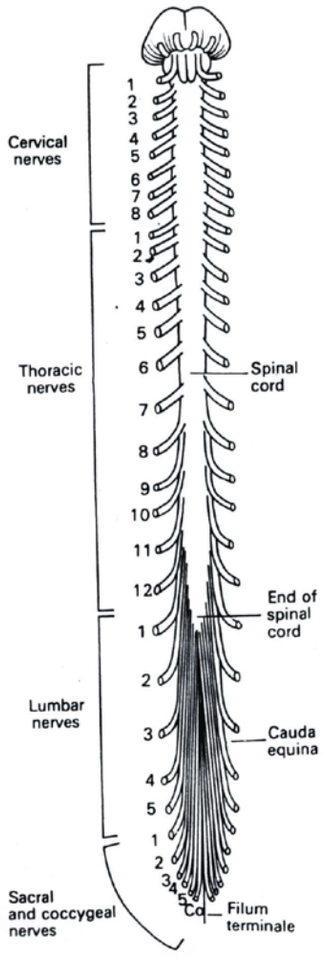

Fig. 14.5 *Spinal Cord and Nerves*

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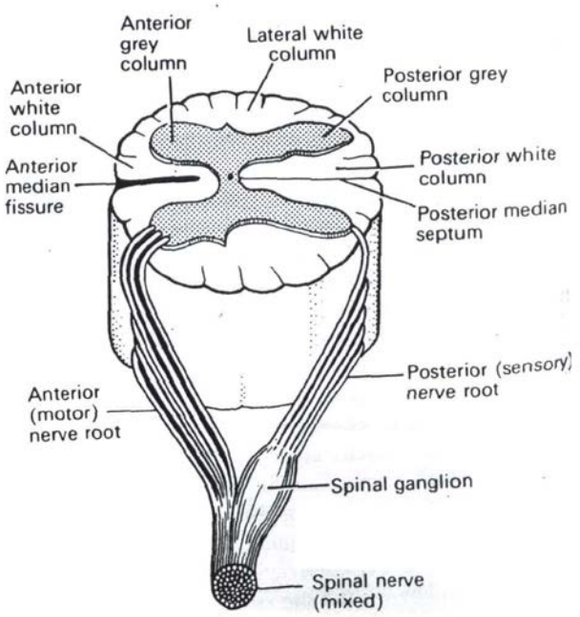

Fig. 14.6 *Spinal Cord Section with Nerve Roots*

Posterior columns of grey matter

It has nerve cells that receive sensory impulses from the body periphery. Their nerve fibres form the white matter of the spinal cord. The sensory impulses received by these cells are transmitted by fibres of these cells to the brain.

Anterior columns of grey matter

They have cells of lower motor neuron. These cells can be stimulated by:

- Axons of upper motor neurons
- Cells of connector neurons connecting anterior and posterior columns to form reflexes

Posterior root ganglia (spinal ganglia)

It is a collection of nerve cells on the pathway of sensory nerves. It is located outside the spinal cord. All sensory nerve fibres pass via these ganglia. These cells promote onward transmission of nerve impulses.

White Matter

White matter is arranged in three columns or tracts:

(i) Anterior

(ii) Posterior

(iii) Lateral

These tracts are formed by the following types of fibres:

(i) Sensory nerve fibres ascending to the brain

(ii) Motor nerve fibres descending from the brain

(iii) Fibre connector neurons

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Sensory nerve tracts (afferent or ascending)

Skin and tendons are two main sources through which sensations travel:

Skin: Skin has sensory receptors called cutaneous receptors. They are, in fact, sensory nerve endings and are stimulated by pain, heat, cold and touch. These sensations are carried by neurons to sensation areas in the opposite hemisphere of the cerebrum where sensations are perceived.

Tendons: These structures have proprioceptors, which are sensory nerve endings. These nerve endings reach:

- Sensory area of opposite hemisphere of cerebrum
- Cerebellar hemisphere of the same side

These, along with impulses from eyes and ears balance the posture of the body.

