Based on National Curriculum of Pakistan 2022-23

Textbook of

Biology

Grade 12

National Curriculum Council
Ministry of Federal Education and Professional Training

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Textbook of Biology for Grade 12
based on National Curriculum of Pakistan (NCP) 2022-23

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PREFACE

This Textbook for Biology Grade 12 has been developed by NBF according to the National Curriculum of Pakistan 2022-2023. The aim of this textbook is to enhance learning abilities through inculcation of logical thinking in learners, and to develop higher order thinking processes by systematically building the foundation of learning from the previous grades. A key emphasis of the present textbook is creating real life linkage of the concepts and methods introduced. This approach was devised with the intent of enabling students to solve daily life problems as they grow up in the learning curve and also to fully grasp the conceptual basis that will be built in subsequent grades.

After amalgamation of the efforts of experts and experienced author, this book was reviewed and finalized after extensive reviews by professional educationists. Efforts were made to make the contents student friendly and to develop the concepts in interesting ways.

The National Book Foundation is always striving for improvement in the quality of its textbooks. The present textbook features an improved design, better illustration and interesting activities relating to real life to make it attractive for young learners. However, there is always room for improvement, the suggestions and feedback of students, teachers and the community are most welcome for further enriching the subsequent editions of this textbook.

May Allah guide and help us (Ameen).

Dr. Kamran Jahangir
Managing Director

UTILITY OR PRACTICAL APPLICATIONS OF THE SUBJECT

1. **Digestive system:** The digestive system has several practical applications in daily life that directly impact out health, energy levels, and over all wellbeing. It includes: energy for physical and mental activity, healthy eating habits, weight management, hydration, stress management, probiotics (like yogurt etc.) and gut health, preventing digestive disorders, healthy aging. The digestive system is important for converting the food we eat into the nutrients and energy needed for everyday task.
2. **Circulatory system:** The circulatory system plays a crucial role in our daily lives by supporting various physiological processes essential for health and survival. The practical applications include: oxygen transport, nutrient delivery, waste removal, body temperature regulation, immune response, wound healing, hormonal distribution. The circulatory system is fundamental to keeping us alive and enabling our bodies to adapt to different conditions and needs throughout the day.
3. **Respiratory system:** The respiratory system plays a vital role in daily life, as it is responsible for gas exchange, ensuring that oxygen enters the body and carbon dioxide is expelled. Here are some practical applications of respiratory system in daily life. These include: breathing for energy, physical exercise, speaking and singing, managing stress, sense of smell, maintain blood pH, immune defense. These everyday functions highlight the essential role of the respiratory system in keeping the body functioning properly.
4. **Urinary system:** The urinary system plays a vital role in maintaining homeostasis and overall health in our daily lives. Some of its practical applications are: waste elimination, water balance, electrolyte balance, blood pressure regulation, pH balance, detoxification and vitamin D activation. In daily life, the urinary system's continuous filtering and balancing functions are critical to keeping the body in optimal working condition and preventing issues like dehydration, kidney stones or electrolyte imbalance.
5. **Nervous system:** The nervous system is critical in regulating and coordinating nearly all bodily functions, enabling us to interact with and respond to our environment. Some of the practical applications of the nervous system in daily life are: reflexes and quick reactions, coordination of movement, learning and memory, sensory perception, communication, emotional regulation, automatic bodily function, focus and attention, sleep regulation. The nervous system is central to almost every action and experience in daily life, from basic survival reflexes to complex emotional response and intellectual activities.
6. **Endocrine System:** The main function of the endocrine system is to release hormones into the blood while continuously monitoring the levels. The hormones affect nearly all aspects of health; directly or indirectly. Some examples are metabolism, homeostasis, growth and development, reproduction, sleep-wake cycle, and mood etc.
7. **Skeletal System:** The skeletal system is the body's support structure. It gives the body its shape, allows movement, makes blood cells, provides protection for the organs and stores minerals.
8. **Thermoregulation:** It ensures your body stays at the right temperature, preventing you from getting too cold or too hot.
   Homeostasis: It is highly developed in warm-blooded animals living on land, which must maintain body temperature, fluid balance, pH and oxygen within rather narrow limits.
9. **Immunity:** Your body has three lines of defence against germ attack. First line keeps them out of your body, second line combats all invading microbes while third line conquers infections. Antibodies provide resistance against future infections. Allergies, autoimmune disorders and transplant rejections are defective immune responses.

10. **Biotechnology:** Studying biotechnology is important in many ways. Biotechnology is rapidly growing field in biology that offers numerous career in life including research, pharmaceuticals, agriculture, environmental management and bioengineering. Biotechnology lead advancements in healthcare, help in development of new drugs, vaccines and diagnostic tools. It plays a key role in treating diseases like cancer, genetic disorders and infections through personalized medicine and gene therapy. Biotechnology play a role in agricultural Improvement by developing genetically modified crops that increase crop yield and are pests, diseases and environmental stress resistant varieties. Biotechnology help to solve environmental issues by bioremediation like pollution, waste management and the conservation of biodiversity.
11. **Biostatics and data analysis:** Studying biostatistics is important for several reasons, especially in health and life sciences: Biostatistics is used in data analysis for medical and researchers. It plays a key role in clinical trials and epidemiological studies. It is highly important in the field of public health by tracking disease outbreaks, understanding health trends public health awareness. Scientific Research in biological and medical fields used biostatistics to design experiments, manage data and interpret results. It is also important for risk assessment and factors for diseases, identifying correlations between health behaviors prediction of future health risks.
12. **Structural biology and computational biology:** Structural and computational biology are emerging fields of biology. These include advanced studies and complex techniques but they provide hope for the treatment of cancer, AIDS, Alzheimer's and genetic diseases. Scientists of the world add their findings on online platforms like PDB so that everyone can freely access them and attain seemingly impossible achievements.
13. **Climate change:** The concepts taught in this chapter about climate change, its impacts on ocean ecosystems, and species extinction have practical applications that can directly influence daily life. By understanding how climate change affects ocean temperatures, acidification, and biodiversity, individuals are encouraged to make eco-friendly choices, such as reducing their carbon footprint, using energy-efficient appliances, and opting for sustainable transportation. Awareness of the vulnerability of marine species can guide people to support sustainable seafood choices and marine conservation efforts, such as participating in beach clean-ups and supporting conservation organizations.

    Knowledge about ocean acidification and the role of carbon dioxide absorption can drive personal actions like supporting reforestation and using renewable energy sources. People can also contribute to reducing climate impacts by supporting renewable energy projects, minimizing plastic use to protect marine life, and engaging in local efforts to conserve wetlands and native habitats. Educating others, especially the younger generation, about the impacts of climate change helps build a community that prioritizes sustainability and conservation.

    By understanding these changes, communities can also adapt better to extreme weather events, shifting their agricultural practices to more climate-resilient methods and preparing urban infrastructure for changing conditions. Through these actions, individuals can play a vital role in both mitigating climate change and adapting to its effects, ultimately helping to preserve biodiversity and maintain the health of ecosystems.
14. **Selected Topics:**Understanding biological warfare is important because it helps us prepare for potential threats to public health, like those seen in the past with plague and anthrax attacks. Practical biodefense measures, such as tracking disease outbreaks and developing vaccines, can help communities respond quickly to any biological threats. By learning about these strategies, we can create safer environments and work together to protect ourselves and our neighbors from possible attacks.
15. **Pharmacological Drugs:** Use of these drugs helps bridge the gap between theoretical knowledge about medicines and its practical application to patients.

(Authors)

بِسۡمِ اللّٰہِ الرَّحۡمٰنِ الرَّحِیۡمِ

اللہ کے نام سے شروع جو بڑا مہربان، نہایت رحم والا ہے

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DIGESTIVE SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-24] Describe the mechanical and chemical digestion in the oral cavity.
2. [B-12-R-25] Explain swallowing and peristalsis.
3. [B-12-R-26] Illustrate with a diagram the structure of the stomach and relate each component with mechanical and chemical digestion in the stomach.
4. [B-12-R-27] Identify the role of the nervous system and gastrin hormone on the secretion of gastric juice.
5. [B-12-R-28] Describe major actions carried out on food in the three regions of small intestine.
6. [B-12-R-29] Trace the absorption of digested products from the small intestine lumen to the blood capillaries and lacteals of the villi.
7. [B-12-R-30] Describe the component parts of the large intestine with their respective roles.
8. [B-12-R-31] Correlate the involuntary reflex for egestion in infants and the voluntary control in adults.
9. [B-12-R-32] Explain the storage and metabolic role of liver.
10. [B-12-R-33] Describe the composition of bile and relate the constituents with respective roles.
11. [B-12-R-34] Outline the structure of pancreas and explain its function as an exocrine gland.
12. [B-12-R-35] Relate secretion of bile and pancreatic juice with the secretin of hormone.

Our body needs nutrients from the food we eat in order to stay healthy and function properly. Nutrients include carbohydrates, proteins, fats, vitamins, minerals and water. The digestive system breaks down and absorbs nutrients to use for important activities like energy, growth and repairing cells.

Anatomically and functionally the digestive system can be divided into a tubular gastrointestinal tract (GIT) and accessory digestive organs. The organs of GI tract are oral cavity, pharynx, esophagus, stomach, small intestine and large intestine. The accessory digestive organs are the teeth, tongue, salivary glands, liver, gall bladder and pancreas.

The GIT is a continuous tube from mouth to the anus. It is specialized at various points along its length, with each region designed to carry out different role. GIT is approximately 9 m (30 ft.) long. It passes across the thoracic cavity and enters the abdominal cavity at the level of diaphragm.

Extra reading material

The digestive tube consists of four major layers: an internal mucosa and an external serosa with a submucosa and muscularis in between. These four layers are present in all areas of the digestive tract from esophagus to the anus.

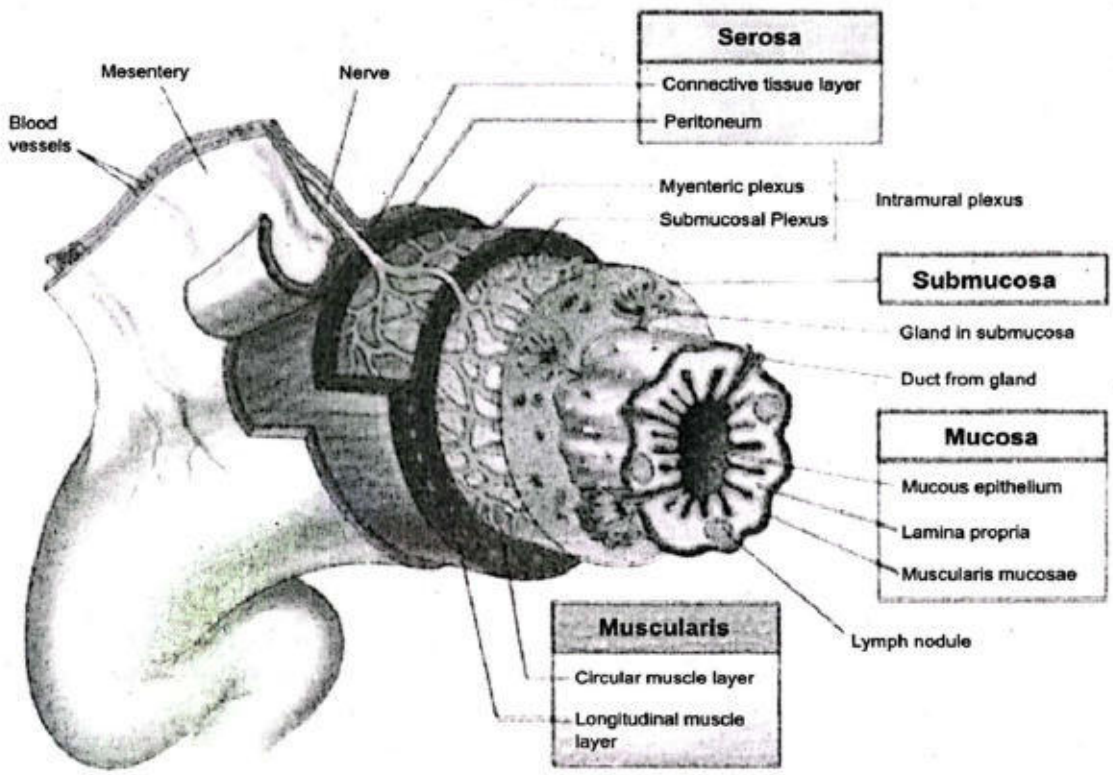


Fig. 1.1: Histological layers of the digestive tract

1.1 ORAL CAVITY

The **oral cavity** or more commonly known as buccal cavity is surrounded by the lips, cheeks, a tongue and a palate and includes a space between the palate and tongue. The **tongue** has rough

projections called **papillae** on the surface of the tongue cause friction; useful in handling the food. The papillae also contain **taste buds.** The palate forms the roof of the oral cavity. Different **teeth** are adapted to handle food in different ways. There are three pairs of **salivary glands.** These glands secrete enzymes having saliva. In the oral cavity mechanical and chemical digestion takes place.

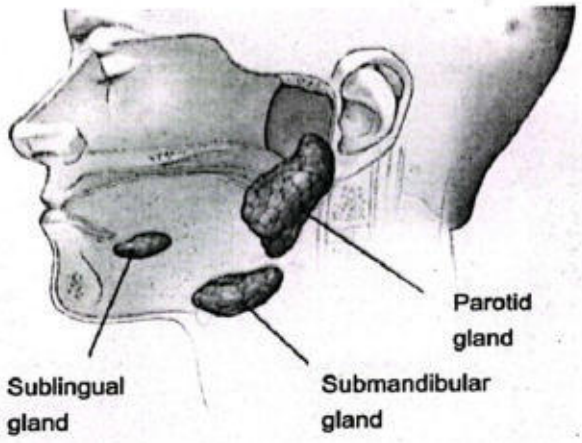


Fig. 1.2: Human salivary glands

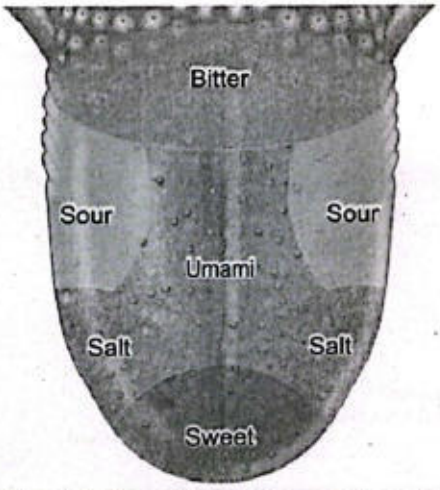


Fig. 1.3: Location of human taste buds on tongue

Mechanical digestion

Mechanical digestion is the physical division of a mass of food into smaller pieces. Through chewing of food destroys the cellulose of starch covering and increases the efficiency of the digestive process. Food taken into the mouth is chewed or masticated by the teeth. **Mastication** breaks large food particles into smaller ones, which have a much larger surface area for the action of digestive enzymes.

Chemical digestion

Chemical digestion in the oral cavity is minor. The two enzymes secreted in the oral cavity are **salivary amylase** and **lingual lipase.** The watery part of saliva contains the digestive enzyme called salivary amylase (ptyalin). Salivary amylase is chemically identical to pancreatic amylase and digests starch. It breaks the covalent bonds between glucose molecules in starch and other polysaccharides to produce maltose, maltotriose, (maltotriose is a trisaccharide and isomaltose (isomaltose is a disaccharide similar to maltose, instead of the α-(1-4)-linkage.). Lingual lipase hydrolyzes triglyceride ester bonds to form diacylglycerols and monoacylglycerols. As a result of chemical and mechanical digestion and oval mass bolus is formed which is to be swallowed.

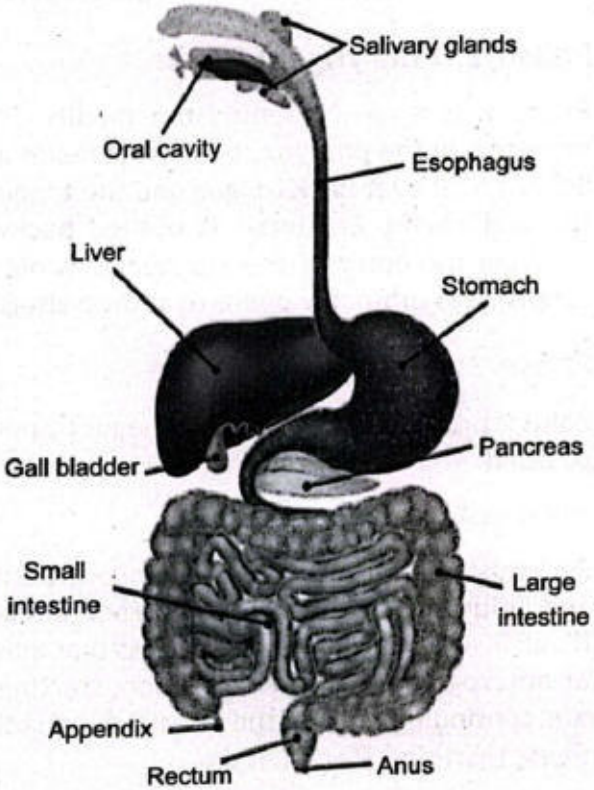


Fig. 1.4: Human digestive system

1.2 SWALLOWING AND PERISTALSIS

Swallowing Mechanism

The act of swallowing involves a set of reflexes. It can be divided into three phases.

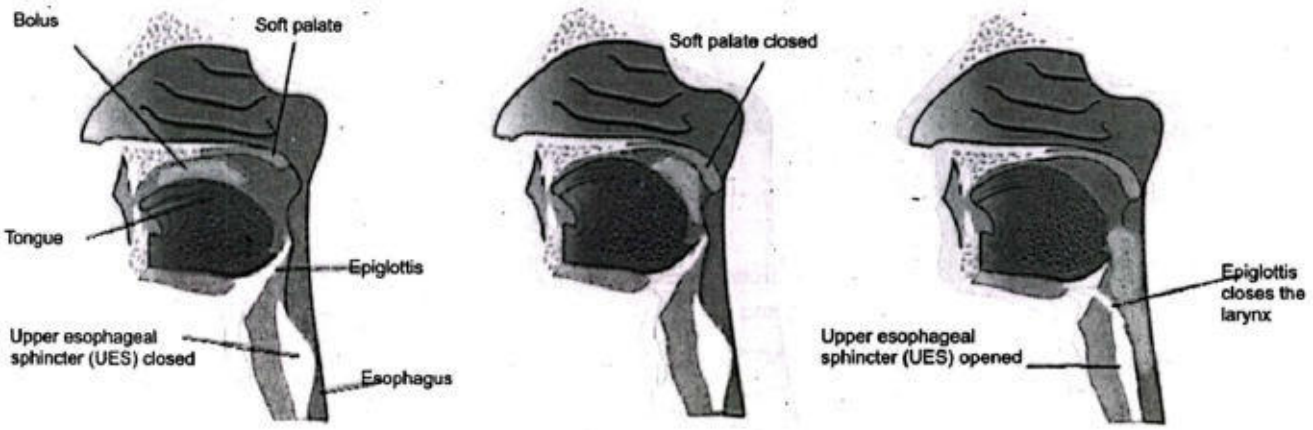


Fig. 1.5: Process of swallowing

Phase 1: Oral Phase

This process is the only voluntary part of swallowing. Food is moistened with saliva and food bolus is formed. The tongue pushes the bolus to the back of the throat. It starts with lip closure.

Phase 2: Pharyngeal Phase

Pharynx is a cavity behind the mouth. **Pharyngeal phase** starts with stimulation of tactile receptors in the pharynx, swallow reflexes are initiated. Soft palate lifts to close nasal airways. Bolus moves over back tongue and the tongue blocks the oral cavity to prevent the food going to the oral cavity. **Epiglottis** is pushed backward over larynx. Larynx and vocal folds contract covering the entry of the trachea to protect airways, respiration temporary arrested. **Upper esophageal sphincter** opens to allow passages to the esophagus.

Phase 3: Esophageal Phase

Bolus is propelled down the esophagus by peristalsis. The larynx moves down back to the original position.

Peristalsis

Peristalsis is a wave-like muscular contraction that propels food and fluids through the digestive tract and other tubular organs. It's an involuntary, rhythmic process that moves contents along in an anterograde (forward) direction, starting from the esophagus and continuing through the intestines and other systems.

Functions of Peristalsis

Propulsion: Peristalsis pushes food and fluids through the digestive system, enabling digestion and absorption.

Anti-peristalsis is the wave-like muscle contractions in the digestive tract that move contents backward instead of the usual forward direction. This is typically associated with vomiting reflex.

Mixing: In the stomach and small intestine, peristalsis helps mix the food with digestive juices and exposes it to the absorptive surfaces.
Waste Removal: In the large intestine, peristalsis drives waste products towards the rectum for elimination.
Other Systems: Peristalsis also occurs in other tubular organs like the urinary tract (moving urine from the kidneys to the bladder) and bile ducts (moving bile from the gallbladder to the duodenum).

Mechanism of Peristalsis

Muscle Contractions: Peristalsis involves the contraction of circular and longitudinal muscles in the walls of the digestive tract and other tubes.
Wave-like Movement: These contractions create a wave-like motion that pushes the contents along.
Involuntary: The process is controlled by the nervous system, particularly the **myenteric plexus** in the digestive tract.

> The **myenteric plexus** lies in between the outer longitudinal and inner circular smooth muscle layers of the intestines. By stimulating these muscles, it controls motility along the gastrointestinal tract.

Examples of Peristalsis

Swallowing: When you swallow, the muscles in your esophagus contract in a peristaltic wave to move the food bolus down to the stomach.
Digestion: In the small intestine, peristalsis moves the digested food (chyme) along, allowing nutrients to be absorbed.
Waste Removal: In the large intestine, peristaltic waves push waste products towards the rectum, where they are eliminated as stool.

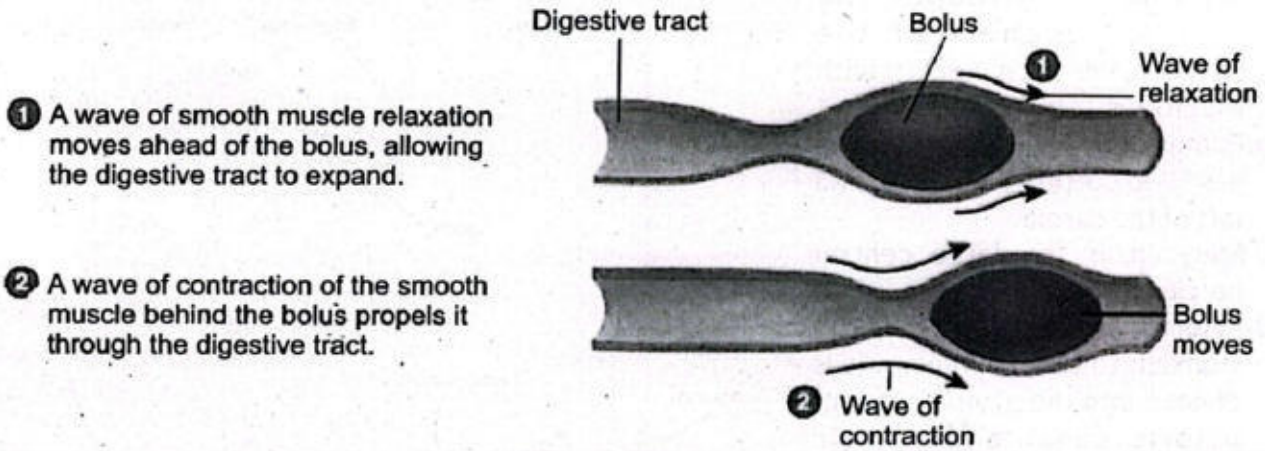


Fig. 1.6: Peristalsis

1.3 ESOPHAGUS AND STOMACH

Here we will discuss the structure of esophagus and stomach. We will relate each component of stomach with mechanical and chemical digestion.

Esophagus

The esophagus or oesophagus is located in the center of the chest in an area called the

mediastinum. It lies behind trachea and in front of the vertebral column. It is about 25cm long.

At the opening of the upper esophagus, there's a ring-shaped muscle called the **upper esophageal sphincter.** It senses when food or liquid is coming towards it. When it gets the signal, the sphincter relaxes or opens so that food can enter esophagus. When there is no food or liquid in sight, it stays closed. The esophagus passes through diaphragm and connects to the stomach. Once inside the esophagus, peristalsis pushes the food downward and reaches the lower esophagus.

At the opening of the lower esophagus, there is another ring-shaped muscle called the **lower esophageal sphincter (LES).** Like the upper esophageal sphincter (UES), it senses when food and liquid are coming. It relaxes and lets the food pass through to the stomach. When there is no stimulus, it usually stays shut to prevent stomach acid and digestive juices from getting into the esophagus.

As esophagus is a passage way so no digestion takes place here.

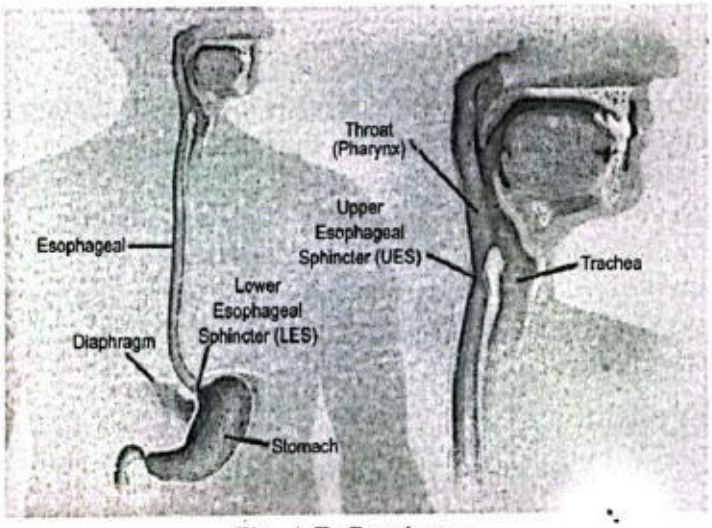


Fig. 1.7: Esophagus

Stomach

Divisions of the Stomach: The stomach has four main anatomical divisions; the cardia, fundus, body and pylorus:

a. **Cardia:** It surrounds the superior opening of the stomach, which connects it with esophagus.
b. **Fundus:** It is the rounded, often gas filled portion superior to and left of the cardia.
c. **Body:** It is the large central portion inferior to the fundus.
d. **Pylorus:** This area connects the stomach to the duodenum. It is divided into the pyloric antrum, pyloric canal and pyloric sphincter. .
e. **Pyloric antrum:** It is the lower or distal portion above the duodenum. A sphincter, which regulates the passage of chyme into the duodenum, is called the **pyloric sphincter.**

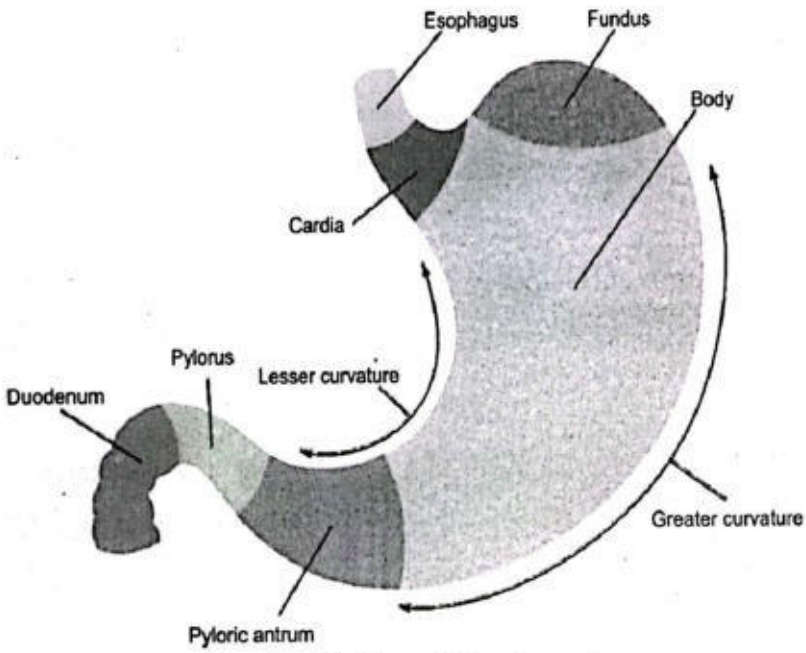


Fig. 1.8: Division of the stomach

Greater and Lesser Curvatures

The medial and lateral borders of the stomach are curved, forming the lesser and greater curvatures.

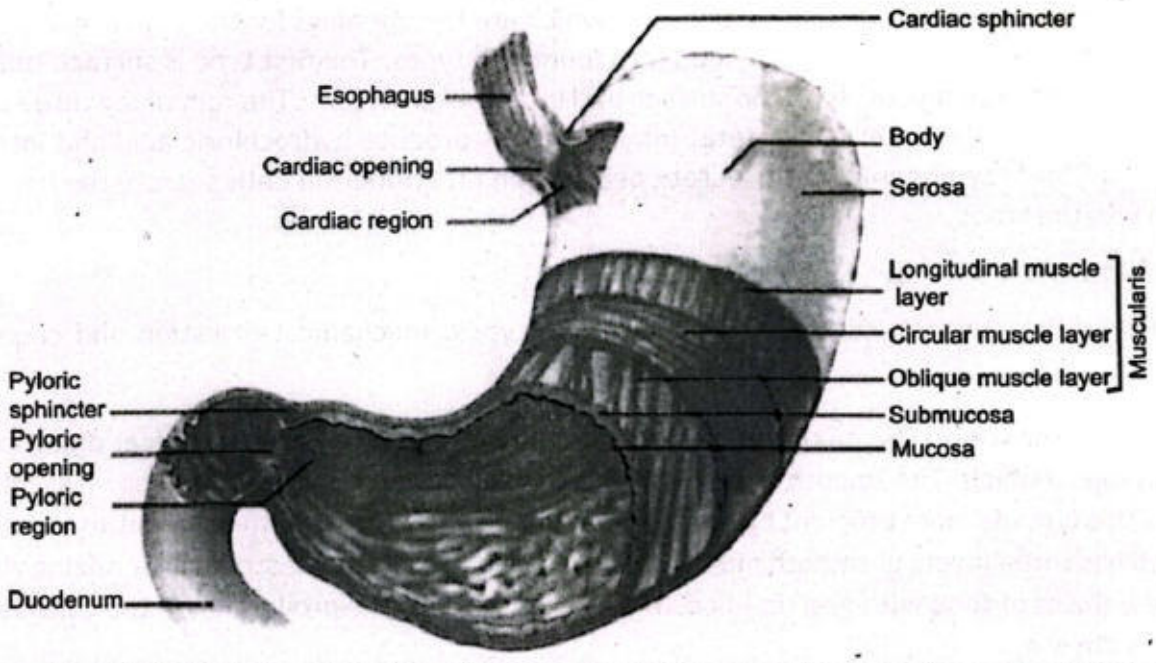


Fig. 1.9: Cutaway section of the stomach reveals muscular layers and internal anatomy

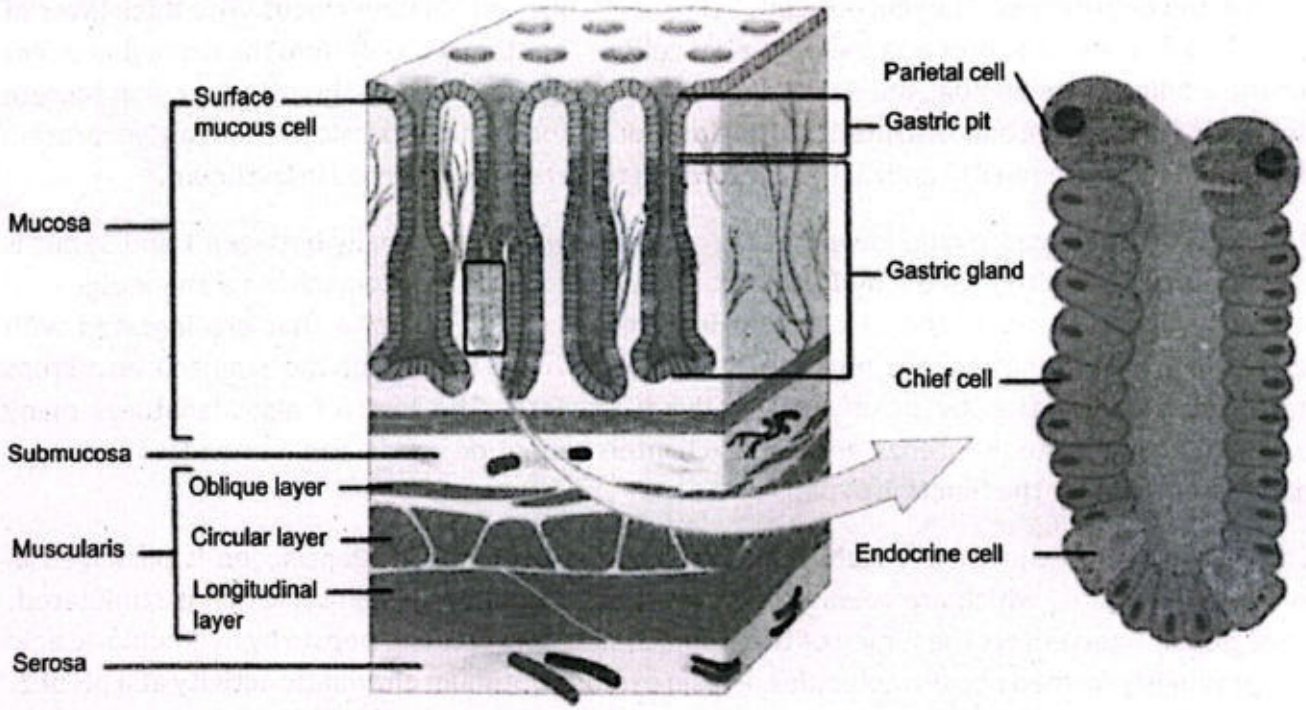


Fig. 1.10: A section of stomach wall that illustrates its histology, including several gastric pits and glands

There are four distinct layers in the stomach wall. The **serosa** is the outer most layer of the stomach. The **muscularis** of the stomach consists of three layers: an outer longitudinal muscle layer, a middle circular muscle layer and an inner oblique muscle layer. The next two layers are **submucosa** and **mucosa.** The stomach is lined with simple columnar epithelium. The mucosal surface forms numerous tube like **gastric pits**, which are the openings for the gastric glands. The epithelial cells of stomach can be divided into four main types. The first type is **surface mucous cells**, which produce mucus, is on the surface and lines the gastric pit. The remaining three are in the gastric gland. They are: (1) **Parietal (oxyntic) cells** produce hydrochloric acid and intrinsic factors (2) **Chief (zymogenic) cells** secrete pepsinogen (3) **Endocrine cells** secrete the hormone gastrin into the blood.

Functions of stomach

Digestion in the stomach can be divided into two types: mechanical digestion and chemical digestion.

Mechanical digestion: The mixing action of the stomach walls allows mechanical digestion to occur in the stomach. The smooth muscles of the stomach produce contractions known as **mixing waves.** This is made more efficient by the fact that unlike other region of the alimentary canal the stomach has three layers of smooth muscles. The churning action of the stomach or mixing waves mix the boluses of food with gastric juice. This mixing leads to the production of the thick liquid known as **chyme**.

Chemical digestion: Stomach secretions include mucus, hydrochloric acid, gastrin, intrinsic factor and pepsinogen. The mucous cells secrete viscous and alkaline mucus. The thick layer of mucous lubricates and protects the epithelial cells of the stomach wall from the damaging effect of the acidic chyme and pepsin. **Parietal cells** in the gastric glands of the pyloric region secrete **intrinsic factor** and a concentrated solution of hydrochloric acid. Intrinsic factor is a glycoprotein that binds with vitamin B12 and makes the vitamin to be readily absorbed in the ileum.

Hydrochloric acid causes the low pH of the stomach, which is normally between 1 and 3, but is usually close to 2. Although the hydrochloric acid secreted into the stomach has a minor digestive effect on digested food, one of its main functions is to kill bacteria that are ingested with essentially everything humans put into their mouths. The low pH of the stomach also stops carbohydrate digestion by inactivating salivary amylase. The low pH also denatures many proteins so that proteolytic enzymes can reach internal peptide bonds, and it provides the proper pH environment for the function of pepsin.

Chief cells within the gastric glands secrete inactive **pepsinogen**. Pepsinogen is packaged in **zymogen** granules, which are released by exocytosis when pepsinogen secretion is stimulated. Once **pepsinogen** enters the lumen of the stomach, it is converted to **pepsin** by hydrochloric acid and previously formed pepsin molecules. Pepsin exhibits optimum enzymatic activity at a pH of 2. Pepsin catalyzes the cleavage of some covalent bonds in proteins, breaking them into smaller peptide chains.

1.4 ROLE OF THE NERVOUS SYSTEM AND GASTRIN HORMONE ON THE SECRETION OF GASTRIC JUICE

Approximately 2-3 litres of gastric juice are produced each day. Both nervous and hormonal mechanisms regulate gastric secretions. Hormones that regulate stomach secretions include gastrin, secretin, gastric inhibitory polypeptide and cholecystokinin (CSK).

The sensations of the taste and smell of food, stimulation of tactile receptors during the process of chewing and swallowing and pleasant thoughts of food stimulate centres within the medulla that influence **gastric secretion.** Neuronal stimulation of the stomach mucosa results in the secretion of **acetylcholine,** which stimulates the secretory activity of both the parietal and chief cells and stimulates the secretion of **gastrin** from endocrine cells. Gastrin is released into the circulation and travels to the parietal cells, where it stimulates additional gastric juice secretion.

The greatest volume of gastric secretions is initiated by the presence of food in the stomach. The primary stimuli are distention of the stomach and the presence of amino acids and peptides in the stomach. Peristaltic waves occur less frequently, are significantly more powerful than mixing waves, and force the chyme near the periphery of the stomach toward the pyloric sphincter. The pyloric sphincter usually remains partially closed because of mild tonic contraction. Each peristaltic contraction is sufficiently strong to force a small amount of chyme through the pyloric opening and into the duodenum.

1.5 SMALL INTESTINE

The small intestine is part of the digestive system. When food leaves stomach, it enters the small intestine. The small intestine connects to the large intestine. The intestines are responsible for breaking food down, absorbing its nutrients and solidifying the waste. The small intestine is the longest part of the GI tract, and it is where most of the digestion takes place.

The small intestine is about 6 m long and consists of three parts: the duodenum, the jejunum and the ileum.

Duodenum

The duodenum is the first part of the small intestine ranging from 20-25 cm (8-10 inch) in length. It extends from the pyloric sphincter of the stomach. It is a short structure and shaped like a "C". It surrounds the head of the pancreas.

Pancreatic juice: The secretion of pancreas is called pancreatic juice. It is poured through the pancreatic duct. Pancreatic juice is slightly alkaline. Its pH is about 8. It neutralizes the acidic action of digestive enzymes secreted by the stomach. The important enzymes are (a) Pancreatic amylase (b) Pancreatic lipase (c) Trypsinogen (4) Chymotrypsinogen.

Pancreatic amylase: It is the starch digesting enzyme. It hydrolyses the polysaccharides to maltose and even to glucose.

Pancreatic lipase: It is the principal enzyme for the hydrolysis of fats. It hydrolyses fats to neutral fat in parts to its (i) mono and diglycerols (diglycerides). (ii) glycerol (iii) fatty acids.

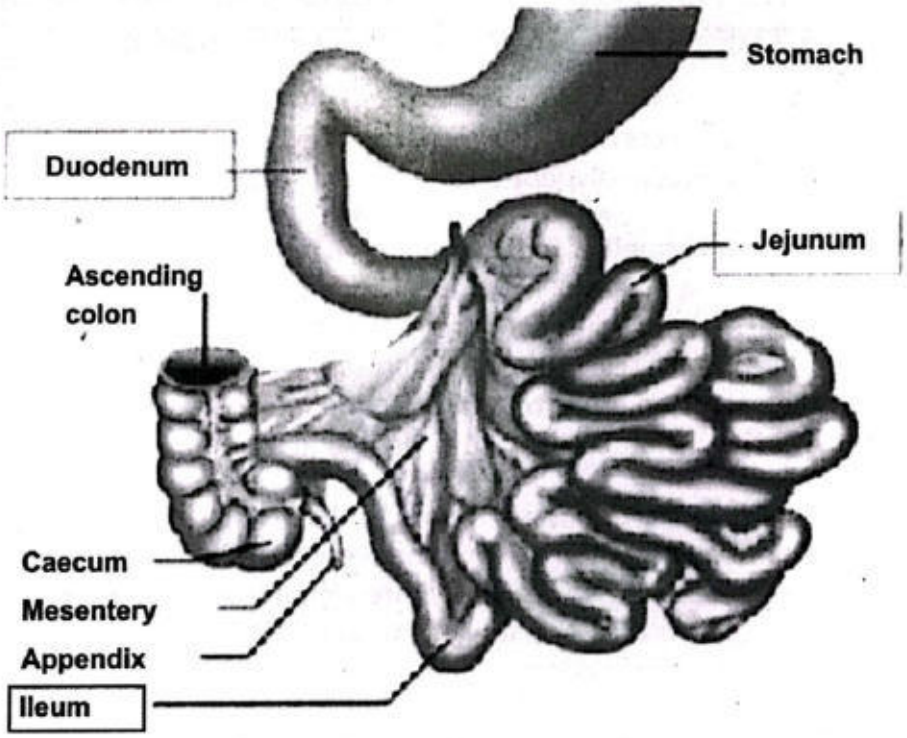


Fig. 1.11: Small intestine

Enzyme precursors

Two important enzyme precursors are found in pancreatic juice. They are trypsinogen and chymotrypsinogen. Both are the inactive forms.

Trypsinogen: The intestinal glands secrete an activator enzyme called **enterokinase.** The enterokinase converts trypsinogen into trypsin. Trypsin then activates more trypsinogen. The trypsin is the active form, which acts on proteins and converts them into polypeptides.

Chymotrypsinogen: The inactive chymotrypsinogen is converted to active form chymotrypsin by trypsin.

Bile: Bile is manufactured in liver but stored in gall bladder. Bile emulsifies fat causing them to breakdown into numerous small droplets called **emulsion. Emulsification** provides relative large surface area of lipid for the action of lipase enzyme and hence speed up the digestion of fats and oils.

SCIENCE TITBITS

Mucus is secreted in large amount by duodenal glands, intestinal glands, and goblet cells. The mucus provides the wall of intestine with protection against the irritating effects of acidic chyme and against the digestive enzymes that enter the duodenum from the pancreas.

Jejunum and ileum

Jejunum is about 2.5 m long and ileum is about 3.5 m long. Here the digestion of protein carbohydrates and fats is completed. The lining of the jejunum and ileum secrete several enzymes.

- **Amino peptidase:** It splits polypeptides into dipetides.

1. **Erepsin:** It splits peptides into amino acids.
2. **Lactase:** It converts lactose to glucose and galactose
3. **Maltase:** It converts maltose to glucose.
4. **Sucrase:** It converts sucrose to glucose and fructose.

Pancreatic lipase completes the digestion of fats into fatty acids and glycerol. By the action of enzymes, chyme is turned into a watery emulsion called **chyle.**

1.6 ABSORPTION OF DIGESTION PRODUCTS

The ileum is the major site of nutrient absorption. Tiny finger like projections of the mucosa form numerous villi, which are 0.5-1.5 mm in length. Each villus is covered by simple columnar epithelium. It contains a blood capillary network and a lymph capillary called a lacteal. The structural features increase the surface area of small intestine and make it the largest part of the alimentary canal. The internal walls are folded to increase surface area for absorption. Villi and microvilli further increase surface area for absorption. To reach the blood or lymph a nutrient molecule must pass through an epithelial cell of the intestinal lining and through a cell lining the blood capillaries or lymph vessel.

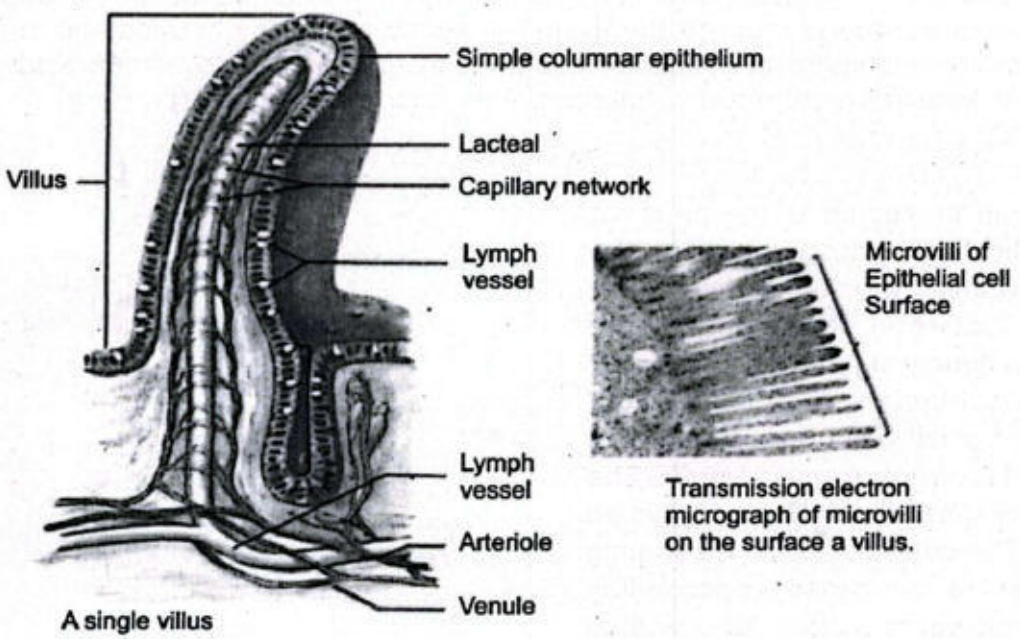


Fig. 1.12: Structure of villus

Absorption of carbohydrates

Absorption occurs by a combination of simple diffusion and active transport. The monosaccharides are transferred by facilitated diffusion to the capillaries of intestinal villi and are carried by the hepatic portal system to the liver, where non-glucose sugars are converted to glucose. Glucose enters the cell through facilitated diffusion.

SCIENCE TITBITS

Lipoproteins are referred to as high or low-density lipoproteins. A lipoprotein with high lipid content has a very low density (LDL), whereas a lipoprotein with high protein content has a relatively high density (HDL). Chylomicrons, which are made up of 99% lipid and only 1% protein, have an extremely very low density.

Absorption of lipids

Lipids are digested into fatty acids and glycerol. After glycerol and fatty acid are absorbed by epithelial cells, they are recombined into fats within these cells. The fats are then mixed with cholesterol and proteins, forming small globules called **chylomicrons**, most of which are transported by exocytosis out of epithelial cells into lacteals. Lymph containing chylomicrons, eventually drains from the lymphatic system into large veins that return blood to the heart.

SCIENCE TITBITS

The appendix contains a small amount of mucus associated lymphoid tissue which gives the appendix an undetermined role in immunity. However, the appendix is known to be important in foetal or fetal life as it contains endocrine cells that release biogenic amines and peptide hormones important for homeostasis for during early growth and development. Appendicitis is an inflammation of the vermiform appendix and usually occurs because of obstruction of the appendix. The removal of appendix is called appendectomy.

Absorption of proteins

Individual amino acids are absorbed in epithelial cells of villi and enter in the **hepatic portal system**, which transports them to the liver. The amino acids may be modified in the liver or released into the bloodstream and distributed throughout the body. Most amino acids are used as building blocks to form new proteins, but some amino acids may be used for energy.

1.7 LARGE INTESTINE

The **caecum** or **cecum** is the proximal part of the large intestine, where the large and small intestines meet. The junction between ileum and large intestine is **ileocecal junction** guarded by **ileocecal sphincter**. Attached to the caecum is a small blind tube about 9 cm long called the **vermiform appendix.** The walls of the appendix contain many lymph nodules. The **colon** is about 1.5 m long and consists of four parts: the **ascending colon, transverse colon, descending colon**, and **sigmoid colon.** The **rectum** is a straight, muscular tube that begins at the termination of the sigmoid colon and ends at the anus guarded by sphincter.

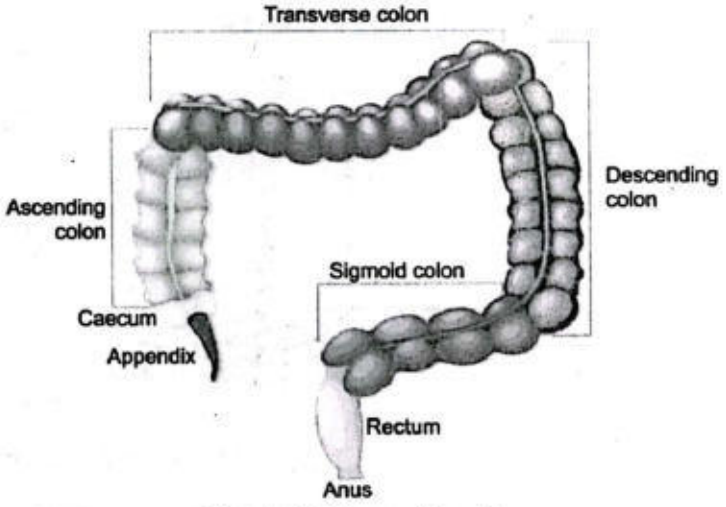


Fig. 1.13: Large intestine

Functions of large intestine

The large intestine performs several important functions. The major functions of the large intestine are: (a) Absorbing water and electrolytes (b) Absorption of vitamins (c) Reducing acidity and protecting from infections.

Absorbing water and electrolytes: Further digestion or breaking down of nutrients does not take place in the large intestine. The proximal half of the large intestine functions to reabsorb some of the water and electrolytes making the stool solid. The substances that remain in the tube becomes faeces, which is stored for a time in the distal portion (rectum) of the large intestine.

Absorption of vitamins: The large intestine also helps in absorption of vitamins made by bacteria that normally live in the large intestine. These bacteria also produce large amounts of vitamins. The most important of these is Vitamin K and Biotin (a B vitamin).

Reducing acidity and protecting from infections: The mucosa of the large intestine also:
(a) Secretes bicarbonates to neutralize the increased acidity resulting from the formation of these fatty acids and other digestive components at earlier parts of the intestines. (b) Acts as a mucosal barrier and protects from microbial infections and invasions.

1.8 DEFAECATION

Defaecation is the term for the act of expelling feces from the digestive tract via the anus

Defaecation reflex in infants

In infants the defaecation (defecation) reflex is involuntary meaning that anal sphincter relaxes automatically to allow stool to pass, specially shortly after feeding. This reflex is particularly active in the first week of life.

Defaecation reflex in adults

When it is appropriate, a person usually can initiate the defaecation reflex (North America spelling: defecation) by holding a deep breath and contracting the abdnominal muscles. The action increases the internal pressure and forces the faeces or feces into the rectum. When the rectum is filled, its wall is distended and the defaecation reflex is triggered. As a result, peristaltic waves in the descending colon are stimulated, and the internal and anal sphincter relaxes. The external anal sphincter is signalled to relax and the faeces are forced to the outside. The defaecation reflex persists only for a few minutes and quickly dies. A person usually can inhibit defaecation voluntarily by keeping the external sphincter contracted.

1.9 STORAGE AND METABOLIC ROLE OF LIVER

The liver has two main parts: the larger right lobe and the smaller left lobe. The lobes contain many blood vessels. Blood travels through the liver. The lobes also contain thousands of lobules (small lobes). These lobules connect with many bile ducts, tubes that transport bile from the liver to the small intestine. There are two distinct sources that supply blood to the liver, including: Oxygenated blood flows in from the hepatic artery and nutrient-rich blood flows in from the hepatic portal vein.

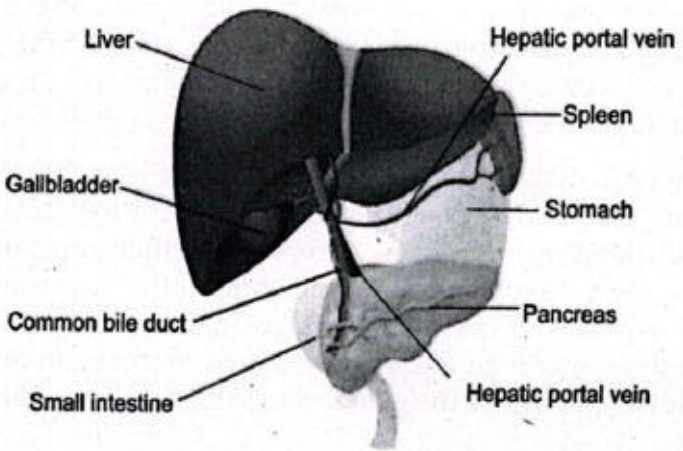


Fig. 1.14: Liver

The liver regulates most chemical levels in the blood and excretes a product called bile. This helps carry away waste products from the liver. All the blood leaving the stomach and intestines passes through the liver. The liver processes this blood and breaks down, balances, and creates the nutrients and also metabolizes drugs into forms that are easier to use for the rest of the body or that are nontoxic. More than 500 vital functions have been identified with the liver.

Some of the more well-known functions are given below:

1. Production of bile, which helps carry away waste and breakdown fats in the small intestine during digestion
2. Production of certain proteins for blood plasma e.g. serum albumin, globulins and fibrinogen
3. Production of cholesterol and special proteins to help carry fats through the body
4. Conversion of excess glucose into glycogen for storage (glycogen can later be converted back to glucose for energy) and to balance and make glucose as needed
5. Regulation of blood levels of amino acids, which form the building blocks of proteins
6. Processing of hemoglobin for use of its iron content (the liver stores iron)
7. Conversion of poisonous ammonia to urea (urea is an end product of protein metabolism and is excreted in the urine)
8. Clearing the blood of drugs and other poisonous substances
9. Regulating blood clotting
10. Resisting infections by making immune factors and removing bacteria from the bloodstream
11. Clearance of bilirubin, from breakdown of red blood cells. If there is an accumulation of bilirubin, the skin and eyes turn yellow.

When the liver has broken down harmful substances, its by-products are excreted into the bile or blood. Bile by-products enter the intestine and leave the body in the form of feces. Blood by-products are filtered out by the kidneys and leave the body in the form of urine.

1.10 COMPOSITION AND ROLE OF BILE

The **gall bladder** (North American spelling: gallbladder) is a saclike structure on the inferior surface of the liver that is about 8 cm long and 4 cm wide. The gall bladder is connected to the common bile duct by the cystic duct. **Bile** is continually secreted by the liver and stored in the gall bladder.

Composition of bile: The liver produces and secretes bile. It is stored in the gall bladder. Bile contains no digestive enzymes. Bile consists of water, bile salts: sodium glycocholate and sodium taurocholate, bile pigment, bilirubin, cholesterols, lecithin (a phospholipid) mucus, cells and cell debris.

Role of constituents of bile: Bile salts reduce the surface tension of fat globules and emulsify them into droplets and thus increase their total surface area. This process is called **emulsification**. These small droplets are then acted upon by the enzyme lipase. **Bilirubin** results from the breakdown of haemoglobin. In the intestine, bacteria convert bilirubin into pigments that give the faeces its characteristic brown colour. Some of these pigments are absorbed from intestine, modified in the kidneys and excreted in the urine, contributing to the characteristic yellowish colour of the urine. Bile salts help in the absorption of fatty acids from the intestinal tract.

1.11 STRUCTURE AND FUNCTION OF PANCREAS

The pancreas is a complex organ composed of both endocrine and exocrine tissues that perform several functions. The endocrine part of the pancreas consists of pancreatic islets (islets of Langerhans). The pancreas consists of a head, located within the curvature of the duodenum, a body and a tail, which extends to the spleen.

Head: The widest part, located in the C-shaped curve of the duodenum (the first part of the small intestine).
Neck: Connects the head to the body.
Body: The main part of the pancreas, located behind the stomach and to the left of the superior mesenteric vessels.
Tail: The tapered end, located near the splenic hilum (the point where the spleen connects to other structures).

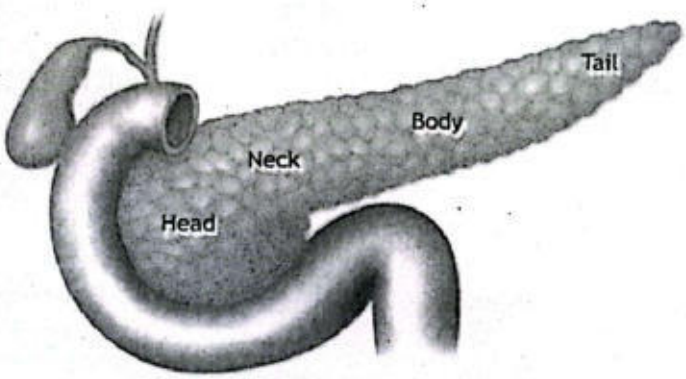


Fig. 1.15: Structure of pancreas

Pancreas as an exocrine gland

The exocrine secretion of the pancreas is called pancreatic juice and has two major components: an aqueous component and an enzymatic component. Bicarbonate neutralizes the acidic chyme that enters the small intestine from the stomach. The enzymatic component of the pancreatic juice is important for the digestion of all major classes of food. The major proteolytic enzymes are **trypsin, chymotrypsin**, and **carboxypeptidase**.
They are secreted in their inactive forms as trypsinogen, chymotrypsinogen, and procarboxypeptidase and are activated by the removal of certain peptides from the larger precursor proteins. If these were produced in their active forms, they would digest the tissues producing them. **Trypsinogen** is activated by the proteolytic enzyme enterokinase into **trypsin.** **Trypsin** then activates more trypsinogen, as well as **chymotrypsinogen** and **procarboxypeptidase. Amylase**, continues the polysaccharide digestion that was initiated in the oral cavity. **Pancreatic lipases**, breakdown lipids into free fatty acids, glycerides, cholesterol. **Deoxyribonucleases** and **ribonucleases**, reduce DNA and ribonucleic acid to their component nucleotides, respectively.

1.12 RELATION OF SECRETION OF BILE AND PANCREATIC JUICE WITH THE SECRETIN OF HORMONE

Secretion of bile and pancreatic juice is related to the hormone secretin.

Secretion of bile is related to secretin hormone

Fatty acids in the lumen of the duodenum stimulate endocrine cells to release the hormone **cholecystokinin** (CCK). CCK stimulates contractions in the smooth muscle of the gall bladder allowing bile release into the duodenum.
Acidic chyme in the lumen of the duodenum stimulates other endocrine cells to release the hormone **secretin**. Secretin produced by the duodenum is carried through the circulatory system to the liver and stimulates liver to release bicarbonate into the bile.

Secretion of pancreatic juice is related to secretin hormone

Pancreatic juice secretion is regulated by the hormones **secretin** and **cholecystokinin** which is produced by the walls of the duodenum upon detection of acidic food, proteins, fats and vitamins. Pancreatic secretion consists of an aqueous bicarbonate component from the duct cells and enzymatic component from the **acinar cells**. A clear alkaline secretion of the pancreas containing enzymes that aid in the digestion of proteins, carbohydrates, and fats.

The predominant effect of **secretin** on the pancreas is to stimulate duct cells to secrete water and bicarbonate. As soon as this occurs, the enzymes secreted by the **acinar cells** are flushed out of the pancreas, through the pancreatic duct into the duodenum.

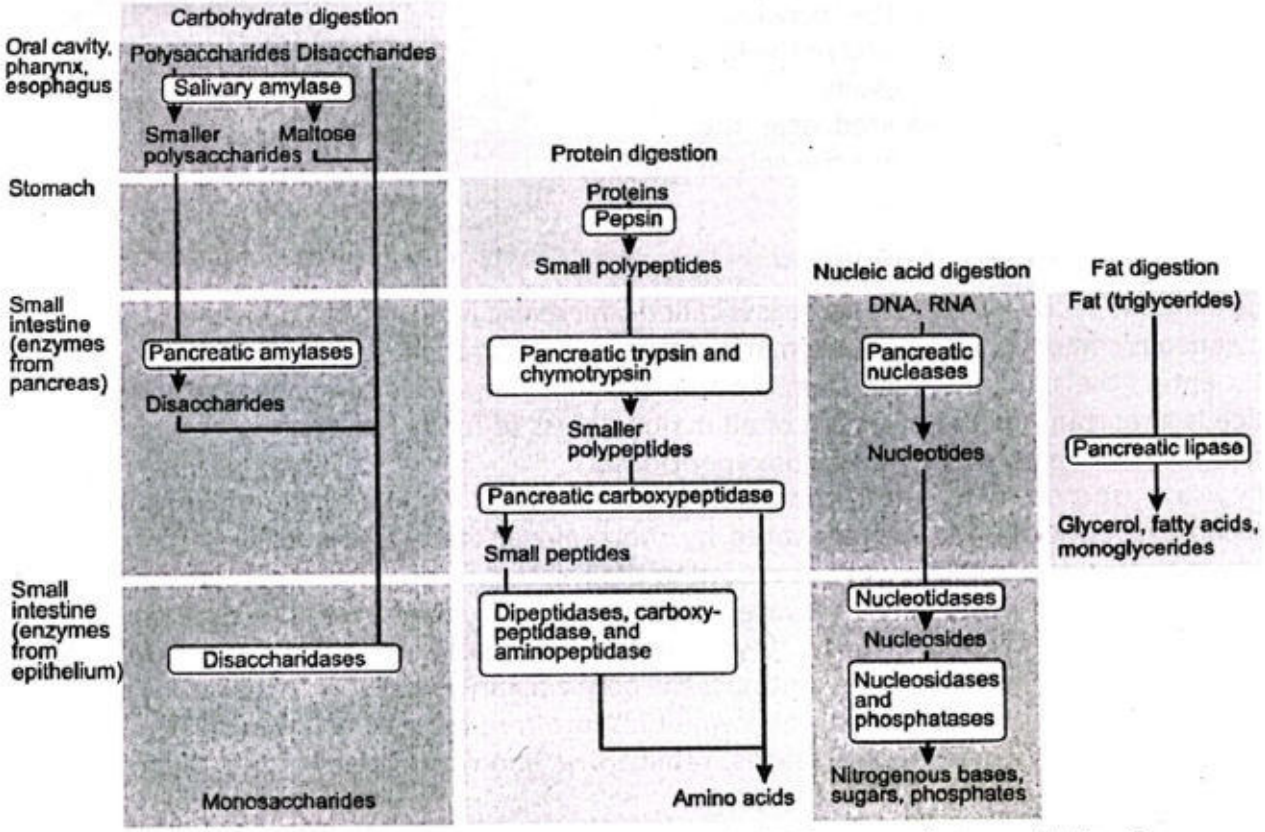


Fig. 1.16: Flow chart showing action of enzymes in GIT from mouth to small intestine

STEAM ACTIVITY 1.1

I. Investigate the action of amylase on starch

Materials required

starch solution, amylase (saliva), water bath, 2 test tubes, and iodine.

Substrate= starch, Enzyme = amylase, Product= maltose

Procedure

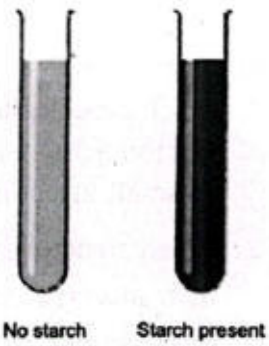
1. Dissolve some starch in water to form a starch solution.
2. Add equal amount of starch solution to each of the two test tubes. Mark the test tubes as A and B.
3. Add saliva to the test tube marked as A. Shake the test tube to mix the contents. Do not add saliva in the test tube marked as B
4. Leave both the test tubes for ten minutes in a water bath at 37 °C (body temperature).
5. Add a few drops of iodine solution in both the test tubes.

Content of test tube	Chemical used in the test	Original colour of chemical	Final colour of chemical when added to test tube
Starch and saliva	Iodine	Yellow	Yellow
Starch	Iodine	Yellow	Blue/black

Conclusion:

1. Test tube A = iodine and saliva = yellow coloured solution
2. Test tube B = iodine and saliva = blue/black coloured solution

Therefore, amylase digests starch



II. Carryout qualitative food test for protein

Materials required

2 droppers, test tube, sodium hydroxide, copper sulphate

Method

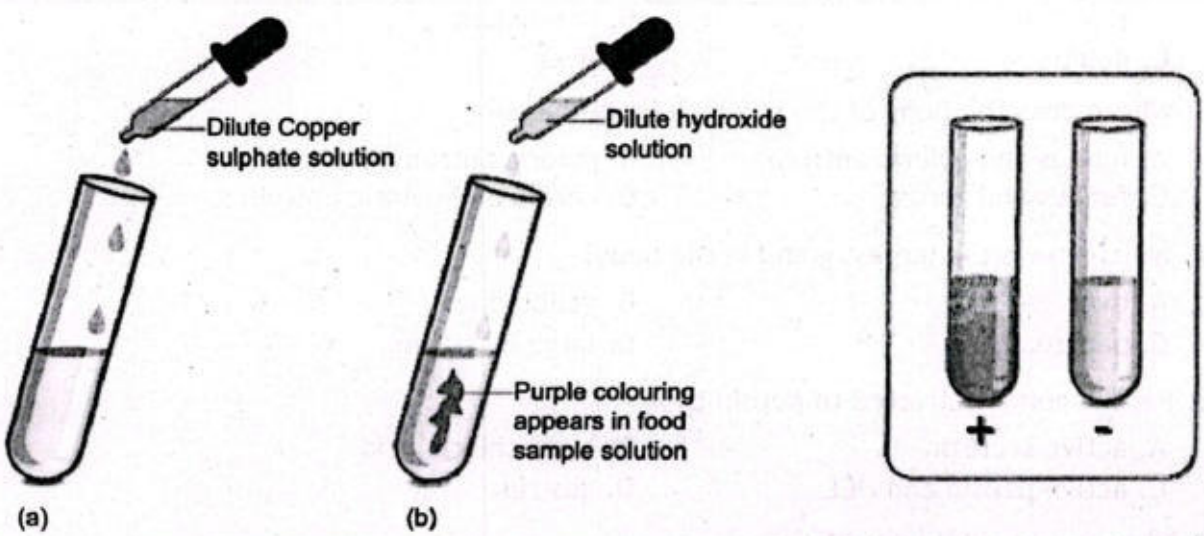
1. Dissolve a sample of food such as yogurt and egg in water.
2. Add a few drops of sodium hydroxide (which is colourless)

Caution: Sodium hydroxide is corrosive; do not let it get on your skin.

3. Add a few drops of copper sulphate (which is blue)

Result: If the colour changes from blue to purple protein is present.

Food tasted	Final colour observed	Protein present or absent
Yogurt	Purple	Present
Egg	Purple	Present



Conclusion: Yogurt and egg contain protein

STEAM ACTIVITY 1.2

Observe, identify draw and label prepared histological slides showing cross section of human: stomach, small intestine, liver and gall bladder.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Which among the following is the longest?
   A. stomach B. esophagus
   C. small intestine D. large intestine
2. Which structure does the appendix come off?
   A. transverse colon B. descending colon
   C. ascending colon D. small intestine
3. Which part of the Large intestine attaches to the appendix?
   A. transverse colon B. descending colon
   C. ascending colon D. cecum
4. What is the name of the part of the stomach attached to the esophagus?
   A. fundus B. pylorus
   C. body D. cardia
5. Where does the pancreatic duct directly join to?
   A. jejunum B. duodenum
   C. ileum D. liver
6. Where does the body of the stomach lie between?
   A. fundus and pyloric antrum B. pyloric antrum and cardia
   C. fundus and cardia D. cardia and pyloric antrum
7. Which one is the largest gland in the body?
   A. liver B. gallbladder
   C. pancreas D. large intestine
8. Pepsinogen is activated to pepsin by
   A. active secretin B. hydrochloric acid
   C. active pepsin and HCL D. gastrin
9. Liver secretes bile into the
   A. duodenum B. ileum
   C. jejunum D. ascending colon

10. Emulsification of fat will not occur in the absence of

A. lipase
B. bile pigment
C. bile salt
D. pancreatic juice

11. Fatty acids and glycerol are first absorbed by

A. lymph vessel
B. villi
C. blood capillaries
D. hepatic portal vein

12. The hormone responsible for stimulating secretion of hydrochloroic acid by stomach cells is

A. pepsin
B. secretin
C. gastrin
D. insulin

13. Enzyme trypsinogen is changed to trypsin by

A. gastrin
B. enterokinase
C. secretin
D. hydrochloric acid

14. Which of the following hormones stimulates the production of pancreatic juice and bicarbonate?

A. insulin and glucagon
B. cholecystokinin and secretin
C. gastrin and insulin
D. glucagon and insulin

15. Secretin and cholecystokinin are secreted in

A. pyloric region
B. Ileum
C. duodenum
D. esophagus

16. Which of the following is synthesized and stored in the liver cells?

A. galactose
B. lactose
C. glycogen
D. insulin

17. Which juice secreted by the alimentary canal plays an important role in the digestion of fats?

A. pancreatic juice, saliva
C. mucus, Hydrochloric acid
B. saliva, hydrochloric acid
D. bile juice, pancreatic juice

18. What is the role of mucus secreted by the stomach?

A. to digest protein
C. to kill germs in the food
B. to digest fats
D. to protect lining of the stomach

19. The majority of the water from the indigestible food is absorbed in the_____?

A. stomach
B. foodpipe
C. pancreas
D. large intestine

20. Which hydrolytic enzymes react in a low pH environment?

A. peroxidases
B. hydrolases
C. amylases
D. proteases

Section II: Short Answer Questions

1. What is mechanical digestion?
2. What is chemical digestion?
3. Describe peristalsis.
4. Name and write the function of epithelial cells of stomach of man.
5. Give one reason as to why some enzymes in stomach and intestine are secreted in inactive form?
6. Name the enzymes involved in protein digestion.
7. How could no secretion of HCl in our stomach affect food digestion?
8. How the stomach does protect itself from the damaging effect of HCl?
9. Why there are villi in the intestine and not in stomach?
10. Trypsin acts at alkaline pH. What provides the alkalinity?
11. What would happen to the activity of the intestinal enzymes if the pH in the small intestine remained at 2?
12. How does the absorption of fat differ from absorption of glucose?
13. Describe defaecation reflex in infants.
14. Describe defaecation reflex in adults.
15. Bile juice contains no digestive enzymes, yet it is important for digestion. Why?
16. What is the role of hormone gastrin in digestion?
17. What is the role of hormone secretin in digestion?
18. Describe the storage role of liver.
19. What is gall bladder? Write its function.
20. Write the differences between:
    (a) pharynx and larynx
    (b) pepsinogen and pepsin

Section III: Extensive Answer Questions

1. Describe the process of swallowing in man.
2. Describe the human stomach with diagram.
3. Describe the structure of human small intestine.
4. Explain the absorption of digested products from the small intestine lumen to the blood capillaries and lacteals of the villi.
5. Describe the large intestine of man. What are the functions of large intestine?
6. What is bile? Describe the composition of bile. What is the role of constituents of bile?
7. How secretion of bile is related to the secretion of hormone secretin?
8. Write the functions of liver of man.
9. What is the structure of pancreas? Explain the functions of pancreas as an exocrine gland.

BLOOD CIRCULATORY SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-36] State the location of heart in the body and define the role of pericardium.
2. [B-12-R-37] Describe the structure of the walls of heart and rationalize the thickness of the walls of each chamber.
3. [B-12-R-38] Trace the flow of blood through the heart as regulated by the valve.
4. [B-12-R-39] State the phases of heartbeat.
5. [B-12-R-40] Explain the roles of A node, AV node and Purkinje fibers in controlling the heartbeat.
6. [B-12-R-41] List the principles and uses of Electrocardiogram.
7. [B-12-R-42] Describe the detailed structure of arteries, veins and capillaries.
8. [B-12-R-43] Describe the role of arterioles in vasoconstriction and vasodilation.
9. [B-12-R-44] Describe the role of pre-capillary sphincters in regulating the flow of blood through the capillaries.
10. [B-12-R-45] Trace the path of the blood through the pulmonary and systemic circulation (coronary, hepatic-portal and renal circulation).
11. [B-12-R-46] Compare the rate of blood flow through arteries, arterioles capillaries, venules and veins.
12. [B-12-R-47] Define blood pressure and explain its periods of systolic and diastolic pressure.
13. [B-12-R-48] State the role of baroreceptors and volume receptor in regulating the blood pressure.
14. [B-12-R-49] Define the term thrombus and differentiate between thrombus and embolus.
15. [B-12-R-50] Identify the factors causing atherosclerosis and arteriosclerosis.
16. [B-12-R-51] Categorize Angina pectoris, heart attack, and heart failure as the stages of cardiovascular disease development.
17. [B-12-R-52] State the congenital heart problem related to the malfunction of cardiac valves.
18. [B-12-R-53] Describe the principles of angiography.
19. [B-12-R-54] Outline the main principle of coronary bypass, angioplasty and open-heart surgery.
20. [B-12-R-55] Define hypertension and describe the factor that regulate blood pressure and lead to hypertension and hypotension.
21. [B-12-R-56] List the changes in lifestyles that can protect man from hypertension and cardiac problems.
22. [B-12-R-57] Describe the formation, composition and function of intercellular fluid.
23. [B-12-R-58] Compare the composition of intercellular fluid with that of lymph.
24. [B-12-R-59] State the structure and role of lymph capillaries, lymph vessels and lymph trunks.
25. [B-12-R-60] Describe the functions of lymph nodes and state the role of spleen as containing lymphoid tissue.

Why do we need a transport system? You have read in the previous chapter that what is digestion? In chapter 1 you have read what are cells? All the cells of our body need food from small intestine and oxygen from the lungs. Carbon dioxide and waste chemicals have to be removed from the lungs and kidneys respectively. Our bodies are too large for materials to simple diffuse in and out. So we have a system of internal transport - a circulatory system that transports oxygen and carbon dioxide, distributes nutrients to the body cells and conveys the waste products of metabolism to specific site for disposal. The cardiovascular system consists of a strong muscular heart, three kinds of blood vessels: arteries, capillaries, veins and blood. The study of the diseases of cardiovascular system is called **angiology**.

2.1 HUMAN HEART

Location: The size of heart varies with the body size. The human heart is about the size of an adults fist. The heart is within the mediastinum, which is bordered laterally by the lungs, posteriorly by the backbone and anteriorly by the sternum. It's base lies beneath the second rib. It's distal end extend downward and to the left, terminating as bluntly pointed apex at the level of the fifth intercostal space.

Role of pericardium

The pericardium is a closed sac that surrounds heart. The inelastic nature of the pericardium as a whole prevents the heart from being overstretched or overfilled with blood. The pericardium is a fibre membrane found as an external covering around the heart. It protects the heart by producing a serous fluid, which serves to lubricate the heart and prevent friction between the surrounding organs. Apart from the lubrication, the pericardium also helps by holding the heart in its position and by maintaining a hollow space for the heart to expand itself when it is full. The pericardium consists of two parts, the outer part and inner part. **Visceral Layer** is directly covers the outside of the heart. **Parietal Layer** forms a sac around the outer region of the heart that contains the fluid in the pericardial cavity.

2.2 STRUCTURE OF WALLS OF HEART

The heart consists of four chambers: two atria (meaning, entrance chamber) and two ventricles (meaning, belly). The atria lie above the ventricles. The heart wall is composed of the three layers of tissue: The epicardium, the myocardium, and the endocardium. The **epicardium** is a thin serous membrane comprising of the smooth outer surface of the heart. The thick middle layer of the heart, the **myocardium**, is composed of cardiac muscle cells. The smooth inner surface of the heart chambers is the **endocardium**, which consists of simple squamous epithelium over a layer of connective tissue. The heart valves are formed by a fold of the endocardium, making a double layer of endocardium with connective tissue in between.

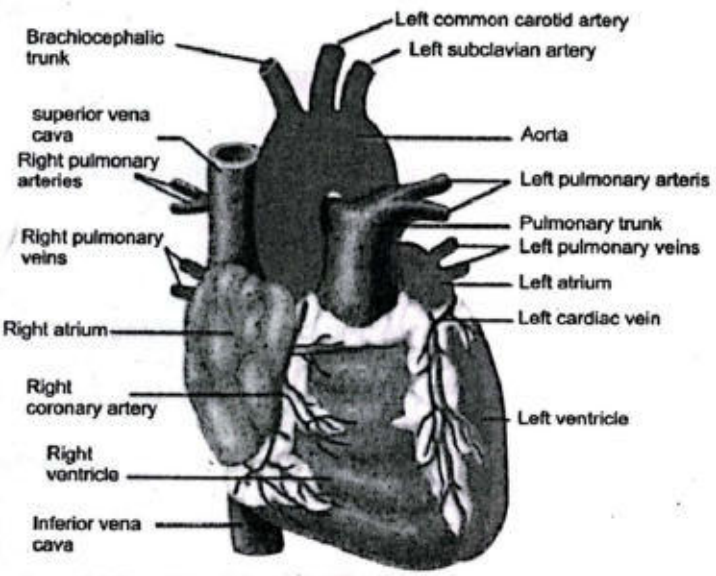


Fig. 2.1: Human heart, external view

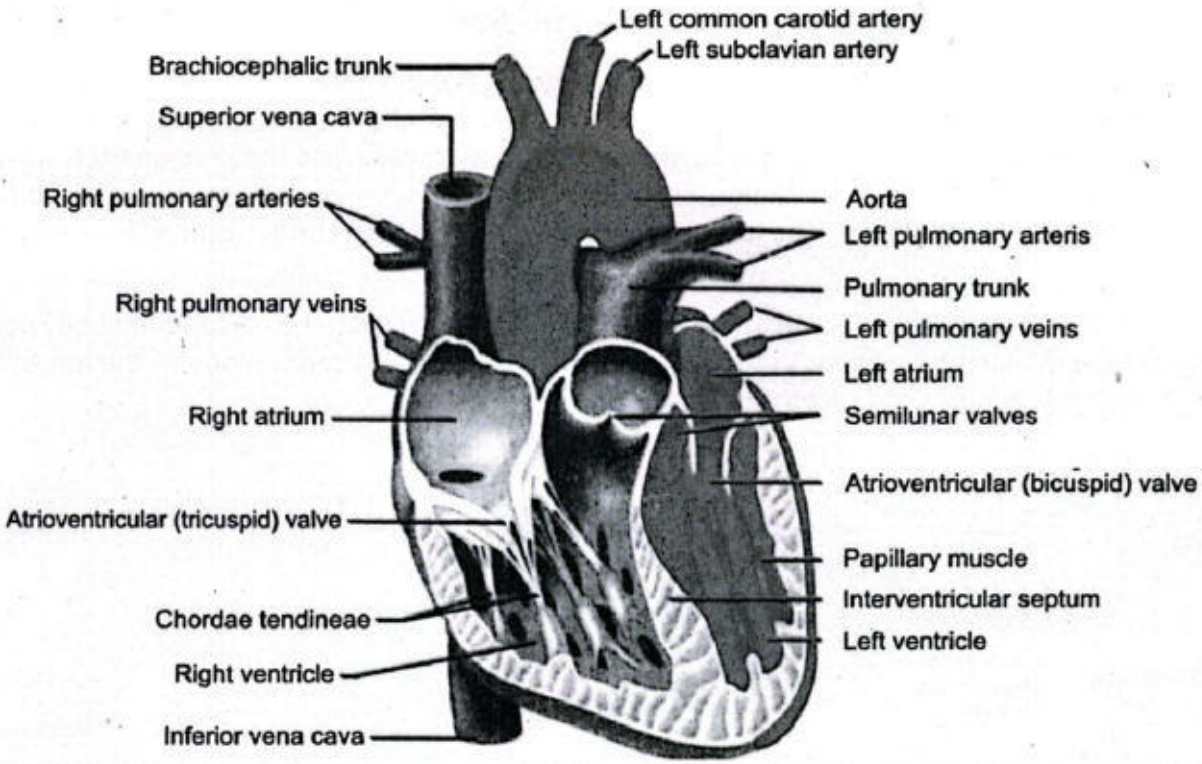


Fig. 2.2: Dissection of a human heart, as seen from the front, with the ventral part of both atria and both ventricles removed

The thickness of the walls of each chamber is different: The atria have comparatively thin walls as they only have to force blood into the ventricles and this does not require much power. On the other hand, the ventricles have to force blood out of the heart hence they have relatively thick walls, especially the left ventricle which has to pump blood around the whole body. The right ventricle has thinner walls than the left ventricle in a ratio of 1:3, it pumps blood to the lungs, which are at a short distance from the heart.

The **right atrium** receives the superior vena cava, the inferior vena cava, and the coronary sinus. The **left atrium** receives the four pulmonary veins. The two atria are separated from each other by the **interatrial septum.**

The atria open into the ventricles through **atrioventricular canals.** The **right ventricle** opens into the pulmonary trunk, and the **left ventricle** opens into the aorta. The two ventricles are separated from each other by the **interventricular septum.**

An **atrioventricular valve** is on each atrioventricular canal and is composed of **cusps**, or flaps. The atrioventricular valve between the right atrium and the right ventricle has three cusps and is called the **tricuspid valve.** The atrioventricular valve between the left atrium and left ventricle has two cusps and is therefore called the **bicuspid** or **mitral valve.** Each ventricle contains cone-shaped muscular pillars called **papillary muscles.** These muscles are attached by thin, strong connective tissue strings called **chordae tendineae** to the cusps of the atrioventricular valves. The papillary muscles contract when the ventricles contract and prevent the valves from opening into the atria by pulling on the chordae tendineae attached to the valve cusps. The aorta and pulmonary trunk possess **aortic** and **pulmonary semilunar valves.**

2.3 FLOW OF BLOOD THROUGH THE HEART

The superior vena cava and the inferior vena cava, both carrying deoxygenated blood, enter the right atrium. The right atrium sends blood through the tricuspid valve to the right ventricle. The right ventricle sends blood through the pulmonary semilunar valve into the pulmonary trunk and the two pulmonary arteries to the lungs. Four pulmonary veins, carrying oxygenated blood from the lungs, enter the left atrium. The left atrium sends blood through the bicuspid valve to the left ventricle.

The left ventricle sends blood through the aortic semilunar valve into the aorta to the body parts. The heart is a double pump because the right ventricle of the heart sends blood to the lungs, and the left ventricle sends blood throughout the body.

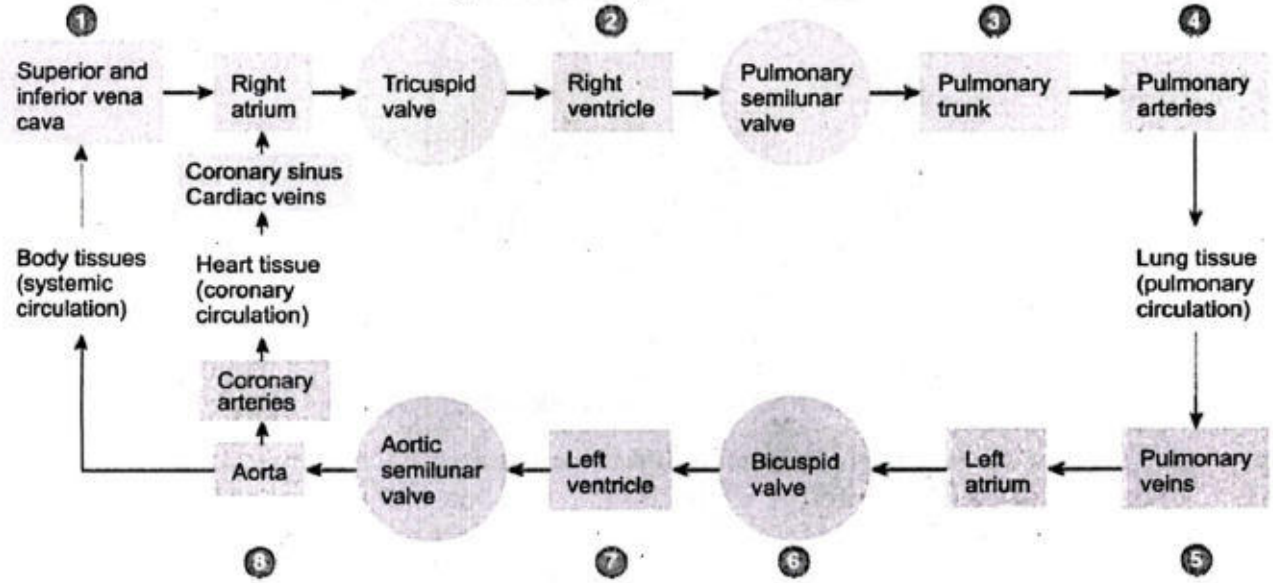


Fig. 2.3: Passage of blood through heart

2.4 PHASES OF HEARTBEAT

In a continuous, rhythmic cycle heart is passively filled with blood from the large veins and then the heart actively contracts, propelling the blood throughout the body. Its alternating relaxations and contractions make up the **cardiac cycle**. The cardiac cycle is a sequence of one heartbeat.

Phases of heartbeat

The term **systole** means to contract and **diastole** means to dilate. Atrial systole is contraction of the atrial myocardium and atrial diastole is relaxation of the atrial myocardium. Similarly ventricular systole is contraction of the ventricular myocardium and ventricular diastole is the relaxation of the ventricular myocardium. When the word "systole" and "diastole" are used without reference to specific chambers, they mean ventricular systole or diastole.

In **atrial diastole** blood enters the right atrium from the body through the vena cavae. At first the bicuspid and tricuspid valves are closed, but as the atria fill with blood, pressure in them rises. Eventually it becomes greater than that in the relaxed ventricles and the valves are pushed opens. In atrial systole the two atria contract simultaneously and blood is pushed through the atrio-ventricular valve into the still relaxed ventricles.

At this phase semilunar valve is closed, tricuspid and bicuspid valves are open.

In **ventricular systole** almost immediately the ventricles contract. When this occurs the pressure in the ventricles rises and closes the atrioventricular valves, preventing blood from returning to the atria. This pressure forces, open semilunar valves of the aorta and the pulmonary artery and blood enters these vessels. In this phase the tricuspid and bicuspid valves are closed.

In **ventricular diastole** the high pressure developed in the aorta and pulmonary artery tends to force some blood back towards the ventricles and close the semilunar valves of the aorta and pulmonary artery. Hence back flow in the heart is prevented. In this phase bicuspid valve and tricuspid valve are open, aortic semilunar valve, and pulmonary semilunar valve are closed. The normal cardiac cycle is of 0.7 to 0.8 second depending on the capability of cardiac muscle to contract. The heart muscles rest 0.1 to 0.3 second between the beats.

SCIENCE TITBITS

When a stethoscope is used to listen to the heart sounds, distinct sounds normally are heard. The first heart sound is a low-pitched sound, often described as a "lub" sound. It is caused by vibration of the atrioventricular valves which close near the beginning of ventricular systole. The second heart sound is a higher pitched sound often described as a "dub" sound. It results from closure of the aortic and pulmonary samilunar valves, near the end of systole. 'lub' is also written as 'lubb' and 'dub' as 'dupp'.

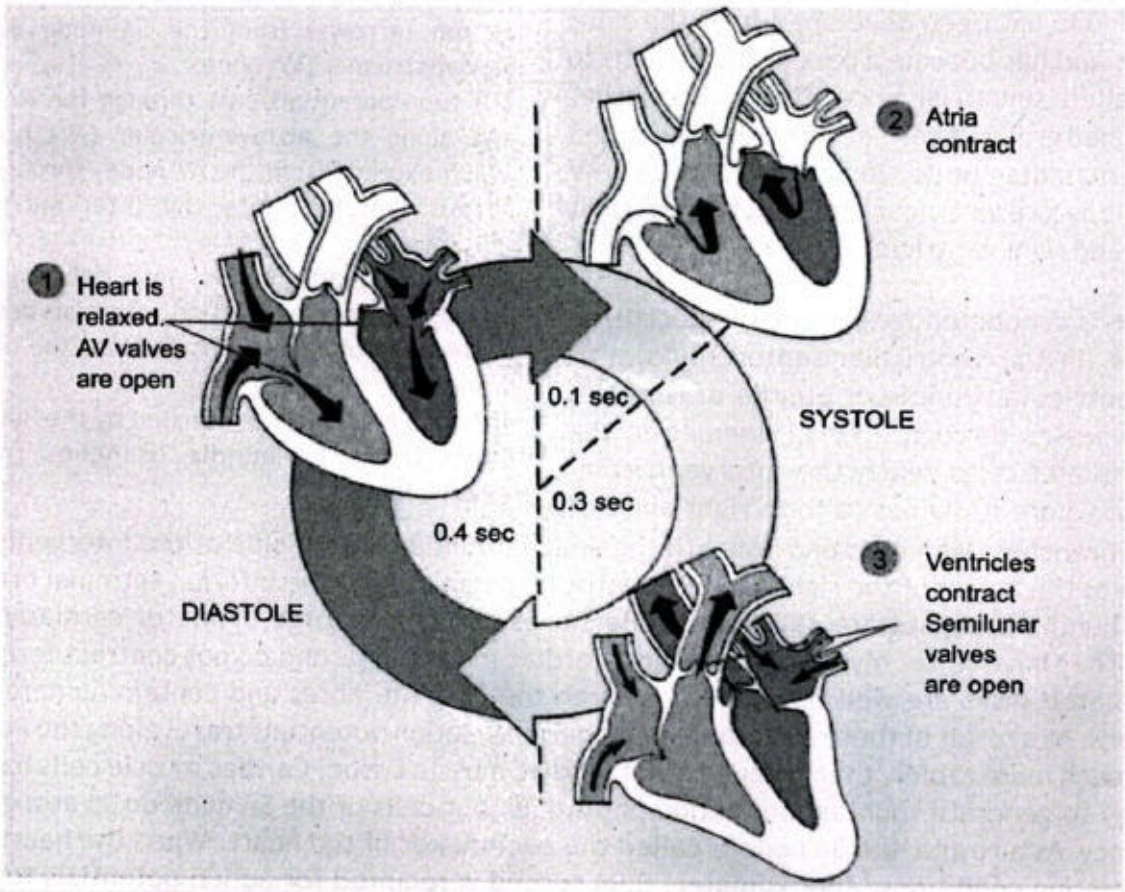


Fig. 2.4: Cardiac cycle

2.5 CONDUCTING SYSTEM OF THE HEART

The heart will go on beating after it has been cut right out of the body. Cardiac muscles are **myogenic** i.e., its rhythmic contraction arise from within the muscle itself. Cardiac muscle has an intrinsic rhythmicity that allows the heartbeat to originate in and be conducted through the heart without extrinsic stimulation. Specialized strands of interconnecting cardiac muscle tissue that coordinate cardiac contraction constitute the **conduction system.** The components of the conduction system are the (a) Sinoatrial node, (b) Atrioventricular node, (c) Atrioventricular bundle (d) Conducting myofibrils.

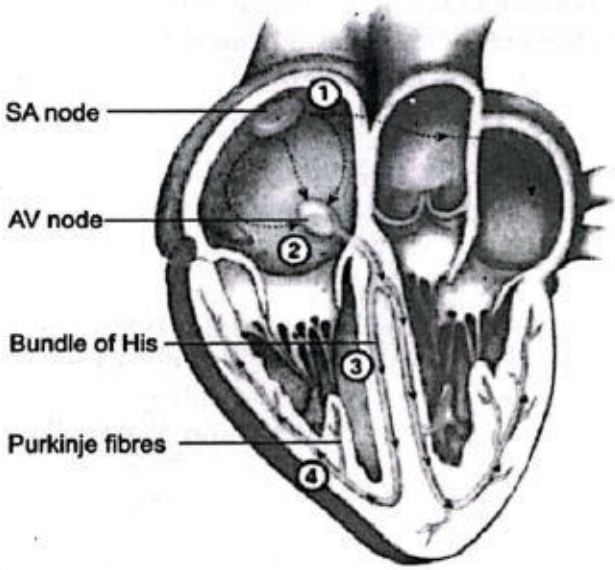


Fig. 2.5: Conducting system of the heart
1. Action potentials originate in the sinoatrial (SA) node and travel across the wall of the atrium (arrows) from the SA node to the atrioventricular (AV) node.
2. Action potentials pass through the AV node and along the atrioventricular (AV) bundle, which extends from the AV node, through the fibrous skeleton, into the interventricular septum.
3. The AV bundle divides into right and left bundle branches, and action potentials descend to the apex of each ventricle along the bundle branches.
4. Action potentials are carried by the Purkinje fibres from the bundle branches to the ventricular walls.

Sinoatrial node in short is called **SA node.** It consists of specialized plexus of cardiac muscles embedded in the upper wall of the right atrium. It is close to where vena cavae enter the atrium. The SA node has been developed from the sinus venosus and has become a part of the atrium, so it is called sinoatrial node. There is another specialized group of cardiac muscle fibres called **atrioventricular node.** In short it is called **AV node.** It is present near the junction of right atrium and right ventricle.

AV node is connected to a strand of specialized muscles (in the ventricular septum) known as **atrioventricular bundle** or **bundle of His.** This bundle passes through a small opening in the fibrous skeleton to reach the interventricular septum, where it divides to form right and left bundle branches, which extend beneath the endocardium on either side of the interventricular septum to the apices of the right and left ventricles respectively. The inferior, terminal branches of the bundle branches are called **Purkinje fibres,** which are large-diameter cardiac muscle fibres. They have fewer myofibrils than most cardiac muscle cells and do not contract forcefully. **Intercalated disks** are well developed between the Purkinje fibres and contain numerous gap junctions. As a result of these structural modifications, action potentials travel along the Purkinje fibres much more rapidly than through other cardiac muscle tissue. Cardiac muscle cells have the capacity to generate spontaneous action potentials, but cells of the SA node do so at a greater frequency. As a result, the SA node is called the **pacemaker of the heart.** When the heart beats under resting conditions, approximately 0.04 second is required for action potentials to travel from the SA node to the AV node.

Within the AV node action potentials are propagated slowly compared with the remainder of the conducting system. As a consequence, there is a delay of 0.11 second from the time action potentials reach the AV node until they pass to the AV bundle. The total delay of 0.15 second allows completion of the atrial contraction before ventricular contraction begins.

Science, Technology and Society Connections

• **Rationalize the use of artificial pacemaker in patients of cardiac arrhythmias.**
A **cardiac arrhythmia** is a disturbance in electrical rhythm of heart. It may be bradycardia (heart beat less than 40 beats per minute) or **tachycardia** (heart beat more than 100 beats per minute). Pacemaker supplies electrical initiation to myocardial contraction. The pacemaker is put surgically under the skin where it may be programmed. It generates electrical rhythm at a set rate, so in this way arryhthmia are controlled.

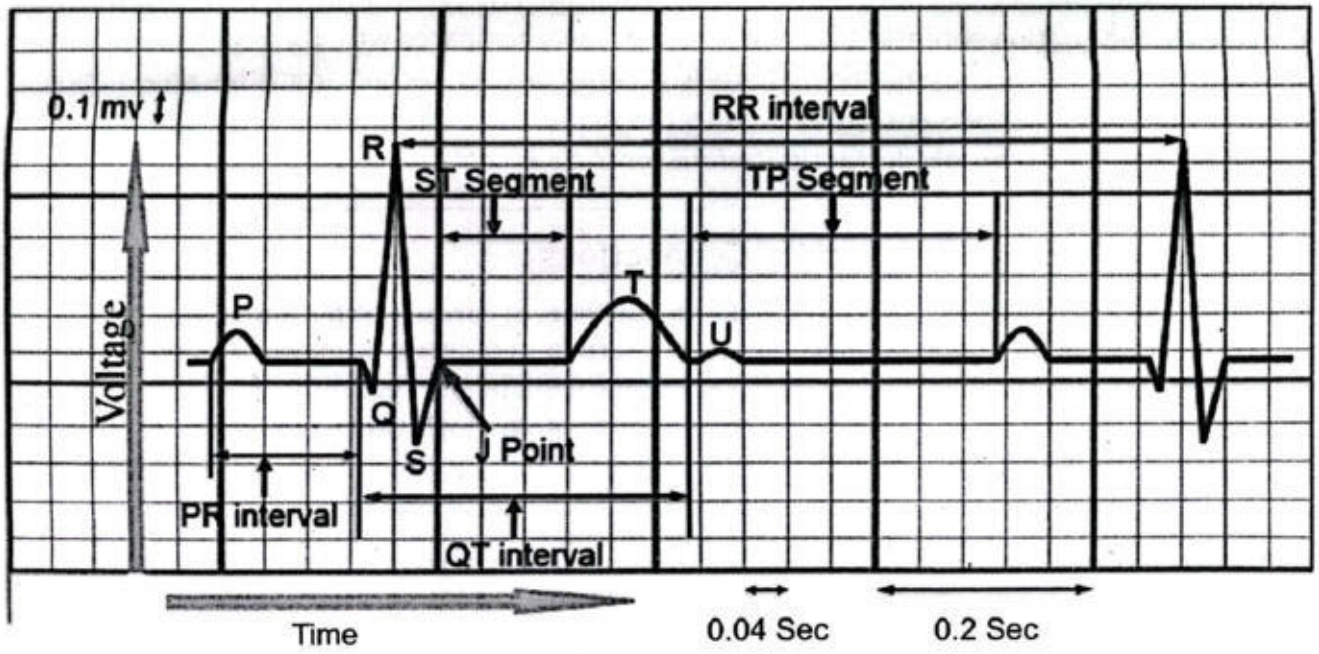
2.6 ELECTROCARDIOGRAM

The electrical impulses that pass through the conduction system of the heart during the cardiac cycle can be recorded as an electrocardiogram (ECG). The electrical changes result from depolarization and repolarization of cardiac muscle fibres and can be detected on the surface of the skin using an instrument called the **electrocardiograph.** The principal aspects of an ECG are shown in the given figure. The wave deflections, designated P, QRS, and T, are produced as specific events of the cardiac cycle occur.

Depolarization of the atrial fibres of the SA node produces the **P wave.** The ventricles of the heart are in diastole during the expression of the P wave. On the ECG recording, the **P-R interval** is the period of time from the start of the P wave to the beginning of the QRS complex. This interval indicates the amount of time required for the SA depolarization to reach the ventricles. The **QRS complex** begins as a short downward deflection (Q), continues as a sharp upward spike (R), and ends as a downward deflection (S). The QRS complex indicates the depolarization of the ventricles. During this interval, the ventricles are in systole and blood is being ejected from the heart. The time duration known as the **S-T segment** represents the period between the completion of ventricular depolarization and initiation of repolarization. The **T wave** is produced by ventricular repolarization. A normal ECG indicates that the heart is functioning properly. The P wave represents excitation and occurs just prior to contraction of the atria. The second wave, or the QRS complex, occurs just prior to ventricular contraction. The third, or T, wave occurs just before the ventricles relax. The J (junction) point in the junction between termination of the QRS complex and the beginning of the ST segment.

Uses of electrocardiogram

An ECG is a painless test that measures heart electrical activity to show whether or not it is working normally. ECG can detect arrhythmias (irregular heartbeat), conduction defects, size and position of heart chambers, damage to heart muscle, impaired blood flow to heart muscle, the effect of cardiac medicines and function of artificial pacemakers.



• PR interval	0.12 - 0.20 sec	• QT interval	0.4 - 0.43 sec
• QRS duration	0.08 - 0.10 sec	• RR interval	0.6 - 1.0 sec

Fig. 2.6: Electrocardiogram (ECG)

2.7 BLOOD VESESLS

There are three types of blood vessels, the **arteries** (and arterioles), which carry blood away from the heart, the **veins**, which return blood to the heart, and **capillaries**, which permit exchange of materials with the tissues.

2.7.1 Arteries

Arteries carry blood away from the heart. Arteries are pink in colour and are situated within the muscles. Arteries vary in size.

Arteries branch into **arterioles** and **capillaries**. The lumens of arteries have no valves. The wall of an artery consists of three layers or tunics: tunica adventitia, tunica media and tunica intima.

The outermost layer is called **tunica adventitia**. It is composed of white fibrous connective tissue. The middle layer is called **tunica media** and has variable amount of elastic fibres. It is many layered in thickness. It consists of one or two layers of circular smooth muscle cells.

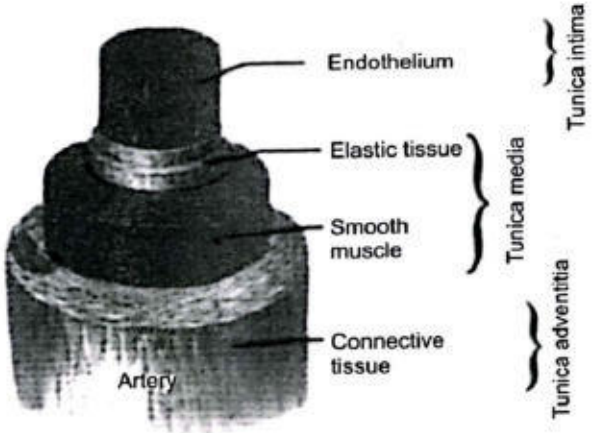


Fig. 2.7: Artery

The innermost layer of the artery is called **tunica intima**. It is composed of simple squamous epithelium and elastic fibres composed of elastin. Arterioles transport blood from small arteries to capillaries. Aorta is approximately 23 mm and arterioles are about 0.2 mm in diameter.

2.7.2 Capillaries

The capillary wall consists primarily of endothelial cells. Most capillaries range from 7 to 9 µm in diameter, and thus branch without a change in their diameter. Capillaries are approximately 1 mm long. Red blood cells flow through most of capillaries in a single file.

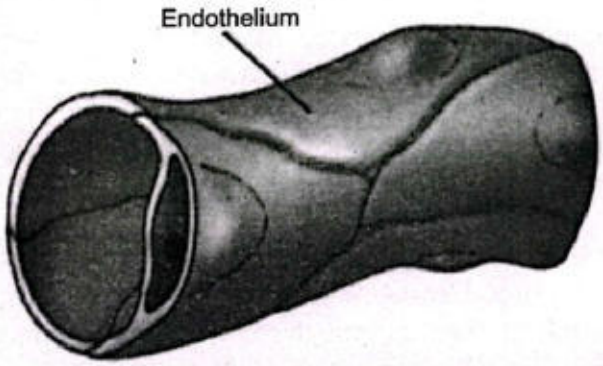


Fig. 2.8: Capillary

2.7.3 Veins

The blood vessels that bring blood back to the heart are called veins. Veins are relatively not deep in the muscles. Veins can be seen as blue vessels under the skin. A vein also consists of **tunica adventitia,** tunica media and tunica intima. Tunica adventia is composed of collagenous connective tissue. **Tunica media** is composed of a thin layer of circularly arranged smooth muscle cells, collagen fibres and a few sparsely distributed elastic fibres. **Tunica intima** is a smooth muscle and consists of endothelial cells, thin layer of elastic fibres. **Venules** with a diameter of 40 to 50 µm are tubes composed of endothelium. The venules collect blood from the capillaries and transport it to the small veins.

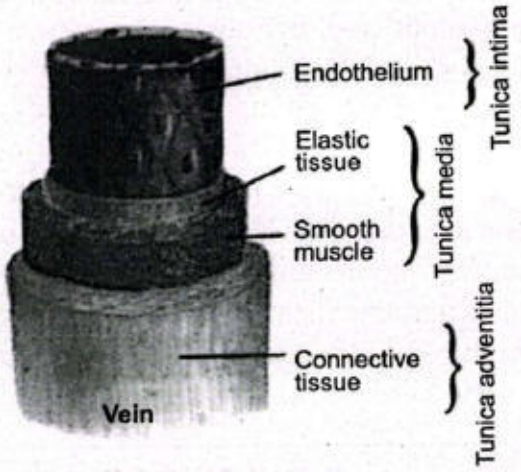


Fig. 2.9: Vein

Valves in veins

Veins having diameters greater than 2mm contain valves that allow blood flow toward the heart but not in the opposite direction. Valves are present only in the lower part of the body especially in the abdomen and hind limbs. In the upper region above the heart there is no valve. As the blood pressure in the veins is comparatively low, so the flow of blood in the veins is helped by gravity, semilunar valve and muscular contraction.