Motor nerve tracts (efferent or descending)

Efferent or descending neurons are those neurons, which transmit impulses away from the brain. Few effects of the stimulation of motor neuron are as follows:

- Contraction of voluntary (striated/skeletal) muscle
- Contraction of involuntary muscle
- Secretion glands controlled by autonomic nerves

Voluntary Muscle Movement

Mostly muscles contract and joints move; the stimulus to contract is generated at the level of consciousness in cerebrum. However, few nerve impulses are also generated below the level of consciousness in midbrain, brain stem and cerebellum. It is linked with the coordination of muscle activity, e.g., in case of very fine movement being required or if there is a need to maintain posture and balance. Efferent impulses from the brain to the body muscles travel in bundles of nerve fibres or tracts in the spinal cord. These motor pathways from the brain to the body muscles are made up of two types of neurons:

(i) Upper motor: Fibres start from betz cells in precentral sulcus area of the cerebrum and terminate close to the cells of lower motor neurons in the anterior columns of grey matter in the spinal cord. Fibres, before the termination, travel in internal capsule, pons, medulla. They also decussate either in medulla or in the spinal cord.

(ii) Lower motor: Fibres start from the cells in anterior column of grey matter in the spinal cord. These fibres come out of the spinal cord via inter-vertebral

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foramen by anterior root. Each fibre joins a sensory fibre and mixed spinal nerve is developed. Near termination, the axon is divided into very tiny fibres forming motor end plats. Motor end plats and muscle fibres form a *motor unit*. Motor unit contract as a whole and result in smooth coordinated muscle movement.

Involuntary Muscle Movement

In such movements, you are not conscious about it. Cells, from which neurons arise, are located below the cerebrum, i.e., in the midbrain brain stem, cerebrum or spinal cord. They control muscle activity to maintain body posture and balance and to coordinate muscle movement.

Ventricle of Brain

They are irregular-shaped cavities located in different parts of the brain. They have C.S.F., i.e., cerebrospinal fluid in them. They are of the following four types:

(i) Right lateral ventricle

(ii) Left lateral ventricle

(iii) Third ventricle

(iv) Fourth ventricle

Right and left ventricle: Each is located in a cerebral hemisphere below the corpus callosum, one on each side of the median plane. Both lateral ventricles are separated by a thin membrane called septum lucidum. They communicate with the third ventricle by an inter-ventricular foramen.

Third ventricle: It is a cavity located below the lateral ventricle and over two parts of the thalamus. It communicates with the fourth ventricle by a canal called cerebral aqueduct.

Fourth ventricle: It is located below and behind the third ventricle between cerebellum and pons. It is a lozenge-shaped cavity. It is linked to the central canal of spinal cord from below and to subarachnoid spaces from above.

Spinal Nerves

As you know, nerves of the peripheral nervous system are comprised of sensory nerve fibres and motor nerve fibres. The sensory nerve fibres convey impulses from the sensory end organs to the brain. Motor nerve fibres convey impulses from the brain to the effector organs via the spinal cord.

There are 31 pairs of spinal nerves. They leave the vertebral canal through the inter-vertebral foramina formed by the adjoining vertebrae. The composition of these nerves is given as follows:

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Cervical:	08
Thoracic:	12
Lumber:	05
Sacral:	05
Coccygeal:	01

Spinal nerves arise from both sides of the spinal cord and come out through the inter-vertebral foramina. Each nerve has:

- Motor nerve root
- Sensory nerve root
- Pre-ganglionic fibre from autonomic nervous system

Hence, each nerve is a mixed nerve. Each spinal nerve coming out of an inter-vertebral foramen is divided into following three:

(i) Ramus communicans

(ii) Posterior ramus

(iii) Anterior ramus

(i) Ramus communicans: It is a part of pre-ganglionic sympathetic neurons of autonomic nervous system.

(ii) Posterior ramus: It runs backward and divides into medial and lateral branches to supply:

- Skin of small areas of posterior aspects of head, neck and trunk
- Muscles of small areas of posterior aspects of head, neck and trunk

(iii) Anterior ramus: It supplies the anterior and lateral aspect of neck, trunk, upper limb and lower limb.

Plexuses

Plexuses are large masses of nerves. In a plexus, nerve fibres are regrouped and rearranged before proceeding to supply skin, bones, muscles and joints of a particular area. There are five main plexuses of mixed nerves, formed on each side of the vertebral column. These are given as follows:

- Cervical
- Brachial
- Sacral
- Coccygeal

Cervical plexus: It is formed by the anterior rami of the first four cervical nerves (refer to Figure 14.7). It lies under the sternocliedomastoid muscle. The phrenic nerve originates from the cervical roots 3, 4 and 5.

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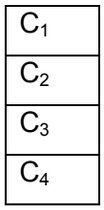

Fig. 14.7 Cervical Plexus

Brachial plexus: It is formed by the union of the anterior rami of lower four cervical nerves and large part of first thoracic nerve (Figure 14.8).

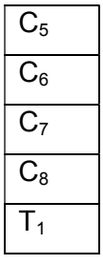

Fig. 14.8 Brachial Plexus

Lumbar plexus: It is formed by the union of the anterior rami of first three and part of fourth lumbar nerves.

Scaral plexus: It is formed by the union of the anterior rami of:

- Lumbosacral formed by trunk 5th and part of 4th lumbar nerve
- First sacral nerves
- Second sacral nerves
- Third sacral nerves

Coccygeal plexus: It is formed by the union of part of the 4th and 5th sacral nerves and by the coccygeal nerves. Thoracic nerves do not form plexuses.

Cranial Nerves

There are twelve pairs of cranial nerves, arising from the nuclei in brain. A few are motor and sensory while others are mixed. The following are the twelve cranial nerves:

1. Olfactory
2. Optic
3. Oculomotar
4. Trochlear
5. Trigeminal
6. Abducent
7. Facial

8. Vestibulocochlear
9. Glossopharyngeal
10. Vagus
11. Accessory
12. Hypoglossal

The locations and functions of these twelve cranial nerves are summarized in Table 14.2.

Table 14.2 *Summary of Locations and Functions of Cranial Nerves*

Sl.No.	Name	Central Connection	Peripheral Connection	Function
1.	Sensory Olfactory	Small area located in temporal lobe	Nasal muscus membrane	Smell
2	Sensory Optic	Vision area located in occipital	Retinal layer of eye	Vision
3	Occulomotor (Motor)	Floor of aqueduct of midbrain	• Superior recti of eye • Inferior recti of eye • Ciliary muscles of eye • Circular muscle of iris fibres	Eyeball movement, regulate papillary size to focus
4	Trochlear (Motor)	Nerve cells near floor of aqueduct of midbrain	Superior oblique of eye	Eye ball movement
5	Trigeminal (Mixed)	• Motor fibres from pons • Sensory fibres from trigeminal gauglion	• Mastication muscles • Gums, cheek, lower jaw, iris, cornea	Chewing sensation from face
6	Abducent (Motor)	Floor of fourth ventricle	Lateral rectus	Eye movement
7	Facial (Mixed)	Pons	• Sensory fibres tongue • Motor fibres facial muscles	Taste Facial expression
8.	Vestibulo Cochlear (Sensory) a) Vestibular b) Cochlear	Cerebellum; Hearing area of cerebrum	Semi-circular canals in inner ear; Organ of corti in cochlea	Maintenance of balance; Sense of learning
9.	Lossopharyngeal (Mixed)	Medulla	• Parotid gland • Back of tongue and • Pharynx	Salivary secretion; Sense of taste; Pharyngeal movement
10.	Vagus (Mixed)	Medulla	Pharynx and larynx In thorax • Organs • Glands In abdomen • Ducts • Blood Vessels	Control secretion and movement
11.	Accessory (Motor)	Medulla	Muscles Like • Trapezius • Laryngeal • Pharyngeal • Sternocleedo mastoid	Move • Head • Shoulder • Pharynx • Larynx
12.	Hypoglossol (Motor)	Medulla	Tongue organ	Moves tongue

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14.3.1 Reflexes

In biology, reflex have been defined as actions entailing reasonably modest sections of behaviour which take place directly or are a sudden response to specific stimulation associated with them. Most reflexes of placental mammals seem to be instinctive. These are genetic and are a general feature of the species and mostly hereditary. Reflexes comprise not only simple actions such as chewing, swallowing, blinking, jerking of the knee and the reflexes of scratching; they also include walking, standing, and reproducing. They are developed due to the intricate patterns of several well-coordinated actions of the muscles; reflexes shape the base of most natural and unconscious conduct in creatures.

Several instinctive reflexes are exhibited by human beings as well, these are intricate adjustments of muscles so that the distant receivers such as the eyes and ears can perform to the best of their ability and coordinate with other parts of the body. These also involve undertaking complex actions like digestion of food.