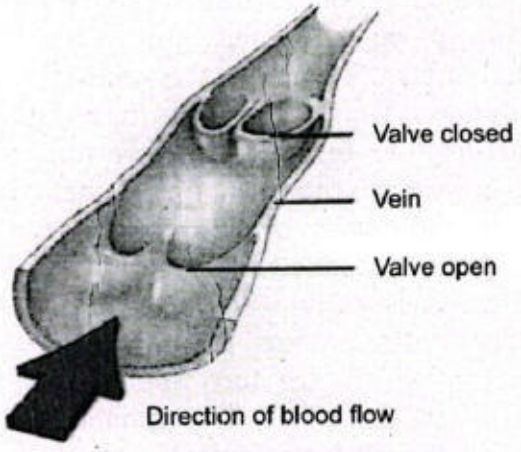


Fig. 2.10: Valves in veins

2.8 ROLE OF ARTERIOLES IN VASOCONSTRICTION AND VASODILATION

The amount of blood flowing through a blood vessel can be regulated by contraction or relaxation of smooth muscle in the tunica media. A decrease in blood flow results from **vasoconstriction**, a

decrease in blood vessels diameter caused by smooth muscle contraction whereas an increase in blood flow is produced by vasodilation an increase in blood vessel diameter because of smooth muscle relaxation. Blood circulation is also controlled by hormones (vasoconstriction agents) acting on arterioles. Norepinephrine is an especially powerful vasoconstriction hormone while epinephrine is less potent.

Several substances called kinins (vasodilator agents) can cause powerful vasodilation are formed in the blood and tissue fluids of some organs. e.g., histamine. Most of the prostaglandins are vasodilator agents though some of the prostaglandins are vasoconstrictor.

• Justify how Vasodilation and Vasoconstriction is Reflective of Emotions?
During emotional rage such as apprehension and rage vasodilation occurs due to secretion of epinephrine. It is a hormone that is responsible for fear, flight and fright conditions. The sympathetic vasodilator fibres are part of a regulatory system that originates in cerebral cortex and ends at postganglionic neurons in blood vessels on skeletal muscles, activate them to release acetylcholine, and vasodilation occurs. Blood discharge through thoroughfare channels rather than capillaries so heat loss occurs and the skin becomes hot and red. While in vasoconstriction blood supply becomes less to skin, so heat is preserved and the skin becomes cold. Situations such as shock, hypotension and tachycardia occur by stimulation of arterial stretch receptors and production of hypertension and bradycardia (slowness of the heart) occur by increased intracranial pressure.

2.9 ROLE OF PRE-CAPILLARY SPHINCTERS

Arterioles supply blood to each capillary network, blood then flows through the capillary network and into the venules. Blood flows from arterioles through metarterioles. From a metarteriole blood flows into a thoroughfare channel. Several capillaries branch from the thoroughfare channels. Flow in these capillaries is regulated by smooth muscle cells called precapillary sphincter, which are located at the origin of the branches. This sphincter can open and close the entrance to the capillary. Precapillary sphincters are normally either completely open or completely closed and the degree of constriction of the metarteriole also varies. The precapillary sphincters and metarterioles often open and close cyclically several times per minute, with the duration of the open phases being about proportional to the metabolic needs of the tissue. The cyclic opening and closing is called **vasomotion**.

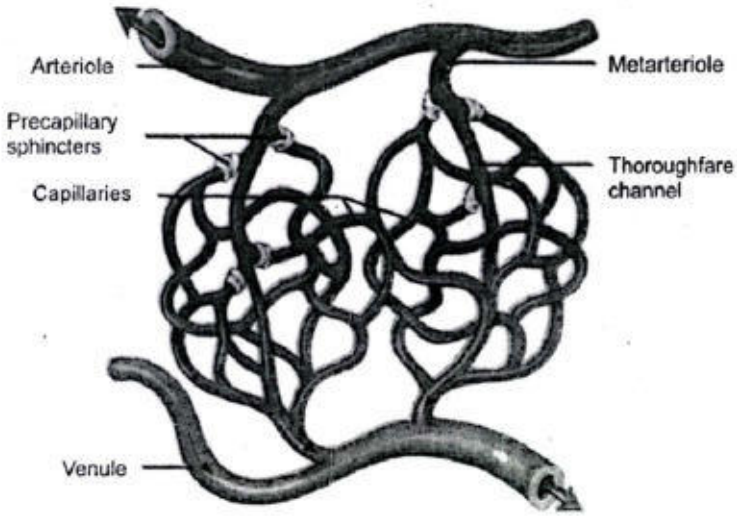


Fig. 2.11: Capillary network

2.10 PATH OF BLOOD THROUGH THE PULMONARY AND SYSTEMIC CIRCULATION

We will discuss here the path of blood through the pulmonary and systemic circulation.

Pulmonary circulation

The left atrium receives oxygenated blood from the lungs through two pairs of **pulmonary veins,** which open by common aperture into it. From left atrium the blood flows into the left ventricle. The superior and inferior vena cavae bring deoxygenated blood and open into the right atrium. From right atrium blood flows into the lungs for oxygenation by a **pulmonary arch** or **trunk** which divides into two **pulmonary arteries,** each going to the lung of its own side. This part of circulation is called **pulmonary circulation** or **circuit.** The pulmonary arteries carry deoxygenated blood and pulmonary veins carry oxygenated blood.

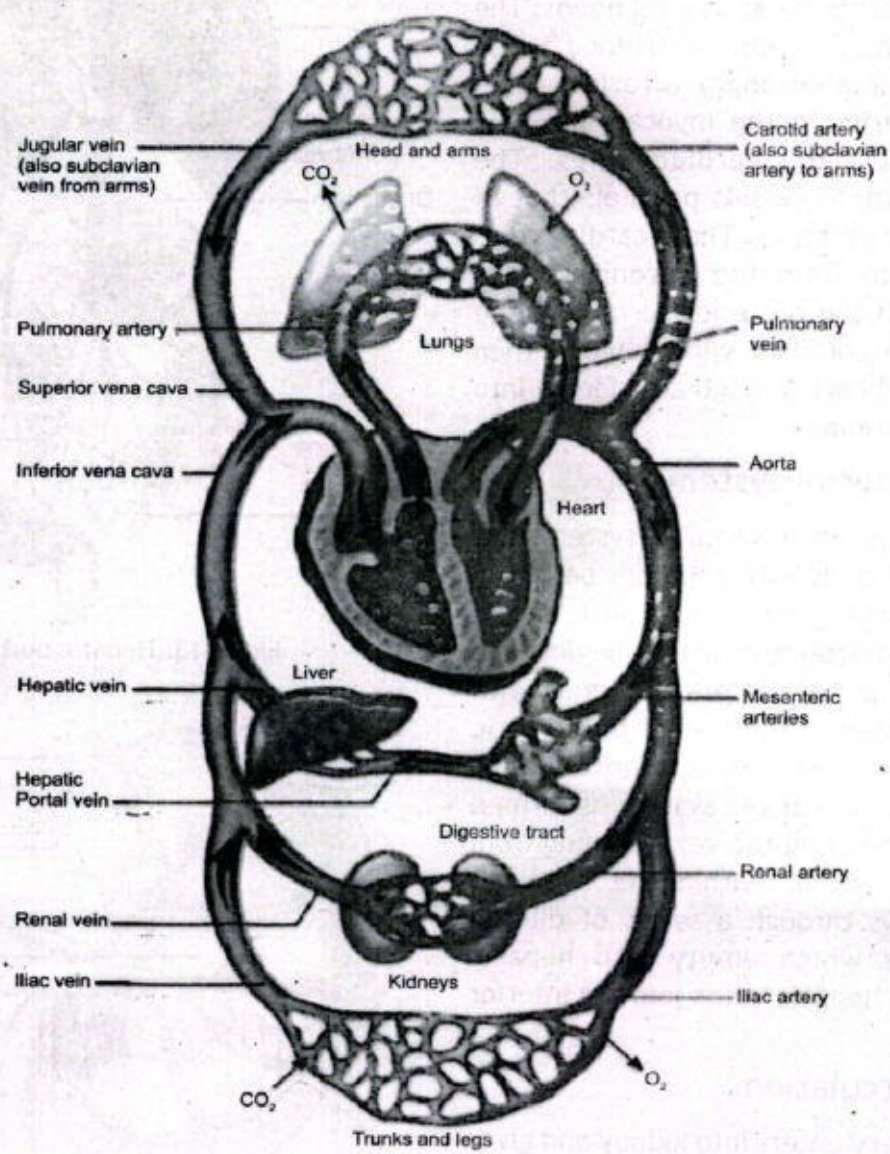


Fig. 2.12: Cardiovascular system

Systemic circulation

The systemic circuit includes all the **arteries** and **veins** other than involved in pulmonary circuit. The largest artery in the systemic circuit is the **aorta**. The largest veins are the **superior** and **inferior venae cava**. The path of systemic blood to any organ in the body begins in the **left ventricle** which pumps blood in the aorta. Branches from aorta go to the organs and major body regions. The **superior vena cava** collects blood from the head, the chest and the arms. The **inferior vena cava** collects blood from the lower body regions. Both enter the right atrium. The aorta and the vena cavae are the major pathways in the systemic circuit. In most instances the artery and the vein that serve the same organ are given the same name.

Coronary circulation

The wall of the heart has its own supply of blood vessels to meet its vital needs. The myocardium is supplied with blood by the **right** and **left coronary arteries**. From the capillaries in the myocardium, the blood enters the **cardiac veins**. The course of these vessels parallels that of the coronary arteries. These cardiac veins converge to form the **coronary sinus channel** on the posterior surface of the heart. The coronary venous blood then enters the heart through an opening into the right atrium.

Hepatic portal system

A **portal** system is vascular system that begins and ends with capillary beds and has no pumping mechanism such as the heart. The **portal system** that begins with capillaries in the viscera and ends with the capillaries in the liver is the hepatic portal system. The **hepatic portal vein**, the largest vein of the system, is formed by the union of all the veins coming from digestive system. Within the liver the blood flows through a series of dilated capillaries which empty into hepatic veins. The **hepatic veins** join the inferior vena cava.

Renal circulation

Renal artery enters into kidney and gives branches which pass through medulla. In cortex they give rise to **afferent**

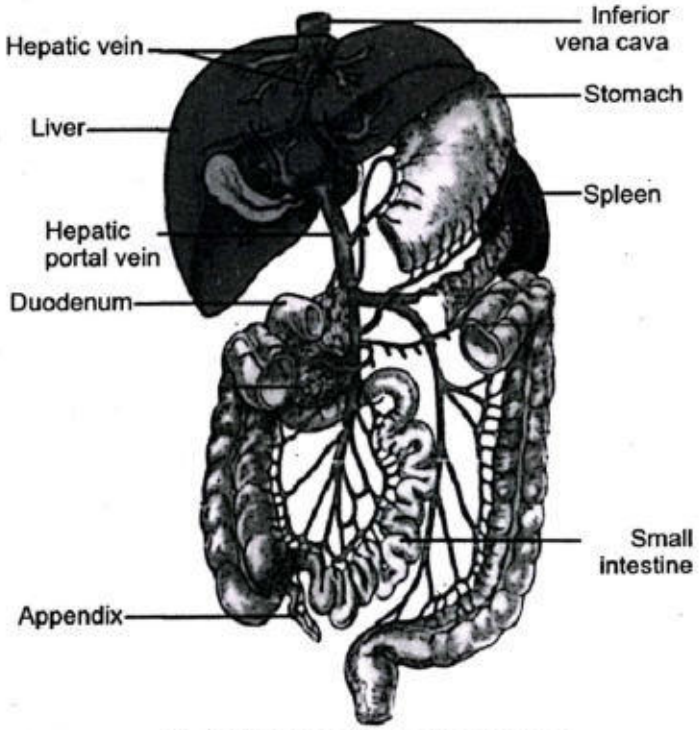


Fig. 2.13: Hepatic portal system

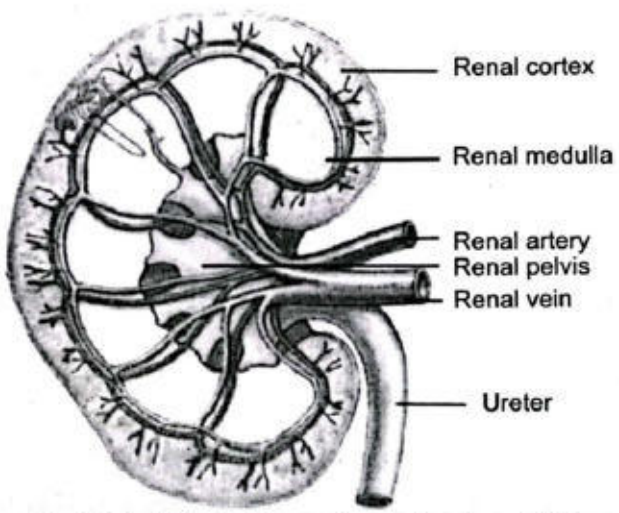


Fig. 2.14: Principal arteries and veins of kidney

glomerular arterioles From here blood enters the **peritubular capillaries** and **vasa recta.** From these capillary networks the blood is drained through veins and leave the kidney as a single renal vein that empties into the inferior vena cava.

2.11 RATE OF BLOOD FLOW IN BLOOD VESSELS

Blood flow means simply the quantity of blood that passes through a given point in the circulation in a given period. The overall blood flow in the circulation of an adult at rest is about 5000 ml/min. This is called **cardiac output.** It is the amount of blood pumped by the heart in a unit period.

Comparison of the rate of blood flow through arteries, arterioles, capillaries, venules and veins

Blood travels over a thousand times faster in the aorta, i.e., about 30cm/sec on average than in capillaries i.e., about 0.26 cm/sec. You might think that blood should travel faster through capillaries than through arteries, because the diameter of capillaries is very small. However, it is the total cross-sectional area of capillaries that determines flow rate. Each artery conveys blood to such an enormous number of capillaries that the total cross-sectional area is much greater in capillary beds than in any other part of the circulatory system. For this reason the blood slows substantially as it enters the arterioles from arteries and slows further still in the capillary beds. As blood leaves the capillaries and enters the venules and veins it speeds up again as a result of the reduction in total cross-sectional area. The carotid sinus and aortic arch baroreceptor reflexes are important in regulating blood pressure moment to moment.

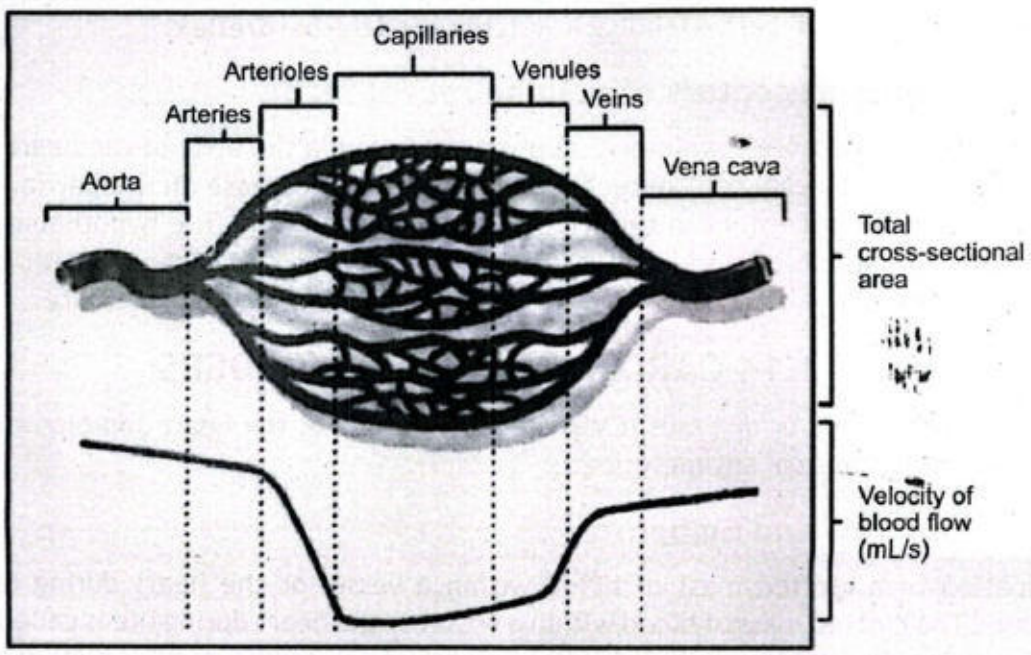


Fig. 2.15: Blood vessel types and velocity of blood flow: Total cross-sectional area for each of the major blood vessel types is the space through which blood flows, measured in square centimeters. The cross-sectional area of the aorta is about 2.5 cm^2. The crosssectional area of each capillary is much smaller, but there are so many that the total cross-sectional area is more than that of the aorta. The line at the bottom of the graph shows that blood velocity drops dramatically in arterioles, capillaries, and venules. As the total cross-sectional area increases the velocity of blood flow decreases

2.12 BLOOD PRESSURE

Blood pressure is the force exerted by the blood against any unit area on the inner walls of the blood vessel. The standard reference for the blood pressure is the mercury (Hg) manometer, which measures pressure in millimetres of mercury (mm Hg). If the blood pressure is 100 mm Hg the pressure is great enough to lift a column of mercury 100 mm. When the ventricles of the heart contract the arterial blood pressure is the highest. It is called **systolic pressure.** When the ventricles of the heart relax, the arterial blood pressure is the lowest. It is called **diastolic pressure.**

2.13 BARORECEPTORS AND VOLUME RECEPTORS

Baroreceptors can be divided into two categories based on the type of blood vessel in which they are located: high-pressure arterial baroreceptors and low-pressure baroreceptors or volume receptors

High-pressure arterial baroreceptors

These are mechanoreceptors located in the walls of the aorta and carotid sinus in the carotid arteries. They sense the blood pressure and relay the information to the brain, so that a proper blood pressure can be maintained. Stimulation of parasympathetic nerves in these areas caused by cardiac output, produces vasodilatation throughout the body and consequent reduction in blood pressure as well as a slowing the heart rate. The opposite occurs when blood pressure is low. In this case, a fall in blood pressure increases nerve impulse transmission along sympathetic nerves. This causes body-wide vasoconstriction and a rise in blood pressure. Baroreceptors act immediately as part of a negative feedback system called the **baroreflex.**

Low-pressure baroreceptors or volume receptors

Low-pressure baroreceptors or volume receptors are found in the atria of the heart and carotid arteries. When these receptors detect a blood volume decrease in the atria, a signal is transmitted from the receptors to the hypothalamus in the brain. The hypothalamus, in turn, increases the production of antidiuretic hormone (ADH) which will cause water retention in kidney. This increases the blood volume, resulting in the increase of blood pressure.

2.14 CARDIOVASCULAR DISORDERS

Cardiovascular disorders or diseases (CVD) are the diseases of the heart and blood vessels. The CVD are the leading cause of untimely death.

2.14.1 Thrombosis and Embolism

The formation of a clotted mass of blood within a vessel or the heart during life is called **thrombosis.** The clotted mass of blood within a vessel or the heart during life is called **thrombus.** The occlusion (a closing of an opening) of some part of the cardiovascular system by any mass transported to the site through the blood stream is called embolism. **Embolus** (plural: emboli) is a detached intravascular solid, liquid or gaseous mass that is carried to a site distant from its point of origin. About 99% emboli arise from dislodgement of thrombi and are therefore called **thromboemboli.** Thrombus and embolus cause death.

2.15 HEART PROBLEMS

In this section we will discuss cardiovascular diseases, such as: atherosclerosis and arteriosclerosis.

2.15.1 Atherosclerosis and arteriosclerosis

Atherosclerosis is the plaque deposition of cholesterol in the arteries resulting in the narrowing of the arteries lumen. Later, fibres are deposited in the cholesterol and these often start to calcify and become hard, a process known as **arteriosclerosis.** The plaque first forms thrombus and may detach to form embolus. The major factors that cause atherosclerosis and arteriosclerosis are: Hypercholesterolemia, (hyperlipidemia), Hypertension, Cigarette smoking, Diabetes mellitus, the other minor risk factors are: (a) Increasing age, (b) Lack of exercise, (c) Stressful competitive life, (d) Obesity.

2.16 STAGES OF CARDIOVASCULAR DISEASE DEVELOPMENT

In this section we will discuss cardiovascular diseases, such as: angina pectoris, heart attack, heart failure.

2.16.1 Angina pectoris

Due to atherosclerosis a person may feel occasional chest pain, a condition known as angina pectoris. Angina is most likely to occur when the heart is labouring hard because of physical or emotional stress. Angina is a signal that part of the heart is not receiving a sufficient supply of oxygen and that part of the heart attack could occur in future.

2.16.2 Heart attack

Many heart attacks occur without warning. A blood clot may completely block a coronary artery, or atherosclerosis may reach a critical level causing massive damage to the heart muscle. All of a sudden, the person feels a heavy squeezing ache or discomfort in the centre of the chest. The pain may radiate to shoulder, arm neck or jaw. Other symptoms may include sweating, nausea, shortness of breath and dizziness or fainting. The whole process is called **myocardial** (heart muscle) **infarction** (death due to lack of oxygen). When heart muscles die, they are not replaced because cardiac muscles do not divide. When a person survives a heart attack scar tissue (a type of connective tissue) grows into the areas where the heart muscles have died. The scar tissue cannot contract as cardiac muscle. As a result the damaged heart is permanently weakened.

2.16.3 Heart failure

Congestive heart failure is inability of heart to pump all the blood coming to it. The cardiac output is unable to keep pace with the venous return.

2.16.4 Congenital heart problem

Congenital heart problems result from abnormalities in the embryonic development. It can be related to the malfunctioning of cardiac valves e.g., **Valvular stenosis.**

2.17 DIAGNOSIS OF CARDIOVASCULAR DISORDERS

Modern research efforts have resulted in improved diagnosis of CVD, their treatment and preventions.

a. Principles of angiography

Cardiac catheterization is a technique in which specially designed catheter is inserted into a vein or artery and advanced into the heart under radiographic fluoroscopic guidance. This allows the operator to obtain angiograms by injecting contrast media into an area of interest. It is used to evaluate disease of the mitral valve, aortic valve and aorta, to determine the size and function of the left ventricle.Coronary angiography is used to detect stenosis (narrowing of a tube) and guide revascularisation procedures such as balloon angiography and stenting.

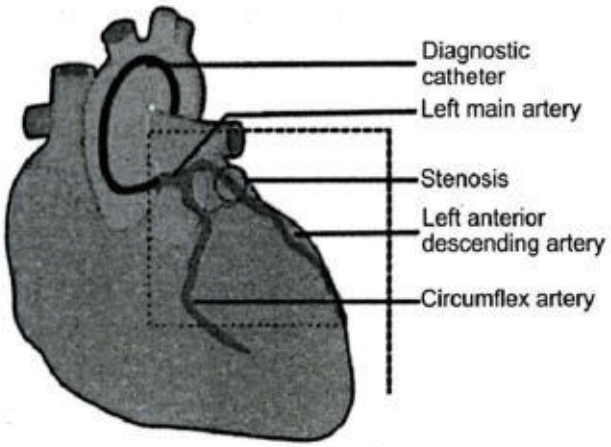


Fig. 2.16: Coronary angiogram-schematic of the vessels and branches

b. Coronary bypass

A coronary bypass is a surgical procedure that relieves the effects of obstruction in the coronary arteries. The technique involves taking healthy segments of blood vessel from other parts of the patient's body usually a vein from the leg or an artery of thorax to bypass obstructions in the coronary arteries.

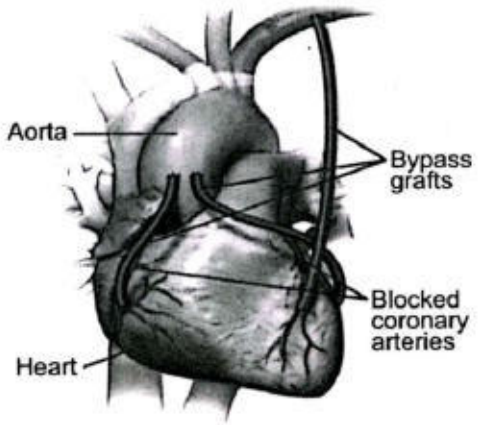


Fig. 2.17: Coronary artery bypass graft.

c. Angioplasty

In angioplasty a cardiologist threads a plastic tube into an artery of an arm or a leg and guides it through a major blood vessel toward the heart. When the tube reaches the region of plaque in a coronary artery a balloon is attached to the end of the tube is inflated forcing the vessel open. However, the artery may not remain open, so slotted tubes called **stents** are expanded inside the artery to keep the artery open. Stents are coated with heparin to prevent blood clotting and chemicals to prevent arterial closing.

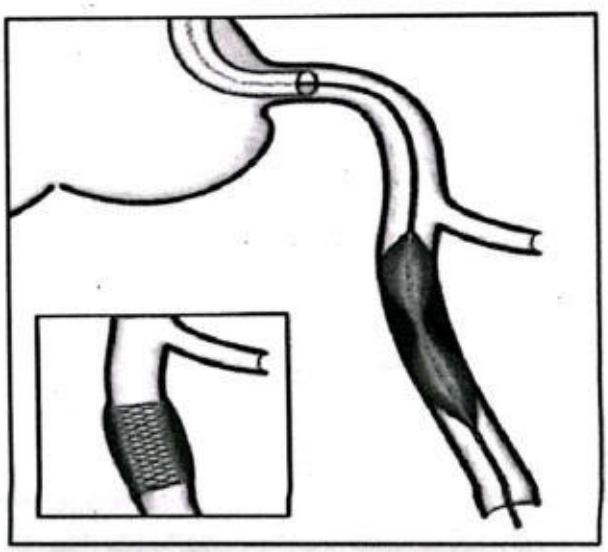


Fig. 2.18: Coronary artery bypass graft.

d. Open heart surgery

This is a surgery in which the patient's chest is opened. The surgery is performed on the heart. The term "open" refers to the chest, not to the heart itself. The heart may or may not be opened depending on the particular type of surgery. Heart surgery is used to correct heart problems in children and adults. An incision is made through the breastbone (sternum) while the patient is under general anesthesia. Tubes are used to re-route the blood through a special pump called a heart-lung bypass machine. This machine adds oxygen to the blood and keeps the blood warm and moving through the rest of the body while the surgeon is repairing the heart. Using the machine allows the heart to be stopped. Stopping the heart makes it possible to repair the heart muscle itself, the heart valves, or the blood vessels outside the heart. After the repair is done, the heart is started again, and the machine is removed. The breastbone and the skin incision are then closed.

2.18 HYPERTENSION AND HYPOTENSION

Hypertension

Blood pressure (BP) is the measurement of the pressure or force of blood pushing against blood vessel walls. The BP reading has two numbers. The top number is the **systolic blood pressure**, which measures the pressure on the artery walls when the heart beats or contracts. The bottom number is the **diastolic blood pressure**. This measures the pressure on the artery walls between beats when the heart is relaxing. The physicians' measure blood pressure in millimeters of mercury (mmHg). Your blood pressure may be different at different times of the day. High blood pressure is also called **hypertension**. When the blood pushes harder against the walls, your blood pressure goes up.

Definition: Hypertension is defined as blood pressure higher than 140/90 mmHg.

A diagnosis of hypertension may be made when one or both readings are high. 120/80 mmHg is normal blood pressure

2.18.1 Factors regulating blood pressure

Blood pressure is influenced by various factors. These factors can be broadly categorized into controllable and uncontrollable risk factors.

Controllable Factors

a. Diet: High sodium intake, a diet low in potassium, and excess saturated fat can elevate blood pressure.
b. Physical Activity: Lack of regular exercise is a significant risk factor.
c. Weight: Being overweight or obese increases the risk of high blood pressure.
d. Stress: High stress levels can lead to temporary increases in blood pressure.
e. Sleep: Insufficient or poor quality sleep can affect blood pressure regulation.
f. Medications: Some medications, including cough and cold medicines, can interfere with blood pressure control.

Uncontrollable Factors

a. Age: The risk of high blood pressure increases with age.
b. Genetics: Family history of hypertension can increase your predisposition.

c. Medical Conditions: Conditions like kidney disease, thyroid problems, and obstructive sleep apnea (Sleep apnea is a common condition that occurs when you're breathing stops and restarts many times while you sleep) can affect blood pressure.

Other Factors

Baroreceptors: These are sensory receptors in blood vessels that monitor blood pressure and send signals to the brain to adjust heart rate and blood vessel constriction.

a. **Cardiac Output:** This refers to the amount of blood pumped by the heart with each beat, and it is influenced by heart rate and stroke volume.
b. **Total Peripheral Resistance:** This is the resistance to blood flow in the blood vessels, and it is affected by factors like blood vessel diameter and blood viscosity.
c. **Blood Volume:** The amount of blood in the circulatory system also impacts blood pressure.
d. **Blood Viscosity:** The thickness of blood can affect its flow and pressure.

2.18.2 Hypotension

Low blood pressure is a condition in which the force of the blood pushing against the artery walls is too low. It's also called hypotension. Blood pressure is measured in millimeters of mercury (mm Hg). In general, low blood pressure is a reading lower than 90/60 mm Hg.

2.18.3 Protection from hypertension and cardiac problem

To protect yourself from hypertension and cardiac problems, make significant lifestyle changes. Look at these changes:

1. Heart-Healthy Diet

a. Focus on fruits, vegetables, whole grains, and lean protein: These foods are rich in nutrients and fiber, which can help lower blood pressure and cholesterol.
b. Limit saturated and Tran's fats: These fats can raise LDL cholesterol, increasing the risk of heart disease.
c. Reduce sodium intake: High sodium levels can contribute to high blood pressure.
d. Choose anti-inflammatory foods: Foods like dark green leafy vegetables, orange-colored vegetables, and legumes can help reduce inflammation, which is linked to heart disease.

2. Regular Physical Activity

a. Aim for at least 150 minutes of moderate-intensity aerobic activity or 75 minutes of vigorous activity per week: This could include walking, running, swimming, or dancing.
b. Incorporate strength training exercises: These help build muscle, which can improve overall metabolism and help manage weight.

3. Maintain a Healthy Weight

a. Calculate your Body Mass Index (BMI) to determine if you're at a healthy weight: Being overweight or obese increases the risk of hypertension and heart disease.
b. Combine a healthy diet with regular physical activity to lose weight and maintain it: This helps lower blood pressure and cholesterol levels.

4. Quit Smoking

a. Smoking damages blood vessels and increases the risk of heart attack and stroke: Quitting smoking is one of the most important steps you can take to improve your heart health.

5. Manage Stress

a. Find healthy ways to manage stress, such as exercise, yoga, meditation, or spending time with loved ones: Chronic stress can contribute to high blood pressure and other health problems.
b. Get enough sleep: Aim for 7-9 hours of quality sleep per night to allow your body to recover and manage stress.

2.19 INTERCELLULAR FLUID AND LYMPH

The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland. About one sixth of the body consists of spaces between the cells, which collectively are called the **interstitium**. The fluid in these spaces is the **interstitial fluid** or **intercellular fluid.**

2.19.1 Interstitial fluid

Formation: The fluid in the interstitium is derived by filtration and diffusion from the capillaries.

Composition: Interstitial fluid contains almost the same constituents as plasma except for much lower concentrations of proteins because proteins do not pass outward through the walls of the capillaries with ease.

Function: The interstitial fluid allows rapid transport of water molecules electrolytes, nutrients, cellular excreta, oxygen, carbon dioxide etc. Materials are exchanged between the blood and interstitial fluid and between the interstitial fluid and the body cells. In other words, to get from the blood to body cells or vice versa, materials must pass through the interstitial fluid.

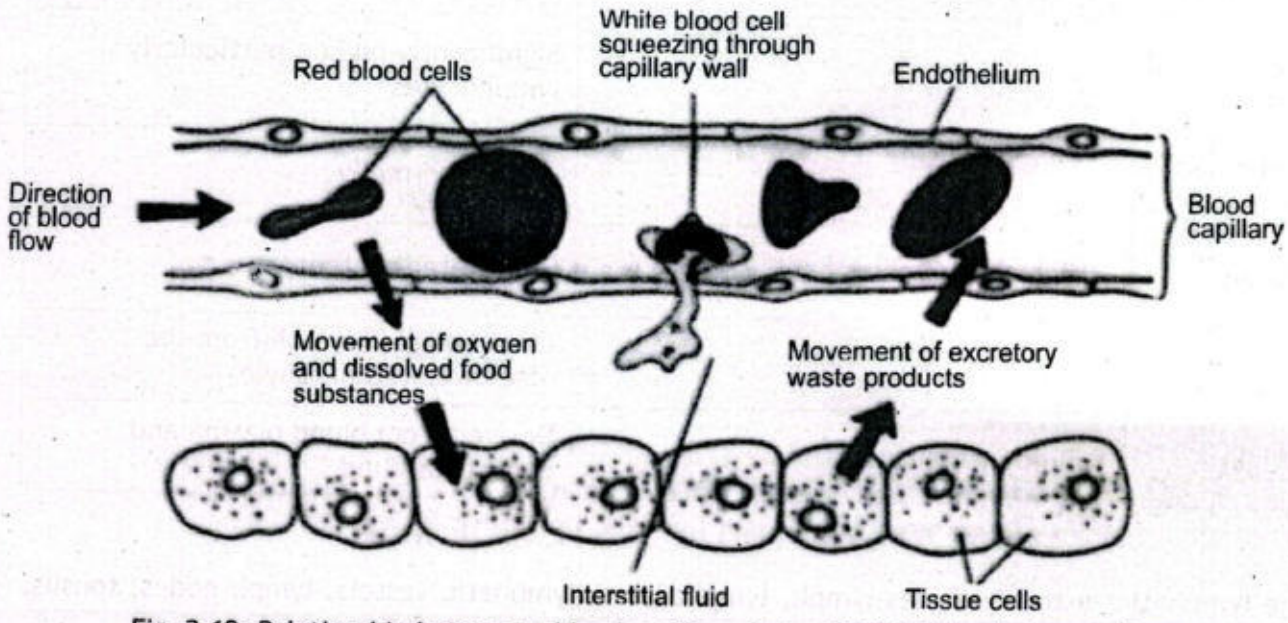


Fig. 2.19: Relationship between a blood capillary, interstitial fluid and tissue cells

2.19.2 Comparison of the composition of interstitial fluid and lymph

The composition of intercellular fluid is primarily water. along with electrolytes sugars, salts, acids, hormones, neuro-transmitters and cell wall products. The tissue fluid that had entered the lymphatic capillaries is called **lymph** and passes through the lymphatic vessels back to the blood. In addition to water lymph contains solutes such as ions, nutrients, gases and some proteins, hormones, enzymes and waste products. As lymph moves through the lymphatic system it accumulates more white blood cells (lymphocytes) proteins.

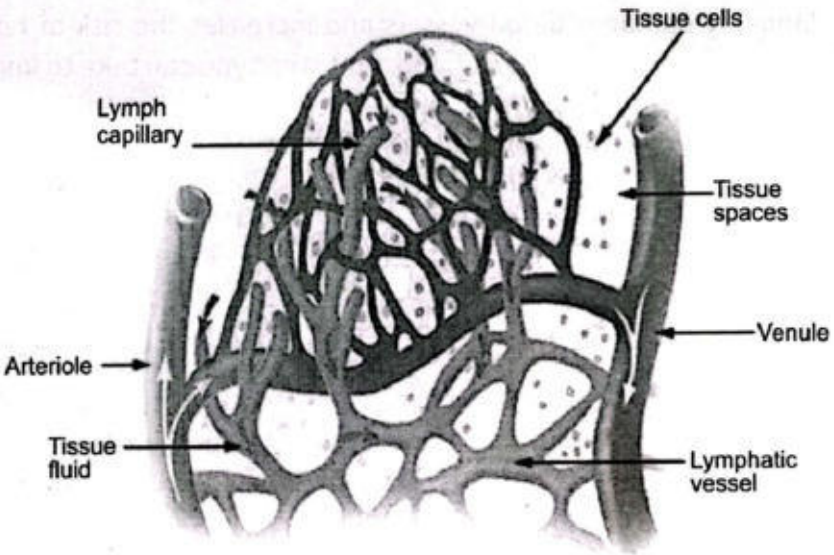


Fig. 2.20: Lymphatic vessels

Table 2.1 Differences between composition of intercellular fluid and lymph

Feature	Intercellular Fluid	Lymph
Major Electrolytes	High potassium, high phosphate, moderate magnesium, low sodium	High sodium, high chloride, moderate potassium, moderate phosphate
Proteins	Higher concentration of proteins	Lower concentration of proteins than plasma
White Blood Cells	–	Significantly higher, particularly lymphocytes
Red Blood Cells	–	Absent normally
Water	High water content	High water content
Fats	–	Can be high in lymph from the digestive system (chyle)
Origin	Fluid inside cells	Derived from blood plasma and interstitial fluid

2.20 LYMPHATIC SYSTEM OF MAN

The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland.

2.20.1 Lymph vessels

Lymphatic pathways begin as lymphatic capillaries. These tiny tubes emerge to form larger lymphatic vessels, which in turn lead to the collecting ducts that unite with the veins in the thorax.

a. Lymphatic Capillaries

Lymph capillaries are microscopic, closed-ended tube. See the figure given (Fig: 2.21). They extend into the spaces within interstitial spaces, forming complex networks that parallel the networks of blood capillaries. The walls of the lymphatic capillaries, like those of blood capillaries, consist of a single layer of squamous epithelial cells. This thin wall makes it possible for interstitial fluid from interstitial spaces to enter the lymphatic capillary. Once the fluid is inside a lymphatic capillary, it is called **lymph**. Each villus contains a lymph capillary called **lacteal**. The lacteal absorbs fats and other substances from digestive tract.

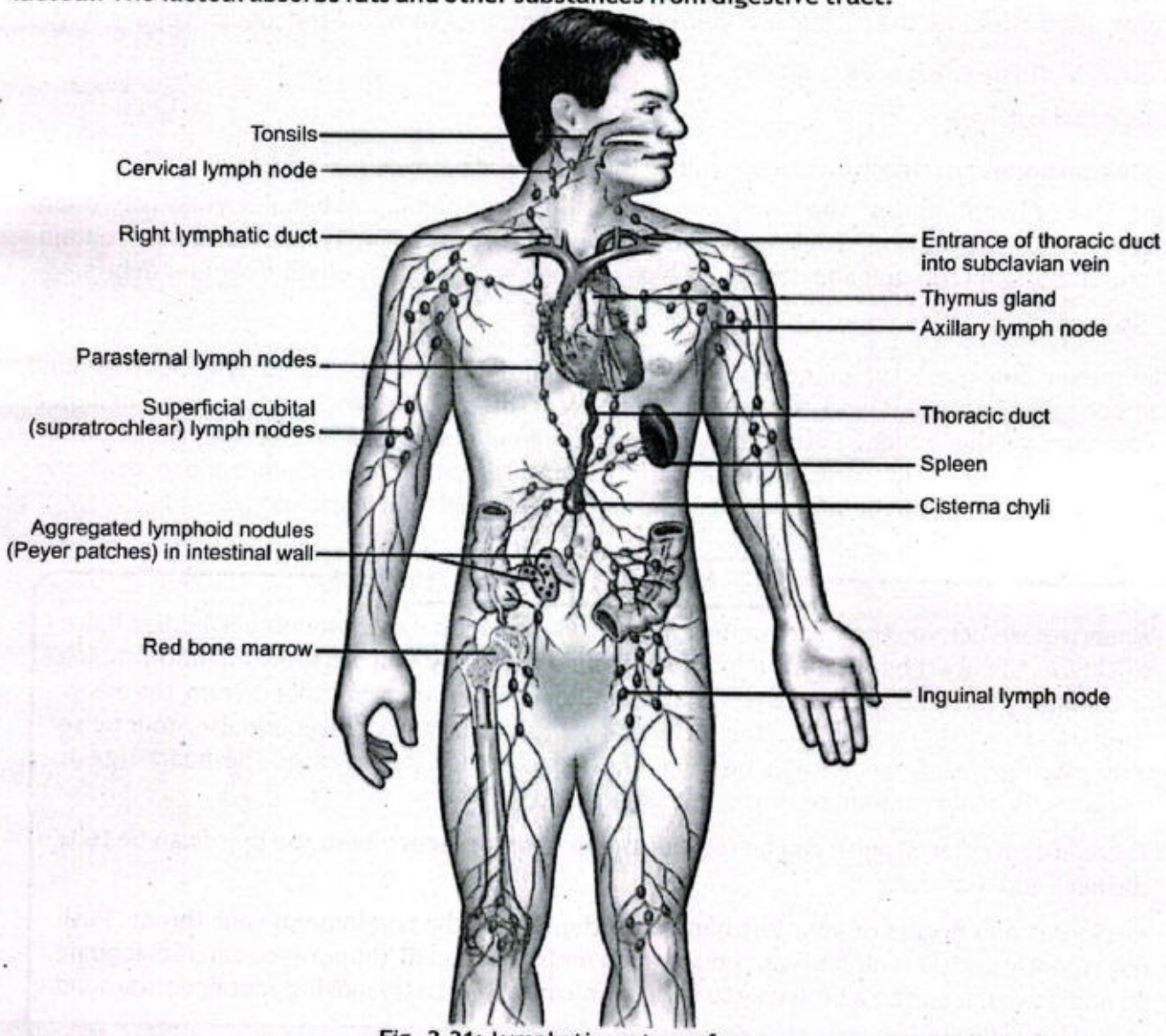


Fig. 2.21: Lymphatic system of man

b. Lymphatic Vessels

Lymphatic vessels are formed by merging of lymphatic capillaries, have walls similar to those of veins. Also like veins, lymphatic vessels have flap like valves, which help to prevent the backflow of lymph. Typically, the lymphatic vessels lead to specialized organs called **lymph nodes.** After leaving these structures, the vessels merge to form still larger lymphatic trunks.

c. Lymphatic Trunks

Lymphatic trunks, the drain lymph from relatively larger portions of the body, are named for the region they serve. The lymphatic trunks then join one of two collecting ducts, the thoracic duct or the right lymphatic duct. The **thoracic duct** is the larger and longer of the two collecting ducts. It receives lymph from the lower body regions, left side, and left side of the head and neck, and empties into the left subclavian vein near the junction of the left jugular vein. The **right lymphatic duct** receives lymph from the right side of the head and the neck, right arm and right thorax. It empties into the subclavian vein near the junction of the right and jugular vein.

2.20.2 Lymph nodes and spleen

a. Lymph nodes

The **lymph nodes** are structures located along the lymphatic pathways.

Functions of lymph nodes: The lymph nodes contain a large number of lymphocytes. The lymph nodes act against foreign particles, such as bacteria and viruses. The lymph nodes also contain macrophages, which engulf and destroy foreign substances, damaged cells and cellular debris.

b. Spleen

The spleen helps get rid of germs. It contains white blood cells called lymphocytes and macrophages. These cells work to attack and destroy germs and remove them from the blood that passes through the spleen. Filters blood by removing cellular waste and getting rid of old or damaged blood cells. It stores blood and iron for future use. It makes white blood cells and antibodies that help to fight infection. It maintains the levels of fluid in your body.

STEAM ACTIVITY 2.1

When we are active, the heart pumps faster to help blood move around our bodies more quickly. As the heart beats and pumps blood around your body, you can feel a slight throbbing or thumping in some parts where an artery (blood vessel carrying blood from the heart around the body) comes close to the surface of your skin. This is called your pulse. Your pulse tells you how fast your heart is beating; this is called your heart rate. The heart rate is measured in beats per minute, sometimes shortened to BPM.

There are few places pulse can be felt but the two main places where the pulse can be felt; the neck and the wrist

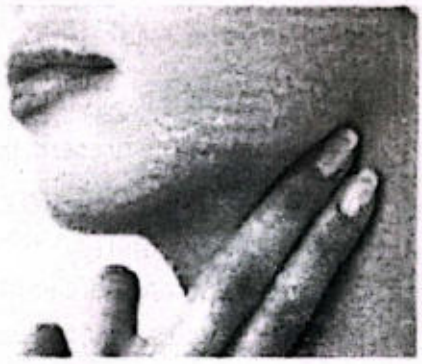
Neck: Put two fingers of your left hand onto the side of the windpipe in your throat. Push down gently and you will find your pulse which feels like a small 'thump' (you can feel it going up and down). It can be a bit tricky to find, so you may have to try moving your fingers around to find the right spot.

Wrist: Using the pointer and middle fingers of your right hand, slide from the base of your left thumb (the squishy part of your palm) to where your hand meets your wrist. You might need to move the fingers around until you find the right spot. When you have found the pulse, count how many times you feel it while timing 30 seconds. Multiply this number by 2 to calculate your heart rate in beats per minute (BPM).

Pulse Experiment

Material required: A stopwatch, timer or clock with a second hand, Pencil Record sheet.

on the wrist



on the neck

Step 1: Begin by finding your resting heart rate by taking your pulse. This is how fast your heart is beating each minute when not doing physical activity. Set a timer for one minute. Sit down and relax, taking slow deep breaths.

Step 2: Then set a timer for 30 seconds and take your pulse on the wrist or neck. Record this number in the table below and multiply it by 2 to calculate your resting heart rate in beats per minute.

Step 3: Jog on the spot for 30 seconds. Set your timer and take your pulse again for 30 seconds. Record and calculate beats per minute.

Step 4: Rest for one minute to allow your heart rate to slow down again.

Step 5: Continue doing the activities named on the record sheet for 30 seconds, taking your pulse after each to find BPM. Ensure you take one minute of rest after each time you take your pulse

Record Sheet			
Name of the activity	**Length of the activity**	**Beats counted in 30 seconds**	**Heart rate .BMP, Multiply by 2 to calculate beats in 60 seconds**
Sitting	60 seconds		X2 = ---------- BPM
Jogging on the spot	30 seconds		X2 = ---------- BPM
Stretching	30 seconds		X2 = ---------- BPM
Running as fast as on the spot	30 seconds		X2 = ---------- BPM

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Which one of the following has the thickest wall?

   A. right ventricle B. left ventricle C. right atrium D. left atrium

2. The reason why tricuspid and bicuspid valves are closed is

   A. ventricular relaxation B. ventricular filling

   C. atrial systole D. attempted backflow of blood into the atria

3. Tricuspid valve is present between

   A. ventricle and pulmonary artery

   B. ventricle and aorta

   C. left auricle and left ventricle

   D. right auricle and right ventricle

4. From where does the aorta originate?

   A. Right ventricle B. Left atrium C. Right atrium D. Left ventricle

5. How many aortic valves are present?

   A. 1 B. 2 C. 3 D. 4

6. The epicardium:

   A. Is also known as the parietal pericardium.

   B. Is a layer of cardiac muscle.

   C. Is the visceral pericardium.

   D. Lines the heart chambers.

7. The tissue which forms a loose-fitting sac around the heart is the:

   A. Visceral pericardium. B. Parietal pericardium.

   C. Myocardium. D. Epicardium.

8. The valve between the left ventricle and the blood vessel leaving the left ventricle is the:

   A. Bicuspid valve B. Tricuspid valve

   C. Pulmonary semilunar valve D. Aortic semilunar valve

9. During the period of ejection in the cardiac cycle, the atrioventricular valves are ..... and the semilunar valves are.....

   A. closed, closed B. closed, open

   C. open, closed D. open, open

10. The second heart sound, described as "dupp" is actually the sound of the
    A. Atria contracting
    B. Ventricles contracting
    C. Atrioventricular valves closing
    D. Semilunar valves closing

11. Cardiac output is determined by:
    A. heart rate
    B. stroke volume
    C. blood flow
    D. heart rate and stroke volume

12. Which one is the definition of cardiac.cycle?
    A. The contraction of the atria.
    B. Circulation of blood in the heart.
    C. The contraction and relaxation of the ventricles.
    D. It is sequence of events that occurs during a complete heartbeat.

13. For how long is the cardiac cycle, if the heart rate is 75 beats/min?
    A. 0.7 sec
    B. 0.8 sec
    C. 0.5 sec
    D. 0.4 sec

14. The fluid that passes through the lymphatic vessels
    A. flows toward the lungs
    B. passes from the lymphatic vessels into the arteries
    C. enters the left ventricle of the heart through the right thoracic duct
    D. moves in a single direction toward the heart

15. Lymph nodes may be located in the human body in the tissues of the
    A. stomach and brain
    B. groin and neck
    C. ventricle and atrium
    D. thyroid gland and adrenal gland

16. A red blood cell, entering the right side of the heart, passes by or through the following structures:
    1. atrioventricular valve 2. semilunar valve 3. right atrium 4. right ventricle 5. Pulmonary trunk
    In which order will the red blood cell passes the structures?
    A. 2 → 3 → 1 → 4 → 5
    B. 3 → 1 → 4 → 2 → 5
    C. 3 → 5 → 1 → 2 → 4
    D. 5 → 3 → 1 → 4 → 2

17. The rhythmic beating of cardiac muscle in the mammalian heart is initiated by the.
    A. atrio-ventricular node
    B. parasympathetic nervous system
    C. Purkinje tissue
    D. sino-atrial node

18. What produces systolic blood pressure?
    A. contraction of the right atrium B. contraction of the right ventricle
    C. contraction of the left atrium D. contraction of the left ventricle
19. *Human* heart is
    A. myogenic B. neurogenic C. cardiogenic D. digenic
20. Pacemaker is situated in heart
    A. in the wall of right atrium B. on interauricular septum
    C. on interventricular septum D. in the wall of left atrium

Section II: Short Answer Questions

1. Why do we have a circulatory system?
2. What are the contraction and relaxation of human heart called?
3. Where is SA node, AV node, Purkinje fibre, Bundle of His located?
4. Why action potentials travel along the Purkinje fibres more rapidly than through other muscle fibres?
5. Name the artery supplying blood to the heart.
6. What is blood pressure?
7. Why SA node is called pacemaker of the heart?
8. What is a cardiac cycle?
9. What is an arterial pulse? What is the normal human pulse rate?
10. Why is AV node essential for the conduction of cardiac impulse?
11. What are the risks associated with atherosclerosis?
12. Why can you feel your pulse in arteries but not in veins? If there is no pulse in your veins what pushes the blood in veins back to the heart?
13. Define the term thrombus and differentiate between thrombus and embolus.
14. Identify the factors causing atherosclerosis and arteriosclerosis.
15. List the advantages and disadvantages of coronary bypass.
16. List the changes in the life styles that can protect man from hypertension and cardiac problems.
17. What is the major feature of human lymphatic system?
18. Justify why blood circulatory system is dependent on the lymphatic system.
19. Interpret why the swelling of the lymph node is cause of concern.
20. Write the differences between:
    (a) bicuspid valve and tricuspid valve
    (b) systole and diastole
    (c) SA node and AV node
    (d) P-wave and T-wave of ECG
    (e) blood capillaries and lymph capillaries
    (f) baroreceptor and volume receptor

Section III: Extensive Answer Questions

1. Draw, label and describe the external structure of human heart.
2. Describe the flow of blood through human heart as regulated by the valves.
3. State the phases of heartbeat in man.
4. Describe the conducting system of human heart.
5. Explain electrocardiogram with the help of diagram.
6. Describe the structure of blood vessels in man.
7. What is the role of precapillary sphincter?
8. Describe pulmonary circulation and systemic circulation.
9. Describe hepatic portal system
10. Give an account of blood pressure in man.
11. Compare the rate of blood flow through arteries, arterioles, capillaries, venules and veins.
12. Explain the following:
    a. Principle of angiography
    b. Coronary bypass
    c. Angioplasty
    d. Open heart surgery
13. Explain hypertension and hypotension. What are the factors that regulate blood pressure?
14. Describe the lymphatic system of man.

RESPIRATORY SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-01] Define the respiratory surface and list its properties.
2. [B-12-R-02] Describe the main structural features and functions of human respiratory system.
3. [B-12-R-03] Explain the ventilation mechanism in humans.
4. [B-12-R-04] Discuss the transport of oxygen and carbon dioxide through blood.
5. [B-12-R-05] Outline the role of respiratory pigments.
6. [B-12-R-06] State the causes, symptoms and treatment of upper respiratory tract infections (sinusitis, otitis media) and lower respiratory infections (pneumonia, pulmonary tuberculosis).
7. [B-12-R-07] Describe the disorders of lungs (emphysema and COPD)
8. [B-12-R-08] List the effects of smoking on respiratory system.

Like other life processes, the respiration process also occurs at cellular level and organismic level. The process of respiration that occurs at cellular level is also called **internal respiration** which is a catabolic process. It involves the breakdown of complex organic compounds into simpler molecules with the release of energy. On the other hand, the process of respiration that occurs at organismic level is also called **external respiration.** It involves the inhaling of oxygen and exhaling of carbon dioxide. Both the processes are interlinked as the oxygen, required for cellular respiration, is inhaled from environment while the carbon dioxide which is produced in cellular respiration, is exhaled into the environment. This chapter deals with various aspects of respiration.

3.1 PROPERTIES OF RESPIRATORY SURFACE

The area where gaseous exchange with the environment actually takes place is called the **respiratory surface**. The respiratory surface must have the following properties so that diffusion can occur effectively:

- It must be moist and permeable so that gases can pass through.
- It must be thin, because diffusion is only efficient over distance of 1 mm or less.
- It should possess a large surface area so that sufficient amount of gases can be exchanged according to the organism's need.
- It should possess a good blood supply.
- There should be a good ventilation mechanism to maintain a steep diffusion gradient across the respiratory surface.

3.2 RESPIRATORY SYSTEM OF MAN

The body system which is responsible for the exchange of gases between body fluid and outer environment is called **respiratory system.**
The human respiratory system can be divided into two regions, upper respiratory tract and lower respiratory tract.

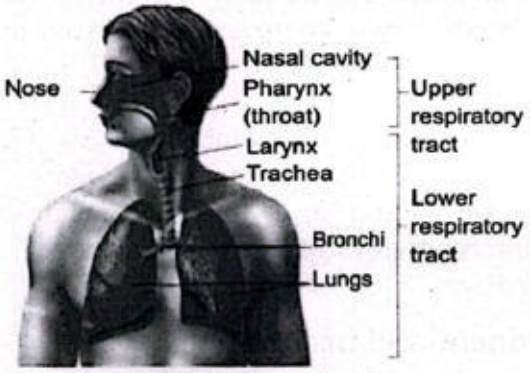


Fig. 3.1: Human respiratory tract

3.2.1 Upper Respiratory Tract

The upper respiratory tract includes nostrils, nasal cavity and pharynx.

Nose

The nose is only externally visible part of the respiratory system. Human nose is composed of bones, cartilage and fatty tissues. The external openings of nose are called **nostrils** and the inner hollow spaces are called **nasal cavities**. There are two nasal cavities which are partitioned by means of nasal septum (the part of nasal bone). The anterior parts of nasal cavities near the nostrils are called **vestibules** which contain hair. Both the nostrils and nasal cavities are lined by ciliated mucous membranes.

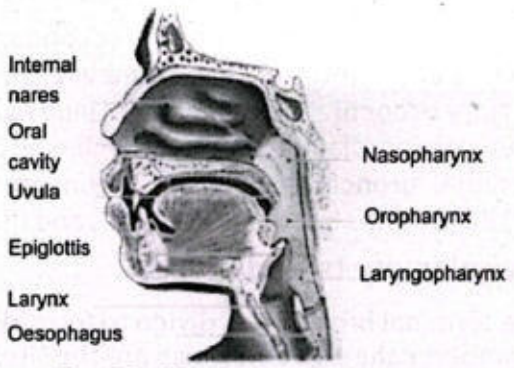


Fig. 3.2: Human respiratory tract

Nose hair, mucus and cilia serve as a defence mechanism against the harmful pathogens and particulate matter present in the air. The mucus and cilia filter the air and prevent the entry of foreign particles such as microorganisms, dust and particulate matter inside the respiratory system. The mucus also helps in moistening the air. Cilia move the trapped substances to the pharynx for their removal. Underneath the mucous membrane, there are blood capillaries that help to warm the air to about 30°C, depending upon the external temperature.

Pharynx

Pharynx is cone-shaped passageway leading from the oral and nasal cavities to the esophagus and larynx. The pharynx is part of the digestive system and also the respiratory system. The human pharynx is conventionally divided into three sections: the nasopharynx, the oropharynx, and the laryngopharynx

3.2.2 Lower Respiratory Tract

The lower respiratory tract includes the larynx, trachea, bronchi and lungs.

Larynx

The larynx is an enlargement in the airway at the top of the trachea and below the pharynx. The larynx is composed primarily of muscles and cartilages. One of the cartilages is the **epiglottis**. This structure usually stands upright and allows air to enter the larynx. During swallowing, however larynx is raised and the epiglottis is pressed downward. As a result, the epiglottis partially covers the opening into the larynx and helps to prevent foods and liquids from entering the air passages. The opening of the larynx is called **glottis**. It is also lined with mucus membrane. Inside the larynx, there are two vocal cords which are responsible for vocalization.

Trachea

The trachea or windpipe is a membranous tube. It consists of dense regular tissue and smooth muscle reinforced with 15-20 C-shaped pieces of cartilage.

SCIENCE TITBITS

The alveoli of human lungs are lined with a **surfactant**, a film of lipoprotein that lowers the surface tension and prevents them from closing. Surfactant also speeds up the transport of oxygen and carbon dioxide between the air and liquid lining the alveolus and helps to kill any bacteria, which reach the alveoli. Surfactant is constantly being secreted and reabsorbed in a healthy lung.

Bronchi and bronchioles

The trachea divides to form two smaller tubes called **primary bronchi**.

The primary bronchi divide into **secondary bronchi** within each lung. There are two secondary bronchi in the left lung and three in the right lung. The secondary bronchi, in turn, give rise to **tertiary bronchi**. The bronchi continue to branch, finally giving rise to **bronchioles** which are less than 1mm in diameter. The bronchioles also subdivide several times to become even smaller **terminal bronchioles**. In the secondary bronchi, the C-shaped cartilages are replaced with cartilage plates but the bronchioles and their terminal branches have no cartilage structures.

Alveolar ducts and alveoli

The terminal bronchioles divide to form **alveolar ducts**. These alveolar ducts end at tiny air filled chambers called **alveoli** which are the sites of gas exchange between the air and the blood. There are over 700 million alveoli present in the lungs.

The wall of each alveolus is only 0.1 μm thick. On its outsides is a dense network of blood capillaries. Lining each alveolus is moist squamous epithelium. This consists of very thin, flattened cells, reducing the distance over which diffusion must occur. Collagen and elastin proteins are also present in their walls which allow the alveoli to expand and recoil easily during breathing.

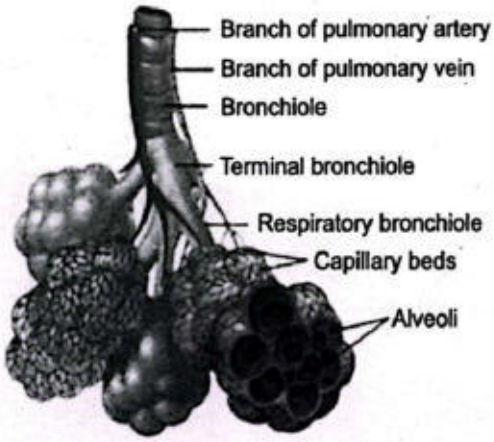


Fig. 3.3: Alveoli

External structure of lungs

The lungs are the principal organs of respiration. Each lung is conical in shape, with its base resting on the diaphragm and its apex extends to a point just above the clavicle. The right and left lungs are separated medially by the heart and **mediastinum**, which is the area between the lungs.

The left lung has two lobes, **superior lobe** and **inferior lobe**. The left lung shares space with the heart. The right lung has three lobes. The **hilum** is a triangular shaped depression of both the lungs where the blood vessels and airways pass into the lungs. The lungs are spongy due to presence of alveoli.

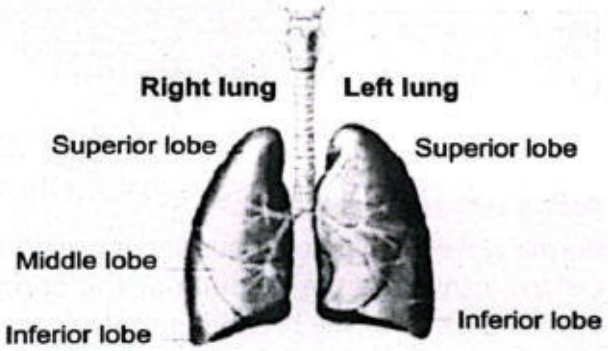


Fig. 3.4: Human lungs

3.3 MECHANISM OF VENTILATION (BREATHING)

The lungs themselves neither draw in air nor push it out. The diaphragm and the intercostal muscles accomplish the expansion and contraction of the lungs. The **diaphragm** is a large dome of skeletal muscle that separates the thoracic cavity from abdominal cavity. There are two sets of **intercostal muscles** between each pair of ribs: the external intercostal and the internal intercostal. The muscle fibres run diagonally but in opposite direction in the two sets of muscles. Breathing takes place in two phases i.e., inspiration and expiration.

Inspiration: It is taking in of air; it is the active phase of breathing. During inspiration contraction of the diaphragm causes its dome shape to flatten or less dome shape whereas contraction of the external intercostal and relaxation of the internal intercostal causes the rib cage to move upward and forward. Both these events result in increase of inner space of thoracic cavity. Consequently, the pressure in the thorax and hence in the lungs, is reduced to less than atmospheric pressure. Air therefore enters the lungs and alveoli become inflated.

Expiration: It is the removal of air out of the lungs; it is the passive phase of breathing. During expiration relaxation of the diaphragm causes it to become more dome shape whereas relaxation of the external intercostal and contraction of the internal intercostal cause the rib cage to move downward and backward. Both these events result in decrease of inner space of thoracic cavity. Consequently, the pressure in the thorax and hence in the lungs, is increased to more than atmospheric pressure, therefore, air is forced to expelled from the lungs.

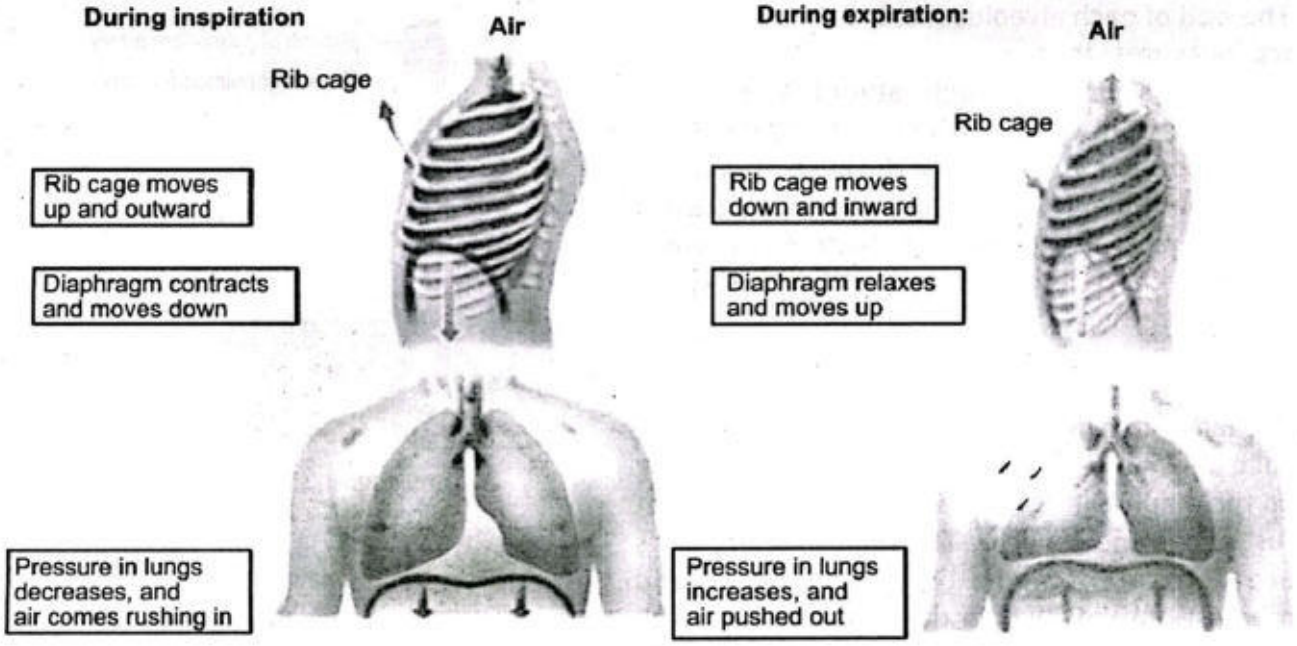


Fig. 3.5: Mechanism of breathing in human

3.3.1 Control of Breathing (Ventilation)

Normally we are not conscious of our breathing because it is controlled involuntarily. A **breathing centre** located in the **medulla** of the brain carries out involuntary control of breathing. The ventral portion of the breathing centre acts to increase the rate and depth of inspiration and is called **inspiratory centre**. The dorsal and lateral portions inhibit inspiration and stimulate expiration. These regions form the **expiratory centre**.

Through the **cerebral cortex** it is possible to consciously or unconsciously increase or decrease the rate and depth of the respiratory movement. A person may also stop breathing voluntarily. Occasionally people are able to hold their breath until the blood partial pressure of oxygen declines to a level low enough that they lose consciousness. After consciousness is lost, the respiratory centre resumes its normal function in automatically controlling respiration. Emotions acting through the **limbic system** of the brain can also affect the respiratory centre.

3.4 TRANSPORT OF GASES

Like other materials, respiratory gases are also transported in various regions of the body by means of blood. The blood transports oxygen from the lungs to different tissues and carbon dioxide from tissues to the lungs.

3.4.1 Transport of Oxygen in Blood

Approximately 97% of oxygen is carried by the red blood cells as **oxyhaemoglobin**, while 3% is transported as dissolved oxygen in the **plasma**. At its high partial pressure oxygen binds with haemoglobin.

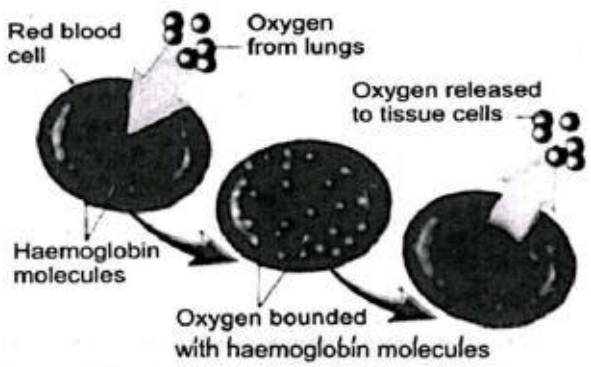


Fig. 3.6: Human lungs

This binding is reversible that occurs in the lungs in the presence of enzyme carbonic anhydrase. Each molecule of haemoglobin can bind with four molecules of oxygen to form oxyhaemoglobin.

$$Hb + 4O_2 \xrightarrow{\text{Carbonic anhydrase}} Hb4O_2$$

The ability of haemoglobin to bind with oxygen is called **oxygen carrying capacity** of blood.

SCIENCE TITBITS

The oxygen carrying capacity of blood is directly proportional to the partial pressure of oxygen (PO_2). Maximum oxygen carrying capacity of arterial blood is 20 ml/100 ml of blood (100% saturated) which is achieved at 100 mmHg Po_2. The 5 ml of O_2 is released to the tissues by each 100 ml blood. Oxygen carrying capacity is sensitive to a variety of environmental conditions like rise in body temperature, drop in pH of blood and partial pressures of carbon dioxide and oxygen.

SCIENCE TITBITS

The amount of haemoglobin is 15 gms/100 ml of blood. Since 1gm Hb can combine with 1.34 ml of O_2, therefore 100 ml blood combines with 20 ml O_2 (100% saturated). Normally each 100 ml of arterial blood contains 19.4 ml O_2 (i.e., it is 97% saturated; PO_2 is 95 mmHg), while 100 ml of venous blood contains 14.4 ml O_2 (i.e., it is 75% saturated; Po_2 is 40 mmHg).

3.4.2 Transport of Carbon dioxide in Blood

Carbon dioxide is transported in the blood in three main ways: (i) In the form of bicarbonate ions. (ii) In the form of carboxyhaemoglobin. (iii) Dissolved in plasma.

(I) As bicarbonate ions

Approximately 70% of carbon dioxide is carried in the blood as bicarbonate ions. Carbon dioxide diffuses into the blood, enters the red blood cells and combines with water to form carbonic acid in the presence of enzyme carbonic anhydrase. The chemical reaction can be depicted as follows:

$$CO_2 + H_2O \underset{}{\overset{\text{Carbonic anhydrase}}{\rightleftharpoons}} H_2CO_3$$

Carbonic acid, H_2CO_3 is an unstable compound and dissociates to form hydrogen ions and bicarbonate ions.

$$H_2CO_3 \overset{\text{Carbonic anhydrase}}{\rightleftharpoons} H^+ + HCO_3^-$$

Accumulation of H^+ ions increases acidity in the blood, i.e., it leads to the decrease in pH. This does not occur since haemoglobin buffers the hydrogen formed. The hydrogen ion readily associates with oxyhaemoglobin ($Hb4O_2$) to form haemoglobinic acid (HHb) and oxygen is released to the tissue.

$$Hb4O_2 + H^+ \longrightarrow HHb + 4O_2$$

From inside of the erythrocytes negatively charged HCO_3^- ions diffuse to the plasma. This is balanced by the diffusion of chloride ions, (Cl^-), in the opposite direction. This is achieved by special bicarbonate-chloride carrier proteins that exist in the RBC membrane. This protein moves the two ions in opposite directions, maintaining the balance of ions on either side. This is called the chloride shift or **Hamburger' phenomenon.**

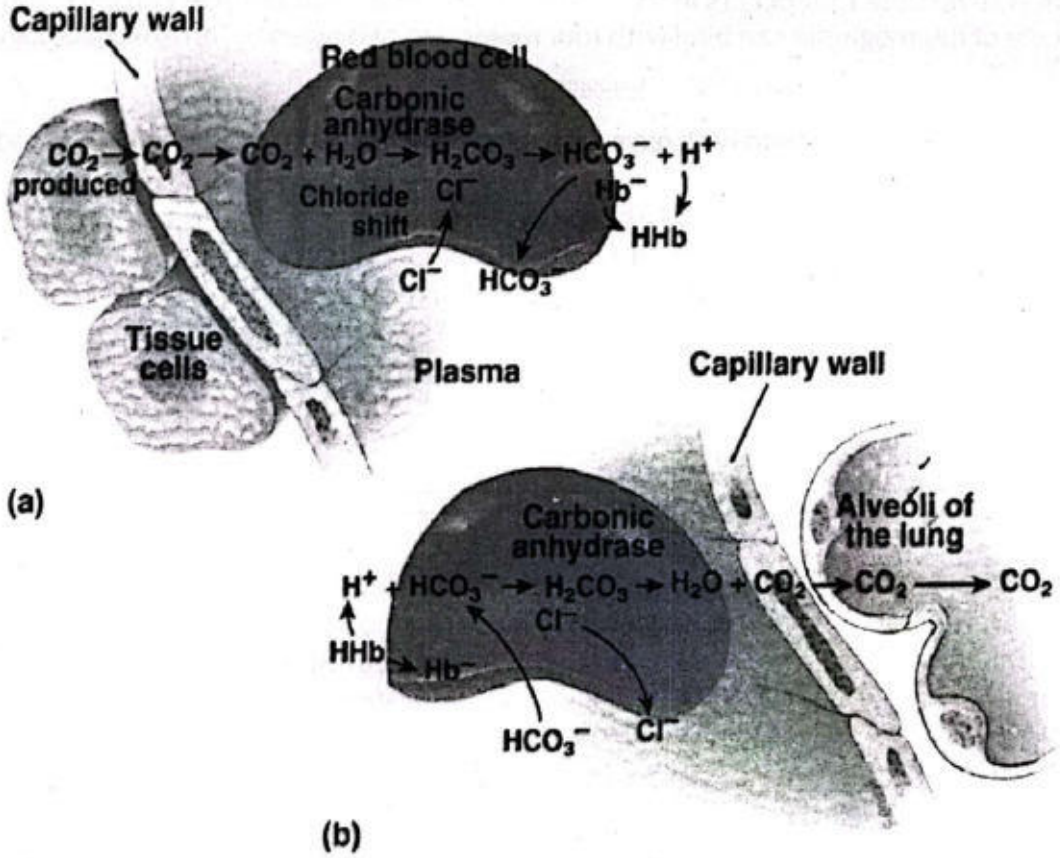


Fig. 3.7: Transport of CO_2 as bicarbonate ions (a) Transfer of CO_2 from tissues to blood (b) Transfer of CO_2 from blood to lungs.

The chloride ions that enter the RBC combine with potassium (K+) to form potassium chloride, whereas bicarbonate ions in the blood plasma combine with Na+ to form sodium bicarbonates. The blood pH is thus maintained at approximately 7.4 by the buffer mechanism that exists in blood.

Transport of CO_2 depends on the partial pressure of CO_2. The partial pressure of Co_2 is higher in tissues than blood so it diffuses into blood here it react with water and transported to the lungs as *bicarbonate ion*. In lungs process reverses and bicarbonate ions combine with hydrogen ion to release carbon dioxide and water.

(II) As Carbaminohaemoglobin

About 23% of carbon dioxide is carried as carbaminohaemoglobin. CO_2 combines with the globin part of haemoglobin. The reaction depends upon the partial pressure of CO_2. When the PCO_2 is higher in the tissues than blood, formation of carbaminohaemoglobin occurs. When the PCO_2 is higher in the blood than tissues as in case of lungs, carbaminohaemoglobin releases its CO_2.

(iii) As dissolved CO_2 in plasma

Only 7% of carbon dioxide is carried this way. This is rather inefficient way to carry carbon dioxide, but it does occur.

3.5 ROLE OF RESPIRATORY PIGMENTS

Respiratory pigments are coloured molecules, which act as oxygen carriers by binding reversibly to oxygen. All known respiratory pigments contain a coloured non-protein portion e.g., **haem** in the haemoglobin. The two well-known respiratory pigments are haemoglobin and myoglobin.

Haemoglobin

It contains four globin protein chains, each associated with haem, an iron-containing group. Iron combines loosely with oxygen and in this way oxygen is carried in the blood. At high oxygen concentrations, the pigment combines with oxygen, whereas at low oxygen concentrations the oxygen is quickly released.

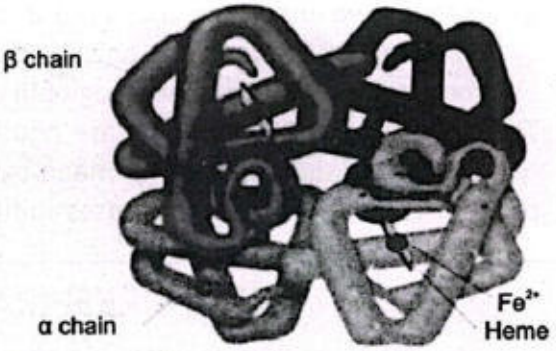


Fig. 3.8: Haemoglobin

Myoglobin

It consists of one polypeptide chain. This chain is associated with an iron containing ring structure. This iron can bind with one molecule of oxygen. It is found in skeletal muscles and is the main reason why meat appears red. It serves as an intermediate compound for the transfer of oxygen from haemoglobin to aerobic metabolic processes of the muscle cells. Myoglobin releases oxygen when the partial pressure of oxygen is below 20 mmHg. In this way it stores oxygen in resting muscle, only releasing it when supplies of oxyhaemoglobin have been exhausted.

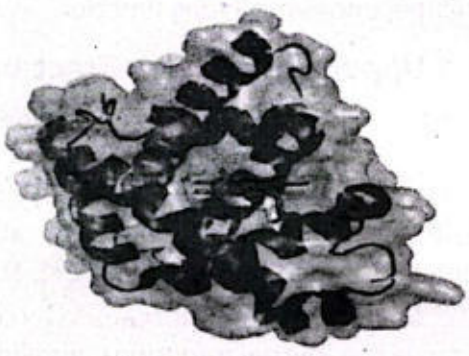


Fig. 3.9: Myoglobin

Table 3.1 Differences between haemoglobin and myoglobin

Haemoglobin	Myoglobin
It consists of four polypeptide chains.	It consists of one polypeptide chain.
Each molecule possesses four iron containing haem groups.	Each molecule possesses one iron containing haem group.
Four oxygen molecules can bind to each haemoglobin molecule.	Only one oxygen molecule can bind to each myoglobin molecule.
It is found in RBCs.	It is found in muscles.
It transports oxygen.	It stores oxygen.
It has less affinity with oxygen.	It has more affinity with oxygen.
It loses oxygen at PO_2 60 mmHg.	It loses oxygen at PO_2 20 mmHg.

Science, Technology and Society Connections

Describe the carbon monoxide poisoning (caused by gas heaters left on overnight in closed environments).

Gases that have undergone incomplete combustion produce CO and toxic fumes (hydrogen cyanide). In carbon monoxide poisoning caused by gas heaters, left on overnight in closed environments, CO binds to haemoglobin preventing the uptake of oxygen by haemoglobin. The symptoms of CO poisoning are nausea, vomiting, headache, mental status changes, and cherry-red lips. CO binds to haemoglobin with affinity 249 times greater than that of oxygen. CO poisoning also decreases ability of haemoglobin to release oxygen to tissue.

3.6 RESPIRATORY DISORDERS

Respiratory disorders refer to diseases that affect the lungs and other parts of the respiratory system. These conditions can range from mild to severe, and they often impact breathing, oxygen exchange, and overall lung function.

3.6.1 Upper Respiratory Tract Infection

The infections of the upper respiratory tract include sinusitis and otitis media etc.

Sinusitis

Sinusitis is an inflammation of the nasal sinuses that may be acute (symptoms last 2 - 8 weeks) or chronic (symptoms last much longer). The sinuses are holes in the skull between the facial bones.

Cause: Sinusitis is generally caused by cold and wet climate. Atmospheric pollution, smoke, dust, overcrowding, dental infections, viral infections etc., also cause sinusitis.

Symptoms: Fever, nasal obstruction, raspy voice, pus-like nasal discharge, loss of sense of smell, facial pain or headache that is sometimes aggravated by bending over.

Treatment: If a bacterial infection is present, antibiotics or sulpha drugs are usually prescribed. Beside it the physician may also prescribe nebulization which can be useful in reducing inflammation in the sinuses and nose and to accelerate recovery.

Otitis media

Otitis media is inflammation or infection located in the middle ear.

Causes: Middle ear infections are usually a result of a malfunction of the eustachian tube. When this tube is not working properly, it prevents normal drainage of fluid from the middle ear, causing a buildup of fluid behind the eardrum. When this fluid cannot drain, it allows for the growth of bacteria and viruses in the ear that can lead to acute otitis media. The following are some of the reasons: (i) A cold or allergy which can lead to swelling and congestion of the lining of the nose, throat, and eustachian tube (this swelling prevents the normal drainage of fluids from the ear) (ii) A malformation of the eustachian tube.

Symptoms: The following are the most common symptoms of otitis media. However, each child may experience symptoms differently. Symptoms may include: (a) unusual irritability

(b) Difficulty sleeping or staying asleep (c) Tugging or pulling at one or both ears. (d) Fever, especially in infants and younger children (e) Fluid draining from ear(s) (f) Loss of balance (g) Hearing difficulties (h) Ear pain.

Treatment: It may include: (a) Antibiotic medication by mouth or ear drops (b) Medication (for pain and fever) (d) A combination of the above.

3.6.2 Lower Respiratory Tract Infection

The infections of lower respiratory tract include, pulmonary tuberculosis etc.

Pneumonia

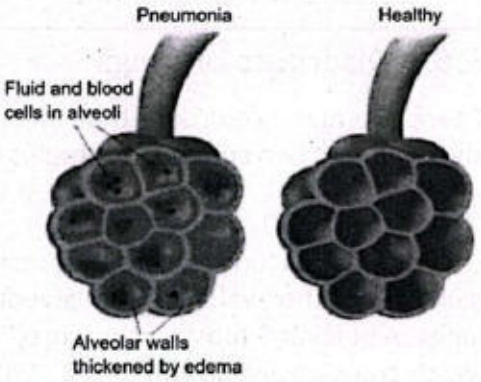


Fig. 3.10: Pneumonia

Pneumonia is an infection that inflames the air sacs in one or both lungs. The air sacs may fill with fluid or pus, causing cough with phlegm or pus, fever, chills, and difficulty breathing.

Causes: A variety of organisms, including bacteria, viruses and fungi, can cause pneumonia.

Symptoms: These may include: (a) Chest pain when you breathe or cough (b) Confusion or changes in mental awareness (in adults age 65 and older (c) Cough, which may produce phlegm (d) Fatigue (e) Fever, sweating and shaking chills. (f) Lower than normal body temperature (in adults older than age 65 and people with weak immune systems) (g) Nausea, vomiting or diarrhea (h) Shortness of breath.

Treatment: Some treatments may include:

1. **Antibiotics:** Pneumonia caused by bacteria is treated with an antibiotic.
2. **Antifungal medications:** Antifungal can treat pneumonia caused by a fungal infection.
3. **Antiviral medications:** Viral pneumonia usually isn't treated with medication and can go away on its own.
4. **Draining of fluids:** If you have a lot of fluid between your lungs and chest wall (pleural effusion), a physician may drain it. This is done with a catheter or surgery.

Pulmonary Tuberculosis

Pulmonary Tuberculosis (TB) is a highly contagious chronic bacterial infection of lungs. When people have pulmonary tuberculosis, the alveoli burst and are replaced by inelastic connective tissue. The cells of the lung tissue build a protective capsule around the bacilli and isolate them from rest of the body. This tiny capsule is called **tubercle**. The tubercles can rupture, releasing bacteria that infect other parts of the lung.

Cause: Pulmonary tuberculosis is caused by *Mycobacterium tuberculosis*.

Symptoms: There is a low-grade intermittent fever usually in the evening, night sweats, weight loss, anorexia, depression, weakness and dry cough with sputum, dull ache in the chest due to Inflammation of the pleura of the lungs.

Treatment: Taking medicines for 9 months regularly can cure T.B disease. This is called **Daily Observed Treatment Short Course (DOTS)**. This treatment is given to patients under supervision to ensure that the "medicines intake" completely cures the patient.

SCIENCE TITBITS

The spread of pulmonary TB can be controlled by some preventive measures like:

1. Living room should be well ventilated and bright.
2. Always cover the mouth with cloth during coughing and sneezing.
3. Avoid spitting openly.
4. Always burry or burn the sputum of patient.
5. The patients should spit in a utensil with lime powder to prevent the spread of disease.
6. The use of masks and other respiratory isolation procedures to prevent spread to medical personal is also important.

3.6.3 Disorders of lungs

There are many disorders that affect lungs. Emphysema and COPD are two common examples of disorders of lungs.

Emphysema

Emphysema is a lung disease that results from damage to the walls of the alveoli in the lungs. A blockage (obstruction) may develop, which traps air inside the lungs. With fewer alveoli, less oxygen moves into your bloodstream.

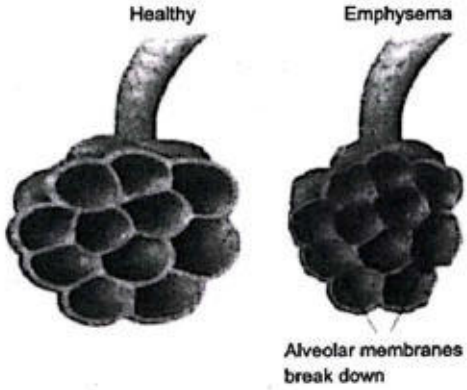


Fig. 3.11: Emphysema

Causes: Smoking is the main cause of emphysema. There are other causes. These include: (a) Marijuana (b) Vaping and e-cigarettes (c) Cigar smoke. (d) Air pollution. (e) Dust.
Symptoms: These include: (a) Long-term coughing (smoker's cough). (b) Wheezing. (c) Shortness of breath, especially during light exercise like climbing steps. (d) Constant feeling of not being able to get enough air. (e) Tightness in the chest. (f) Increased mucus production. (g) Abnormal mucus color (yellow or green). (h) Ongoing fatigue. (i) Heart problems.
Treatment: Treatment options may include: (a) Quitting smoking. (b) Bronchodilators (c) Inhaled and oral corticosteroids (d) Antibiotics (e) Anti-inflammatory medications.

Chronic obstructive pulmonary disease (COPD)

Chronic obstructive pulmonary disease (COPD) is the name for a group of lung conditions that cause breathing difficulties. It includes: (a) emphysema - damage to the air sacs in the lungs (b) chronic bronchitis - long-term inflammation of the airways
Causes: COPD happens when the lungs become inflamed, damaged and narrowed. The main cause is smoking. Some cases of COPD are caused by long-term exposure to harmful fumes or dust. Others are the result of a rare genetic problem that makes the lungs more vulnerable to damage.

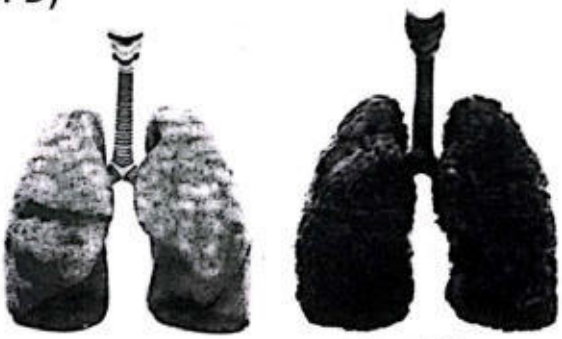


Fig. 3.12: Effects of smoking on lungs

Symptoms: The main symptoms of COPD are: (a) shortness of breath, (b) a persistent chesty cough, with phlegm (c) frequent chest infections (d) persistent wheezing

Treatment: Treatments include: (a) stopping smoking (b) inhalers and medicines - to help make breathing easier (c) pulmonary rehabilitation -a specialized programmed of exercise and education (d) surgery or a lung transplant- although this is only an option for a very small number of people.

3.6.4 Effects of smoking

The effects of smoking on respiratory system are:

1. Cigarette smoking causes about 87% of lung cancer.
2. Besides lung cancer, cigarette smoking is also a major cause of cancer of the mouth, larynx and esophagus.
3. Cigarette smoking causes other lung diseases e.g., chronic bronchitis, emphysema.
4. Cigarette smokes contain chemicals which irritate the air passages and lungs, causing early morning cough.
5. Smokers are likely to get pneumonia because damaged or destroyed cilia cannot protect lungs from bacteria and viruses that float in the air.
6. Almost immediately, smoking can make it hard to breathe. Within a short time, it can also worsen asthma and allergies.

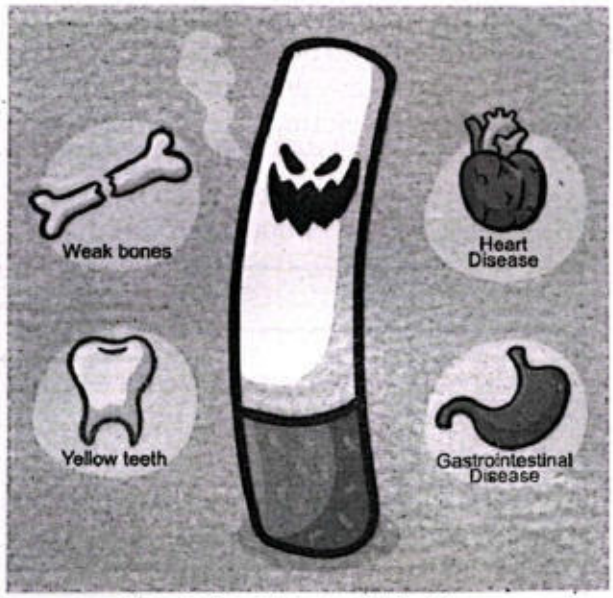


Fig. 3.13: Effects of smoking

Science, Technology and Society Connections

Mouth to mouth artificial respiration. (Cardiopulmonary Resuscitation (CPR)

Mouth to mouth artificial respiration is called resuscitation. It is a technique used to recover a person who has stopped breathing. In this technique, the rescuer presses his or her mouth against the mouth of the victim and allowing for passive inhalation, forces air into the lungs at intervals of several seconds.

What to do:

1. Stretch out victim on his back and kneel close to his side. Loosen any tight clothing around his neck or chest.
2. Remove foreign objects if present from victim's mouth and throat by finger sweeping.
3. Lift up chin and tilt head back as far as possible. If the head is not tilted, the tongue may block the throat.

4. Begin the resuscitation immediately. Pinch the nostrils together with the thumb and index finger of the hand that is pressing on the victim's forehead. This prevents the loss of air through the nose during resuscitation.
5. Inhale deeply.
6. Place *your mouth* tightly around the victim's mouth (over mouth and nose of small children) and blow into the air passage with brief intervals. Continue this activity so long as there is any pulse or heartbeat.
7. Watch the victim's chest. When you see it rise, stop blowing, raise your mouth, turn your head to the side and listen for exhalation.
8. If patient is revived, keep him warm and do not move him until the doctor arrives, or at least for half or one hour.

STEAM ACTIVITY 3.1

a. How to measure your respiratory rate

Your respiratory rate is also known as your breathing rate. This is the number of breaths you take per minute.

You can measure your breathing rate by counting the number of breaths you take over the course of one minute while you are at rest.

To get an accurate measurement:

1. Sit down and try to relax.
2. It's best to take your respiratory rate while sitting up in a chair or in bed.
3. Measure your breathing rate by counting the number of times your chest or abdomen rises over the course of one minute.
4. Record this number.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. When blood leaves the capillary bed most of the carbon dioxide is in the form of
   A. carbonate ions
   B. bicarbonate ions
   C. hydrogen ions
   D. hydroxyl ions
2. When you inhale, the diaphragm
   A. relaxes and moves upward
   B. relaxes and moves downward
   C. contracts and moves upward
   D. contracts and moves downward
3. With which other system do specialised respiratory systems most closely interface in exchanging gases between the cells and the environment?
   A. the skin
   B. the excretory system
   C. the circulatory system
   D. the muscular system
4. Which of the following is the respiratory surface in human respiratory system:
   A. larynx
   B. trachea
   C. bronchi
   D. alveoli

5. How is most of the oxygen transported in the blood?

A. dissolved in plasma
B. bound to haemogloibin
C. as bicarbonate
D. dissolved in water

6. The lateral walls of the chest cavity of man are composed of the:

A. ribs
B. intercostal muscles
C. ribs and intercostal muscles
D. ribs, intercostal muscles and diaphragm

7. Which of the following factors is the most effective in accelerating the rate of breathing in man?

A. a lack of oxygen in the blood
B. a lack of oxygen in the tissues
C. an excess of carbon dioxide in the lungs
D. an excess of carbon dioxide in the blood

8. Which of the following changes will increase the body's rate of carbon dioxide excretion into the alveoli?

A. holding the breath
B. the breakdown of alveolar tissue as a result of disease
C. a decrease in the partial pressure of carbon dioxide in the alveolar air
D. a decrease in the pulmonary circulation

9. Breathing is an example of

A. counter current exchange
B. cellular respiration
C. ventilation
D. diffusion

10. Which sequence most accurately describes the sequence of airflow in the human respiratory system?

1. pharynx 2. bronchus 3.trachea 4.larynx 5.alveolus 6.bronchiole

A. 4, 1, 3, 2, 5, 6
B. 1, 4, 3, 2, 5, 6
C. 4, 1, 3, 2, 6, 5
D. 1, 4, 3, 2, 6, 5

11. Which one of the following changes takes place during inspiration?

A. Decrease in thoracic cavity
B. Relaxation in diaphragm
C. Relaxation in external intercostal muscles
D. Sternum moves towards ventral and anterior direction

12. The volume of air that can be exhaled after normal exhalation is the

A. tidal volume
B. residual volume
C. inspiratory reserve volume
D. expiratory reserve volume

13. Hemoglobin

A. combine reversely with only oxygen
C. attach to the alveolar wall
B. all have four heme group
D. none of them

14. The maximum volume of air contained in the lung by a full forced inhalation is called _____.

A. Tidal volume
B. Vital capacity
C. Ventilation rate
D. Total lung capacity

15. Dissociation of O_2 from oxyhaemoglobin is facilitated by:

A. decreased temperature
B. decreases H^+
C. decreased PO_2
D. exercise

16. Which of these correctly orders the structures through which air passes during inhalation?

A. pharynx → trachea → larynx → bronchi
B. pharynx → larynx → trachea → bronchi
C. larynx → pharynx → bronchi → trachea
D. larynx → pharynx → trachea → bronchi

17. The pharynx is also known as the:

A. windpipe
B. trachea
C. voice box
D. throat

18. What is the correct path air takes when it enters the trachea on its way to the lungs?

A. bronchi /bronchioles /pulmonary capillaries/ alveoli
B. bronchioles/ bronchi/ alveoli/ pulmonary capillaries
C. bronchi / pulmonary capillaries/alveoli/ bronchioles
D. bronchi /bronchioles/alveoli / pulmonary capillaries

19. Which of the following is correct for the partial pressure of oxygen in alveoli?

A. less than carbon dioxide
B. less than the blood
C. more than the blood
D. equal to that of the blood

20. Which of the following is the respiratory surface in human respiratory system:

A. larynx
B. trachea
C. bronchi
D. alveoli

Section II: Short Answer Questions

1. What is respiratory surface? Write the properties of respiratory surface.
2. What organs constitute the respiratory system?
3. How nose and nasal cavity function in filtering the incoming air?
4. What is the role of 'pharynx' in human respiration?
5. Describe function of human larynx.
6. Describe the structure and function of alveoli.
7. How the contraction and relaxation of human lungs take place?
8. What is chloride shift?
9. What are the advantages of having millions of alveoli rather than a pair of simple balloon like lungs?
10. Write the differences between:
    (a) Internal and external respiration
    (b) Upper and lower respiratory tract
    (c) Bronchi and bronchioles

(d) Oxyhaemoglobin and carboxyhaemoglobin
(e) Haemoglobin and myoglobin

11. List the effects of smoking.

Section III: Extensive Answer Questions

1. Describe the human upper respiratory tract.
2. Describe the human lower respiratory tract.
3. Describe the mechanism of breathing in man.
4. How the control of breathing takes place?
5. Explain the transport of oxygen in blood.
6. Explain the transport of carbon dioxide in blood.
7. What is the role of respiratory pigments in man?
8. Describe the cause, symptoms and treatments of:
   (a) Sinusitis
   (b) Otitis media
   (c) Pneumonia
   (d) Pulmonary tuberculosis
   (e) Emphysema
   (f) Chronic obstructive pulmonary disease (COPD)

URINARY SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-09] List various nitrogenous compounds excreted during the process of excretion.
2. [B-12-R-10] Explain the nature of excretory products in relation to habitats.
3. [B-12-R-11] Outline different organs of the urinary system.
4. [B-12-R-12] Describe the structure of the kidney.
5. [B-12-R-13] Relate the structure of kidney with its function.
6. [B-12-R-14] Explain the detailed structure of a nephron.
7. [B-12-R-15] Explain the process of glomerular filtration, selective re-absorption and tubular secretion ass the events in kidney functioning.
8. [B-12-R-16] Explain regulatory mechanism involved in concentration of urine.
9. [B-12-R-17] Justify the functioning of kidneys as both excretion and osmoregulation.
10. [B-12-R-18] Compare the function of two major capillary beds in kidneys i.e., glomerular capillaries and peritubular capillaries.
11. [B-12-R-19] List the urinary tract infections and the bacteria responsible.
12. [B-12-R-20] Explain the causes and treatments of kidney stones.
13. [B-12-R-21] Outline the causes of kidney failure.
14. [B-12-R-22] Explain in detail the mechanism and problems related to dialysis.
15. [B-12-R-23] Describe the principles and the problems associated with kidney transplant.

The body cells form a variety of wastes, and if these substances are allowed to accumulate, their effects are likely to be toxic. The body fluids, such as the blood and lymph, carry wastes away from the tissues that produce them. Other parts remove these wastes from the blood and transport them to the outside. The respiratory system, for example, removes carbon dioxide from the blood and the urinary system removes various salts and nitrogenous wastes.

The urinary system also helps to maintain the normal concentrations of water and electrolytes within the body fluids, to regulate the pH and volume of body fluids, and to control red blood cell production and blood pressure.

4.1 EXCRETION

Metabolism produces a number of toxic by-products, particularly the nitrogen containing compound. The **excretion** is the removal of chemical waste from the body which are produced by the metabolic processes within cells.

4.1.1 Nitrogen as excretory product

Animals excrete a variety of nitrogenous waste products, but ammonia, urea and uric acid predominate. A major factor in determining the mode of nitrogen excretion is the availability of water in the environment

4.1.2 Relationship between Excretory Products and Habitats

The exact nature of excretory product is determined mainly by the availability of water to the organism which is based upon its habitat. The correlation with habitat is: (a) ammonia - aquatic (b) urea - aquatic and terrestrial (c) uric acid - terrestrial.

Ammonia

Ammonia is highly toxic because it tends to raise the pH of body fluids and interferes with membrane transport functions. It is highly soluble in water and diffuses rapidly across cell membrane. It is therefore excreted rapidly. One gram of nitrogen, in the form of ammonia, requires five hundred ml of water to dissolve it to nontoxic level. Such plenty of water can only be afforded by many aquatic organisms, particularly those in freshwater e.g., most fishes, protozoans, sponges,cnidaria, echinoderms and crustaceans. Animals which excrete ammonia as their major nitrogenous waste product are called **ammonotelic.**

Urea

Organisms with less freshwater available, such as some marine organisms and all terrestrial organisms remove their most of the nitrogenous waste in the form of urea. They will often invest some energy to convert the ammonia into urea, which is 100,000 times less toxic than ammonia. One gram of nitrogen, in the form of urea, requires 50 ml of *water to dilute* it to nontoxic level. Animals which excrete urea as their major nitrogenous waste product are called **ureotelic.** Examples include mammals e.g. man, many amphibians and some marine animals like shark.

CRITICAL THINKING

Where do you think the carbon dioxide used in the formation of urea comes from? Where does the remainder of excess carbon dioxide go to be excreted?

SCIENCE TITBITS

Humans excrete small quantities of uric acid but this is produced from the breakdown of nucleic acid and not from breakdown of proteins. Approximately one gram of uric acid is excreted in urine per day.

Uric acid

Uric acid is byproduct of breakdown of purine and is less toxic than urea, and can precipitates from solution, allowing the 4 nitrogen atoms per uric acid molecule to be excreted. One gram of nitrogen, in the form of uric acid, requires just 1 ml of water for its excretion. It has evolved in two groups with major water shortage problems, terrestrial invertebrates e.g., land snail, many insects and egg-laying vertebrates e.g. reptiles (snakes, lizards) and birds. These animals are called **uricotelics**. The examples includes many terrestrial insects, reptiles and most birds.

4.2 URINARY SYSTEM OF MAN

The excretory system (urinary system) consists of kidneys, ureters, urinary bladder and a tubular urethra. The kidneys lie on either side of the vertebral column between the twelfth thoracic and third lumbar vertebrae.

Each **ureter** is a tubular organ about 25 cm long, which begins as the funnel-shaped renal pelvis. It extends downward parallel to the vertebral column to join the urinary bladder. It transports urine from the kidney to the urinary bladder. The **urinary bladder** is a hollow and distensible muscular organ. It is located within the pelvic cavity. It serves as urine reservoir. The **urethra** is a tube that carries urine from urinary bladder to the outside of the body.

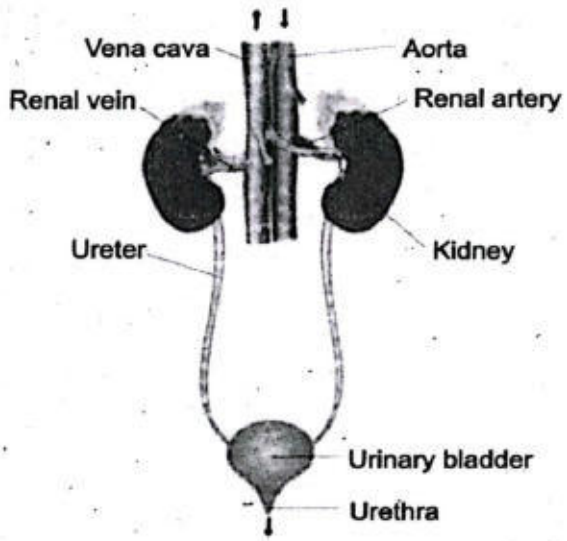


Fig. 4.1: Excretory system of man

4.2.1 Structure of kidney

Location: The **kidneys**, are a pair of bean-shaped structures. These are located just below and posterior to the liver in the peritoneal cavity. The adrenal glands are on top of each kidney. Kidneys filter blood and purify it. The filtrate coming out of the kidneys is called **urine**. The reason why the right kidney is slightly lower than the left is due to considerable space occupied by the liver on the right side.

Structure: Externally, the kidneys are surrounded by three layers. The outermost layer is a tough connective tissue layer called the **renal fascia**. The second layer is called the **perirenal fat capsule**, which helps anchor the kidneys in place. The third and innermost layer is the **renal capsule**.

Internally, the kidney has three regions—an **outer cortex**, a **medulla** in the middle, and the **renal pelvis** in the region called the **hilum** of the kidney. The hilum is the concave part of the bean-shape where blood vessels and nerves enter and exit the kidney; it is also the point of exit for the ureters. The renal cortex is granular due to the presence of nephrons—the functional unit of the kidney. The medulla consists of multiple pyramidal tissue masses, called the **renal pyramids**. In between the pyramids are spaces called **renal columns** through which the blood vessels pass. The tips of the pyramids, called **renal papillae**, point toward the renal pelvis. There are, on average, eight renal pyramids in each kidney. The renal pyramids along with the adjoining cortical region are called the **lobes of the kidney**. The renal pelvis leads to the **ureter** on the outside of the kidney. On the inside of the kidney, the renal pelvis branches out into two or three extensions

called the **major calyces**, which further branch into the **minor calyces**. The ureters are urine-bearing tubes that exit the kidney and empty into the **urinary bladder**.

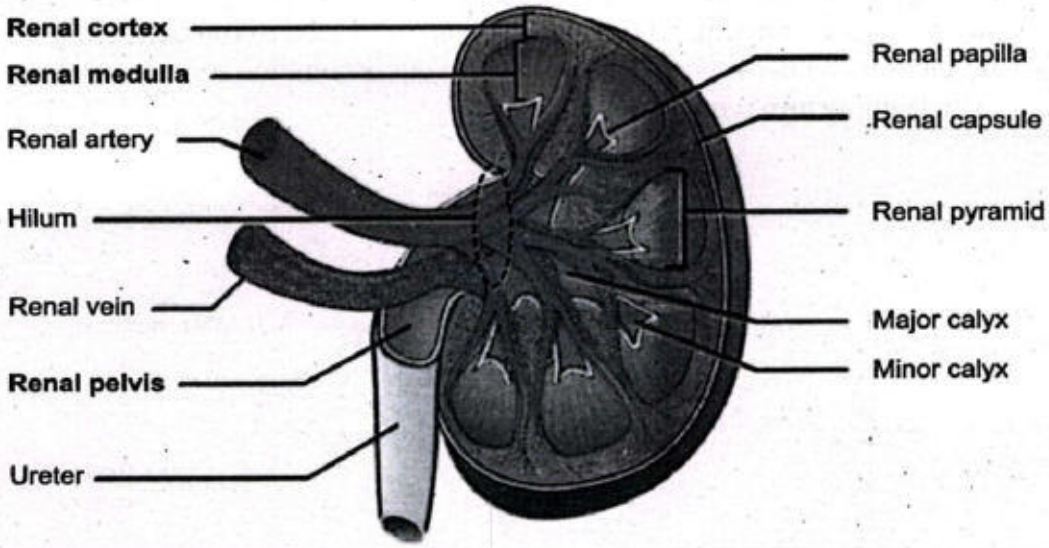


Fig. 4.2: Internal anatomy of the kidney

4.2.2 Relationship between structure and function of kidney

The main parts of kidney anatomy with related function are given below:

Kidney capsule (renal capsule): The renal capsule consists of three layers of connective tissue or fat that covers kidneys. It protects the kidneys from injury, increases their stability and connects kidneys to surrounding tissues.

Renal artery: The renal artery is a large blood vessel that controls blood flow into kidneys. For most people at rest, the renal kidneys pump a little over 5 cups (1.2 liters) of blood to kidneys each minute.

Renal cortex: It is the outer layer of kidney, where the nephrons (blood-filtering units) begin. The renal cortex also creates the hormone erythropoietin (EPO), which helps make red blood cells in the bone marrow.