Some of the instinctive reflexes encompassing only the eyes may be as follows:

- The shifting of both the eyeballs is occasionally clubbed with head being turned as well, this is done to observe the distant object and bring it into the path of the vision.
- Adjustment of the retina by contracting the intraocular muscles so that objects can be seen clearly, for far off distance as well as near.
- When there is too much light falling on the retina the pupil contracts to adjust to the light.
- Excessive blinking as a result of penetrating lights or when cornea is touched.

In simple words, a reflex action may be seen as a function of the reflex arc that has a perfect mechanism. The basic parts of the reflex arc are the sensory-nerve cells. These are the receivers that collect stimulus. These then connect with respective cells in the nerves and muscles are activated to perform the action. The theory of reflex arc is not as simple as it may appear as several cells of the nerves are needed for communicating the action to other parts of the body. These are prevailing in the reflex circuits. Due to the combined efforts of the nervous system in advanced organisms, conduct is much more than mere reflexes. It is due to a combination of several individual reflexes which combine together as per the situation. Several involuntary, unrestricted reflexes are, therefore, altered and adapted as per the new stimulation, providing a conditioned response.

14.3.2 Autonomic Nervous System

The internal parts of the intestine and the gut are controlled by the body's autonomic nervous system. It helps in carrying internal information of the body to the central nervous system (CNS) and in controlling the activities of internal body parts such

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as the gut, the heart and also it carries the secretion from the medulla to the epinephrine and norepinephrine glands.

The internal environment of the body is maintained by the autonomic nervous system. It helps in homeostasis as it balances the body's levels of blood sugar, oxygen levels, carbon dioxide levels, body temperature, controls the salt concentration in the blood. The automatic nervous system besides controlling the working of the internal organs also helps in controlling the emotions and expressiveness of individuals. The levels of excitement or anxiety are controlled by the system of autonomic nerves.

The autonomic nervous system correspondingly is equipped with two divisions namely, the sympathetic division and the parasympathetic division. The two divisions of the autonomic nervous system have an opposing effect on the internal organs they are innervating with.

The sympathetic division, as shown on the left-side of the Figure 14.9, is the system that functions during emergencies of the body. The division readies the body to give out energy and helps in protecting from any expected damages. It reacts by shutting down the gut, speediness of the heart, escalates the blood pressure, enlarges the eye's pupils, provided extra glucose so that the blood sugar levels are boosted and the body has excess energy. It does all these actions so that the body is prepared to fight against emergency.

The second division of the nervous system is often understood as the caretaking division, the right-side of Figure 14.9 shows the parasympathetic division. It helps in replacing and recovering the wear and tear occurring during the lifespan. The functions of the sympathetic division are entirely different from the functions of the parasympathetic division.

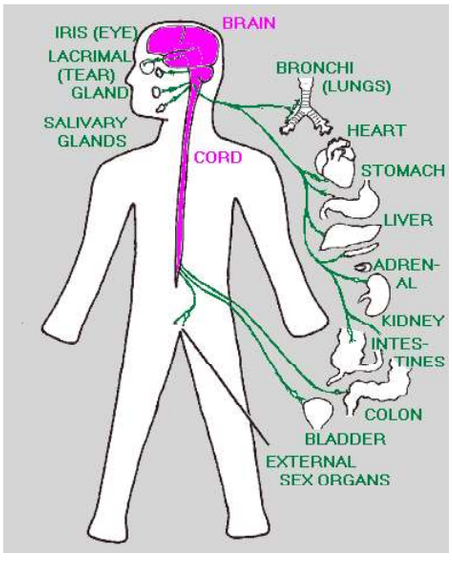

Fig. 14.9 *Cross-Section of Human Body*

14.4 COMMON TESTS IN NEUROLOGICAL DISORDERS: EEG, EMG, MRI AND NCV

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It is not easy to evaluate and diagnose the damages of the body's nervous system. The symptoms of most conditions overlap with each other and the complexity is further enhanced since most conditions do not give indications. In order to simplify the diagnosis of the neurological disorders, several methods and tests are used by the doctors. Some of these are as follows:

- **Electroencephalogram (EEG):** This is the testing of the brain. The continuous electrical activity of the brain is recorded and electrodes are secured on the scalp so that the procedure can be conducted.
- **Magnetic Resonance Imaging (MRI):** In this method of diagnosis, large magnets are used in combination with radiofrequencies. The picture and the structure of the internal body part are produced on the computer.
- **Electromyography (EMG) and Nerve Conduction Velocity (NCV):** Both are electro-diagnostic tests which not only help in studying and evaluating but at the same time can be used in diagnosing muscular and motor neuron disorders. During testing, electrodes are injected into the muscle, or positioned on the skin that overlaps on a muscle or group of muscles. The electrical activity and responses of the muscles are documented.