Renal medulla: The renal medulla is the inner part of the kidney. It contains most of the nephrons with their glomeruli and renal tubules. The renal tubules carry urine to the renal pelvis.

Renal papilla: These pyramid-shaped structures transfer urine to the ureters.

Renal pelvis: This funnel-shaped structure collects urine and passes it down two ureters. Urine travels from the ureters to the bladder, where it's stored.

Renal vein: This vein is the main blood vessel that carries filtered blood out of the kidneys and back to your heart. Each of your kidneys has a renal vein.

4.2.3 Structure of a nephron

The **nephron** is the functional unit of kidney. A nephron consists of a **renal corpuscle** and a **renal tubule**. A renal corpuscle is composed of a network of capillaries called **glomerulus** which is surrounded by a thin double-walled structure called **Bowman's capsule**. The Bowman's capsule is an expansion at the closed end of a **renal tubule**. The renal tubule leads away from the Bowman's capsule and becomes highly coiled. This coiled portion of the tubule is called **proximal convoluted tubule**.

The proximal convoluted tubule dips toward the renal pelvis into the medulla forming a sharp loop called **loop of Henle**. The loop of Henle consists of a descending limb and an ascending limb. The ascending limb returns to the region of the renal corpuscle, where it becomes highly coiled again, and is called the **distal convoluted tubule** which is connected to the **collecting duct**. The collecting duct receives many nephrons. Many collecting ducts combine together to form larger collecting ducts which empty into renal pelvis.

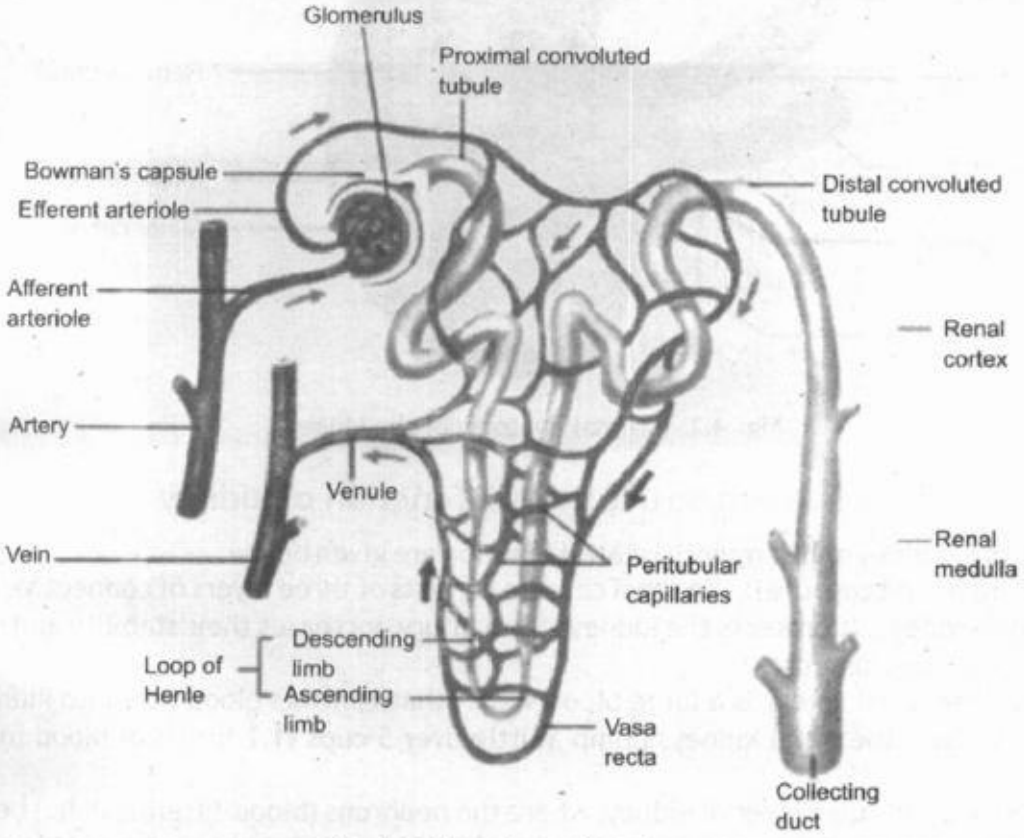


Fig. 4.3: Structure of nephron

Blood circulation to nephron

The renal artery within the kidney gives rise to branches that project into the cortex and give rise to **afferent arterioles**. The afferent arterioles supply blood to the glomerular capillaries of the renal capsule. **Efferent arterioles** arising from the glomeruli give rise to a plexus of capillaries called the **peritubular capillaries** around the proximal and distal tubules. Specialized part of the peritubular capillaries called **vasa recta** course into the medulla along with the loops of Henle and then back toward the cortex. The peritubular capillaries drain into renal vein. The renal vein exits the kidney and connects to the inferior vena cava.

4.3 URINE FORMATION

The formation of urine involves glomerular filtration, tubular reabsorption and tubular secretion. **Glomerular filtration** (pressure filtration) takes place in the **renal capsule** under pressure. The pressure comes from the blood pressure and is known as **hydrostatic pressure**. Glomerular capillaries have exceptionally high blood pressure than any other part of capillary bed in the body.

The diameter of efferent arteriole is half as compared to the afferent arteriole so as the blood enters the narrow capillaries, pressure rise. Due to such a high pressure, water and small solute molecules (ions, glucose and amino acids) are filtered out of the glomerular capillaries and are collected into the Bowman's capsule. Larger molecules like proteins, as well as red blood cells and platelets are left behind in the blood. The filtered fluid in the capsule is called **glomerular filtrate.** It has a chemical composition similar to that of blood plasma.

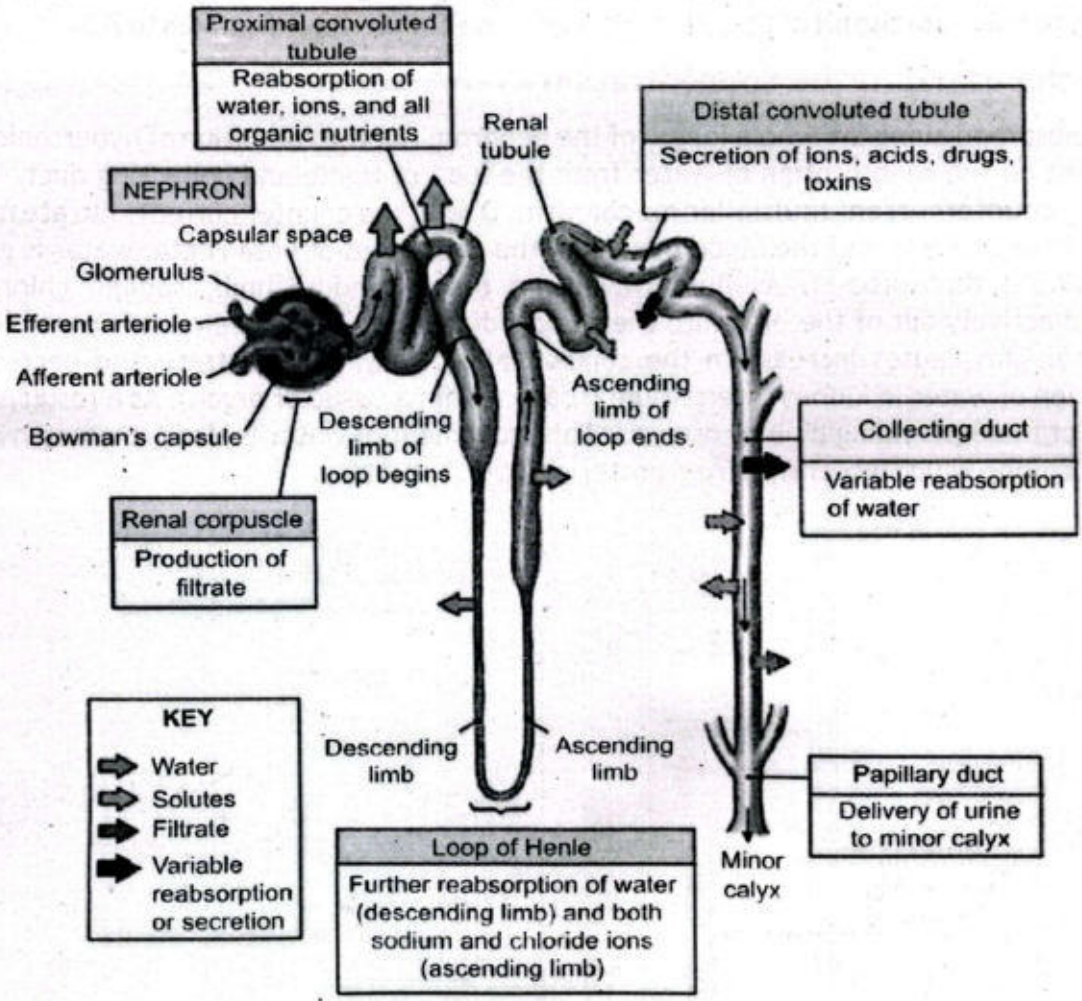


Fig. 4.4: Urine formation

SCIENCE TITBITS

There are two types of nephrons, **cortical nephrons** and **juxtamedullary nephrons.** Cortical nephrons are found in the cortex. They have their renal corpuscle in the superficial renal cortex and have relatively short loops of Henle. 70 to 80% nephrons in human kidney are cortical. Under normal conditions of water availability, the cortical nephrons deal with the control of blood volume by forming diluted urine. Juxtamedullary nephrons have their renal corpuscle close to the junction of the cortex and medulla. They have long loop of Henle which extends deep into the medulla. These types of nephrons are relatively rare and only comprise 20-30% of the nephrons in the human kidney. When water is in short supply, increased water retention occurs through juxtamedullary nephrons.

Selective reabsorption, is the process by which certain substances that have been filtered out of the blood during ultrafiltration are reabsorbed. These substances include glucose, amino acids, vitamins, inorganic salts and some water. As only certain substances are reabsorbed, it is known as selective reabsorption.

Tubular secretion is the process by which certain substances e.g., ammonium and hydrogen ions are secreted mainly by the tubular epithelial cells of loop of Henle into the lumen of the tubule. However, to some extent this process also occurs in convoluted tubule. The main purpose of this secretion is to maintain the pH of the urine. Normal urine has pH range from 4.8 to 7.5.

4.3.1 Mechanism of urine concentration

Water is reabsorbed along the whole length of the nephron, but the formation of hypertonic urine is dependent on the reabsorption of water from the loop of Henle and collecting duct. This is achieved by **countercurrent multiplier mechanism**. Due to the counter current, filtrate moving in limbs of loop of Henle and the blood moving in the capillaries of **vasa recta**, water is greatly (approx. 99.5%) reabsorbed . As fluid travels up the ascending limb, sodium chloride is transported actively out of the limb into the surrounding area. This movement is controlled by **aldosterone**. This causes increase in the concentration of water in filtrate and decrease in concentration of water in kidney interstitium (space within a tissue or organ). As a result, water passes out of the descending limb by osmosis. This movement of water is also promoted by **anti-diuretic hormone** which is secreted from posterior lobe of pituitary.

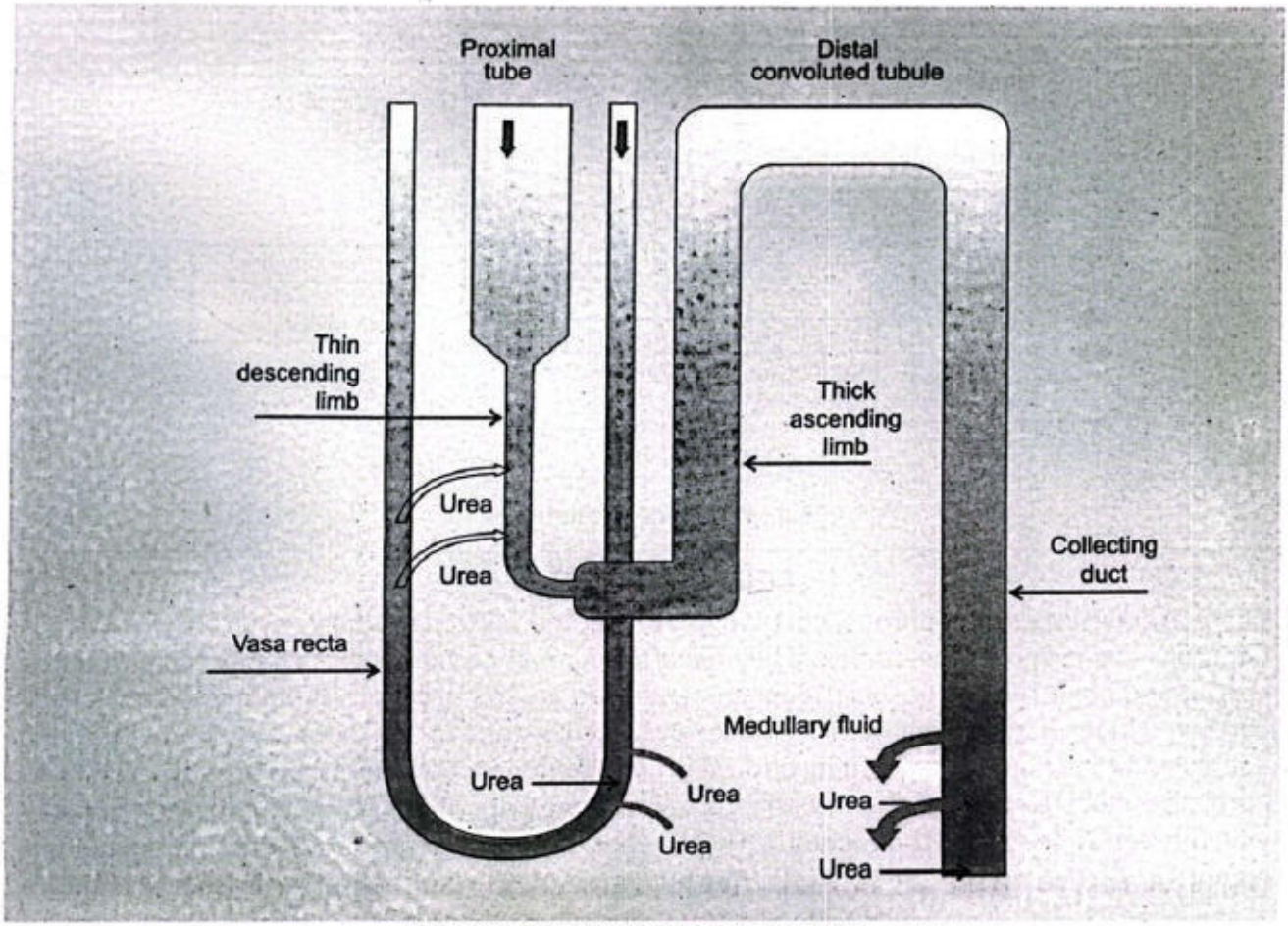


Fig. 4.5: Counter current mechanism

Table 4.1: Comparision of function of glomerular capillaries and peritubular capillaries

Glomerular capillaries	Peritubular capillaries
These function as a filtration unit of kidney.	They filter waste from the blood so the waste can leave the body through urine.
The glomerular function ensures that essential plasma proteins are retained in blood and the filtrate is passed on as urine.	Peritubular capillaries also reabsorb nutrients the body needs to work properly, such as minerals.
Blood cells and proteins pass through the glomerulus harmlessly.	The peritubular capillaries reabsorb essential minerals and nutrients, along with excess water.

SCIENCE TITBITS

In addition to their excretory and osmoregulatory role, kidneys also help to control the red blood cell formation by secreting the hormone **erythropoietin** and help to regulate blood pressure by secreting the (EPO) enzyme **renin**.

4.4 FUNCTIONS OF KIDNEY

Kidneys function as excretory as well as osmoregulatory organs.

Excretory functions: The excretory functions include the filtration of nitrogenous wastes from the blood and its removal outside the body in the form of urine.

Osmoregulatory Function: Being osmoregulatory organ, these are concern with the formation of diluted urine during the state of flooding and form concentrated urine during the state of dehydration.

4.5 DISORDERS OF URINARY TRACT

The normal aging process in human affects kidney function in various ways. Urinary tract infections (UTI) are fairly common. **Urology** is the branch of medicine which deals with diseases and abnormalities of urinary tract and their treatment.

4.5.1 Urinary Tract Infection

Although males can get a urinary tract infection, the condition is fifty times more common in women. In general, the higher risk in women is mostly due to the shortness of the female urethra, which is 1.5 inches compared to 8 inches in men. Bacteria from faecal matter at the anal opening can be easily transferred to the opening of the urethra. Almost all parts of the urinary tract are affected by the infection except ureters which are rarely the site of infection. The types of UTIs depending upon the site are: **urethritis** is an infection of urethra, **cystitis** involves the bladder and if the kidneys are infected the infection is called **pyelonephritis**.

Since the infection is caused by bacteria, it is curable by antibiotic therapy. For prevention, one should drink lot of water to flush out bacteria. Personal hygiene is especially important too.

Table 4.2: Urinary Tract Infection (UTI) Caused by Bacteria	
Bacteria	Diseases
1. *E. coli* 2. *N. gonorrhoeae* 3. *T. palladium*	1. UTI 2. Urethritis, Gonorrhoea 3. Syphilis

4.5.2 Kidney Stones

Urinary stones are hard, crystalline mineral materials that stick together to form small "pebbles" within the kidney or urinary tract. They can be as small as grains of sand or as large as golf balls. They may stay in kidneys or travel out of the body through the urinary tract. The condition of having stones in the kidney is termed **nephrolithiasis.**

SCIENCE TITBITS

There are five major types of urinary stones: **calcium oxalate, calcium phosphate, magnesium ammonium phosphate, uric acid and cystine.** Uric stones are composed of combination of uric acid and calcium oxalate. They are normally 2-3 mm in diameter with either smooth or uneven surface. Branching stone is called **staghorn stone.**

Hypothesize kidney stone by studying the urine test of relevant patient.
When urine is acidic (low pH) the stone is of calcium oxalate.
When the urine is alkaline (high pH) the stone is of calcium phosphate.
When urine is persistently acidic the stone is of uric acid type.

Do you know?
The science concerned with the structure, functions and diseases of the kidneys is called **nephrology.**

Symptoms

Common symptoms include severe pain in lower back, blood in urine, nausea, vomiting, fever and chills, or urine that smells bad or looks cloudy.

Causes

Kidney stones may be caused by increased calcium level in the blood which is termed as **hypercalcemia.** It, in turn, causes high calcium in the urine, the **hypercalciuria.** Increased oxalate level in the urine is called **hyperoxaluria.** Hypercalciuria and hyperoxaluria cause **calcium oxalate** type of kidney stones which are present in 70% of kidney stone patients. **Hyperuricemia** is the increased amount of uric acid in the blood and it causes **uric acid** type of kidney stones which are found in 10% of kidney stone patients. High concentration of cysteine and phosphates in urine also cause kidney stones. Continuous state of dehydration increases the chances of kidney stone formation.

Treatment

Extracorporeal shock wave lithotripsy (ESWL) and Percutaneous Nephro Lithotripsy (PCNL) are common methods for kidney stone treatment. In ESWL, an instrument called **lithotripter** is used to generate shock waves from outside the patient's body focused on the stone, breaking it into small pieces. Most of the fragments then pass spontaneously via the urethra.

In case of larger stone PCNL is preferred in which a tube is inserted from the patient's back into the kidney to create a tract. A scope is run through the tract to directly visualize the stone inside the kidney. Ultrasound equipment can then be inserted to breakup the stone. While watching the

stone through the scope, the stone fragments can be grasped with special equipment and pulled through the tract out from the kidney. Open surgery is now almost never needed except for large bladder stone.

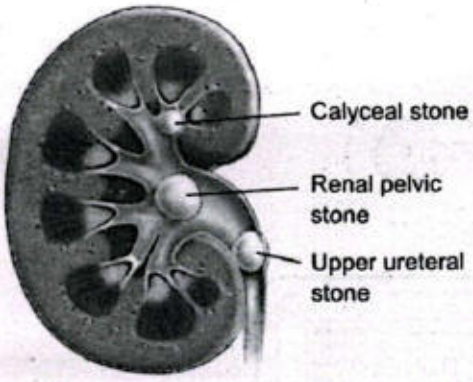


Fig. 4.6: Kidney stone

Fig. 4.7: Extracorporeal shock wave lithotripsy

4.5.3 Kidney Failure

A general term for a decline kidney function particularly the efficiency of the filtering process is called **kidney failure** or **renal failure**. **Chronic renal failure** is the irreversible deterioration in renal function. It is a gradual, slowly progressive and occurs over a period of years.

Chronic renal failure may be caused by: (a) Bacterial infection of the pelvis and surrounding tissue. (b) Nephritis (inflammation of glomeruli). (c) Damage due to high blood pressure. (d) Diabetes mellitus.

Acute renal failure may be caused by: (a) Haemorrhage due to trauma. (b) Vomiting, diarrhoea. (c) Diuresis (excess excretion of urine), sweating. (d) Obstruction of the ureters, bladder or urethra e.g., kidney stone. (e) Severe nephritis.

SCIENCE TITBITS

Chronic kidney failure can progress to **end-stage renal disease (ESRD)** and **uremia**, which is fatal unless artificial filtering (dialysis) or a kidney transplant.

4.5.4 Dialysis: Mechanism

A procedure to filter toxins from the blood by artificial methods when the kidneys are unable to perform this function is called **renal dialysis**. Dialysis works on the principle of kidneys although it is not as effective, efficient or thorough as the natural processes performed by the kidneys. There are two general types of renal dialysis: haemodialysis and peritoneal dialysis.

Haemodialysis

Haemodialysis removes wastes and water by circulating blood outside the body through an external filter, called a **dialyzer**, which consists of tubes of semipermeable membrane. In this process, a **catheter** is inserted into a blood vessel, usually in the arm. *It routes the blood* circulation externally through a machine that removes wastes. The cleansed blood then returns to the body through a second catheter. The haemodialysis machine consists of a pump and a container in which a network of synthetic tubes made up of cellophane membrane, called the **dialyzer**, is situated. The blood moves into the tubes of dialyzer from the top through blood pump. After circulating through the dialyzer, blood leaves the machine from the bottom and transfuses (to pour out into another vessel, to transfer to another's vein) back to the body. On the

other hand, **dialysate** (dialysis fluid) pour into the machine from bottom, which after circulating around the membranous tube, leaves the machine from the top. The dialysate attracts certain substances-minerals, electrolytes, and waste by-products—to cross the membrane from the blood. The dialysate absorbs these substances.

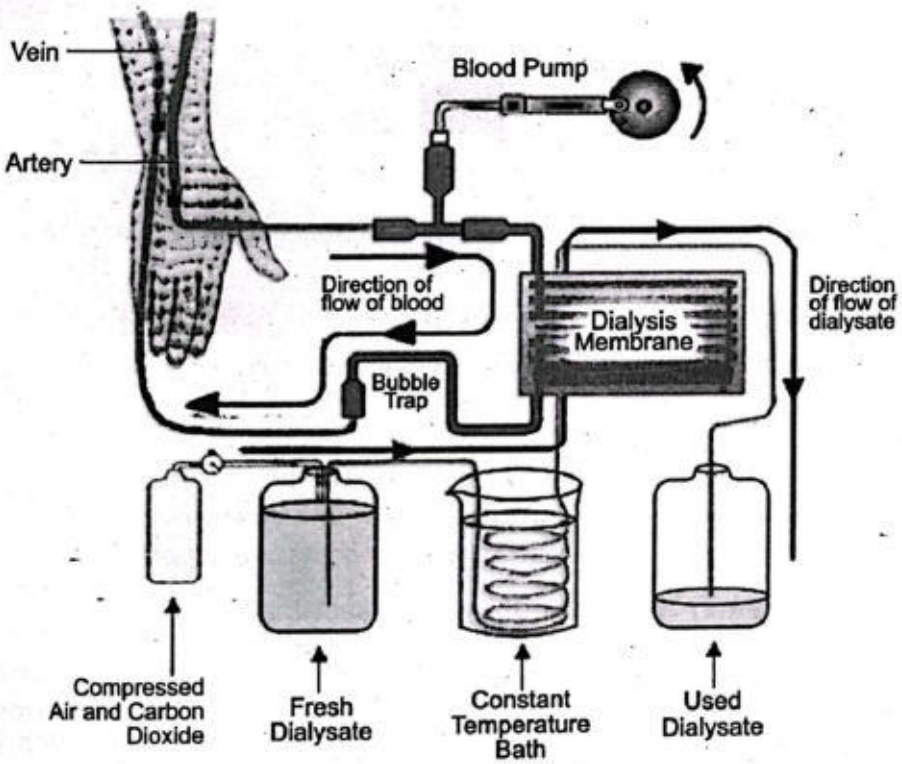


Fig. 4.8: Haemodialysis

Peritoneal dialysis

Peritoneal dialysis involves the use of a natural membrane in the body, the peritoneum, which encloses the abdominal cavity. In this process, two catheters are surgically inserted into the abdominal cavity that serve as the portals (any entrance) through which **dialysate** enters and leaves the cavity. During circulation, when blood passes through the blood capillaries within the peritoneum, the dialysate attracts certain molecules to cross the membrane into the dialysate.

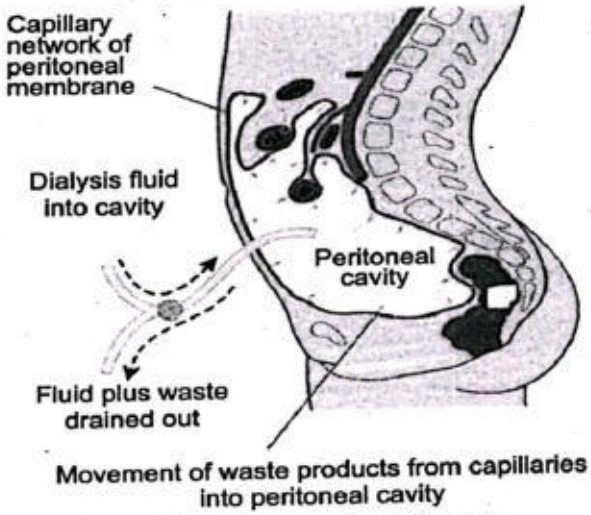


Fig. 4.9: Peritoneal dialysis

4.5.5 Kidney Transplant: Process and Problems

Kidney transplantation is the surgical procedure of placing a fully functioning kidney into a person with chronic kidney failure.

Principles of kidney transplant

The kidney graft is taken from a deceased donor or from a related or unrelated person. ABO blood group compatibility between donor and recipient is essential. It is usual to select donor kidneys on the basis of human leucocytes antigen (HLA) matching as this improves graft survival. A person can live normally with just one kidney.

Problems associated with kidney transplant

The two problems are rejection and toxic effects of cyclosporine. These problems are usually treated simultaneously by adding extra doses of **steroids**. Patients are required to take medications such as **cyclosporine** etc., to suppress their immune system in order to prevent rejection of the transplanted kidney. If at any point a recipient stops taking the medications, rejection can occur; even ten or fifteen years after the transplant.

Science Technology and Society Connections

Describe the importance of kidney donation for the benefit of kidney failure patients.

Kidney donation is a relatively safe operation, and many donors will never feel the loss of their second kidney. It's the most expendable of organs. So giving up a kidney causes no disadvantage to your long-term health. In fact, studies have shown, that kidney donors actually live longer than the general population, because donors come from a pool of people in good health.

Just think people have no problem having only one kidney, so we have to ask, why did Allah give us two kidneys? Perhaps it is so you would have an extra one to donate and save a life.

STEAM ACTIVITY 4.1

Experiment to show blood dialysis and kidney functions

Requirements

Three small beakers or jars (not larger than 250 mL size), Distilled or deionized water Scissors, Ruler, Timer or clock, Paper towels, String (optional)

1. Cut the dialysis tubing into three 4-inch segments.
2. Soak the segments of dialysis tubing in a jar or beaker filled with distilled water for at least one hour.
3. Add 75-100 mL distilled or deionized water to three separate beakers or jars. Label "Normal", "P1", and "P2". These are the water baths.
4. Carefully tie a single knot at one end of all three dialysis tubing segments. Tie the knots as close to the ends as possible. You can also use string to tie the ends.
5. Fill the first dialysis tubing with 2 mL of the Normal Patient Sample. To do this:
   a. Roll the untied end of the dialysis tubing between your thumb and pointer finger to open the end.
   b. Squeeze the transfer pipet bulb and fill the tip to the 2 mL mark.
   c. Gently insert the tip of the transfer pipet deep into the dialysis tubing and slowly transfer the sample into the tubing by applying gentle pres- sure to the bulb.
   d. Remove any trapped air in the dialysis tube without displacing the sample.
   e. Carefully tie the second knot at the open end of the tubing.

f. Rinse the filled-tied dialysis tube with water, especially near the tied ends and place the bag on a paper towel in front of the beaker labeled "Normal" (do the same for P1 and P2 when you fill those).

6. In a *separate container*, rinse the transfer pipet with water by repeatedly squeezing the bulb and flushing the pipette.
7. Repeat steps 5 and 6 for Patients 1 and 2. Quickly place all dyalysis tubes in their respective water baths.
8. Monitor the three dialysis water baths every 5 minutes or so, taking notes as to any changes in the color of the water outside the dialysis bag. Allow the bags to soak for up to 30 minutes.
9. After you have recorded your results, you can cut or untie dialysis tubing, empty, and rinse well to reuse for another experimental trial.

	Normal	Patient 1	Patient 2
Colour at 5 min.			
Colour at 10 min.			
Colour at 15 min.			

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Excretion of hypotonic urine in humans is associated best with the
   A. glomerular capsule
   B. proximal convoluted tubule
   C. loop of the Henle
   D. distal convoluted tubule

2. The walls of the ---------- are made more or less permeable to water, depending on the need to conserve water:
   A. ureter B. urethra C. fibrous capsule D. collecting duct

3. Which of the following will cause a decrease in ADH production?
   A. dehydration
   B. an increase in osmotic pressure of blood
   C. drinking water
   D. abnormally low blood pressure

4. The function of glomerulus and Bowman's capsule of the nephron is to
   A. reabsorb water into the blood
   B. eliminate ammonia from the body
   C. reabsorb salts and amino acids
   D. filter the blood and capture the filtrate

5. In man, glucose is present in blood plasma but not in urine. This is because glucose molecules are
   A. actively transported from the proximal convoluted tubule to blood capillaries
   B. oxidised to supply energy for ultrafiltration
   C. stored in the kidney
   D. too large to enter Bowman's capsule

6. Evidence for glomerular filtration in the kidney could be obtained by comparing the sizes of the molecules present in Bowman's capsule with those in the

A. afferent blood vessel B. collecting duct C. loop of Henle D. proximal tubule

7. The site and principal mechanism for the passage of glucose into the bloodstream in the human kidney is the

A. collecting duct, by active secretion
B. glomerulus, by selective reabsoption
C. glomerulus, by ultrafiltration
D. proximal convoluted tubule, by selective reabsorption

8. A drug reduces mitochondrial activity in kidney nephrons. Which chemical will be present in increased amounts in the urine?

A. ammonia B. glucose C. uric acid D. urea

9. The water content of human blood is regulated by ADH. In which part of the nephron does regulation occur?

A. ascending limb of loop of Henle B. descending limb of the loop of Henle
C. Bowman's capsule D. proximal convoluted tubule

10. The reason why the right kidney is slightly lower than the left is

A. the left kidney is bigger than right
B. considerable space occupied by the heart
C. considerable space occupied by the liver on the right side
D. the right kidney is bigger than the left

11. Which of the following is known as the functional unit of the kidney and is found in the cortex?

A. calyces B. renal pyramids C. nephrons D. medulla

12. This artery passes blood to the kidney

A. common iliac B. cystic C. renal D. coeliac

13. Which structure carries urine from the kidneys to the bladder?

A. nephron B. ureter C. bladder D. urethra

14. The blood vessel which carries blood to the glomerulus is the

A. renal artery B. afferent arteriole
C. renal vein D. peritubular capillaries

15. The basic unit of the renal system is the

A. cortex B. neuron C. nephron D. medulla

16. The centre of the kidney where urine collects before leaving the kidneys is the

A. glomerulus B. proximal tubule C. distal tubule D. renal pelvis

17. An organ or structure that is not a component of the urinary system is the:

A. urethra B. urinary bladder C. ureter D. adrenal gland

18. All of the following belong to the urinary system except:

A. urethra B. ureter C. bladder D. prostate

19. What portion of the nephron extends into the medulla?

A. nephron loop B. proximal convoluted tubule
C. distal convoluted tubule D. papillary duct

20. Fibrous connective tissue that surrounds each kidney is the:

A. cortex B. hilum C. medulla D. renal capsule

Section II: Short Answer Questions

1. Name the organs of the urinary system and write their major functions.
2. Describe glomerular filtration.
3. Describe the countercurrent multiplier mechanism.
4. Name the parts of a nephron and trace the blood supply to the nephron.
5. Name general processes which are involved with urine formation?
6. Describe urinary tract infection.
7. Name three urinary tract infections and bacteria responsible.
8. What are the causes of kidney failure?
9. By what physical processes do solutes enter or leave the blood during dialysis?
10. Why do blood and dialysate flow in opposite direction?
11. Suggest two problems that might occur if the dialysate was pure water.
12. Why women are more likely to acquire UTI as compared to men?
13. Write the differences between:
    (a) osmoregulation and osmoconformers
    (b) ammonotelic and ureotelic
    (c) ureotelic and uricotelics
    (d) proximal and distal convoluted tubule
    (e) afferent and efferent arterioles
    (f) hypercalcemia and hyperuricema
    (g) extracorporeal shock wave lithotripsy and percutaneous nephronlithotripsy
    (h) chronic renal failure and acute renal failure
    (i) peritoneal dialysis and haemodialysis
    (j) renal cortex and renal medulla
    (k) vasodilation and vasoconstriction
    (l) dialyzer and dialysate

Section III: Extensive Answer Questions

1. Discuss relationship between excretory products and habitats.
2. Describe the structure and function of human kidney.
3. Describe the structure of human nephron.
4. Discuss the 'urine formation 'and mechanism of urine concentration in man.
5. What are kidney stones? Discuss the causes and treatment of kidney stones?
6. What is renal dialysis? Describe the two types of renal dialysis.
7. What is kidney transplantation? Describe principles of kidney transplant. What are the problems associated with kidney transplant?

NERVOUS SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-G-01] Recognize receptors as transducers sensitive to various stimuli.
2. [B-12-G-02] Trace the path of a message transmitted to the CNS (central nervous system) for processing.
3. [B-12-G-03] Identify the three neurons (sensory, intermediate, motor) involved in nervous transmission.
4. [B-12-G-04] Identify muscles and glands as the effectors.
5. [B-12-G-05] Annotate the detailed structure of a sensory neuron, associative and motor neuron.
6. [B-12-G-06] Relate the structure of neurons with functions.
7. [B-12-G-07] Differentiate between myelinated and non-myelinated neurons.
8. [B-12-G-08] Explain the function of the three types of neurons with the help of a reflex arc.
9. [B-12-G-09] Define nerve impulse
10. [B-12-G-10] Describe the generation and transmission of nerve impulse.
11. [B-12-G-11] Name the factors responsible for the resting membrane potential of neuron.
12. [B-12-G-12] Evaluate from a graph the phenomena of polarization, depolarization and hyperpolarization of membrane.
13. [B-12-G-13] Compare the velocities of nerve impulse in the axon membrane and in the synaptic cleft.

14. [B-12-G-14] Describe the role of local circuits in saltatory conduction of nerve impulse.
15. [B-12-G-15] Outline the structure of synapse.
16. [B-12-G-16] Explain synaptic transmission of nerve impulse.
17. [B-12-G-17] Classify neurotransmitters as inhibitory and excitatory and list some common examples.
18. [B-12-G-18] Identify the main components of the nervous system.
19. [B-12-G-19] Explain briefly the major parts, functions of major divisions of the brain and its functions of brain.
20. [B-12-G-20] Describe the architecture of human brain.
21. [B-12-G-21] Describe cranial and spinal nerves in man.
22. [B-12-G-22] Explain the structure types and functions of the autonomic nervous system.
23. [B-12-G-29] Explain the structure and functioning of the receptors for smell, taste, and touch/pain.
24. [B-12-G-30] Define narcotic drugs as agents that interact with normal nervous activity.
25. [B-12-G-31] Compare the use and abuse of drugs with respect to heroine, *Cannabis*, nicotine, alcohol and inhalants like nail polish remover and glue.
26. [B-12-G-32] Explain the terms drug addiction and drug tolerance with reference to caffeine and nicotine and their adverse effects.
27. [B-12-G-33] Associate the effects of drug addiction and tolerance with the functioning of the nervous system.
28. [B-12-G-34] Describe the way how pain medicines can reduce or numb pain in the human body.
29. [B-12-G-35] Discuss that certain pain medications are addictive.
30. [B-12-G-36] Classify nervous disorders into vascular, infectious, structural, functional and degenerative disorders.
31. [B-12-G-37] Describe the causes, symptoms and treatment of one type of each category of disorders outlined above (e.g., stroke as vascular, meningitis as infectious, brain tumor as structural, headache as functional, and Alzheimer disease as degenerative disorder).
32. [B-12-G-38] Explain the principles of important diagnostic tests for nervous disorders i.e., EEG, CT scan and MRI.

The body of an animal is frequently exposed to variety of stimuli in its daily life. For an appropriate response to a particular stimulus, usually more than one body parts are involved, their activities are coordinated either by nervous system or endocrine system or both. The system of the body that provides coordination through electric signals among different body parts for the response to a particular stimulus is called **nervous system**. Human nervous system is the most evolved among all the animals. The study of the structure and functions of the nervous system is called **neurology**. The term neurology comes from a combination of two words, "neuron" meaning nerve and "logia" meaning "the study of". Nervous coordination in higher animals consists of three basic steps i.e., reception of stimulus, processing/analysis of information and response to stimulus.

5.1 RECEPTORS ARE TRANSDUCERS

A transducer is an electronic device that converts energy from one form to another. A cell that responds to a stimulus is called a **receptor cell**. Receptor cells are **transducers**. They convert energy from one form such as light, heat or sound into energy in an electrical impulse (electrochemical energy) within a sensory neuron. So receptors are transducers sensitive to various stimuli.

Receptors are biological transducers that convert energy from both external and internal environments into electrical impulses. They may be massed together to form a sense organ, such as the eye or ear, or they may be scattered, as are those of the skin and viscera.

5.2 PATH OF A MESSAGE TRANSMITTED TO THE CENTRAL NERVOUS SYSTEM

Sensory information travels from the body to the spinal cord before reaching the brain.

First order neuron(sensory neuron): The first-order neuron is the initial neuron in a sensory pathway that transmits sensory information from the periphery (like skin, muscles, or organs) to the central nervous system (CNS). The primary role of first order neuron is to detect stimuli (e.g., touch, pain, temperature) and relay that information to the second-order neuron, usually located in the spinal cord or brainstem.

Second-order neuron (interneuron): It receives input from the first-order neuron and typically transmits the information to higher brain centers (such as the thalamus). It is usually located in the spinal cord or brainstem, depending on the specific sensory pathway. The second-order neuron processes the information received from the first-order neuron and may integrate it with other sensory inputs before relaying it to the third-order neuron or directly to the brain regions involved in perception. In the pain pathway, the second-order neuron may be located in the dorsal horn of the spinal cord, where it receives signals from the first-order neurons and then projects to the thalamus.

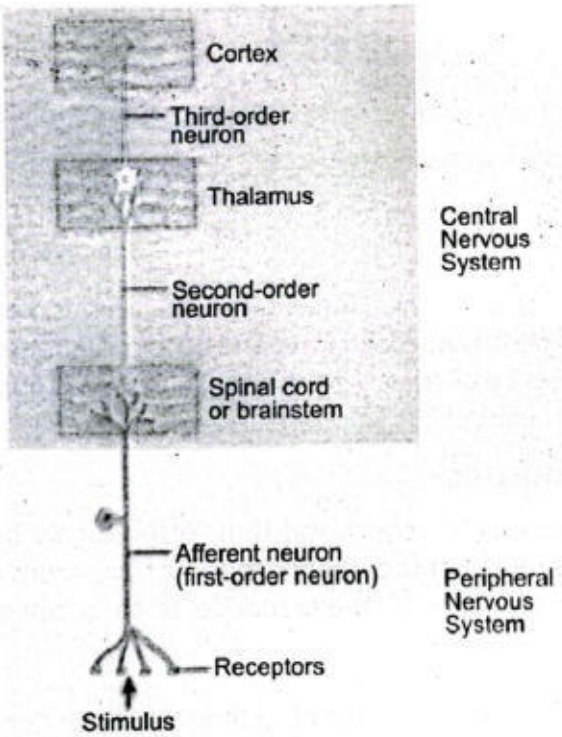


Fig. 5.1: Pathway of message transmitted to the CNS

Third order neuron: The third-order neuron picks up these impulses from the thalamus and relay them to the somatosensory portion of the cerebrum. Somatosensory sensations are pressure, pain, temperature and the body's senses.

5.3 NEURON

Nervous coordination mainly comprises highly specialized cells called **neurons** (new-ronz). Neurons are the basic structural and functional unit of the nervous system.

5.3.1 Structure of Neuron

Although neurons vary considerably in size and shape, they all have three basic components: a cell body, dendrites and an axon.

Cell body

The cell body is the main part of a neuron. It contains a mass of granular cytoplasm and cell

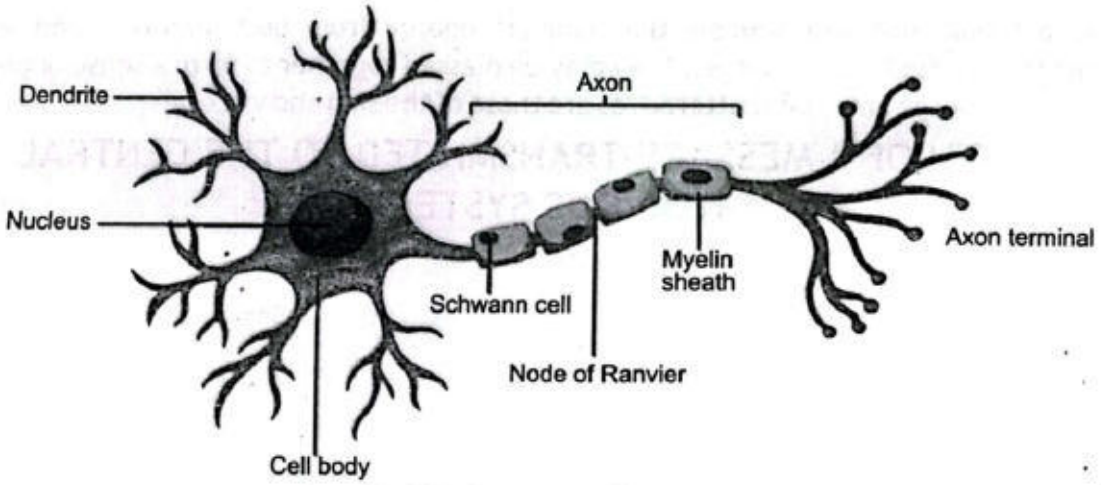


Fig. 5.2: Structure of neuron

membrane. The single large nucleus is centrally placed with a prominent nucleolus. Golgi apparatus, mitochondria and other organelles are present. The cytoplasm is characterised by the presence of **Nissl's granules**. These are group of ribosomes and rough ER associated with protein synthesis.

Dendrites

Dendrites are short and thin, often highly branched cytoplasmic extensions that are gradually tapered from their bases to their tips. Axons of other neurons form synapses with the dendrites. The function of the dendrite is to receive stimuli and conduct impulses to the cell body.

Axon

An axon is comparatively a long and thick nerve fibre which has a constant diameter and can vary in size from a few mm to more than a metre length. It may be branched or un-branched. Axons terminate by branching to form small extensions with enlarged ends called **presynaptic terminals**. Functionally, axons conduct action potentials from the neuron cell body to the presynaptic terminals, i.e., conduct signal (information) away from the cell body.

5.3.2 Types of neuron

All neurons vary somewhat in size, shape and characteristics depending on the function and role of the neuron. Based upon the function there are three types of neurons.

Sensory Neurons: The sensory neurons convert signals received from the environment into corresponding stimuli. The sensory inputs activate the sensory neurons and carry sensory information to the brain and spinal cord. They are pseudo-unipolar in structure.

Motor Neurons: These are multipolar and are located in the central nervous system extending their axons outside the central nervous system .This is the most common type of neuron and transmits information from the brain to the effector (muscles or gland) of the body.

Interneurons: They are multipolar in structure. Their axons connect only to the nearby sensory and motor neurons. They help in passing signals between two neurons.

Do you know?

Interneurons are also called, relay neurons, association neurons, connector neurons, intermediate neurons or local circuit neurons.

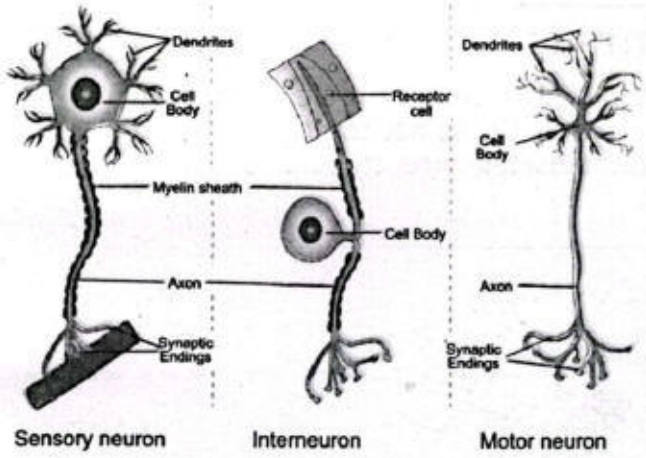


Fig. 5.3: Types of neuron based on function

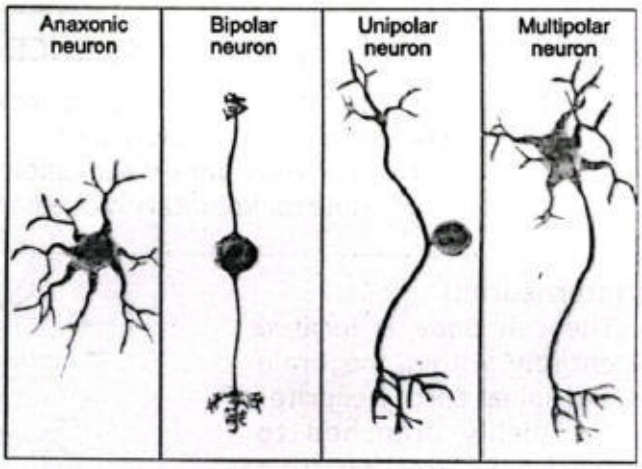


Fig. 5.4: Types of neuron based on structure

5.3.3 Effectors

The two examples of effectors are muscles and glands. The nervous system responds by sending signals to muscles and glands. The signals cause muscles to contract. The signals cause glands to produce secretions. Muscles and glands are called effectors because they cause an effect in response to directions from the nervous system.

5.3.4 Detailed structure of a sensory neuron, associative and motor neuron

a. Sensory neurons (Afferent neurons)

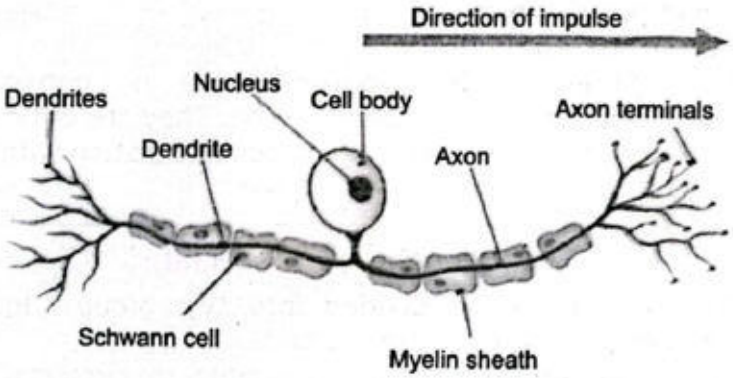


Fig. 5.5: Sensory neuron

The **cell body** or soma is located in the dorsal root ganglion outside the CNS. Sensory neurons have often their cell bodies close to the spinal cord. **Dendrites** are specialized extensions receive signals from sensory receptors. They are often long in peripheral sensory neurons. The **axon** extends from the sensory receptors to the CNS. In some cases they may be myelinated to speed up the signal transmission. Most sensory neurons are unipolar, having a single elevated process that branches into two. One branch connects to the sensory receptors and the other branch connects to the CNS. The signal pathway starts from the sensory receptor, moves along the axon and reaches the spinal cord or brain where further processing occurs.

b. Motor neurons (Efferent neurons)

The **cell body** is located in the spinal cord (for lower motor neurons) or in the brain's cortex (for upper motor neurons). Motor neurons have many **dendrites** that receive inputs from interneuron and other neurons. The **axon** is long and often myelinated to allow rapid signal transmission from CNS to the muscles or glands. Most motor neurons are multipolar. Motor neurons transmit signals from CNS to muscles and glands, allowing for movement and glandular response.

SCIENCE TITBITS

The upper motor neurons are located in the cortex of brain. They send signals to the lower motor neurons in the spinal cord. Lower motor neurons innervate skeletal muscles directly and are responsible for voluntary movement.

c. Interneurons

The cell body is located entirely within the brain and spinal cord. Dendrites are highly branched to receive information from multiple neurons making them important for processing complex information. Their axons are generally short and unmyelinated, as they primarily transmit signals locally within CNS. Interneuron is often multipolar, which allows them to communicate simultaneously. Interneuron serves as connectors between sensory and motor neuron. They are critical in reflexes, neural processing and communication with the CNS.

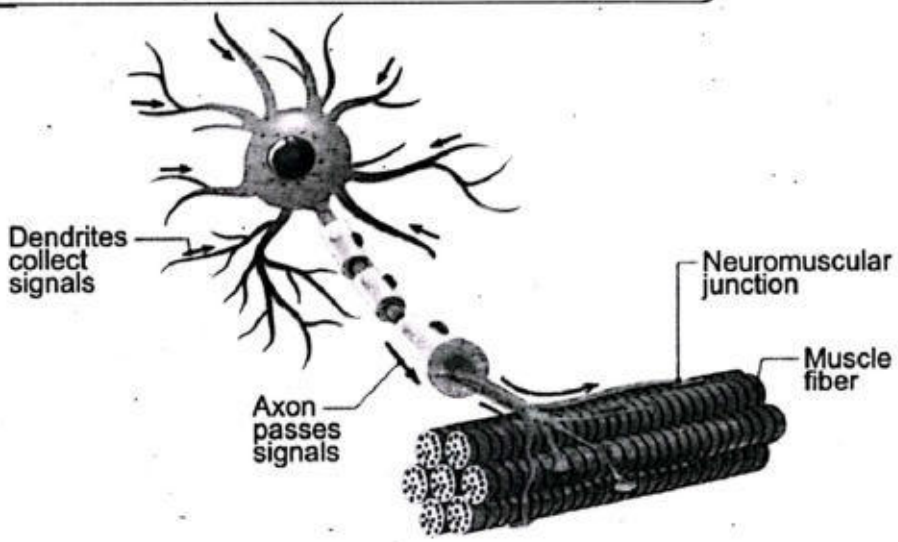


Fig. 5.6: Motor neuron

Extra reading material

Interneuron can be divided into two groups: local interneuron and relay interneuron.

Local interneuron has short axons and form circuits with nearby neurons to analyze small pieces of information.

Relay interneurons have long axons and connect circuits of neurons in one region of the brain with those in other regions. The interaction between interneurons allows the brain to perform complex functions such as learning, and decision-making. Interneurons are multipolar nerve cells, meaning that they have more than one dendrite.

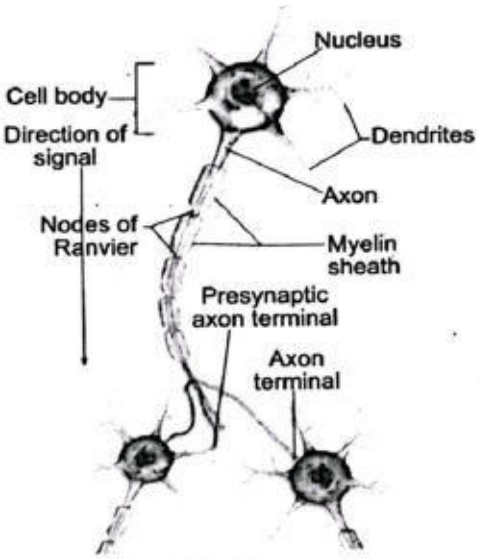


Fig. 5.7: Interneuron

5.3.5 Relate the structure of neurons with functions

The structure of each type of neuron is intricately designed to support its specific function within the nervous system, ensuring efficient communication and response mechanisms

To understand how the structure of each type of neuron relates to its function in the nervous system, we can describe the characteristics of motor neurons, sensory neurons, and interneurons as follows:

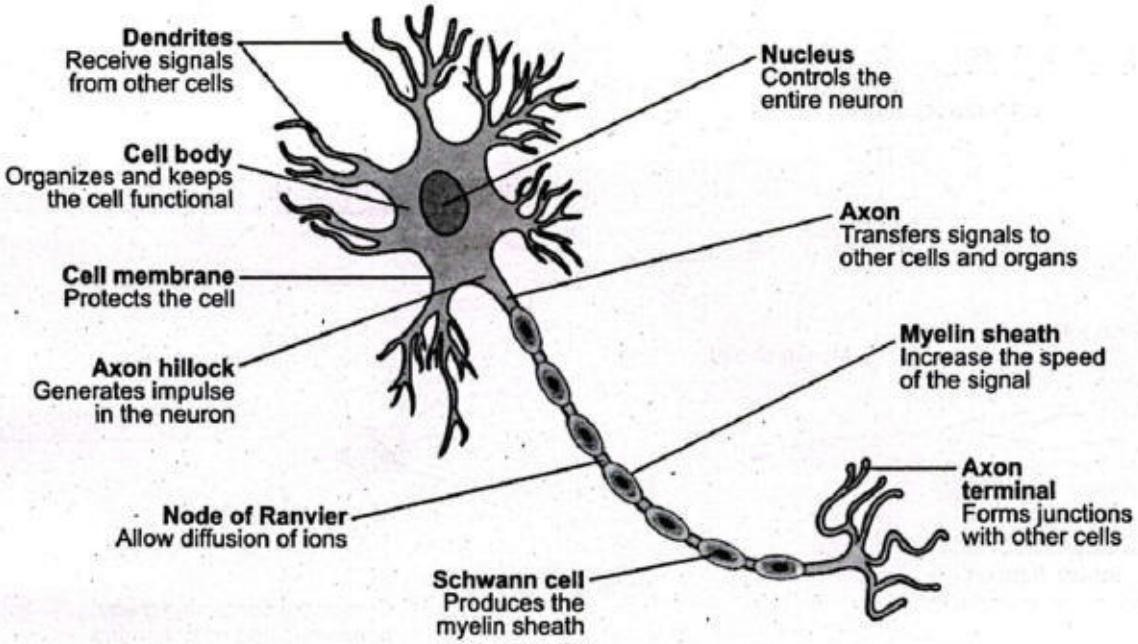


Fig. 5.8: Parts of a neuron with functions

Motor Neurons: These neurons have long axons, which are essential for covering the considerable distances between the central nervous system and target muscles or organs. The axons are myelinated, which enhances the speed of signal transmission, allowing for rapid communication necessary for quick muscle responses

Sensory Neurons: They possess long dendrites and axons, which are vital for receiving signals from sensory receptors and transmitting them over distances to the central nervous system. Sensory neurons are myelinated and often located in ganglia, which are clusters of neuron cell bodies. This arrangement aids in processing sensory information and contributes to reflex actions

Interneurons: They are generally shorter than both motor and sensory neurons, which are suitable for their role in local processing .Interneurons, have numerous branches of axons and dendrites, allowing them to form multiple connections with other neurons. Their partial myelination and clustering in large groups help to enhance the speed of signal transmission despite their shorter length.

Table 5.1 Comparison between three types of neuron

Neuron type	Function	Structure	Location
Sensory neuron	Transmit sensory information to CNS	Unipolar, with long axon, cell body in dorsal root ganglia.	Sensory organs to CNS.
Motor neuron	Transmit motor commands from CNS to muscles.	Multipolar, long, neuron, neuromuscular junction. junction	CNS to muscles/ glands
Interneuron	Relay signals between sensory and motor neuron; involved in processing information	Multipolar short axon, highly branched dendrites.	CNS (brain and spinal cord)

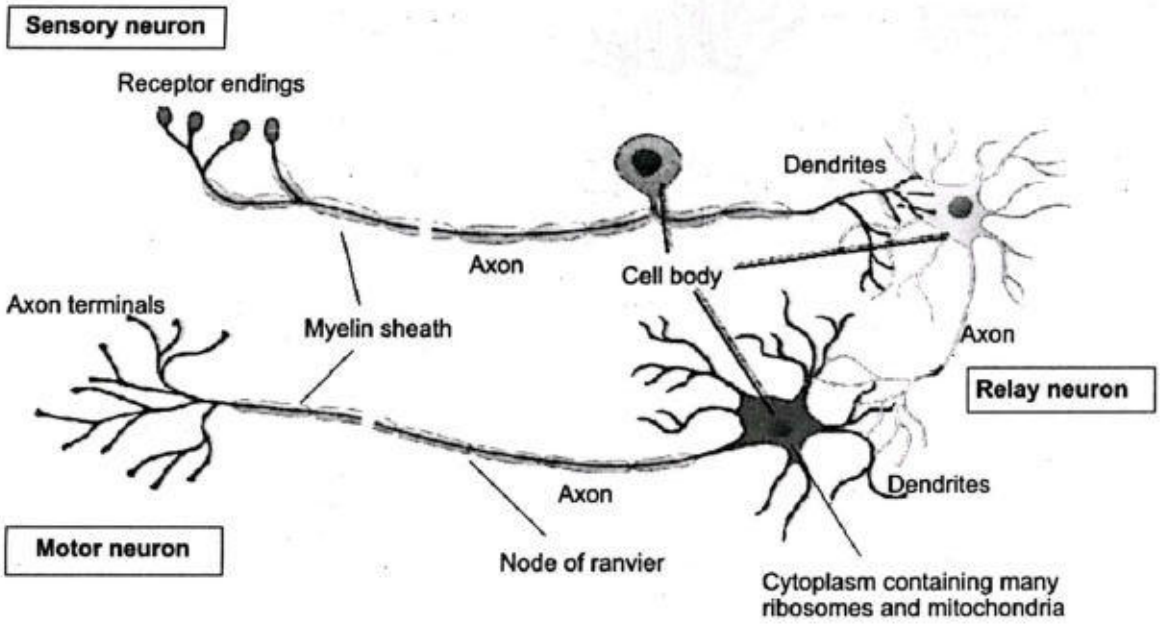


Fig. 5.9: Relationship between three types of neuron

5.3.6 Differences between myelinated and non-myelinated neurons

The axons may be categorized into myelinated (with sheath) and non-myelinated (without sheath). The myelinated fibers are present in the white part of the brain and also in the spinal cord, while the non-myelinated nerve fiber is present in the autonomic nervous system. Myllinated axons tend to be larger in diameter than the non-mylinated axons.

Table 5.2 Difference between myelinated and non myelinated neuron

Myelinated neuron	Non myelinated neuron
They possess myelin sheath.	These do not possess myelin sheath.
The Schwann cells shows wrapping around the nerve axon.	The Schwann cells do not show wrapping but are only present in the groove.
This shows two sheaths in the axis of the cylinder.	This shows only one sheath in the axis of the cylinder.
These transfer nerves impulses very fast.	These transfer nerve impulses very slow.
These appear white in their fresh form.	These appear grey in their fresh form.
They possess nodes and internodes.	These do not possess nodes and internodes.
Nodes of Ranvier are known to present in these neurons.	Nodes of Ranvier are not present in these.
Collateral fibres are produced.	Collateral fibres are not produced.

5.4 REFLEX ARC

Reflex action is an immediate, automatic and involuntary response to external and internal environmental changes. The path of the nerve impulse during reflex action is called reflex arc.

Example

A typical reflex arc includes five fundamental parts: receptors, sensory neurons, interneuron, motor neuron and effectors. For example if one unexpectedly touches a hot object, the hand is rapidly removed from the source of heat. **Receptors** in the skin of the hand are activated by the heat of the object. The receptors stimulate a **sensory neuron** leading to the spinal cord via a spinal nerve. The cell body of the sensory neuron is outside the cord. The sensory neuron enters a **dorsal nerve root** of the spinal cord. The impulse then crosses a synapse to an **interneuron** which lies completely within the cord.

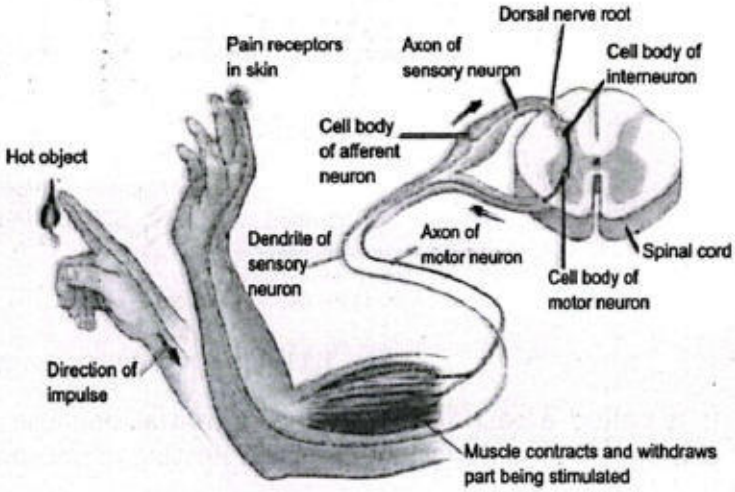


Fig. 5.10: A reflex arc

The impulse travels along the interneuron and then passes across a synapse to the dendrites and the cell body of a **motor neuron** which lies within the spinal cord. The motor neuron eventually branches to form synapses with several muscle cells i.e., an effector. The nerve impulses then move along the motor neuron to the muscles, which cause them to contract.

5.5 NERVE IMPULSE

Nerve impulse is information or signal about a stimulus that is transmitted from receptors to the CNS and from CNS to the effectors. In technical terms a nerve impulse can be defined as a wave of electrochemical changes that travel along the length of neuron, from one end to the other.

5.5.1 Generation and Transmission of Nerve Impulse

Here, word "electrochemical" refers to the electrical potential (a capacity to do electrical work) that exists on neuron membrane. In case of neuron the electrical potential is termed as membrane potential which is exhibited in two different forms i.e., Resting Membrane Potential (RMP) and Active Membrane Potential (AMP).

5.5.2 Resting membrane potential

It is characterized by more positive outer surface of neuron membrane than inner surface. This state is also referred as **polarized** state and the neuron is supposed to be at rest. This means that there is an unequal distribution of ions on the two sides of the nerve cell membrane. This potential generally measures about 70 mV (with the inside of the membrane negative with respect to the outside). So, the resting membrane potential is expressed as -70 mV, and the minus sign indicates that the inside is negative relative to (or compared to) the outside.

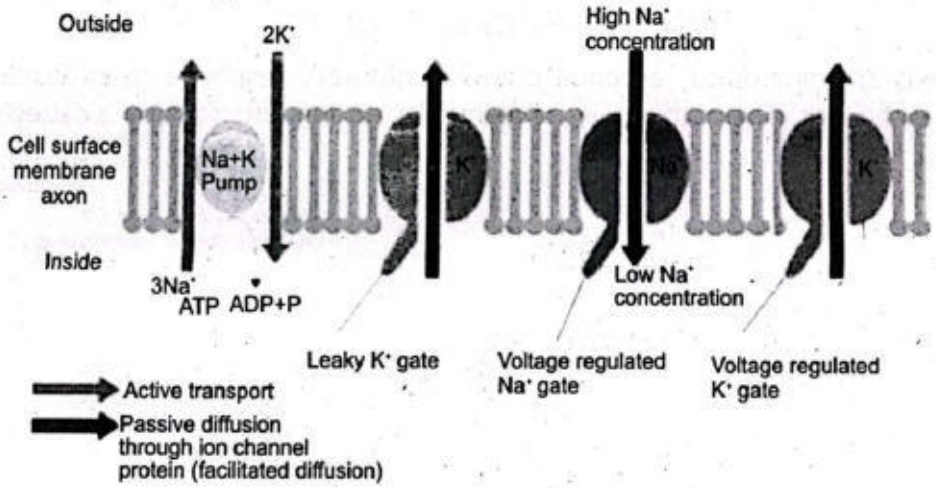


Fig. 5.11: Ionic movement across neuron membrane

It is called a resting membrane potential because it occurs when a membrane is not being stimulated or conducting impulses. Resting membrane potential is established by the following factors:

Distribution and active movement of Na^+ and K^+ ions

The concentration of potassium (K^+) is 30 times greater in the fluid inside the neuron cell than outside and the concentration of sodium ions (Na^+) is nearly 10 times greater in the fluid outside the cell than inside. These ions are continuously moved against their concentration gradient through sodium-potassium pumps by the expenditure of energy. For every two K^+ that are actively transported inward, three Na^+ are pumped out. So inside becomes more negative than outside of the neuron membrane.

Negative organic ions

There are many types of organic compounds in the neuron cytoplasm that also have negative charges. These ions include some amino acids, many proteins and RNA. Presence of these ions in the neuron cytoplasm makes inside of neuron more negative than outside.

Leakage of K^+ ions

Cell membrane of neuron also has many channel proteins called **gates**. K^+ ions leak continuously through leaky K^+ gates. This also makes more positive outside of neuron than inside.
Overall there are more positive charges on the outside than on the inside. This is known as **resting membrane potential**. This potential will be maintained until the membrane is disturbed or stimulated by a sufficiently strong **stimulus** (threshold), then action potential will be produced.

5.5.3 Active membrane potential

Active membrane potential (also called action potential) is characterized by more positive inside of neuron than outside (depolarized state). This happens when positive charges tend to move inside of neuron on receiving a particular stimulus. This electrochemical change appears on a short region of neuron for a brief period of time followed by the recovery of **polarized state.** In this way a wave of action potential begins to move towards other end of neuron. Action potential is established by the following factors.

Threshold stimulus

If a stimulus is capable to produce action potential in neuron, it is called **threshold stimulus.** If stimulus is not capable to excite or fails to arise any response, it is called **sub threshold stimulus.**

Influx of Na^+ ions

When a neuron fibre is stimulated by threshold stimulus, it causes the opening of voltage regulated Na^+ gates. As a result Na gates permit the influx of Na^+ ions by diffusion. Since there are more Na+ ions entering than leaving, the electrical potential of the membrane changes from –70 mV towards zero and then reaches to the 50 mV. This reversal of polarity across two sides of membrane is called **depolarization.** This electropositivity inside and electronegativity outside lasts for about one millisecond till the Na+ gates are not closed.

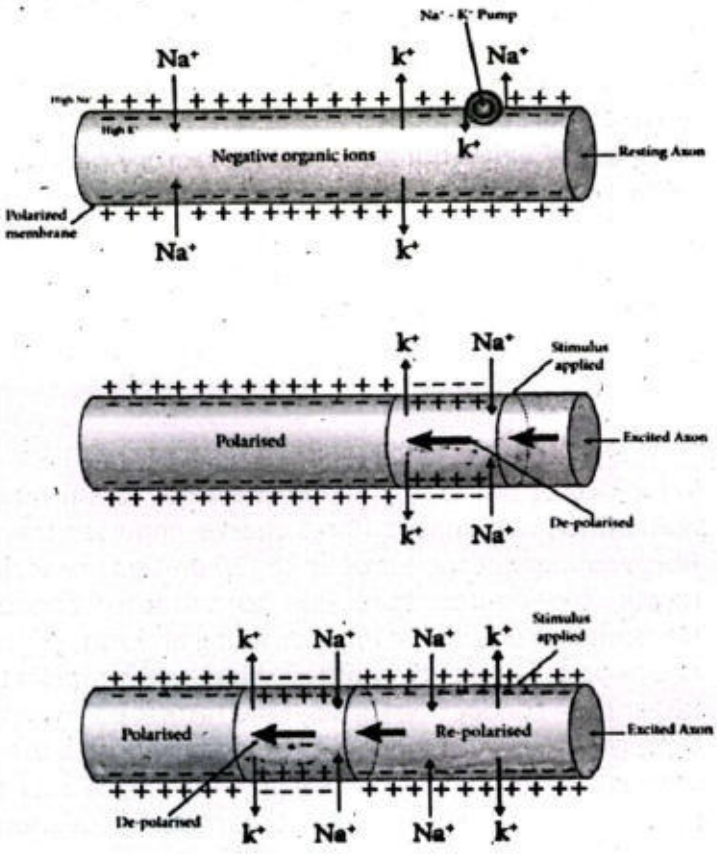


Fig. 5.12: Conduction of nerve impulse

Repolarization of neuron fibre

A fraction of second after the sodium gates open, depolarization of the axon membrane causes potassium gates to open. Potassium therefore diffuses out of the cell. Since the potassium is positively charged, this makes the inside of the cell more negative and starts the process of **repolarization.**

Hyper-polarization (More K^+ ions are on the outside than Na^+ ions on the inside)

At the peak of the action potential, the sodium gates start to close again. Sodium permeability therefore declines. The sodium-potassium pump continues to work during this time, so it gradually begins to restore the original resting potential. This repolarization is shown by the falling phase of the action potential spike and results in the membrane potential returning to its original level. In fact, there is a slight overshoot into a more negative potential than the original resting potential. This is called **hyperpolarization.** It is due to the slight delay in closing all the potassium gates compared with the sodium gates. As potassium ions continue to enter the axon their positive charge restores the normal resting potential.

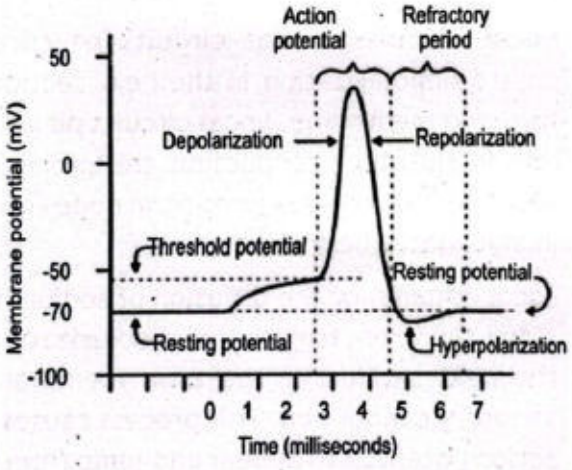


Fig. 5.13: Action potential in a neuron

Refractory period

After an action potential, nerve fibre undergoes a period of recovery in which it regains its original ionic distribution and polarity and prepares itself for the next stimulation. This period of recovery of nerve fibre is called **refractory period.** Although a repolarised neuron fibre has same polarity as that of a polarized neuron fibre but has different ionic distribution. It has more K^+ outside and more Na^+ inside. So the repolarised nerve fibre undergoes a refractory period of few milliseconds during which the original ionic distribution is restored by sodium-potassium pump which actively transports Na^+ ions out and K^+ ions in. This returns the membrane to its resting potential i.e., -70mV. Refractory period lasts for about 4 milliseconds so a neuron can conduct 250 impulses per second.

5.5.4 Velocities of Nerve Impulse

Velocities of nerve impulse in the **axon membrane** and in the **synaptic cleft** are variable. In human non myelinated fibres, nerve impulses travel at 1 to 3 metres per second. Myelinated fibres conduct at speeds of up to 120 meters per second. The velocity of nerve impulse is faster in myelinated neuron fibre due to saltatory conduction. **Saltatory conduction** is the rapid transmission of a nerve impulse along an axon, resulting from the action potential jumping from one node of Ranvier to another, skipping the myelinated regions of membrane. It is up to 50 times faster than conduction through the fastest unmyelinated axons because they don't have to travel throughout every single space before moving to the next. Another reason that myelinated fibres conduct faster impulse is that myelin sheath acts as an insulating sheath and prevents loss of energy, so myelinated neuron fibres require less energy.

Velocity of nerve impulse also depends upon diameter of neuron fibres. Thick neuron fibres conduct faster impulse than thin fibres because resistance to electrical current flow is inversely proportional to the cross sectional area of the conductor, so with the increase in thickness of neuron fibres there is decrease in resistance of fibre to nerve impulse. The short journey across the synapse takes about a millisecond, longer than a nerve impulse takes to travel the same distance. This time is therefore called **synaptic delay.**

5.5 Role of local circuits in saltatory conduction

Local circuits: Local circuits of current create depolarization in the next section of the axon membrane. Local circuits play a key role in saltatory conduction, the process by which nerve impulses jump from node to node in myelinated nerve fibers.

Local circuits, or the diffusion of sodium ions along the axon, trigger the depolarization of the next section of the axon membrane in saltatory conduction. This process causes the action potential to appear and jump from one node of Ranvier to the next.

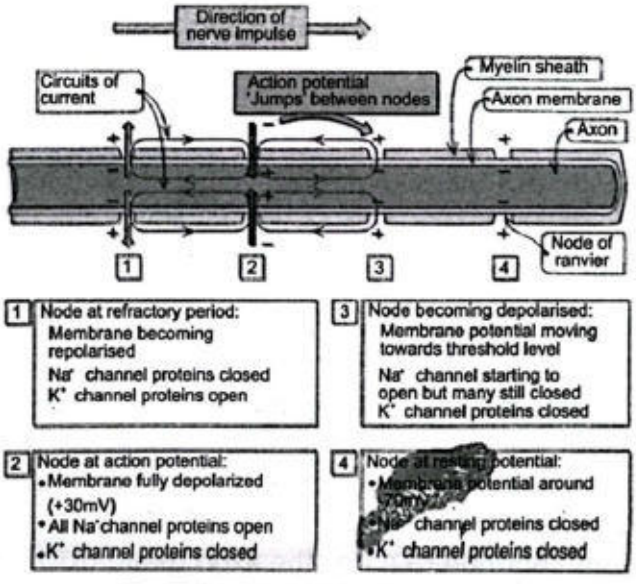


Fig. 5.14: Synaptic transmission

5.6 SYNAPSE

The junction between axon terminal of one neuron and the dendrite of another neuron, where information from one neuron is transmitted or relayed (handed over) to another neuron is called **synapse** (si-napse).

5.6.1 Structure of Synapse

The neurons are not in direct contact at a synapse. There is a gap, called a **synaptic cleft** between them. A single neuron may form synapses with many incoming fibres of different neurons. A neuron which carries an impulse toward a synapse is called **presynaptic neuron.** A neuron which receives the impulse after it crosses the synapse is a **post synaptic neuron.**

5.6.2 Mechanism of Synaptic transmission of nerve impulse

The movement of impulse across the synapse is called a **synaptic transmission.** It takes place in the formation of a message which is transmitted across the synapse in the form of chemical messenger called **neurotransmitter.** The axons usually have several rounded synaptic knobs at their distal ends, which dendrites lack. These knobs contain numerous membranous sacs, called **synaptic vesicles** and when a nerve impulse reaches a knob, some of the vesicles respond by releasing a neurotransmitter. Fig: 15.4 and 15.5 shows the following numbered sequence: (1) An action potential (red arrow) arrives at the synaptic knob. Calcium channels open in the presynaptic membrane. As the calcium ion concentration inside the bulb is lower than the outside, calcium ions rush in. As the calcium concentration increases, synaptic vesicles move towards the membrane. (2) The neurotransmitter vesicles fuse with the plasma membrane of the transmitting cell. (3) The fused vesicles release their neurotransmitter molecules (green) into the synaptic cleft. (4) The released neurotransmitter molecules diffuse across the cleft and bind to receptor molecules on the postsynaptic cell surface membrane. (5) Binding of neurotransmitters to the post synaptic neuron receptors opens some channels and allows Na+ ions to diffuse across the post synaptic membrane. As a result post synaptic membrane depolarizes and an action potential is generated. Since this depolarization brings the membrane potential towards threshold level, it is called **excitatory postsynaptic potential (EPSP).** (6) Once the neurotransmitters have acted on the postsynaptic membrane, they are immediately broken down by enzymes, like acetylcholine is hydrolyzed by acetylcholinesterase and adrenalin by monoamine oxidase.

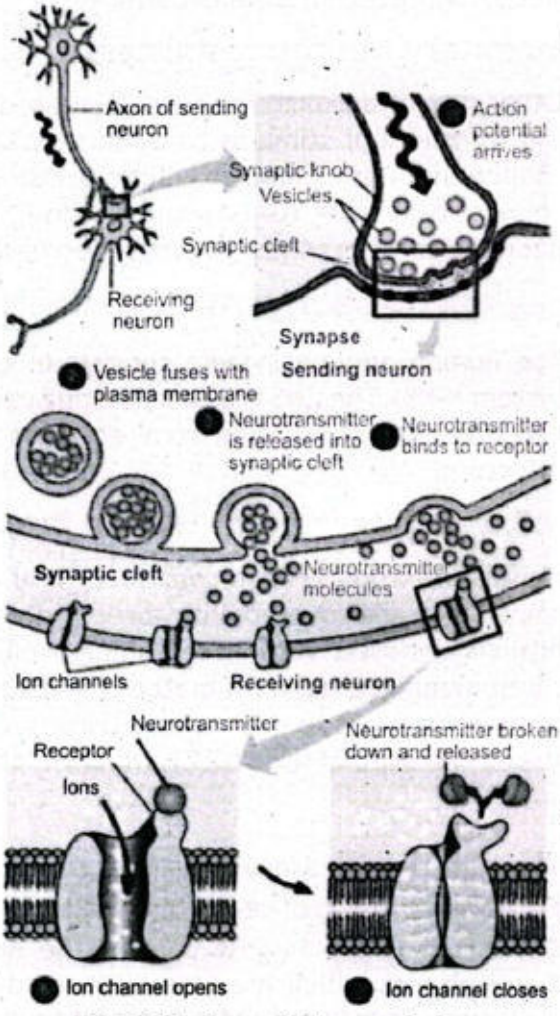


Fig. 5.15: Synaptic transmission

SCIENCE TITBITS

In electrical impulses, which are specialized for rapid signal transmission, the cells are separated by the synaptic cleft of only 0.2 nm, so that an action potential arriving at the pre-synaptic side of cleft, can sufficiently depolarize the post synaptic membrane to directly *trigger* its action potential.

5.6.3 Classifications of Neurotransmitters

Neurotransmitters are classified as excitatory and inhibitory.

Excitatory Neurotransmitters

Neurotransmitters that cause increased membrane permeability to sodium ions and, thus, trigger nerve impulses are said to be **excitatory**. **Acetylcholine** is an excitatory neurotransmitter of peripheral nervous system whereas **biogenic amines** (amino acid derivatives) are important neurotransmitters in central nervous system. They include epinephrine, norepinephrine, serotonin and dopamine, all of which also function as hormones. **Epinephrine** and **norepinephrine** increase the heartbeat rate during stress. **Serotonin** and **dopamine** affect sleep, mood, attention and learning.

Inhibitory Neurotransmitters

Other neurotransmitters cause decreased membrane permeability to sodium ions, thus causing the threshold of stimulus to be raised. This action is called **inhibitory**; because it lessens the chance that nerve impulse will be transferred to an adjoining neuron e.g., amino acids gamma-aminobutyric acid (GABA) and glycine. The **endorphins** are peptides that function as both neurotransmitters and hormones, decreasing our perception of pain.

5.7 MAIN COMPONENTS OF NERVOUS SYSTEM

The human nervous system consists of central nervous system (CNS) and peripheral nervous system (PNS). The CNS is a coordinating centre and it lies in the midline of the body, whereas, the PNS transmits information from receptors to CNS and transmits orders and commands from CNS to effectors.

5.7.1 Architecture of Human Brain and Spinal Cord and their Functions

Central nervous system consists of brain and spinal cord, and both are hollow. The brain and spinal cord are covered with three protective membranes called **meninges** (singular: meninx). Brain is enclosed within the cranium while spinal cord is enclosed within vertebral column. The three meninges are **dura matter** (next to the cranium), **arachnoid matter** (middle membrane) **pia matter** (next to the nervous tissue). Between the arachnoid and pia matter there is a fluid, the **cerebrospinal fluid** (CSF), which helps to cushion the brain from shock.

The Brain

The brain is divided into three part, forebrain, midbrain and hindbrain.

Forebrain consists of cerebrum, thalamus and limbic system.

Cerebrum is the largest part of the human brain. Cerebrum is divided into two **cerebral hemispheres** which are interconnected with each other by a band of axons, called **corpus callosum**. Each hemisphere contains four surface lobes: frontal, parietal, temporal and occipital lobe.

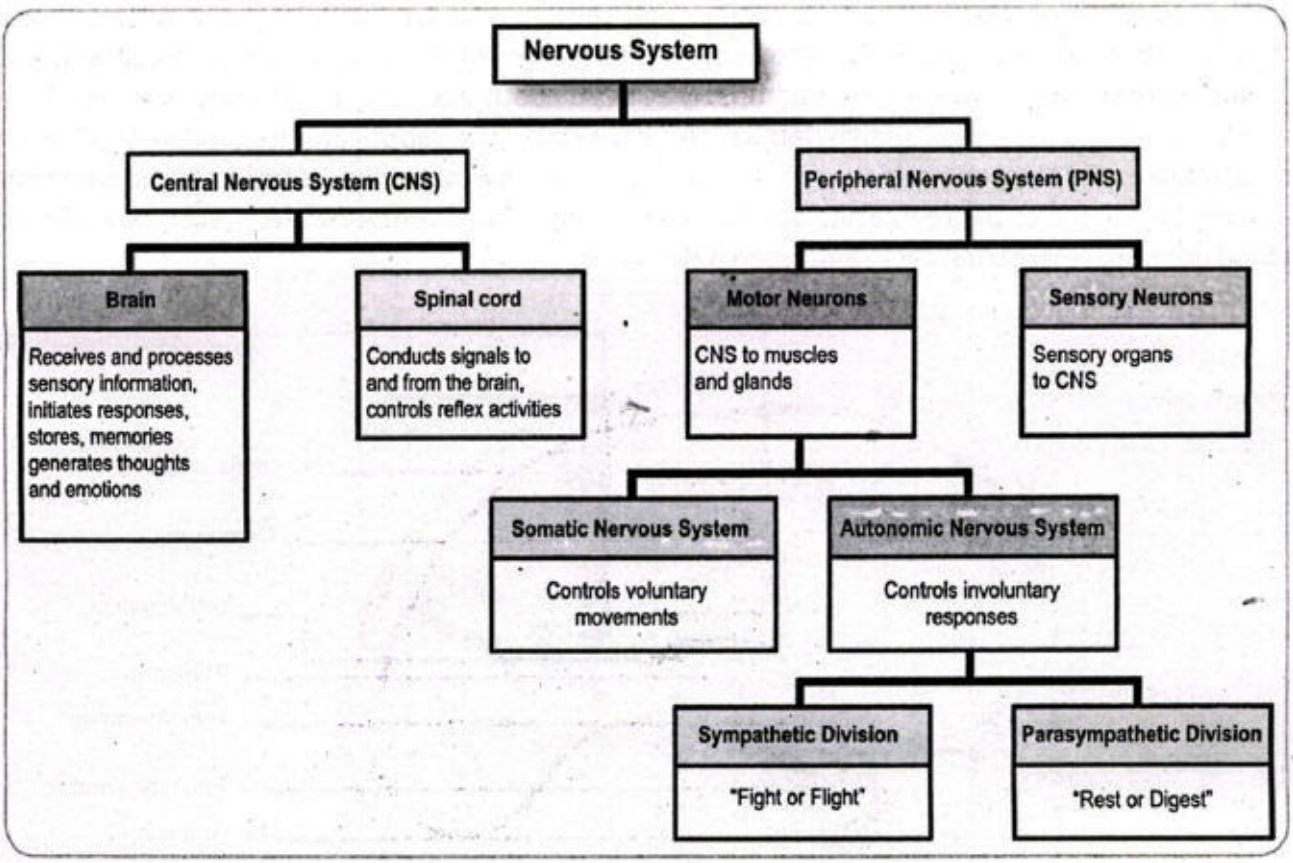


Fig. 5.16: Organization of human nervous system

SCIENCE TITBITS

The surface of the cerebrum is called cerebral cortex. Cerebral cortex has many folds or convulsions forming ridges or gyri (singular, gyrus) which are separated by grooves. A shallow groove is called a sulcus (plural, sulci) and a deep groove is called a fissure. The two hemispheres are separated by longitudinal fissure.

Each lobe further contains different functional areas e.g., auditory (hearing) visual area etc. Each functional area consists of three sub-areas i.e., sensory area, association area and motor area. **Sensory area** receives impulses from different body parts. **Association area** interprets or analyzes the incoming information. The **motor area** controls responses of the body. Cerebrum also functions in the analysis and interpretation of memory, reasoning, judgement, thoughts and dreams.

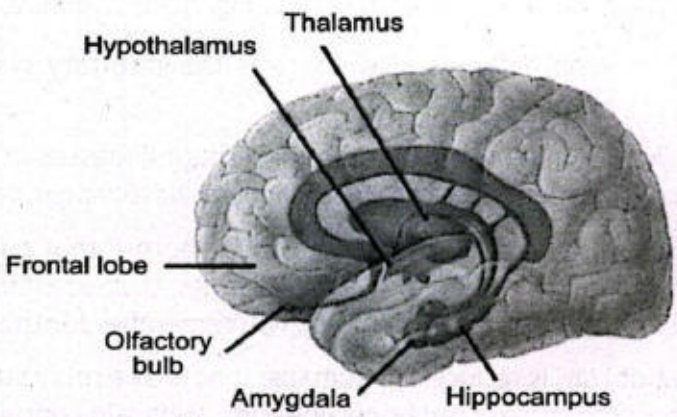


Fig. 5.17: Limbic system

Thalamus is below the cerebrum. It receives all sensory impulses (except sense of smell) and channels them to limbic system and to appropriate regions of the cortex for interpretation. The **limbic system** is a complex set of structures that lies on both sides of the thalamus, just under the cerebrum. It includes the **hypothalamus**, the **amygdala**, the **hippocampus**, and several other nearby areas. On the ventral side of the thalamus is the **hypothalamus**. It maintains homeostasis and contains centres for regulating hunger, sleep, thirst, body temperature, water balance and blood pressure, menstrual cycle and sleep wake cycle.

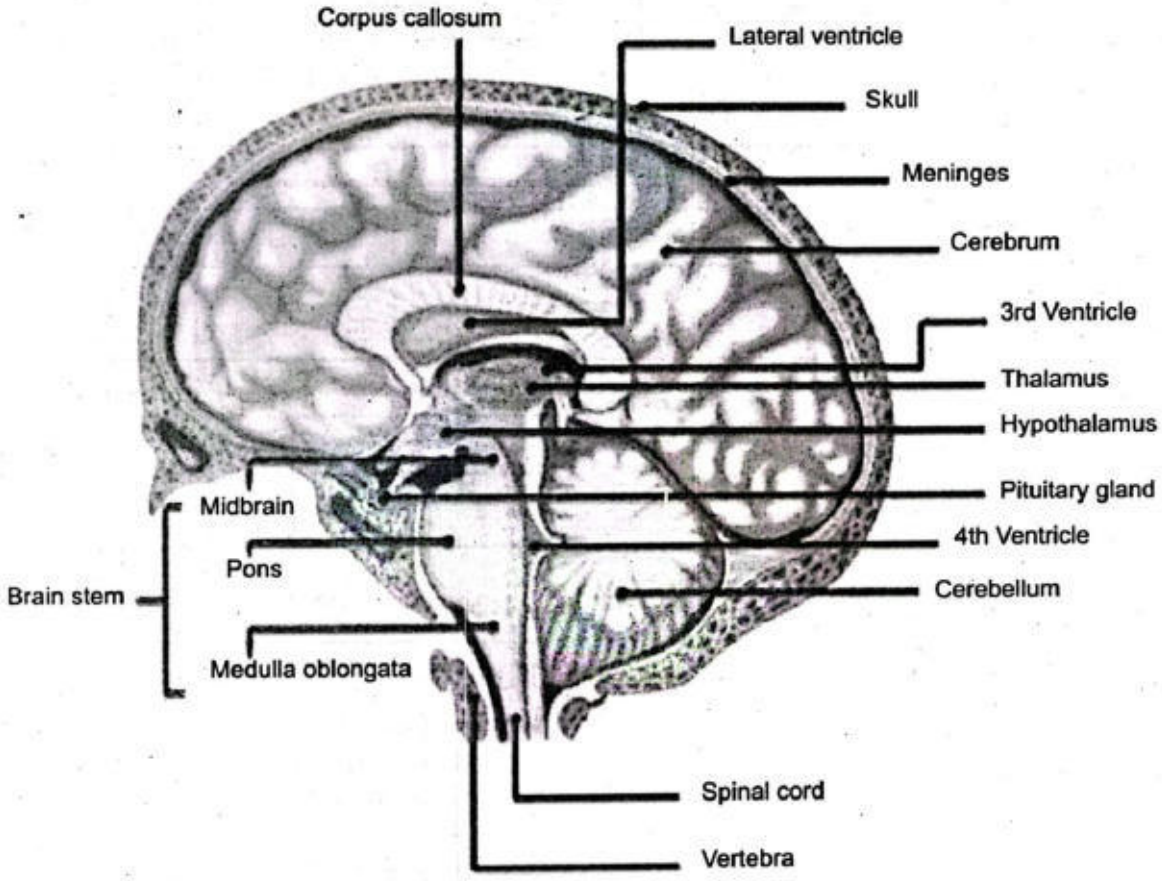


Fig. 5.18: Structure of human brain

The hypothalamus also controls the pituitary gland and thereby serves as link between the nervous and endocrine system.

The **amygdalae** are two almond-shaped masses of neurons on either side of the thalamus. They control feeling and emotions of love, hate, anger, fear, rage and sexual arousal.

The **hippocampus** consists of two "horns" that curve back from the amygdala. It appears to be very important in converting things that are "in your mind" at the moment (in short-term memory) into things that you will remember for the long run (long-term memory).

Midbrain is reduced in humans. It acts as a relay station for tracts passing between the cerebrum and the spinal cord or cerebellum. Midbrain contains reticular formation, which is a relay centre connecting hindbrain with forebrain.

Hindbrain consists of cerebellum, medulla oblongata and pons. **Cerebellum** controls equilibrium i.e., body position and coordination of the actions of individual muscles to produce complex activities such as walking, running, riding bicycles, doing delicate work with hand. The cerebellum is also involved in learning memory storage for behaviour. **Pons** acts as a bridge between the cerebellum, medulla and cerebrum. It also controls rate and pattern of heartbeat and breathing. **Medulla** controls the automatic functions of the body, such as heartbeat, blood pressure, respiration, swallowing etc.

Brain is hollow structure as it has cavities called **ventricles**. There are four ventricles in the brain.

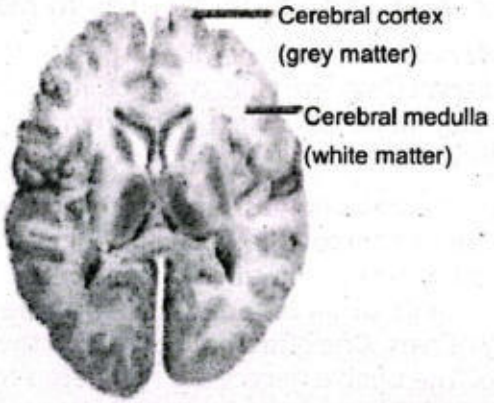


Fig. 5.19: Cross section view of brain

Spinal cord

The spinal cord is the most important structure between the body and the brain. The spinal cord extends from the medulla to the level of the lumbar vertebrae. It is a vital link between the brain and the body. A transverse section of the adult spinal cord shows white matter in the periphery, grey matter inside and a tiny central canal filled with CSF at its centre. **Grey matter** is shaped like the letter "H" or a "butterfly".

The grey matter consists of neuron cell bodies and nonmyelinated parts of the fibres. The **white matter** is made up of bundles of myelinated fibres. Several pairs of spinal nerves originate from ventral and dorsal horn of grey matter. Dorsal root of spinal nerves, also contain ganglia present just beside the spinal cord. Arrangement of grey and white matter in brain is opposite to that of spinal cord.

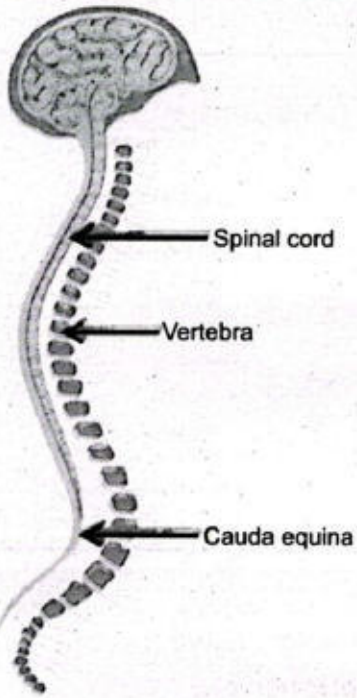


Fig. 5.20: Spinal cord elongated view

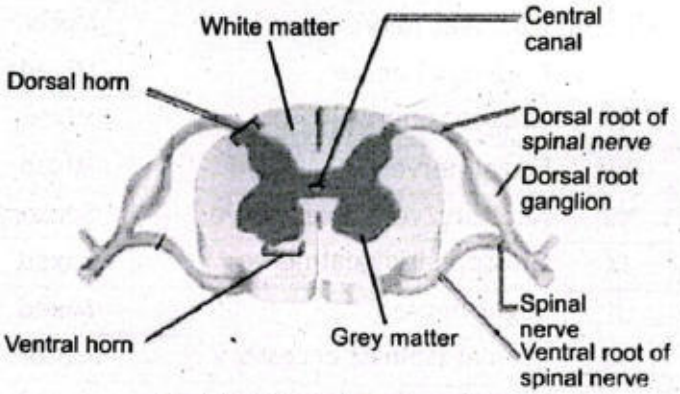


Fig. 5.21: Spinal cord anatomy

5.7.2 Cranial and Spinal Nerves in Man

Cranial Nerves: The peripheral nervous system consists of the nerves that branch out from the central nervous system and connect it to other body parts. The peripheral nervous system includes cranial nerves which arise from the brain and the spinal nerves, which arise from the spinal cord.

A number of cranial nerves send electrical signals between the brain and different parts of the **neck, head** and **torso.** These signals help us to smell, taste, hear and move our facial muscles. The cranial nerves begin toward the back of brain. There are twelve cranial nerve pairs. Each nerve pair splits to serve the two sides of the brain and body. For example, we have one pair of olfactory nerves. One olfactory nerve is on the left side of the brain and one is on the right side of the brain. The twelve nerves are numbered from I to XII using Roman numerals according to the order in which they emerge from the front of the brain to the back of the brain. The twelve cranial nerves each have a specific function. The cranial nerves have been categorized based on number and function.

Extra reading material

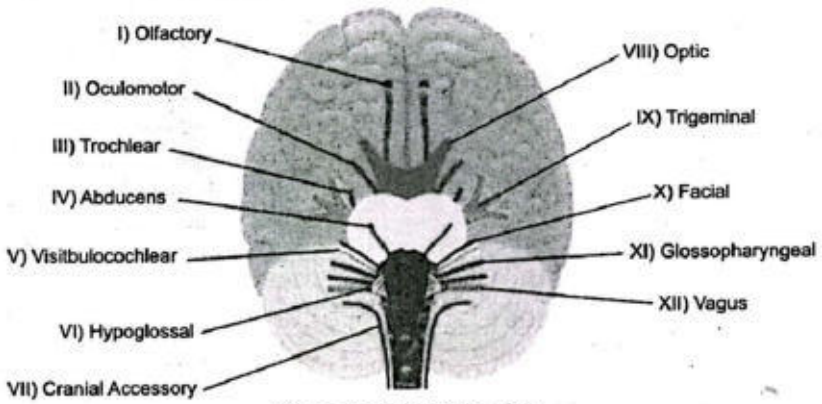


Fig. 5.22: Cranial nerves

Cranial nerves (Extra reading material)			
I	Olfactory nerve	Sensory	Sense of smell
II	Optic nerve	Sensory	Sense of sight
III	Oculomotor nerve	Motor	Movement of eyes.
IV	Trochlear nerve	Motor	Rotation of the eye ball
V	Trigeminal nerve	Mixed	Functioning of the facial parts
VI	Abducens nerve	Mixed	Rotation of the eye ball
VII	Facial nerve	Mixed	Facial expression and sense of taste
VIII	Auditory/vestibular nerve	Sensory	Sense of hearing and balance
IX	Glossopharyngeal nerve	Mixed	Ability to taste and swallow
X	Vagus nerve	Mixed	Digestion and heart rate
XI	Cranial (spinal) accessory	Motor	Shoulder and neck movement
XII	Hypoglossal nerve	Motor	Ability to move tongue

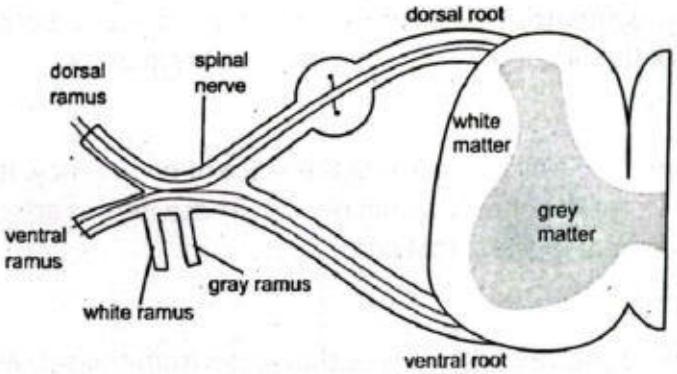


Fig. 5.23: The formation of the spinal nerve from the ventral and dorsal roots

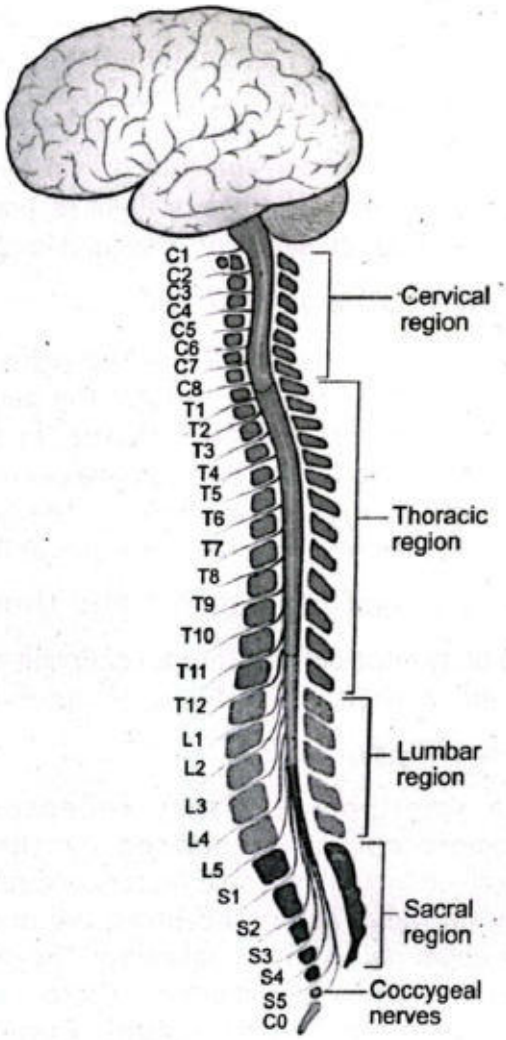


Fig. 5.24: Spinal nerves

Spinal Nerve: A **spinal nerve** carries motor, sensory and autonomic signals between spinal cord and the body. Each spinal nerve is a mixed nerve. It is formed from the combination of nerve root fibers from its dorsal and ventral roots.

There are 31 pairs of spinal nerves one on each side of the vertebral column. These include: Eight cervical nerve pairs (nerves starting in the neck and running mostly to face and head). Twelve thoracic nerve pairs (nerves in the upper body that extend to chest, upper back and abdomen).There are five lumbar nerve pairs (nerves in the low back that run to legs and feet) and five sacral nerve pairs (nerves in the low back extending into the pelvis) and one pair of coccygeal nerves. The spinal nerves are part of the peripheral nervous system.

Outside the vertebral column, the nerve divides into branches. The dorsal ramus contains nerves that serve the posterior portions of the trunk. The ventral ramus contains nerves that serve the remaining anterior parts of the trunk and the upper and lower limbs.

5.7.3 Peripheral Nervous System

The **peripheral nervous system** can also be subdivided into the somatic and autonomic nervous systems.

Somatic nervous system

Generally, the **somatic nervous system** consists of the cranial and spinal nerve fibres that connect the CNS to the skin and skeletal muscles; it is involved in conscious activities.

Autonomic nervous system

The **autonomic nervous system** includes those fibres that connect the CNS to the visceral organs, such as the heart, stomach, intestines and various glands. It is concerned with unconscious

activities. The autonomic system is divided into sympathetic and parasympathetic system. Both of these systems function automatically and usually subconsciously in an involuntary manner.

Sympathetic division

The sympathetic division controls various autonomic functions during the state of emergency. It prepares the body for fight or flight response. It consists of only spinal nerves. These nerves arise from first thoracic segment to second lumber segment of the spinal cord.

Parasympathetic division

A few cranial nerves, including the **vagus nerve**, together with nerves that arise from the sacral portion of the spinal cord, form the **parasympathetic division.** It controls various autonomic functions during the state of rest. In short, the parasympathetic system returns the body functions to normal after they have been altered by sympathetic stimulation. In times of danger, the sympathetic system prepares the body for violent activity. The parasympathetic system reverses these changes when the danger is over.

5.7.4 Sensory Receptors and their Working

The body must detect what is occurring inside and outside the body and is performed by sensory receptors. Here we will discuss receptors for smell, tastes, touch and pain.

Olfactory receptors

The smell or olfactory receptors are chemoreceptors, stimulated by chemicals dissolved in liquids. The olfactory organs, which contain the olfactory receptors, are present in the upper part of the nasal cavity. The olfactory receptor cells are neurons. These cells are surrounded by columnar epithelial cells having cilia at the distal ends. Chemicals that stimulate the olfactory receptors enter the nasal cavity as gases. They must dissolve at least partially in the watery fluids that surround the cilia before they can be detected.

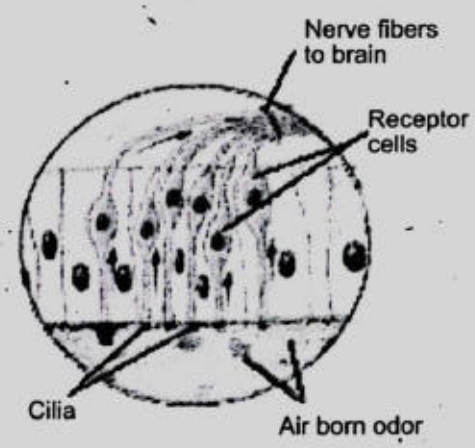


Fig. 5.25: Olfactory receptors in nasal epithelium

Taste receptors

Taste buds occur primarily on the surface of the tongue and are associated with tiny elevations called **papillae**. Each taste bud includes a group of modified epithelial cells, the **taste cells,** which function as receptors. The taste bud has an opening, the **taste pore** on its surface. Tiny projections, called **taste hairs,** protrude from outer ends of taste cells and just protrude through the taste pore. There are four primary taste sensations i.e., sweet, sour, salty and bitter, which are situated at various regions on the tongue. All the four regions overlap at certain places.