Check Your Progress

1. Name the two main components of the nervous system.
2. Mention the four lobes of a cerebral hemisphere.
3. State the functions of cerebrum.

14.5 ANSWERS TO CHECK YOUR PROGRESS QUESTIONS

1. The two main components of the nervous system are central nervous system and peripheral nervous system.
2. The four lobes of a cerebral hemisphere are the following:
   - Frontal
   - Parietal
   - Temporal
   - Occipital
3. Cerebrum performs the following functions:
   (i) It is responsible for various mental activities like memory, intelligence, sense of responsibility, thinking, reasoning, moral sense, learning and

so on. These activities are controlled by the higher centres located in cerebrum.

(i) It is responsible for the sensory perception. For instance, it permits you to register perceptions of pain, temperature, touch, sight, hearing, taste, smell and so on.

(iii) It helps in the initiation and control of voluntary muscle contraction.

14.6 SUMMARY

- Nervous system is the system that controls all the other body systems. It consists of nervous tissues. These nervous tissue are neurons.
- Central nervous system is comprised of the following:
  (a) Brain located in cranial cavity
  (b) Spinal cord located in spinal cavity
- Brain is the most important part of the nervous system. It is located in the cranial cavity and consists of the following parts:
  - o Cerebrum
  - o Midbrain
  - o Pons varoli
  - o Medulla oblongata
  - o Cerebellum or hind brain
- Nerves of important masses of grey matter are:
  - o Basal nuclei
  - o Thalamus
  - o Hypothalamus
- Midbrain is located around cerebral aqueduct, below cerebrum and above pons varolli. It consists of groups of nerve cells and nerve fibres, which connect cerebrum with the lower parts of brain and spinal cord.
- The cerebellum is located posterior to the pons and inferior to the posterior part of the cerebrum. It occupies the posterior cranial fossa.
- The spinal cord is a cylinder-shaped structure, located in the vertebral canal covered by meninges and cerebrospinal fluid.
- Grey matter is H-shaped and has two posterior columns, anterior columns and lateral columns. It also has transverse commissure in addition to these columns.
- Mostly muscles contract and joints move; the stimulus to contract is generated at the level of consciousness in cerebrum. However, few nerve impulses are also generated below the level of consciousness in midbrain, brain stem and cerebellum.

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- Plexuses are large masses of nerves. In a plexus, nerve fibres are regrouped and rearranged before proceeding to supply skin, bones, muscles and joints of a particular area.
- In biology, reflex have been defined as actions entailing reasonably modest sections of behaviour which take place directly or are a sudden response to specific stimulation associated with them.
- In simple words, a reflex action may be seen as a function of the reflex arc that has a perfect mechanism. The basic parts of the reflex arc are the sensory-nerve cells. These are the receivers that collect stimulus.
- The internal parts of the intestine and the gut are controlled by the body's autonomic nervous system.
- It is not easy to evaluate and diagnose the damages of the body's nervous system. The symptoms of most conditions overlap with each other and the complexity is further enhanced since most conditions do not give indications.
- Electroencephalogram (EEG) is the testing of the brain. The continuous electrical activity of the brain is recorded and electrodes are secured on the scalp so that the procedure can be conducted.

14.7 KEY WORDS

- **Arachnoid:** It is a serous membrane present between dura and pia.
- **Plexuses:** These are large masses of nerves.
- **Cerebrum:** It is the largest part of the brain. It is located in the anterior and middle cranial fosse.

14.8 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. Prepare an introduction to the nervous system.
2. Write a short note on the structure of the cerebrum.
3. What is the difference between voluntary muscle movement and involuntary muscle movement?
4. What are the common tests conducted to diagnose neurological disorders?

Long Answer Questions

1. Discuss the main features of the Medulla.
2. Explain the structure of the spinal cord with the help of a diagram.

3. 'The internal environment of the body is maintained by the autonomic nervous system.' Elucidate the statement.
4. What is the significance of reflexes? Discuss.

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14.9 FURTHER READINGS

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