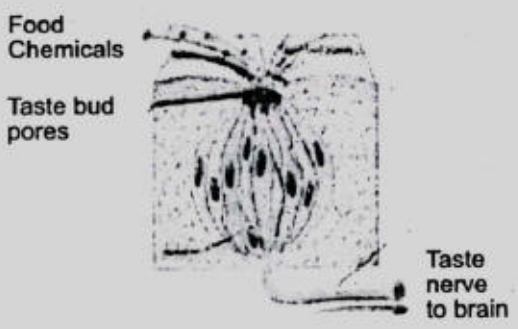


Fig. 5.26: Taste buds on tongue

Sensory receptors in human skin

The dermis of the skin contains receptors for touch, pressure, temperature and pain. **Meissner's corpuscles** and **Merkel disks** are touch receptors. These consist of small, oval masses of flattened connective tissue cells. Two or more sensory nerve fibres branch into each corpuscle. Meissner's corpuscles are especially numerous in the lips, fingertips, palm, and soles. **Paccinian's corpuscles** are also encapsulated nerve endings present in the fatty layer deep into the skin. They are concerned with sensation of pressure. Receptors for touch and pressure are also called **mechanoreceptors**. Skin also has cold and heat receptors to detect the temperature variations.

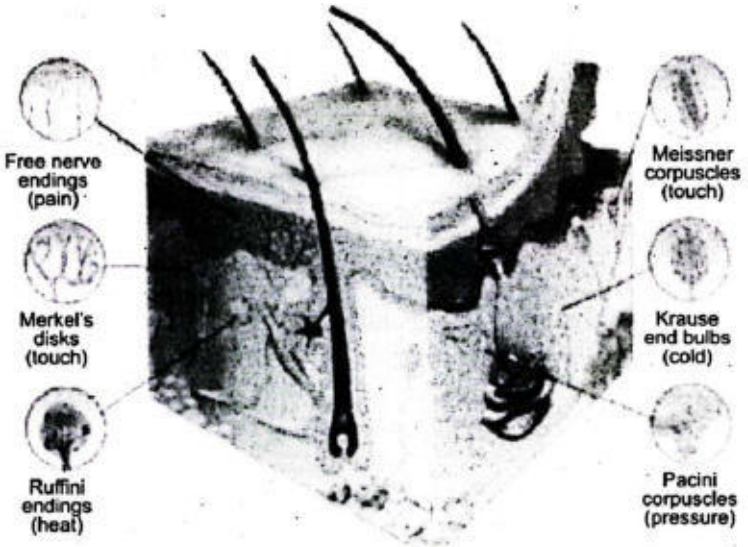


Fig. 5.27: Receptors in human skin

Pain receptors are technically called **nociceptors.** Pain receptors are located at the top of the skin in the epidermis area to detect pain. These receptors are free nerve endings that respond to chemicals released by damaged tissues or excess stimuli of heat or pressure. These receptors are widely distributed throughout the skin and inter tissues, except in the tissue of the brain.

Science, Technology and Society Connections

Ascertain the effect of nerve gas as an inhibitor of acetylcholinesterase.

Acetylcholine and the enzyme, acetyl cholinesterase, enable muscles to contract and relax. Normally, acetylcholine, a neurotransmitter, when released into the synapse of a muscle elicits the contraction of a muscle and is subsequently broken down by the enzyme, acetylcholinesterase, and relaxation of the muscle can occur. However, sarin, a nerve gas, irreversibly binds to acetylcholinesterase blocking it from breaking down the acetylcholine, thereby causing muscles to remain contracted. There exists a structural similarity between the active sites of the acetylcholine and the sarin molecule that enables the sarin molecule to fit into the acetylcholinesterase molecule. If the muscle is the diaphragm, it would remain contracted and the person would not be able to breathe. Nerve gases are extremely toxic; a small droplet can kill a person. They exist in both liquid and gaseous forms.

5.8 EFFECTS OF DRUGS ON NERVOUS COORDINATION

A narcotic is a group of substances when administered diminish the perception of pain. Narcotics bind to certain painkilling sites in the brain. With constant use, they build up in the brain and block the production of **endorphins**, the brain's natural painkilling chemicals. Their side effects are inhibition of the endocrine and autonomous nervous system etc. The narcotics are the drugs that act as agents which interact with the normal nervous activity.

5.8.1 Narcotic Drugs

Common narcotic drugs are heroin, *Cannabis*, nicotine and alcohol etc.

Heroin

Heroin gives a feeling of euphoria along with relief of pain. Side effects can include nausea, vomiting, respiratory and circulatory depression leading to death.

Cannabis

It is the dried flowering tops, leaves and stem of Indian hemp plant *Cannabis sativa*. It includes marijuana and hashish. Usually the users report a mild euphoria, along with alterations in vision and judgement. Intoxication is recognised by the presence of hallucinations, anxiety and depression.

Nicotine

It is an alkaloid derived from tobacco. When smoking a cigarette, nicotine is quickly distributed to all body organs. In peripheral nervous system, nicotine stimulates postsynaptic receptors (like acetylcholine) and leads to increased skeletal muscular activity. It also increases heartbeat rate and blood pressure.

Alcohol

Alcohol act as depressant and slows down the nervous communication. Its short term effects are impairment of vision, judgment and alertness. Long term chronic drinking can damage nervous system, liver and pancreas.

Withdrawal symptoms of alcohol

Individuals who eliminate addictive substances from their lives often feel withdrawal symptoms. Alcohol withdrawal refers to a group of symptoms that may occur from suddenly stopping the use of alcohol. The symptoms are: feeling of anxiety, irritability, depression, headache and hallucinations.

Inhalants

These are volatile organic chemicals, commonly referred to as "glue sniffing". Inhalant abuse now includes aerosols e.g., hair spray and anaesthetics e.g., ether etc. Inhalants rapidly start euphoria followed by central nervous system depression. Deep breathing of the toxic vapours may result in hallucinations or even death.

5.8.2 Drug Addiction and Drug Tolerance

Drug addiction: Drug addiction is a dependence on an illegal drug or a medication. You may want to quit, but most people find they can't do it on their own.

Drug tolerance: Drug tolerance is a person's diminished response to a drug, which occurs when the drug is used repeatedly and the body adapts to the continued presence of the drug e.g. caffeine and nicotine.

CRITICAL THINKING

What measures can be taken to eradicate drug addiction from the society?

a. Caffeine

Caffeine is a drug, and individuals can develop both tolerance and a form of dependence

Caffeine tolerance: Tolerance to caffeine means that the body becomes accustomed to its effects, requiring higher doses to achieve the same level of alertness or stimulation.

Caffeine addiction: It does not cause classic addiction the way some drugs do.

Harmful effects of caffeine: These include insomnia, rapid heart rate, anxiety, frequent urination, digestive issues, fatigue, high blood pressure and irritability tremors

b. Nicotine

Nicotine is the chemical in tobacco that makes it hard to quit.

Nicotine tolerance: It occurs when the body requires increasing amounts of nicotine to achieve the same effects initially felt with lower doses

Nicotine addiction: Nicotine produces pleasing effects in your brain, but these effects are temporary. So you reach for another cigarette. The more you smoke the more nicotine you need to feel good.

Harmful effects of nicotine: These include cancer, nausea, dizziness, emphysema, infertility, insomnia, cardiovascular diseases, headache and mouth ulcer.

Do you know?

Caffeine and nicotine both cause the brain to release dopamine, but the release from caffeine is much smaller. Nicotine changes how the brain works, making it one of the most addictive substances in the world.

5.8.3 Effects of drug addiction and tolerance on the central nervous system

Drugs are chemicals that interfere with the way neurons normally send, receive, and process information. Some drugs can activate neurons because their chemical structure mimics that of a natural neurotransmitter. Drugs interact with the brain and body to alter moods, emotions, and behaviors by changing brain chemistry. Regions of the brain affected by drug abuse are the brain stem, limbic system, and cerebral cortex.

All depressants work by slowing down the functioning of the central nervous system, while stimulants can produce a number of effects on the body such as increased heart rate, improved concentration, increased respiratory rate etc.

5.9 PAIN MEDICINES REDUCE OR NUMB PAIN IN HUMAN BODY

Analgesics are also called painkillers. These medicines reduce or numb pain in the body through various mechanisms that affect the nervous system. There are different types of pain medications and each works in a unique ways to interfere with pain signals. We will discuss here the main categories of pain medications and how they function.

a. Non-Steroid Anti-inflammatory Drugs (NSAIDs): These medicines works by inhibiting the activity of an enzyme called cyclooxygenase (COX), which plays a key role of in the production of prostaglandins. Prostaglandins are chemicals released at the site of injury or inflammation that cause pain, swelling and fever. By reducing the production of prostaglandins, NSAIDs help to reduce inflammation and numb pain.

b. Acetaminophen (Paracetamol): It is believed that it works by acting on brain's pain center. It likely inhibits COX enzymes in the brain, which reduces the perception of pain without the anti-inflammatory effect.

c. Opioids: These are also called narcotics. Opioids bind to opioid receptors in the brain, spinal cord and other parts of the nervous system. These receptors are involved in the transmission and perception of pain. When opioids binds to these receptors they block pain signals from being transmitted to the brain and increase the brain's and increase the brain's threshold for pain, essentially dulling or eliminating the sensation of pain.

d. Local Anesthetics: These work by blocking sodium channels in nerve cells. Sodium channels are essential for the transmission of electric signals along nerves. By blocking these channels, local anesthetics prevent pain signals from travelling from the site of injury to the brain. These are commonly used for procedures where localized numbing is required, such as dental work or minor surgeries.

e. Antidepressants and anticonvulsants: These medicines are used to treat chronic pain, particularly nerve pain. They work by modulating the neurotransmitters involved in pain perception. Such as serotonin and norepinephrine.

f. Corticosteroids: They reduce swelling and inflammation, which in turn reduces pain. They work by inhibiting the production of inflammatory chemicals and suppressing the immune response.

g. Other medicines: These numb localized area. Some are used to relax muscles.

5.9.1 Certain Pain Medications are Addictive

Physicians typically prescribe opioids to manage moderate to severe pain. However, opioids can become addictive because they not only dull pain, but also produce a sense of euphoria (intense happiness). This, combined with tolerance build (needing to increase doses to produce the same effect) can lead to opioid use disorder.

Opioids also cause neurons that produce dopamine the neurotransmitter, which plays a role in how we feel pleasure, or strong reactions to something. This creates feelings of euphoria Physicians reduce the length and strength of opioids to try to prevent addiction.

5.10 DISORDERS OF THE NERVOUS SYSTEM

The disorders of the nervous system may be classified as vascular, infectious, structural, functional and degenerative. While classifying the site of involvement is also considered. We will discuss here causes, symptoms and treatment of few diseases of the major categories.

5.10.1 Vascular Disorders of the CNS

Any disorder of nervous system which occurs due to abnormality in blood circulation is called vascular disorder of the nervous system e.g., strokes, brain haemorrhage.

Stroke

It occurs due to rupture of small cerebral arteries. **Cause:** The cause and risk factors for stroke include hypertension, cigarette smoking, diabetes mellitus, high alcohol intake, thrombosis, blood disorders, blood embolism and cocaine abuse. **Symptoms:** These include sudden loss of function in one region of brain. Weakness and heaviness occur in arm, leg or face. Paralysis occurs on the side of the body opposite the cerebral infarction (a portion of the tissue that is dying because of blood supply to it has been cut off). Aphasia (inability to express through words) may be present. **Treatment:** Medical treatment is aimed at preventing further attacks and stroke.

Anticoagulants and platelet aggregation inhibitor (such as aspirin) is given. Blood pressure management and nursing care is essential.

5.10.2 Infectious Disorders of the CNS

Infections of the central nervous system can be caused by almost any infectious agent, including viruses, bacteria, fungi, protozoa and Platyhelminthes.

Meningitis

It is an inflammation of the meninges. **Cause:** Bacterial or viral infection of meninges. **Symptoms:** usually include stiffness in the neck, headache and fever. In severe cases, meningitis may also cause paralysis, coma or death. **Treatment:** For viral meningitis, there is no specific treatment. Bacterial meningitis is treated with antibiotics and steroids.

5.10.3 Structural Disorders of the CNS

Several disorders disturb the structure of brain are referred as structural disorders, such as tumours.

Tumour

Tumour (tumor) is an abnormal mass of neuroglial cells produced as a result of uncontrolled cell division. **Cause:** It is caused by mutation which may occur at any age in brain and spinal cord. **Symptoms:** These vary widely, depending on the location of the tumour but may include headaches, severe nerve pain, paralysis, seizures, coma and death. **Treatment:** Surgical removal of tumour.

5.10.4 Functional Disorders of the CNS

Headache

Headache is the pain anywhere in the region of the head or neck. It can be a symptom of a number of different conditions of the head and neck. The brain tissue itself is not sensitive to pain because it lacks pain receptors. Rather, the pain is caused by disturbance of the pain-sensitive structures around the brain. There are two major categories of headaches i.e., **primary headaches** (due to the headache condition itself and not due to another cause) e.g., migraine, tension headache; and **secondary headaches** (due to an underlying structural problem in the head or neck such as bleeding in the brain, tumour, meningitis etc. Several analgesic drugs are available for **treatment** of any kind of headache.

5.10.5 Degenerative Disorders of the CNS

Many diseases cause degeneration in different part of the nervous system without an identifiable external cause. Genetic factors are known to be involved. Example of such diseases is Alzheimer's disease.

Alzheimer's disease

Alzheimer's disease is a slowly progressive disease of the brain that is characterized by impairment of memory and eventually by disturbances in reasoning, planning, language, and perception. Although onset of this disease occurs in aged peoples but it is not particularly associated with aging. **Cause:** There is genetic predisposition, so tends to run in families. **Symptoms:** Most prominent symptom is short-term memory loss. **Treatment:** There is no effective treatment for this disease.

5.11 PRINCIPLES OF DIAGNOSTIC TESTS FOR NERVOUS DISORDERS

These days number of diagnostic tests have been developed for nervous disorders. The principle of EEG, CT scan and MRI are discussed here.

Electroencephalography (EEG)

Neurons within the cerebral cortex continuously generate electrical activity. This activity can be recorded by electrodes attached to precise locations on the scalp, producing **electroencephalogram** and this technique is called **electroencephalography (EEG).** An EEG pattern is commonly called **brain waves.**

Fig. 5.28: Receptors in human skin

Computed Tomography Scan (CT Scan)

Computerized tomography is more commonly known by its abbreviated names, CT scan. It is an X-ray procedure that combines many X-ray images with the aid of a computer to generate cross-sectional views and, if needed, three-dimensional images of the internal organs and structures of the body. A CT scan is used to define normal and abnormal structures in the body and/or assist in procedures by helping to accurately guide the placement of instruments or treatments.

CT scanners give doctors a 3-D view of the body. The images are exquisitely detailed but require a dose of radiation that can be 100 times that of standard X-ray.

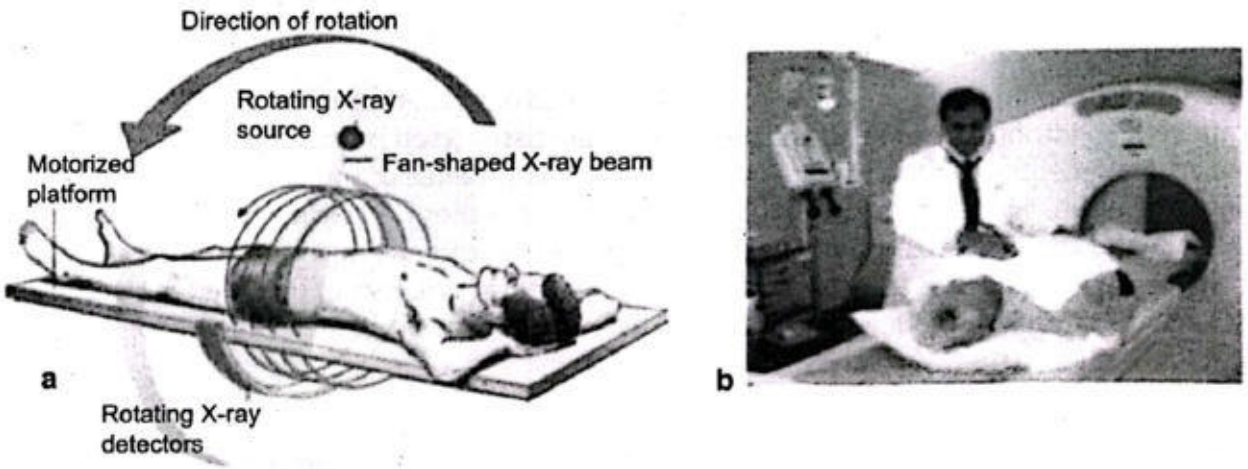


Fig. 5.29: (a) Principle of CT Scan (b) CT Scan

Do you know?

In CT Scan a large donut-shaped X-ray machine or scanner called tomograph takes X-ray images at many different angles around the body. These images are processed by a computer to produce cross-sectional pictures of the body. In each of these pictures the body is seen as an X-ray "slice" of the body, which is recorded on a film. This recorded image is called a tomogram.

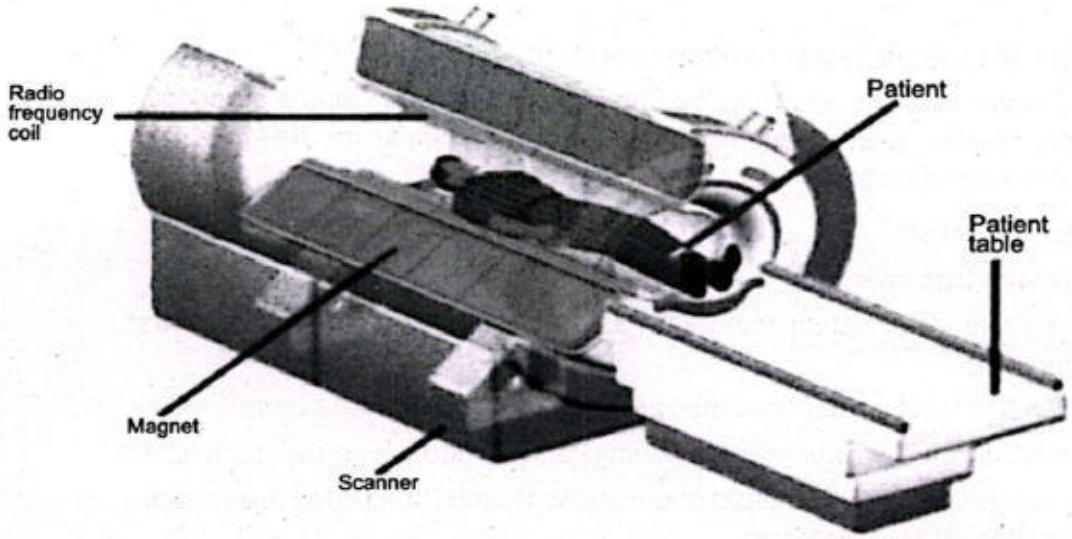


Fig. 5.30: MRI scanner

Magnetic Resonance Imaging

Magnetic Resonance Imaging **(MRI)** scan is a radiology technique that uses magnetism, radio waves, and a computer to produce images of body structures. The MRI scanner is a tube surrounded by a giant circular magnet. The patient is placed on a moveable bed that is inserted into the magnet. The patient is exposed to strong magnetic field and beam of radio waves. The receiver information is processed by a computer, and an image is produced. The image and resolution produced by MRI is quite detailed and can detect tiny changes of structures within the body.

Skills: Interpreting and Communication

• **Conceptualize the activity of brain as an electrical activity, which can be recorded using magnet and tomography.**

Scientists have attempted to conceptualize electrical activity of the brain as a reflection of mental processes. Due to recent advances in computer software and hardware it is now possible to sample more electrical information from the brain by using different radiologic imaging technique such as CT scan, MRI Scan and EEG. Therefore, these techniques have become very useful for the diagnosis of brain disorders.

• **Compare EEG of the brain of a sleeping human with that of a fully awake individual.**

During wakefulness, alpha and beta activities are experienced in the human brain. Alpha activities consist of medium frequency waves. Beta activities consist of irregular low amplitude waves which are present when the individual is very alert and attentive. As the individual gets drowsy, brain experiences theta activities. This is the transition stage between wakefulness and sleep. Sleeping stage contains irregular theta activities where sleep spindles (short bursts of waves of 12-14 Hz) and K complexes (sudden sharp wave forms) are present. Then the next stage of sleep contains high-amplitude delta activities 20 to 50 percent of the time.

STEAM ACTIVITY 5.1

Investigating reflex actions

Researchers can carry out a number of investigations to determine the effect of a specific factor on human reaction times.

A suitable investigation could be the effect of caffeine or the amount of background noise in the room. A simple method to measure the effect is to use the ruler drop test.

Ruler drop test

Work with a partner.

Person A holds out their hand with a gap between their thumb and first finger.

Person B holds the ruler with the zero at the top of person A's thumb

Person B drops the ruler without telling Person A and they must catch it.

The number level with the top of person A's thumb is recorded in a suitable table. Repeat this ten times.

Swap places, and record another ten attempts.

You can use the conversion table to help convert your ruler measurements into reaction time or just record the catch distance in cm.

Catch distance (cm)	Reaction time (ms)
1	50
5	90
10	140
15	170
20	200
25	230
30	250

Example results

	Attempt	Distance on ruler (cm)
	With noise	Without noise
1	25	18
2	38	15
3	36	22
4	31	24
5	38	13

Important: 1 millisecond (ms) is one thousandth of a second. (1/1000 s)

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. The cell transmits impulses from the
   A. effector organ to the spinal cord
   B. receptor cells to the effector organ
   C. receptor cells to the spinal cord
   D. spinal cord to the effector organ

2. Depolarization of an axon is produced by the movement of:
   A. Na^+ into the axon and K^+ out of the axon
   B. Na^+ into the axon to bond with K^+
   C. K^+ into the axon and Na^+ out of the axon
   D. Na^+ and K^+ within the axon towards the axon terminal

3. What will happen if the receptor sites on the post-synaptic membrane are blocked by a drug at the neuromuscular junction?
   A. inhibition of acetylcholine
   B. inhibition of cholinesterase
   C. muscle contraction
   D. muscle paralysis

4. Which of these are the first and last elements in a spinal reflex?
   A. axon and dendrite
   B. sense organ and muscle effector
   C. ventral horn and dorsal horn
   D. motor neuron and sensory neuron

5. Impulses travel very rapidly along nerves to the leg of a man. Which fact accounts for the speed at which they travel?
   A. a nerve impulse is an all or none phenomenon
   B. the nerves contain myelinated fibres
   C. there is a high concentration of Na+ ions inside the axons
   D. there is a potential difference across the axon membranes

6. Where are neurotransmitter receptors located?
   A. on the nuclear membrane
   B. at nodes of Ranvier
   C. on the postsynaptic membrane
   D. in the myelin sheath

7. The human nervous system is capable of a wide range of functions. What is the basic unit of the nervous system?
   A. glial cell
   B. meninges
   C. neuron
   D. cerebrospinal fluid

8. Which of the following is the correct order of meninges from the inner side?
   A. Pia mater - arachnoid mater - durometer
   B. Pericardium - myocardium - endocardium
   C. Durometer - pia mater - arachnoid mater
   D. Durometer - arachnoid mater - pia mater

9. Which of the following structure at a synapse has the neurotransmitter?
   A. schwan cells
   B. synaptic cleft
   C. synaptic knobs
   D. synaptic vesicles

9. The action potential while the propagation of a nerve impulse is due to the movement of_____.
   A. K^+ ions from intracellular to extracellular fluid
   B. K^+ ions from extracellular to intracellular fluid
   C. Na^+ ions from intracellular to extracellular fluid
   D. Na^+ ions from extracellular to intracellular fluid
10. Which one is the ability of neurons to initiate nerve impulses?
   A. myelination B. conductivity C. irritability D. neurotransmission
11. Which of the following is one of the parts of the hindbrain?
   A. hypothalamus B. cerebellum C. corpus callosum D. spinal cord
12. If there is an injury in the hypothalamus region of the brain, it is most likely to affect
   A. regulation of body temperature B. decision making
   C. co-ordination during locomotion D. short-term memory
13. Afferent neurons carry nerve impulses from
   A. CNS to muscles B. CNS to receptors
   C. receptors to CNS D. effector organs to CNS
14. The cranial nerve that regulates the heartbeat
   A. VII B. VIII C. IX D. X
15. Nissl's granules present in the neurons are made up of
   A. protein B. ribosome C. RNA D. DNA
16. A neuron that carries information from the peripheral nervous system to the central nervous system is
   A. afferent neuron B. efferent neuron C. both D. none
17. Which of the following parts of the brain controls the body temperature and urge of eating?
   A. thalamus B. cerebellum C. pons D. hypothalamus
18. The central nervous system consists of the
   A. brain and spinal cord
   B. spinal nerves only
   C. cerebrum and the spinal column
   D. brain stem and the cerebéllum
19. Which one of the following controls involuntary activities such as coughing and sneezing?
   A) medulla B) cerebrum C) pons D) cerebellum
20. Spinal cord and brain are wrapped in protective membranes known as _____
   A) nodes of ranvier B) meninges C) axomembranes D) myelin sheath

Section II: Short Answer Questions

1 Why is neuron co-ordination important?
2. Describe the receptors as transducers sensitive to various stimuli.
3. Name the five fundamental parts of human reflex arc.

4. What is the function of neurotransmitter?
5. What characteristics do the brain and spinal cord have in common?
6. What is limbic system?
7. Name the sensory receptors of human skin.
8. How narcotic drugs interact with the normal nervous activity.
9. Find out some of the common withdrawal symptoms of alcohol.
10. Write the differences between:
    (a) thermoreceptors and nociceptors
    (b) axoplasm and axolemma
    (c) neuroglial cells and Schwann cells
    (d) sensory neuron and motor neuron
    (e) reflex action and reflex arc
    (f) resting membrane potential and active membrane potential
    (g) depolarization and repolarization
    (h) repolarization and hyperpolarization
    (i) refractory period and absolute refractory period
    (j) presynaptic neuron and postsynaptic neuron
    (k) axon and dendndrite
    (l) synaptic knob and synaptic vesicles
    (m) pons and medulla
    (n) white matter and grey matter
    (o) myelinated and nonmyelinated nerve fibres
    (p) cranial nerves and spinal nerves
    (q) drug addiction and drug tolerance
    (r) somatic and autonomic nerves system

Section III: Extensive Answer Questions

1. What is the basic organization of a nervous system?
2. Describe the structure of a neuron.
3. Describe the three types of neurons and write their functions.
4. Describe the mechanism of synaptic transmission.
5. Write the classification of neurotransmitters.
6. Describe the human brain.
7. Describe the structure of spinal cord with diagram.
8. Describe the somatic and autonomic nervous system.
9. Give an account of narcotic drugs.
10. Describe the cause, symptoms and treatment of:
    a. Stroke, b. Headache, c. Meningitis, d. Tumour, e. Alzheimer disease
11. Explain the principles of the following diagnostic tests of nervous disorders:
    a. EEG
    b. CT scan
    c. MRI
12. Describe the way how pain medicines can reduce or numb pain in the human body.

ENDOCRINE SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-G-23] State the role of hormones as chemical messengers.
2. [B-12-G-24] Describe the chemical nature of hormones and correlate it with important hormones.
3. [B-12-G-25] Locate the endocrine glands in human body name the hormones they release and their functions; (pituitary, thyroid, parathyroid, pancreas, adrenal, gonads).
4. [B-12-G-26] Relate problems associated with the imbalance of these hormones.
5. [B-12-G-27] Explain the neurosecretory role of hypothalamus.
6. [B-12-G-28] Outline the concept of Feedback mechanism of hormones. Describe positive feedback with reference to oxytocin and negative feedback with reference to insulin and glucagon.

The cellular functions needed to be continuously regulated. The nerve fibres do not innervate all the cells of the body; a special kind of coordination system is thus required. The endocrine system serves the role to coordinate most body cells. The hormonal system is concerned with control of the different metabolic functions of the body, such as the rate of chemical reactions, the transport of substances through the cell membranes, growth, and secretions. This coordination is called **chemical coordination.**

6.1 HORMONES

Hormones are organic chemicals secreted by a cell.They coordinate different functions in the body by carrying messages through blood to various organs and tissues. Scientists have identified over 50 hormones in the human body so far. Hormones control many different bodily processes, such as: metabolism, homeostasis (constant internal balance), such as blood pressure and blood sugar regulation, fluid (water) and electrolyte balance and body temperature, growth and development, sexual function, reproduction, sleep-wake cycle and mood. Hormones can stimulate changes in target cells even though they are present in extreme concentration. Chemically most hormones are either amines, peptides, proteins or glycoproteins and steroids.

6.1.1 Hormone as a Chemical Messenger

A hormone is a small soluble organic molecule which is effective in low concentration. It is essentially a **chemical messenger** that transports a signal from one cell to another. It has its effect at a site where specific receptors are present, called the target; hence it is termed as **messenger.**

Hormones are chemical messengers that affect and manage hundreds of processes occurring in the body. Often, a bodily process involves a chain reaction of several different hormones.

A hormone will only act on a part of the body, if the cells in the target tissue have receptors that receive the message of the hormone. It's action is like the lock and key model of enzyme action. Think of a hormone as a key and the cells of its target tissue, as specially shaped locks. If the hormone fits the lock (receptor) on the cell membrane, then it'll work; the hormone will deliver a message that causes the target site to take a specific action.

The body uses hormones for two types of communication. The first type is communication between two endocrine glands. One gland releases a hormone, which stimulates another gland to change the levels of hormones that it's releasing. An example of this is the communication between pituitary gland and thyroid. The pituitary gland releases thyroid-stimulating hormone (TSH), which triggers thyroid gland to release its hormones, which then affect various aspects of body.

The second type of communication is between an endocrine gland and a target organ. An example of this is when the pancreas releases insulin, which then acts on the muscles and liver to help analyse glucose.

SCIENCE TITBITS

In 1902, Bayliss and Starling, prepared an extract from the duodenum which stimulated secretion of pancreatic digestive juices when it was injected into the bloodstream. They called the product 'secretin', and coined the term 'hormone', meaning 'to excite' or 'to set in motion.'

6.1.2 Chemical nature of hormones

All the hormones are organic substances of varying structural complexity. Chemically, they may belong to any of the following categories.

(a) **Steroid hormones:** The hormones secreted by the adrenal cortex, testes, ovaries and placenta are composed of steroids e.g., cortisone, aldosterone, testosterone, estrogen, progesterone.

(b) **Proteinaeous hormones:** These are also known as polypeptide or peptide hormones. Somatotrophic, thyrotrophic and gonadotrophic hormones are secreted by the anterior lobe of pituitary gland and insulin hormone is secreted by pancreas.

(c) **Catecholamine:** Adrenaline and noradrenaline are secreted by the adrenal medulla.

(d) **Amino acid derivative:** Thyroxine hormone is secreted by the thyroid gland.

(e) **Peptide Hormones:** These include melanocyte stimulating hormone, the hormones oxytocin and vasopressin, adrenocorticotrophic hormone, calcitonin and parathormone.

6.2 ENDOCRINE SYSTEM OF MAN

Endocrine system is the type of glandular system, consists of some 20 ductless glands lying in different parts of the body. Some of the major endocrine glands, their locations and hormonal secretions are shown in the given figure.

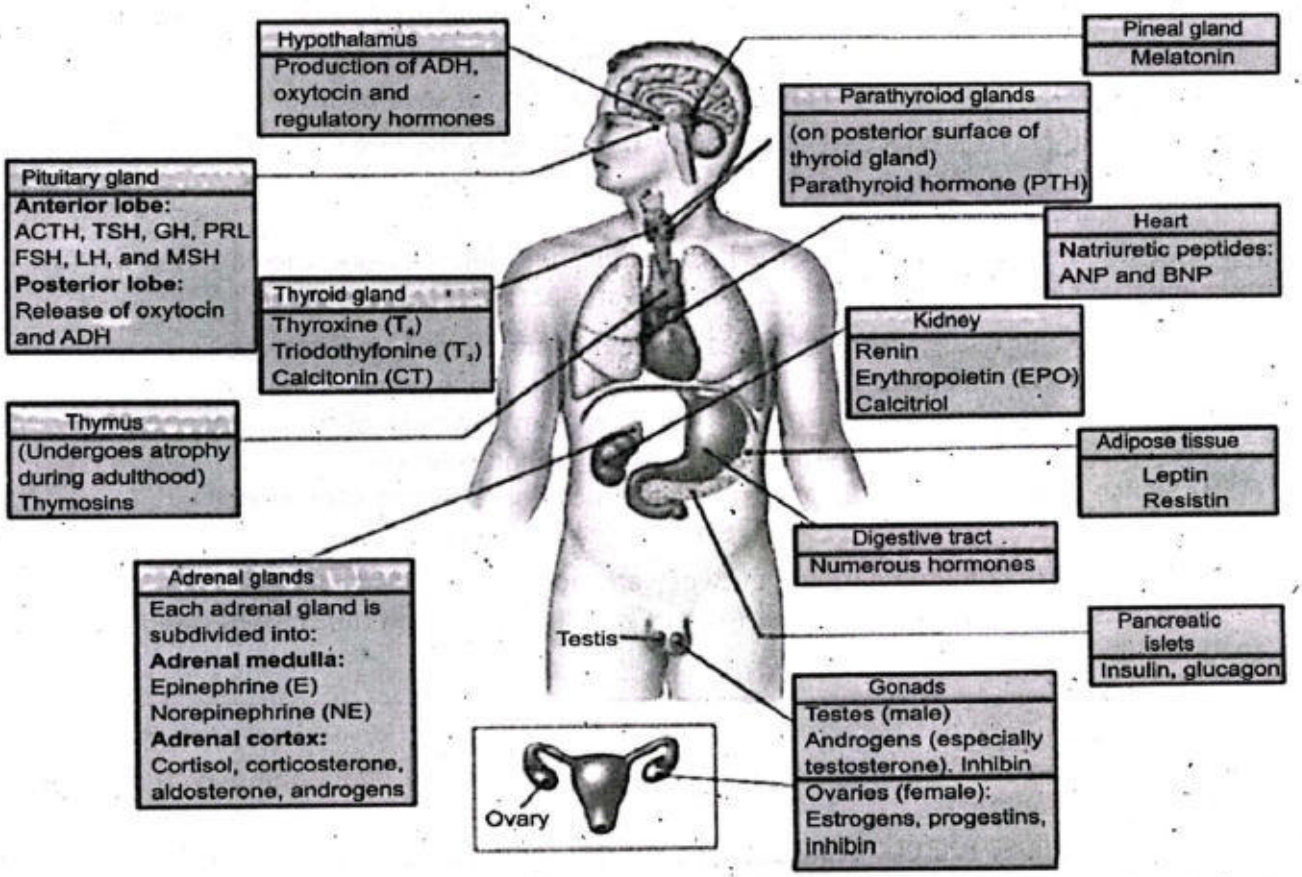


Fig. 6.1: Major endocrine glands and their locations in human

6.2.1 Pituitary Gland

Pituitary gland is located just below the hypothalamus. It is attached to hypothalamus by a stalk called **infundibulum** which is composed of blood vessels and the fibres of neurosecretory cells. Pituitary gland is divided into three lobes, the anterior, posterior and the median.

Anterior lobe of pituitary

Classically, the anterior pituitary is considered the **master gland** of the endocrine system because it secretes numerous hormones, many of which regulate the activity of other endocrine glands. It secretes six hormones, all of which regulate the secretory action of other endocrine glands.

Growth hormone (GH) or Somato-trophic hormone (STH). It is released under influence of hypothalamic **growth hormone releasing factor (GHRF)** and are inhibited by **hypothalamic somatostatin.** GH has a direct effect on growth and development. GH stimulates cell growth and cell division. It also stimulates uptake of amino acids into cells and increases rate of protein synthesis.

Deficiency of GH results in **Dwarfism** in which development is much slower and individual has short stature, however, the body parts stay in proportion and brain development and IQ are unaffected.

Gigantism is result of over secretion of GH during childhood in which the bones are still capable of growth and person increase in height abnormally. Over secretion of GH in adult life causes **acromegaly** in which bones are no longer capable of increasing in length but grow in thickness. Acromegaly is characterised by enlarging the hands, feet, skull, nose and jawbone.

Thyroid stimulating hormone (TSH): Thyrotrophin releasing factor (TRF) from hypothalamus stimulates the synthesis and release of **thyroid stimulating hormone (TSH)** from the anterior pituitary. TSH regulates the endocrine function of the thyroid gland. It increases the number of cells and secretory activity of the thyroid gland. Over secretion of TSH causes **hyperthyroidism** i.e., excess of thyroxin and its under secretion causes hypothyroidism i.e., lack of thyroxin.

Adrenocorticotropic Hormone (ACTH): It is secreted by the release of **corticotrophin releasing factor (CRF)** from hypothalamus which is controlled by steroid level in the blood and by direct nervous stimulation of the hypothalamus as a result of stress e.g., cold, heat, pain, fright and infections. ACTH acts on adrenal cortex and stimulates the secretion of corticosteroids (cortisone and aldosterone).

Follicle stimulating hormone (FSH), luteinising hormone (LH, also called **interstitial cell stimulating hormone, ICSH** in the male) and **prolactin** or **leuteotrophic hormone (LTH)**, are all collectively known as **gonadotropic hormones.** These hormones act upon reproductive system and regulate its function.

Median lobe of pituitary

In humans, median lobe of pituitary is not very prominent. It is a thin layer of cells between the anterior and posterior pituitary. It produces **melanocyte stimulating hormone (MSH).** Secretion of MSH is regulated by hypothalamic MSH inhibitory hormone. Melanocyte stimulating hormone increases in humans during pregnancy too. It stimulates the production and release of melanin by melanocytes in skin and hair.

Exocrine glands are organs or tissues that release substances through ducts or openings onto body surfaces or into body cavities. These substances can include sweat, saliva, tears, breast milk, and digestive juices.

Posterior lobe of Pituitary

Posterior pituitary is not glandular by itself. It does not synthesize any hormone. It is largely made up of axons of neurosecretory cells of hypothalamus.

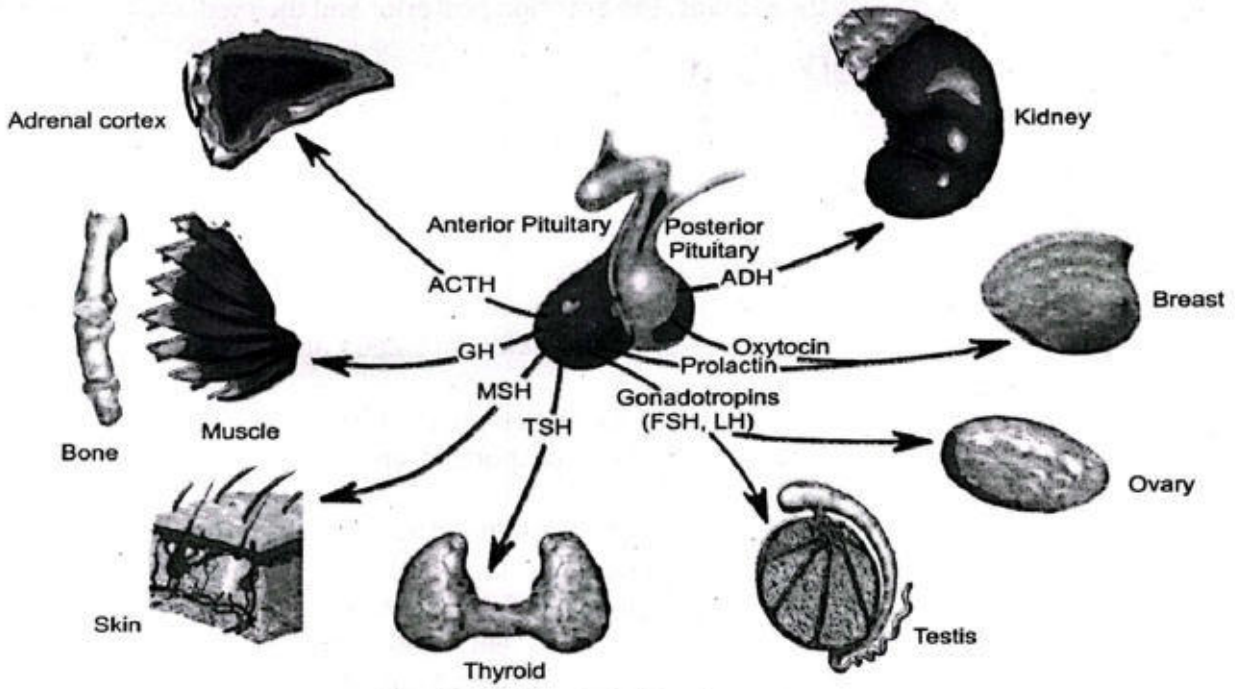


Fig. 6.2: Role of pituitary hormones

Antidiuretic hormone: Posterior pituitary stores antidiuretic hormone (ADH or vasopressin) and oxytocin. These hormones are released in response to nerve impulses from hypothalamus. **ADH** is produced during the state of dehydration, decreased blood volume and low blood pressure. Under secretion of ADH causes **diabetes inspidus** which is characterized by excessive production of diluted urine and frequent thirst. Over secretion may leads to the kidney problems.

Oxytocin: It is released during child birth and in nursing women. During birth it is released in waves, and results in labour contractions. **Over secretion** causes rupturing of uterine wall while **under secretion** of oxytocin inhibits normal labour process. In lactating women, suckling causes the release of oxytocin. During this feeding process it causes the dilation of milk ducts of mother's mammary glands and thus promotes milk ejection.

SCIENCE TITBITS

Under certain conditions, such as severe blood loss, exceptionally large amounts of ADH are released, causing a rise in blood pressure. The alternative name for this hormone, vasopressin, reflects this particular effect.

6.2.2 Thyroid Gland

Thyroid gland is composed of two lobes which are located on either side of the trachea inferior to the larynx. Thyroid gland produces three active hormones, tri iodothyronine (T3), tetra iodothyronine (T4) or thyroxin, and calcitonin.

T3 and T4: These are iodine containing hormones. Tri iodothyronine contains three iodine atoms in structure and thyroxin contains four, hence the names T3 and T4. TSH from anterior pituitary stimulates production and release of these hormones. These hormones show a variety of physiological effects: (1) They promote basal metabolic rate of the body. (2) Enhance glucose

catabolism and synthesis of cholesterol in the liver. (3) Promote development of nervous system in foetus and infants. (4) They act on muscles for their development and functioning. (5) Promote growth and maturation of skeleton. (6) These hormones also promote normal motility of the gastrointestinal tract.

Hyperthyroidism term is applied to excess of these hormones. **Over secretion** of T_3 and T_4 causes **Graves' disease.**

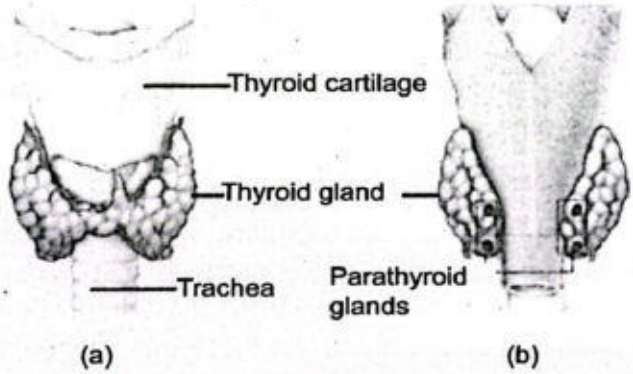


Fig. 6.3: Thyroid and parathyroid gland

SCIENCE TITBITS

T_4 (also known as thyroxin) is the major hormone, about 90%, secreted by the thyroid; T_3 is only 10%. T_3 is four times more potent than T_4; however, action duration of T4 is four times more than T_3.

Do you know?

Graves' disease is believed to be an autoimmune disease. The serum of patients contains abnormal antibodies that mimic TSH and continuously stimulate thyroxin release. The symptoms include high metabolic rate, rapid and irregular heartbeat, increased breathing rate,increased body temperature, sweating and weight loss despite adequate food intake. Mostly exophthalmia (protrusion of the eyeballs) results from Graves's disease and is a classic symptom of hyperthyroidism.

SCIENCE TITBITS

Hormones released from kidney

Renin monitors blood pressure and takes corrective action if it drops.

Erythropoietin acts on the bone marrow to increase the production of red blood cells. Stimuli such as bleeding or moving to high altitudes (where oxygen is scarcer) trigger the release of EPO.

Calcitriol acts on the cells of the intestine to promote the absorption of calcium from the diet.

Hypothyroidism is the **under secretion** of thyroxin. In adults, the full-blown hypothyroid syndrome is called **myxedema** which is characterized by low metabolic rate, feeling chilled, puffy eyes, thick and dry skin with hair lost from the scalp and eyebrows, oedema, tongue swelling, constipation; and enlarged thyroid gland i.e., goiter. Myxedema may result due to deficiency of iodine in diet. **Congenital under secretion** results in a severe **hypothyroidism** in infants called **cretinism** which is characterized by mental retardation with poor physical growth and disproportionate body size. Bone maturation and puberty are severely delayed and infertility is common.

Calcitonin: The C-cells in thyroid gland produce calcitonin. Excessive calcium level of blood stimulate release of calcitonin whereas declining blood calcium levels inhibit its secretion. **Calcitonin** increases the deposition of calcium in bone matrix. Calcitonin inhibits calcium absorption by the intestine and decreases its reabsorption by the kidney tubules allowing its excretion in urine.

Calcitonin appears more important in childhood, when the skeleton grows quickly and the bones are changing dramatically in mass, size, and shape. If deficient, calcium are not deposited in bones and high blood calcium level causes disturbance in the functioning of muscles and nervous system and may lead to kidney stones.

6.2.3 Parathyroid Glands

In human, there are four parathyroid glands. All four glands are located on the thyroid gland. They are small, light coloured masses that stick out from the posterior surface of the thyroid gland. The **parathormone** is the single most important hormone of parathyroid controlling the calcium balance of the blood. Its release is triggered by low blood calcium levels and inhibited by high blood calcium levels. Parathormone works antagonistically to the calcitonin.

Over secretion of parathormone is usually a result of a parathyroid gland tumour. Calcium is released from the bones and bones deform soften and tend to fracture spontaneously. Blood calcium level elevates **(hypercalcemia)** which depresses nervous system and causes weakness of muscles. Excess calcium salts precipitate in the kidneys leading to stone formation.

Under secretion of parathormone causes **hypocalcemia**. This increases the excitability of neurons. Also it can lead to tetany in which muscles remain in contracted state. If untreated, it can be fatal.

6.2.4 Pancreas

Pancreas is composed of two types of tissues. **Exocrine tissue** produces and secretes digestive juice. **Endocrine tissues** are distributed in the form of patches in the pancreas and these patches are called **Islets of Langerhans.** Islets of Langerhans secrete two hormones **insulin and glucagon.**

Insulin is secreted by the **Beta (β) cells** which are larger in number and glucagon is secreted by **alpha (α) cells** which are lesser in number. These cells respond directly to the level of blood glucose. **Insulin** is secreted when the level of blood sugar rises, such as right after a meal. Its overall effect is to reduce blood glucose level to the normal level by increasing the rate of glucose uptake by most body cells especially skeletal muscles and fat cells. It promotes glycogenesis (conversion of glucose to glycogen), increases the use of glucose in cellular respiration, promotes the conversion of excess glucose to fats and inhibits gluconeogenesis (glucose synthesis).

SCIENCE TITBITS

Pancreatic acinar cells are functional units of the exocrine pancreas. They synthesize, store, and secrete inactive digestive enzymes into the lumen of the acinus.

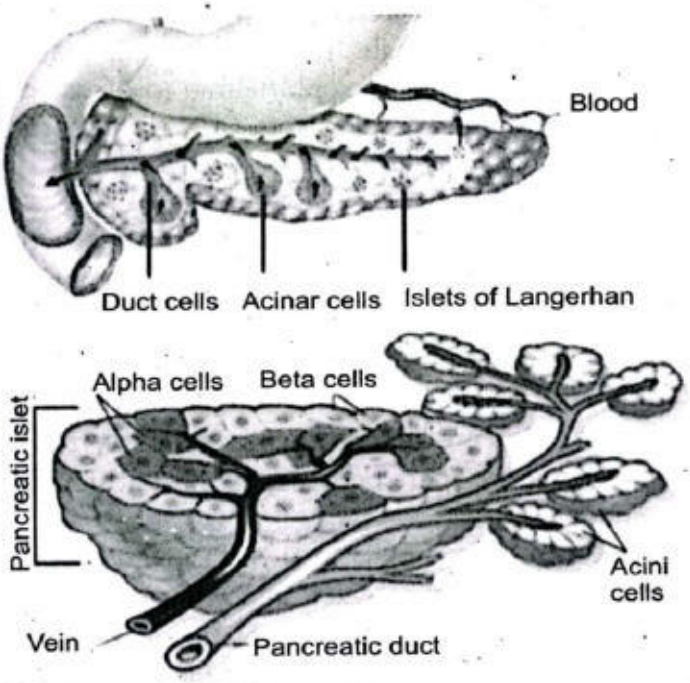


Fig. 6.4: Pancreas and Islets of Langerhans

The **under secretion** of insulin leads to the metabolic disease known as **diabetes mellitus** which is characterized by high glucose level in the blood and urine. If excess of insulin is produced the utilization of glucose is too great and its level falls in the blood which upsets nerve and muscles functioning.

Glucagon is released by **α cells** when blood glucose level is low. Sympathetic nervous system also stimulates its secretion. High blood glucose levels, insulin and somatostatin suppress its secretion. Its role is to increase the blood glucose level. It acts antagonistically to the insulin and thus reverses the activities performed by insulin.

6.2.5 Adrenal Glands

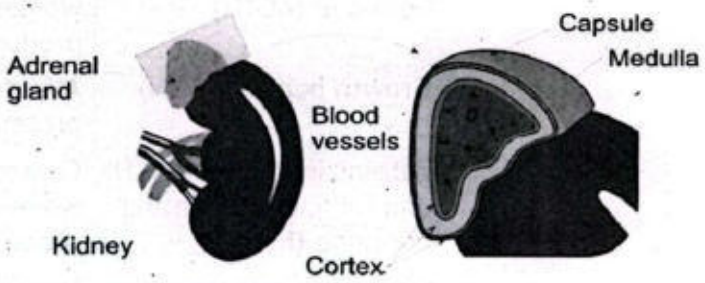


Fig. 6.5: Adrenal gland

Each of the two adrenal glands rests on a kidney. Each adrenal gland is composed of an inner portion called the **medulla** and outer portion the **cortex**.

Epinephrine (adrenaline) and **norepinephrine** are produced by the **adrenal medulla**. Both are released during the state of emergency under the influence of sympathetic nervous system. Both are involved in the body's immediate response to stress. The two hormones exert the same effects in different ways i.e., **synergistic effect**. Epinephrine is the more potent stimulator of metabolic activities, bronchial dilation and increased blood flow to skeletal muscles and the heart but norepinephrine has the greater influence on peripheral vasoconstriction. The net effect is the rise in blood pressure.

Over secretion of these hormones may cause hypertension and aggressive behaviour during routine life. Under secretion causes failure to combat with emergency situation.

The two major types of hormones produced by the **adrenal cortex** are **glucocorticoids**, e.g., **cortisone**, which help to regulate the blood glucose level and mineralocorticoids, e.g., **aldosterone**, which help to regulate the level of minerals in the blood. Both are produced under the influence of ACTH. **Under secretion** of cortical hormones will lead to **Addison's disease** which is characterized by general metabolic disturbance, in particular, weakness of muscle action and loss of salts. Stress situation, such as cold which may leads to collapse and death. **Over secretion** of cortical hormone cause Cushing's disease which is characterized by excessive protein breakdown resulting muscular and bone weakness. Another hormone **androgen** (testosterone) is also produced from adrenal cortex in small amount in both male and female bodies. Its major site of secretion are testes, which are male gonads.

6.2.6 Gonads

Gonads are special type of endocrine glands which beside hormone secretions also produce gametes. Female gonads are ovaries while male gonads are testes.

Ovaries: The ovaries secrete female sex hormones estrogen and progesterone. **Estrogen** is secreted by **Graffian follicle** under the stimulation of FSH but estrogen has negative feedback upon FSH. Estrogen is secreted at the time of puberty and is responsible for secondary sex characteristics in females. It aids in healing and repair of uterine wall after menstruation. Due to its **under secretion** in the young females, they fail to mature sexually. Deficiency of this hormone in adults leads to sterility. Its oversecretion may leads to the development of fibroids (abnormal growth) in uterus and polycystic ovaries.

Table 6.1 Endocrine glands and their hormones

Site of production	Hormone(s) secreted	Hormone function
Pituitary gland	Antidiuretic hormone (vasopressin)	Affects water retention in kidneys; controls blood pressure
	Adrenocorticotropic hormone (ACTH)	Controls production of sex hormones (estrogen in women and testosterone in men) and the production of eggs in women and sperm in men.
	Growth hormone (GH)	Affects growth and development; stimulates protein production; affects fat distribution
	Luteinizing hormone(LH) and follicle-stimulating hormone (FSH)	Controls production of sex hormones (estrogen in women and testosterone in men) and the production of eggs in women and sperm in men
	Oxytocin	Stimulates contraction of uterus and milk ducts in the breast
	Prolactin	Initiates and maintains milk production in breasts; impacts sex hormone levels
	Thyroid-stimulating hormone (TSH)	Stimulates the production and secretion of thyroid hormones
Median lobe of the pituitary gland	Melanocyte-stimulating hormone (MSH)	MSH plays a role in melanin production in the skin, influencing skin pigmentation. It also influences appetite and sex drive.
Kidneys	Renin and angiotensin	Controls blood pressure, both directly and also by regulating aldosterone production from the adrenal glands
	Erythropoietin	Affects red blood cell (RBC) production
Pancreas	Glucagon	Raises blood sugar levels
	Insulin	Lowers blood sugar levels; stimulates metabolism of glucose, protein, and fat
Ovaries	Estrogen	Affects development of female sexual characteristics and reproductive development, important for functioning of uterus and breasts; also protects bone health
	Progesterone	Stimulates the lining of the uterus for fertilization; prepares the breasts for milk production
Parathyroid glands	Parathyroid hormone (PTH)	Most important regulator of blood calcium levels
Thyroid gland	Thyroid hormone	Controls metabolism; also affects growth, maturation, nervous system activity, and metabolism

Adrenal glands	Aldosterone	Regulates salt, water balance, and blood pressure
	Corticosteroid	Controls key functions in the body; acts as an anti-inflammatory; maintains blood sugar levels, blood pressure, and muscle strength; regulates salt and water balance
	Epinephrine	Increases heart rate, oxygen intake, and blood flow
	Norepinephrine	Maintains blood pressure
Testes (testicles)	Testosterone	Develop and maintain male sexual characteristics and maturation
Pineal gland	Melatonin	Releases melatonin during night hours to help with sleep
Hypothalamus	Growth hormone releasing hormone (GHRH)	Regulates growth hormone release in the pituitary gland
	Thyrotropin releasing hormone (TRH)	Regulates thyroid stimulating hormone release from the pituitary gland
	Gonadotropin releasing hormone (GnRH)	Regulates LH/FSH production in the pituitary gland
	Corticotropin releasing hormone (CRH)	Regulates adrenocorticotropin release in the pituitary gland
Thymus	Humoral factors	Helps develop the lymphoid system

Progesterone is produced by **corpus luteum** in response to LH during normal menstrual cycle but it is produced and released from placenta during pregnancy. It inhibits further FSH secretion from pituitary, thus preventing any more follicles from ripening. It causes further thickening and vascularisation of the uterus wall for maintaining state of pregnancy. Progesterone suppresses ovulation. Under secretion of progesterone during menstrual cycle, decreases the chance of pregnancy and may cause early menstruation. Under secretion during pregnancy may leads to the miscarriage.

Testes: The male gonads are testes. Testes produce sperm and male sex hormones called **testosterone** which is secreted from interstitial cells among seminiferous tubules under the influence of ICSH. During puberty, testosterone initiates the maturation of the male reproductive organs and the appearance of secondary sex characteristics and sex drive. In addition, testosterone is necessary for normal sperm production and maintains the reproductive organs in their mature functional state in adult males. Under secretion of this hormone causes the development of feminine characteristics and male sterility.

Skills: Interpreting and Communication

- **Explain on what grounds some companies claim that growth is possible in people having short heights.**

  If growth hormone is administered to young people before growth of their long bones is completed, it causes long bones to grow and they will grow taller. To accomplish this however, GH would have to be administered over a considerable period of time.

Skills: Interpreting and Communication

- **Explain the role of artificially synthesized steroids in sports and their long term effects on its users.**

Steroids are artificial substances. Steroids are developed in order to do the job of testosterone. It can be classified as either anabolic or androgenic. Anabolic functions include those that promote formation of muscles, vertical growth and regulation of weight gain or loss. Androgenic refers to masculine attributes such as agility, strength, and endurance. By the help of these drugs, sportsmen can become bigger, stronger, more agile, and hence more competitive. Artificial steroid users carry many severe health risks. Major medical problems associated with steroids include a weakened immune system, liver disease, kidney disease, high blood pressure, high cholesterol, increased risk for heart disease, blood clots, strokes, tissue damage and cancer.

6.3 NEUROSECRETORY ROLE OF HYPOTHALAMUS

Hypothalamus is part of forebrain. It regulates a wide spectrum of physiological functions such as hunger, thirst, sleep and temperature. Hypothalamus also monitors metabolites and hormone levels in the blood. The hypothalamus is the master control centre of the endocrine system. Its endocrine signals directly control the pituitary gland. It contains special groups of neurosecretory cells. These cells conduct impulses and have developed secretory capacity to a high level. These cells produce regulatory hormones which regulate the synthesis and secretion of pituitary hormones. The hormones produced by the hypothalamus are either the releasing factors which stimulate secretions of pituitary hormones or inhibiting factors which inhibit secretion of pituitary hormones. These are produced in the cell bodies of the cells and packed into the granules and are transported down to the axon by cytoplasmic streaming. The axon endings of the neurosecretory cells synapse with blood capillaries and release their hormones into the blood when stimulated, which carry them to target area. The hormones from hypothalamus and their functions are given in the given table.

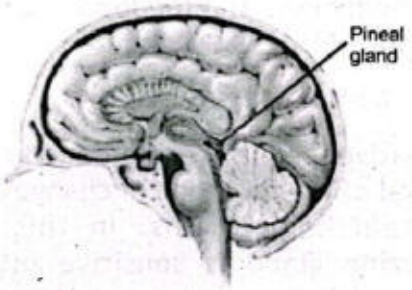
In addition, the neurosecretory cells that arise from the hypothalamus also produce two primary hormones i.e., antidiuretic hormone (ADH) and oxytocin which are stored in posterior lobe of pituitary gland and are released from here when needed.

Table 6.2 Hypothalamic hormones and their effect on pituitary gland

Hormone from the hypothalamus	Anterior pituitary response
Growth hormone releasing factors (GHRF)	Secretion of growth hormone (GH)
Somatostatin	Inhibition of GH
Thyrotrophin releasing factor (TRF)	Secretion of thyroid stimulating hormone (TSH)
Adrenocorticotrophin releasing factor (CRF)	Secretion of adrenocorticotrophic hormone (ACTH)
Prolactin inhibiting factor (PIF)	Inhibits secretion of prolactin
Gonadotrophin releasing hormone (GnRH)	Secretion of FSH and LH

SCIENCE TITBITS

The pineal gland is attached to the hypothalamus. Its primary hormone is **melatonin**. It influences daily rhythms called circadian rhythm. The **thymus** reaches its largest size and is most active during childhood. Thymus produces various hormones called **thymosin**. Certain lymphocytes that originate in the bone marrow and then pass through the thymus are transformed into T lymphocytes with the help of this hormone.



Pineal gland

SCIENCE TITBITS

Other Endocrine Tissues/Cells

Hormones are also produced by organs or tissues whose function is not primarily an endocrine one. Even nerve cells produce hormones. The hormone gastrin, produced by the stomach wall, travels in the blood stream but exerts its effect locally, stimulating the production of pepsinogen and hydrochloric acid. Secretin and cholecystokinin control pancreatic and liver secretions. Both are formed in the cells of duodenal wall. The placenta secretes progesterone, which maintains pregnancy. Prostaglandins are a group of localized hormone. They provide protection during infections. Endorphins are produced in the brain. Endorphins bind to pain receptors and so block sensation of pain.

6.4 FEEDBACK MECHANISM

It is a type of interaction in which a controlling mechanism is itself controlled by the product of reactions it is controlling. After receiving the signal, a change occurs to correct the deviation by depressing it with negative feedback or enhancing it with positive feedback.

6.4.1 Positive feedback

In positive feedback an end product speeds up its production. These responses are not homeostatic and are rare in healthy individuals An example of positive feedback is childbirth. The early contractions of labour begin to force the baby's head against the cervix to dilate (open). Stretch-receptive neurons in the cervix respond to this extension by signalling the hypothalamus, which response by triggering the release of the hormone oxytocin that stimulates more and stronger uterine contractions.

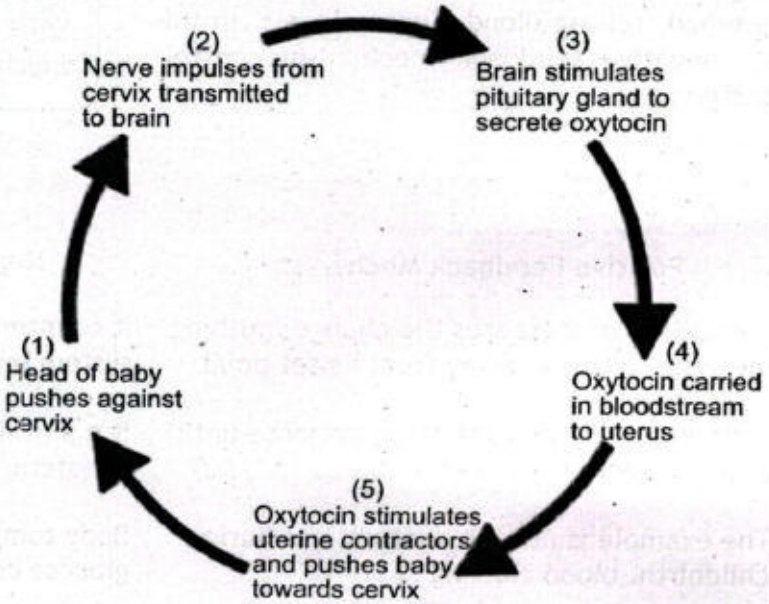


Fig. 6.6: Positive feedback mechanism

Stronger contractions create further pressure on the cervix, which in turn prompts the release of more hormones. The feedback cycle is finally terminated by the expulsion of the baby and its placenta.

6.4.2 Negative feedback

In negative feedback end products results in the reversal of the direction of change and tends to maintain homeostasis. In this system an endocrine gland is sensitive either to the concentration of a substance it regulates or to the concentration of a product from a process it controls. For example if blood glucose becomes too high, beta (β) cells in the islets of Langerhans respond by releasing insulin. Insulin lowers blood glucose by making cell surface membranes more permeable to glucose. It activates transport proteins in the membranes, allowing glucose to pass into the cells. Insulin also activates enzymes inside the cells. Some of these enzymes convert glucose to glycogen. If the levels of blood glucose get too low, alpha (α) cells in the islets of Langerhans secrete glucagon. This hormone fits into the receptor sites on the cell surface membranes, and activates the enzymes inside the cells that convert glycogen to glucose. The glucose then passes out of the cells and into the blood, raising blood glucose levels. In this way, negative feedback mechanism controls blood glucose.

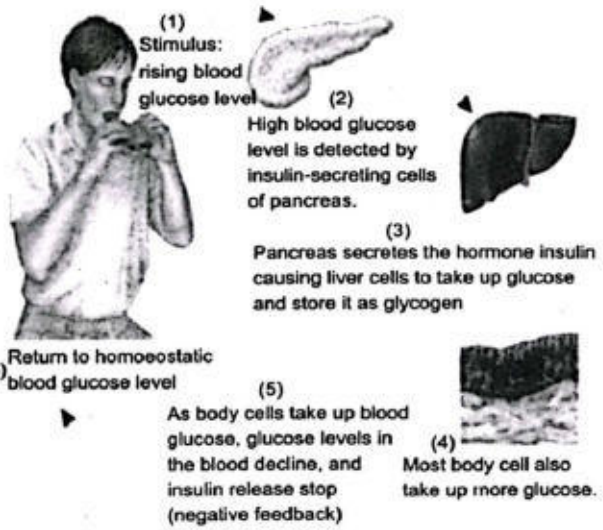


Fig. 6.7: Negative feedback mechanism

CRITICAL THINKING

Is the sensation of thirst associated with a negative or positive-feedback mechanism?

Table 6.3 Difference between positive feedback mechanism and negative feedback mechanism

Positive Feedback Mechanism	Negative Feedback Mechanism
It amplifies or increases the change, pushing *the system further* away from its set point	It counteracts the change, bringing the system back to its set point
It leads to a rapid, escalating response until a specific endpoint is reached	It maintains stability and homeostasis within a system
The example is uterine contractions during childbirth. blood clotting	Body temperature regulation, blood glucose control
The response reinforces the initial stimulus	The response opposes the initial stimulus
The overall function is to rapidly complete a process or reach a specific outcome	The overall function is to maintain a stable internal environment

STEAM ACTIVITY 6.1

1. Hormone Assignment and Role-Playing

a. **Hormone Groups:** Divide the class into groups, with each group representing a specific endocrine gland and its associated hormones (e.g., the pituitary gland could be represented by a group working with growth hormone, LH, and FSH).

b. **Hormone Functions:** Each student within the group will research and understand the specific function of their assigned hormone and how it interacts with other body systems. For example, students representing the thyroid gland would research the role of thyroxine in metabolism.

c. **Role-Playing:** Students act out how their hormone travels in the bloodstream, interacts with target cells (represented by other students or props), and affects the body.

2. Simulating the Endocrine System

a. **Bloodstream:** Use a large space, a hallway, or even an open classroom to represent the bloodstream. Students carrying their hormone "message" (written on a card or prop) will move through this "bloodstream".

b. **Target Organs:** Assign different areas or objects in the "bloodstream" to represent target organs (e.g., a table can be the liver, a chair the heart).

c. **Interactions:** As hormones "travel," students interacting with target organs describe how their hormone affects the organ, using their research as a guide.

3. Assessment

a. **Observation:** Observe student engagement and understanding of hormone functions and interactions during the role-playing simulation.

b. **Written Reports:** Have students write a brief report summarizing the hormone they represented, its function, and how it interacts with different body systems.

c. **Group Presentations:** Encourage groups to present their findings to the class, further reinforcing their understanding.

Example Scenario

A student representing growth hormone (GH) from the pituitary gland "enters the bloodstream" and travels towards a student representing the bones. The GH student would then act out how GH promotes bone growth, possibly by using hands to simulate bone development or explaining how GH influences protein production.

Benefits of this activity

- **Hands-On Learning:** Students actively participate and learn through movement and interaction.
- **Visual Representation:** The simulation creates a visual representation of a complex process, making it easier to understand.
- **Role-Playing:** Students develop a deeper understanding of how hormones work and their functions by actively "becoming" the hormones.
- **Collaborative Learning:** Students work together in groups, fostering collaboration and communication.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Steroid hormones are secreted by
   A. the adrenal cortex
   B. the gonads
   C. the thyroid
   D. both A and B
2. Examples of posterior pituitary hormones are
   A. FSH and LH
   B. prolactin and parathormone
   C. melatonin and prostaglandin
   D. ADH and oxytocin
3. The primary targets for FSH are cells in the
   A. hypothalamus
   B. ovary
   C. thyroid
   D. pituitary
4. Which of the following controls the activity of all others?
   A. thyroid
   B. pituitary
   C. adrenal cortex
   D. gonads
5. Which of the following have antagonistic (opposing) effects?
   A. parathyroid hormone and calcitonin
   B. glucagons and thyroxine
   C. growth hormone and epinephrine
   D. cortisone and ACTH
6. Which of the following hormones has broadest range of targets?
   A. ADH
   B. oxytocin
   C. TSH
   D. epinephrine
7. The pancreas increases its output of insulin in response to
   A. an increase in body temperature
   B. changing cycle of dark and light
   C. a decrease in blood glucose
   D. an increase in blood glucose
8. Name the gland that is located at the base of the throat, just inferior to the laryngeal prominence (Adam's apple) .
   A. pituitary.
   B. pineal gland.
   C. hypothalamus.
   D. thyroid
9. Action of parathormone in the human body
   A. decreases blood sodium level
   B. increases blood sodium level
   C. decreases blood calcium level
   D. increases blood calcium level
10. Which of the following endocrine glands secretes growth hormones?
   A. thyroid gland
   B. pituitary gland
   C. adrenal gland
   D. testes
11. Which of the following pair of endocrine glands is located in the brain?
   A. hypothalamus and thymus
   B. pituitary and parathyroid
   C. thyroid and pineal
   D. hypothalamus and pineal

12.What gland is located just superior to the kidneys?

A. pituitary
B. adrenal
C. pancreas
D. ovaries

13.Which if the following gland which can be classified as an endocrine and an exocrine gland?

A. thyroid
B. thymus
C. pancreas
D. pituitary

14.Which of these hormones is made by the posterior pituitary?

A. FSH
B. LH
C. ACTH
D. ADH

15.Which one of the following is the smallest in the human body?

A. pineal gland
B. pituitary gland
C. adrenal gland
D. parathyroid glands

16. Which of the following hormones are responsible for the "fight-or-flight" response?

A. epinephrine and norepinephrine
B. insulin and glucagon
C. esrtogen and progesterone
D. thyroxin and melatonin

17. Calcitonin is a hormone of which of following:

A. adrenal cortex
B. thyroid gland
C. pituitary gland
D. thymus gland

18. All of the following are hormones of the anterior pituitary except:

A. human growth hormone (GH)
B. follicle-stimulating hormone (FSH)
C. parathyroid hormone (PTH)
D. thyroid-stimulating hormone (TSH)

19. The secretions from which of these glands differs between males and females?

A. adrenal
B. parathyroid
C. gonadal
D. pancreas

20. Calcium level in the blood is regulated by the:

A. thyroid
B. parathyroid
C. posterior pituitary
D. A and B

Section II: Short Answer Questions

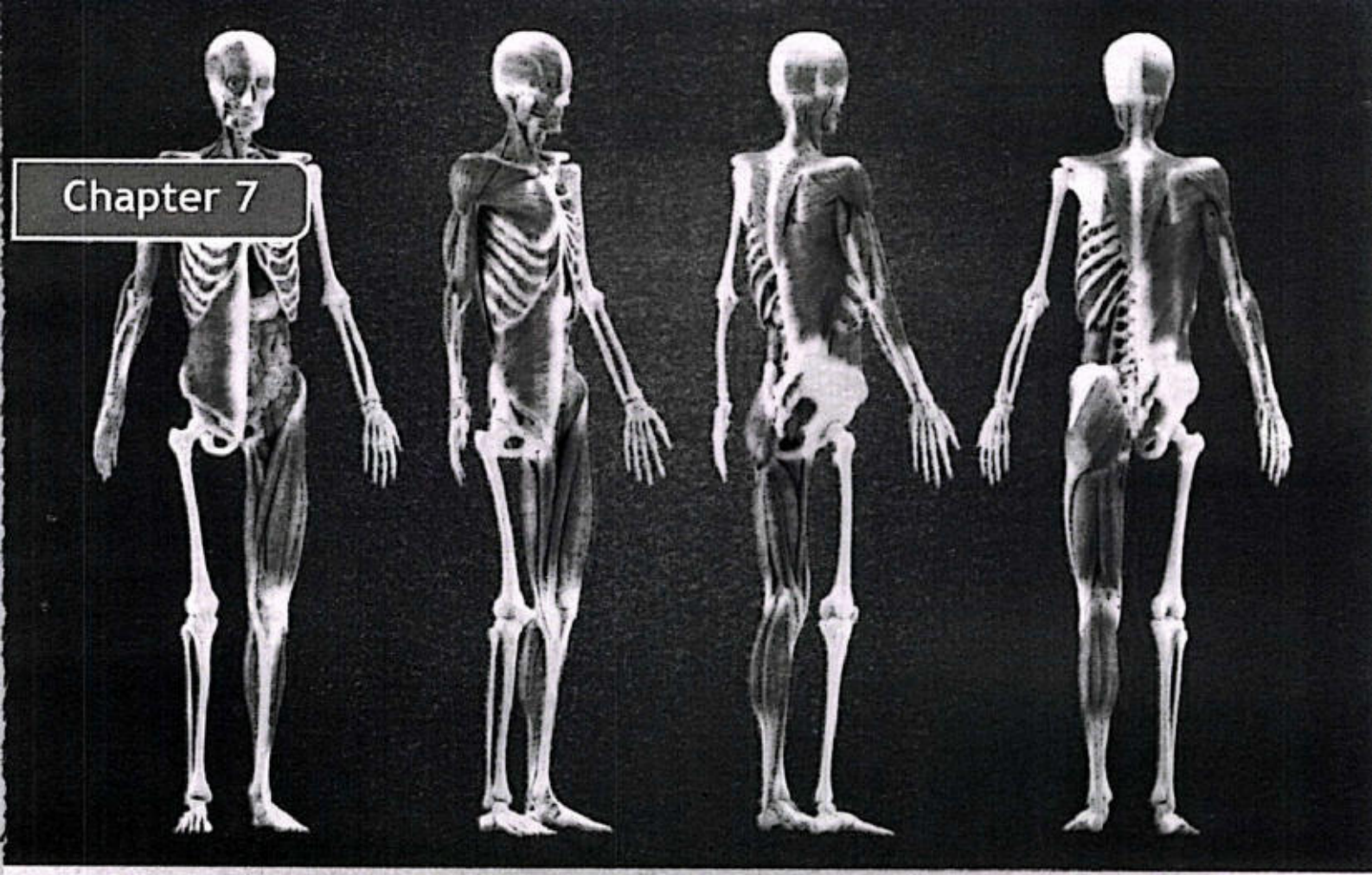
1. Why hormones are called chemical messengers?
2. What are neurosecretory cells?
3. Name the hormones of anterior pituitary gland.
4. Why the anterior lobe of pituitary gland is called master gland?
5. Describe the median lobe of pituitary gland.
6. How the secretion of ADH is controlled?
7. Write the differences between:
   a. exocrine and endocrine glands
   b. steroid hormones and proteinous hormones
   c. first messenger and second messenger
   d. receptor of proteinous hormones and steroid hormones

e. hypothyroidism and hyperthyroidism
f. calcitonin and parathormone
g. beta and alpha cells of Islets of Langerhans
h. insulin and glucagon
i. diabetes inspidus and diabetes mellitus
j. estrogen and progesterone
k. positive and negative feedback

8. What is the relationship between a hormone and a target cell?
9. Locate the endocrine glands in the human body.
10. How does a feedback mechanism regulate the activity of the endocrine system?
11. Make a diagram of positive feedback involving the hormone oxytocin.
12. Predict the effects that insufficient amounts of FSH and LH will have on the menstrual cycle.

Section III: Extensive Answer Questions

1. Describe the function of the endocrine system in the human body.
2. State the role of hormone as chemical messenger.
3. Describe chemical nature of hormone and correlate it with important hormones.
4. Describe the hormones secreted by the anterior lobe of pituitary gland.
5. Describe the hormones secreted by the posterior lobe of pituitary gland.
6. Name the hormones, their functions and imbalance of the Pituitary gland
7. Name the hormones, their functions and imbalance of the Thyroid gland
8. Name the hormones, their functions and imbalance of the Parathyroid glands.
9. Name the hormones, their functions and imbalance of the Pancreas
10. Name the hormones, their functions and imbalance of the Adrenal glands
    a. Gonads
11. Describe the neurosecretory role of hypothalamus.
12. What is feedback mechanism? Describe the positive and negative feedback mechanism with reference to oxytocin, insulin and glucagon.



Chapter 7

SKELETAL SYSTEM OF MAN

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-61] Describe the structure of bone and compare it with that of cartilage.
2. [B-12-R-62] Explain the functions of osteoblasts, osteoclasts and osteocytes.
3. [B-12-R-63] Identify the main divisions of the human skeleton and list the bones of the appendicular and axial skeleton of man.
4. [B-12-R-64] Describe three types of joints i.e, fibrous joints, cartilaginous joints and synovial joints and give example of each.
5. [B-12-R-65] Describe the disorders of human skeleton (disc-slip, spondylosis, sciatica, arthritis, osteoporosis) and their causes.
6. [B-12-R-66] State different types of fractures (simple, compound and complicated) and describe the repair process of simple fractures.
7. [B-12-R-67] Describe the injuries in joints (dislocation and sprain) and their first aid treatment.
8. [B-12-R-68] Compare smooth muscles, cardiac muscles and skeletal muscles.
9. [B-12-R-69] Annotate the ultrastructure of the skeletal muscle.
10. [B-12-R-70] Explain the sliding filaments model of muscle contraction.
11. [B-12-R-71] Describe the action of antagonistic muscles in the movement of knee joint.
12. [B-12-R-72] Explain muscle fatigue, cramps and tetany.
13. [B-12-R-73] Differentiate between tetanus and muscle tetany.

Support in living organisms is necessary to uphold and sustain the body against gravity and other external forces. As the living organisms have been increased in size through the process of evolution, the need for support became greater. This was particularly true once living organisms left water and colonized land. The skeleton in animals contributes to this support.

7.1 HUMAN SKELETON

Human skeletal system consists of bones and cartilage. The skeleton acts as a framework that supports soft tissues. It allows free movement through the action of muscles across joints. The study of bones and cartilage is called osteology.

7.1.1 Structure of Bone

An individual bone is composed of a variety of tissues, including bone tissue, cartilage, fibrous connective tissue, blood and nerve tissue. The terminal broad parts are called **epiphysis** and the middle part along the length of bone is called **diaphysis** or **shaft** which also contains a central cavity filled by **yellow bone marrow.** The outer connective tissue around the bone is called **periosteum** and the inner region is called **endosteum.**

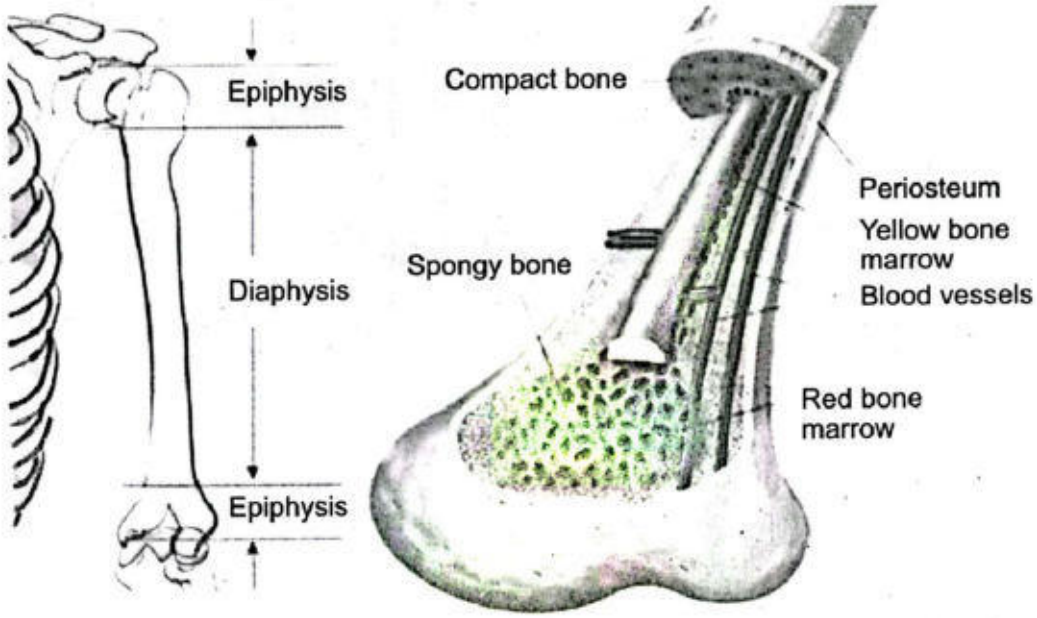


Fig. 7.1: Structure of bone

The endosteum further consists of a peripheral part, called compact bone and the inner bone mass, called **spongy bone.** Most of the spongy bone is present in epiphysis. The **red bone marrow** is also found in the spaces of spongy bone.

7.1.2 Cells associated with bone

There are three types of cells associated with bone (derived from osteogenic cells) i.e., osteoblasts are bone forming cells that synthesize and secrete unmineralized ground substance. Once the osteoblasts are surrounded by matrix, they become the osteocytes.

Osteocytes maintain healthy bone tissue by secreting enzymes and influencing bone mineral content. They also regulate the calcium release from bone tissue to blood. **Osteoclasts are bone** destroying cells. They perform bone resorption, i.e., they breakdown bone and deposit calcium

and phosphate in the blood. The work of osteoclasts is important to the growth and repair of bone.

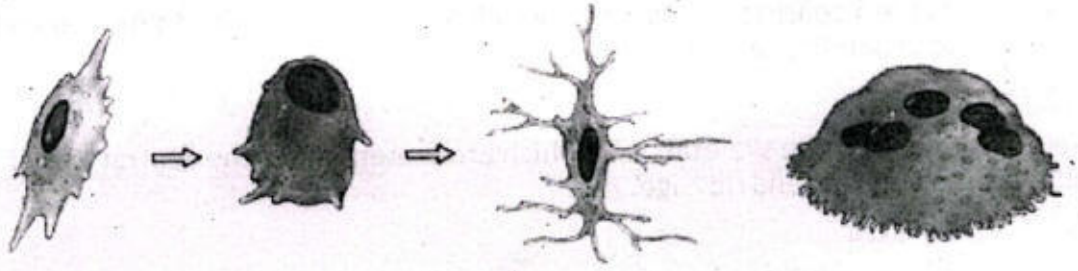


Fig. 7.2: Types of bone cells

7.1.3 Structure of Cartilage

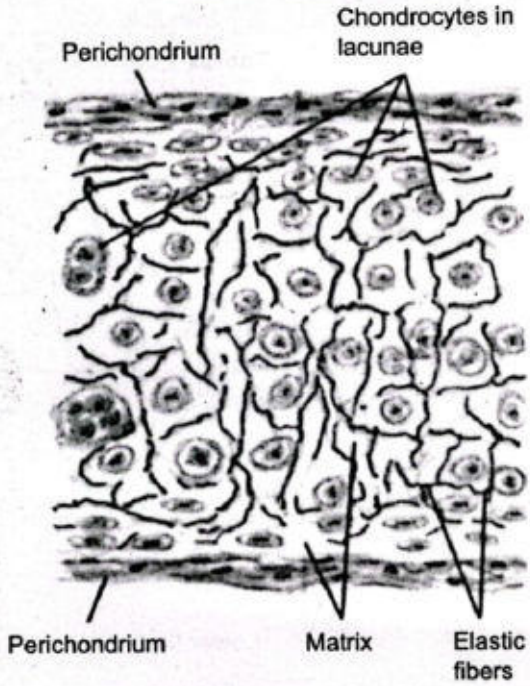


Fig. 7.3: Structure of cartilage

Cartilage is not strong as bone. It is present at particular places only. It is more flexible than the bone because the matrix is gel like and contains many collagenous and elastic fibres. The cartilage matrix is covered by a dense layer of collagen fibres, called **perichondrium**. There are many small cavities distributed in the matrix called **lacunae** which contain cartilage cells. The living cells of cartilage are called **chondrocytes**. Unlike other connective tissues, cartilage does not contain blood vessels and the chondrocytes are supplied by diffusion. Because of this, it heals very slowly. Although the human skeleton is initially made up of cartilages and fibrous membranes, most of these early supports are soon replaced by bones. A few cartilages that remain in adults are of three types. **Hyaline cartilage** is found at the ends of long bones and in the nose, at larynx and trachea. **Fibrocartilage** contains wide rows of thick collagenous fibres is found in the disks located between the vertebrae, cartilage of knee. **Elastic cartilage** is found in the ear flaps and epiglottis.

Table 7.1 Comparison between bone and cartilage

Feature	Bone	Cartilage
Collagen	Densely packed	Loosely packed
Cell types	Osteoblast, osteocytes and osteoclasts	Chondrocytes
Blood vessel	Present	Absent
Minerals	Deposit minerals such as calcium, carbonates, phosphates, etc.	No deposition of minerals
External covering	Covered by periosteum	Covered by pericondrium

7.2 DIVISIONS OF HUMAN SKELETON

Human skeletal system consists of 206 bones which are primarily divided into two division i.e., axial skeleton and appendicular skeleton.

7.2.1 Axial skeleton

Axial skeleton includes those skeletal parts which are present along the central axis of the body, like skull, vertebral column and rib cage.

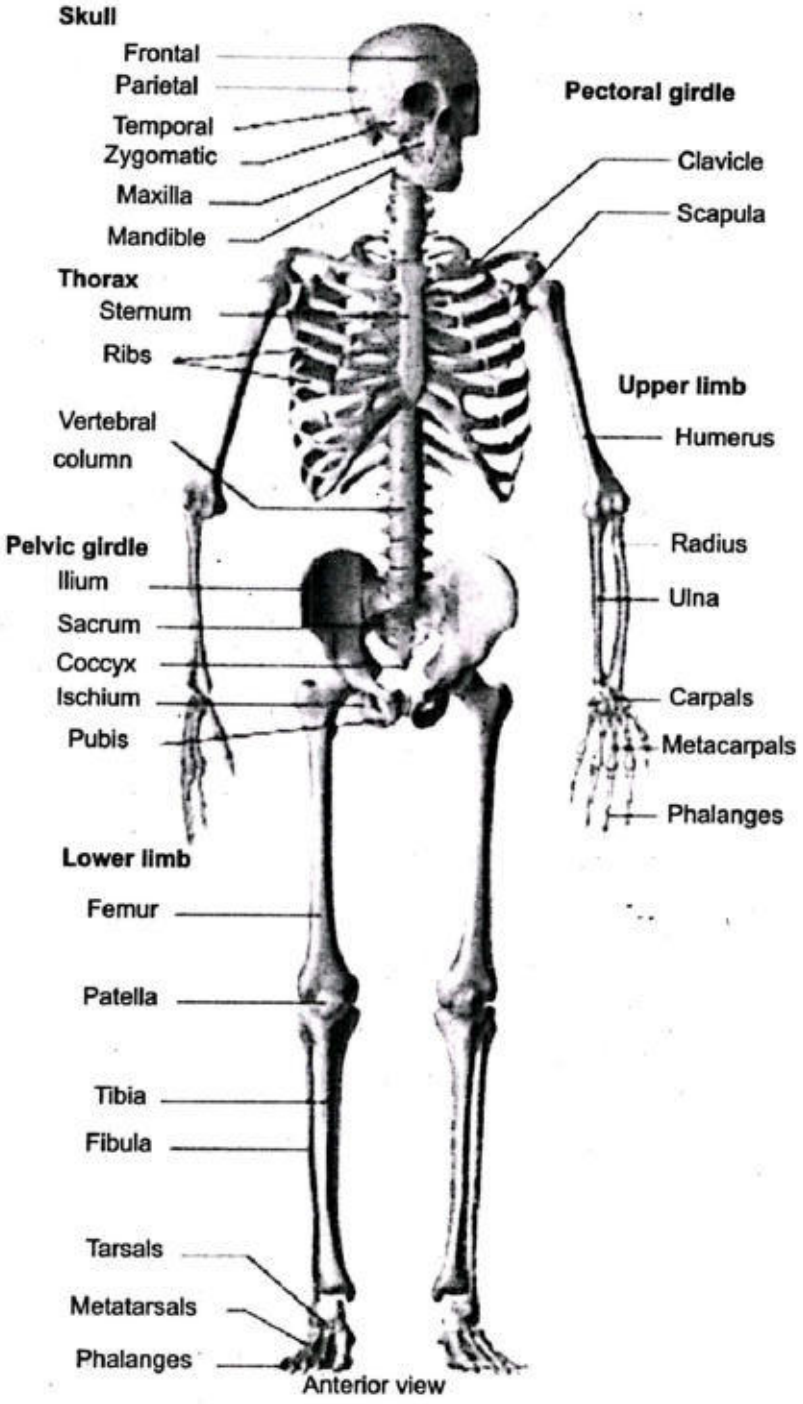


Fig. 7.4: Human skeleton

7.2.2 Head bones

Head contains 29 bones which are divided into four divisions i.e., **cranial bones, facial bones,** ear ossicles and hyoid bone. Cranial bones form cranium (brain box). Out of 8 cranial bones two are paired i.e., **parietal bones** (left and right) and **temporal bone** (left and right) while four are unpaired like **frontal bone, occipital bone, ethmoid bone, sphenoid bone**. Facial bones are fourteen in number and are attached to the cranium to form face. The six paired bones of face are: **lacrimal, zygomatic, nasal bones, inferior nasal concha, maxilla** and **palatine**. The unpaired bones of face are **mandible** and **vomer**. Three pairs of middle ear ossicles are **malleus, incus** and **stapes** (pronunciation: stay-peez). **Hyoid bone** is a small single bone which lies at the base of skull below the tongue. It does not articulate with any other bone of head.

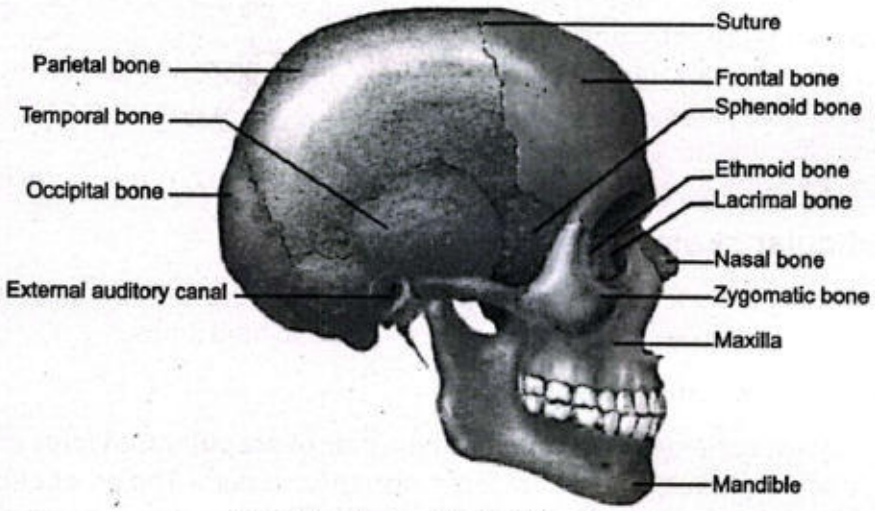


Fig. 7.5: Human Skull (side view)

7.2.3 Vertebral column

The **vertebral column** in human being consists of thirty-three vertebrae. The vertebrae may be divided into following five groups:
(a) Cervical vertebrae - 7, (b) Thoracic vertebrae - 12 (c) Lumbar vertebrae - 5 (d) Sacral vertebrae -5 (e) Coccygeal vertebrae - 4. Cervical vertebrae are the vertebrae of the neck. The **atlas** is the first cervical vertebra. **Axis** is the second cervical vertebra. **Thoracic vertebrae** are rib carrying vertebrae having large spinous processes and are found in chest region. **Lumbar vertebrae** are present in abdominal region. **Sacral vertebrae** are five fused vertebrae forming the **sacrum**. The sacrum articulates with the iliac bones of the hip bone to form the back of the pelvis. **Coccygeal vertebrae** or coccyx are four vertebrae fused in the adults. Sacral and coccygeal vertebrae are together called **pelvic vertebrae**.

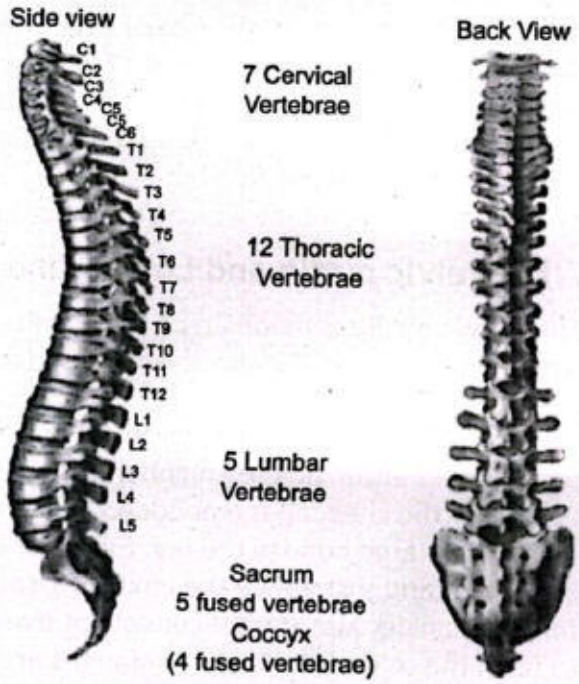


Fig. 7.6: Human vertebral column

7.2.4 Rib cage

The rib cage consists of twelve pairs of ribs. The ribs articulate posteriorly with the thoracic vertebrae. Ten ribs are connected anteriorly with sternum either directly or through the costal cartilage. The rib cage provides support for a semi-vacuum chamber called chest cavity.

The seven pairs of ribs that attach directly to the sternum are called **true ribs**. The 8th, 9th and 10th are called **false ribs**, as these three pairs of ribs are attached to the sternum by means of common costal cartilage. 11th and 12th pairs of ribs are known as **floating ribs**, because they do not attach to the sternum.

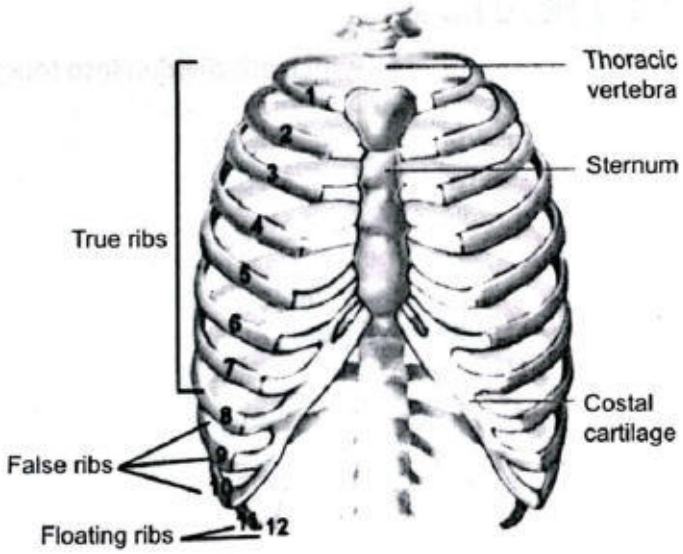


Fig. 7.7: Human rib cage

7.2.5 Appendicular skeleton

Appendicular skeleton includes those skeletal parts which are present in appendages (arms and legs). These are pectoral girdle, pelvic girdle, forelimbs and hind limbs.

7.2.6 Pectoral girdle and Upper limb

Pectoral girdle consists of a pair of **clavicles** and a pair of **scapula**. **Clavicles** are a pair of collar bones. One end of each curved bone articulates with the sternum. The other end articulates with the scapula. **Scapulas** are two shoulder blades.

Upper limb or **Forelimb** consists of humerus, ulna, radius, carpals, metacarpals and phalanges. **Humerus** is a long bone, the end of which has a spherical **head**, which fits into the **glenoid cavity**. **Radius** is a long, outer bone of the forearm (on the thumb side). **Ulna** is a long bone on the inner side of the forearm, and slightly bigger than radius. **Carpals** consist of two rows of eight short bones forming the wrist. The upper row articulates with the radius and forms the wrist joint. **Metacarpals** consist of five bones making up the palm of the hand. Each finger possesses three **phalanges** except thumb which comprises two phalanges.

7.2.7 Pelvic girdle and Lower limb

The **pelvic girdle** is made up of three units the **ileum**, **ischium** and **pubis** which form **coxa**. The two halves of the pelvic girdle are joined at the **pubic symphysis**. A cavity called **acetabulum** is also present.

Lower limb or **Hind limb** consists of femur, patella, tibia, fibula, tarsal, metatarsal and phalanges. **Femur** or the thighbone is a long bone with head, which fits into the acetabulum. **Patella** or the kneecap is embedded in a long tendon which runs over the knee joint. **Tibia** or **shin** bone is the large bone in the leg. **Fibula** or outer bone is a thin bone joins the tibia just below the knee joint and just above the ankle. **Tarsal** is made of seven bones which are tightly attached to form the ankle. **Metatarsal** consists of five bones which articulate with the tarsal and phalanges to form the sole of the foot. **Phalanges** are small bones which make up the toes. Each toe of the foot possesses three phalanges except big toe, which comprises of two phalanges.

7.3 JOINTS

A joint or articulation is a place where two bones or bone and cartilage come together. The scientific study of the structure and function of joints is called arthrology. The joints are classified as fibrous joints (immoveable), cartilaginous joints (slightly moveable) and synovial joints (freely moveable).

7.3.1 Fibrous joints

When the adjacent bones are directly connected to each other by fibrous connective tissue consisting mainly of collagen, it is called fibrous joint. In this joint the bones do not have a joint cavity between them. The gap between the bones may be narrow or wide.

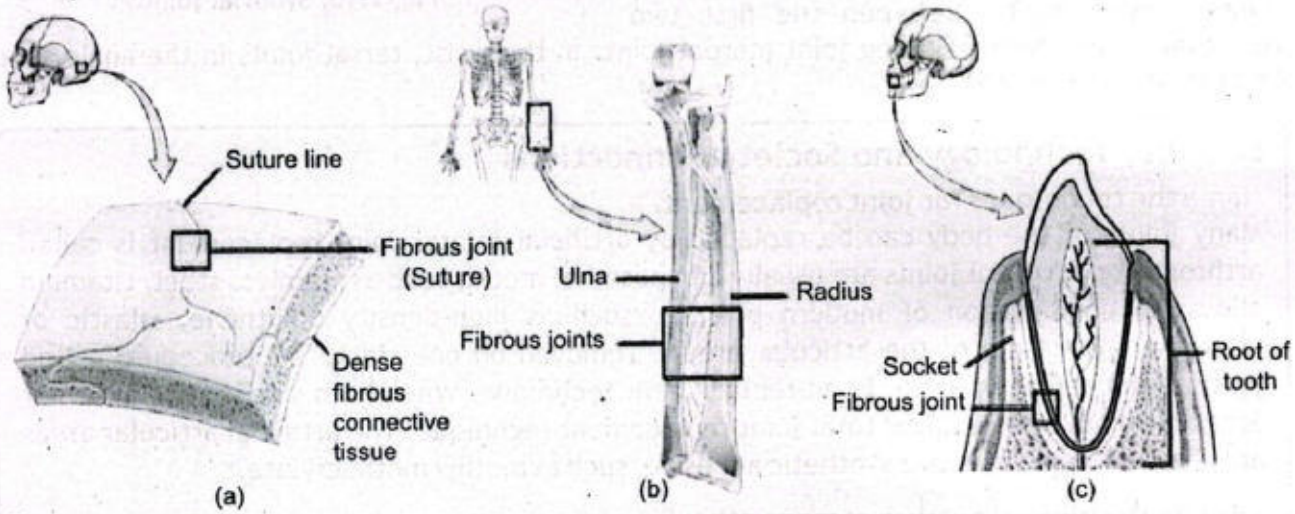


Fig. 7.8: Examples of fibrous joints

Examples: Fibrous joint is found between:
a. Most bones of the skull called suture.
b. The shaft regions of the long bones in the forearm and in the leg.
c. The root of a tooth and the socket in the maxilla or mandible (jawbones),

7.3.2 Cartilaginous joints

At a cartilaginous joint, the adjacent bones are united by cartilage, a tough but flexible type of connective tissue. These types of joints lack a joint cavity and involve bones that are joined together by either hyaline cartilage or fibrocartilage. Cartilaginous joints allow little movement. The examples of cartilaginous joint are:
a. Costal cartilages that attach ribs to the sternum.
b. Pubic symphysis and intervertebral disc.

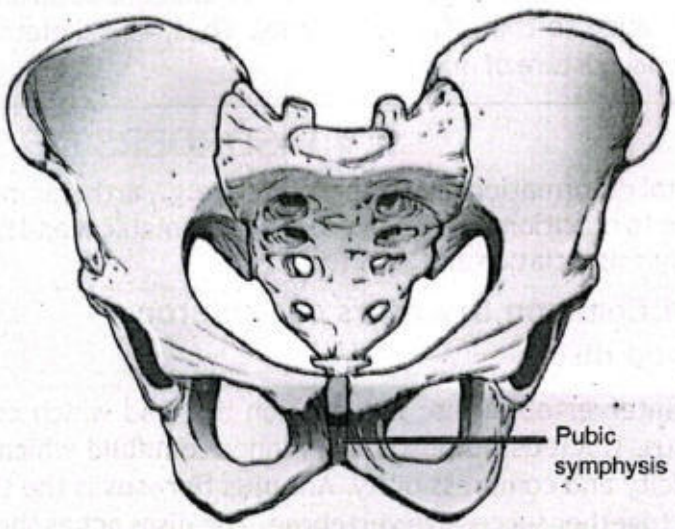


Fig. 7.9: Cartilaginous joint of pubic symphysis

7.3.3 Synovial joints

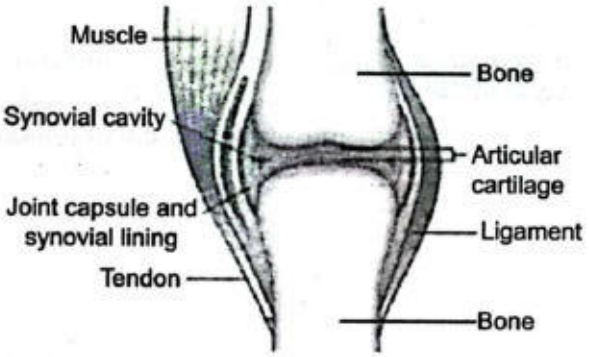


Fig. 7.10: Synovial joint

They are freely moveable joints. The ends of bones are covered with hyaline cartilage and held together by a surrounding, tube like capsule *of dense fibrous* tissue.
The joint capsule is composed of an outer layer of ligaments and an inner lining of synovial membrane, which secretes **synovial fluid.**
Examples: Hinge Joints (elbow, knee, and finger joints , Ball-and-Socket Joints: (shoulder and hip joints), Pivot Joints (between the first two vertebrae in the neck), Gliding joint (carpal joints in the wrist, tarsal joints in the ankle, and facet joints in the spine)

Science, Technology and Society Connections

Name the techniques for joint replacement.
Many joints of the body can be replaced by artificial joints. Joint replacement is called arthroplasty. Artificial joints are usually composed of metal, such as stainless steel, titanium alloys, in combination of modern plastics, such as high-density polythene, silastic or elastomer. The bone of the articular area is removed on one side. This procedure called partial joint replacement or hemi-replacement technique. When both sides of the articular area are removed it is called total joint replacement technique. The artificial articular areas are glued to the bone with a synthetic adhesive, such as methyl methacrylate.

• **Relate the bipedal posture of man with his skeleton and musculature.**
Curvatures of vertebral column help to balance the body for bipedal stance. The intervertebral discs lend flexibility to the vertebral column and absorb vertical shock. The structure of the pelvis, in its attachment to the vertebral column, permits upright posture and locomotion on two appendages (bipedal locomotion). Certain muscles are active posture muscles, whose primary function is to work in opposition to gravity. For example, the strong, complex muscles of the vertebral column are adapted to provide support and movement in resistance to the effect of gravity. Thus, the skeleton and muscular systems maintain the bipedal posture of man.

7.4 DISORDERS OF SKELETON

Skeletal deformation may be hereditary e.g., arthritis may be hormonal e.g., osteoporosis or may be due to nutritional deficiency e.g., osteomalacia and rickets. Here we will describe slipped disc *spondylosis, sciatica* and arthritis.

7.4.1 Common Disorders of Skeleton

Slipped disc

Each intervertebral disc is a cushion like pad which consists of nucleus pulposus and annulus fibrosus. **Nucleus pulposus** is an inner semifluid which acts as a rubber ball to give a disc its elasticity and compressibility. **Annulus fibrosus** is the strong outer ring of fibrocartilage, which holds together successive vertebrae. The discs act as shock absorber. Severe or sudden trauma to spines may result in herniation of one or more discs.

The herniated disc or slipped disc usually involves rupture of annulus fibrosus followed by protrusion of the spongy nucleus pulposus. If protrusion presses on spinal cord or on spinal nerves, generate severe pain or even destruction of these nervous structures. 'Slipped disc' is misleading as it is not the whole disc that slides out of the position.

7.4.2 Spondylosis

It is the immobility and fusion of vertebral joint. Cervical spondylosis results from chronic cervical degeneration, with herniation of disc and aging.

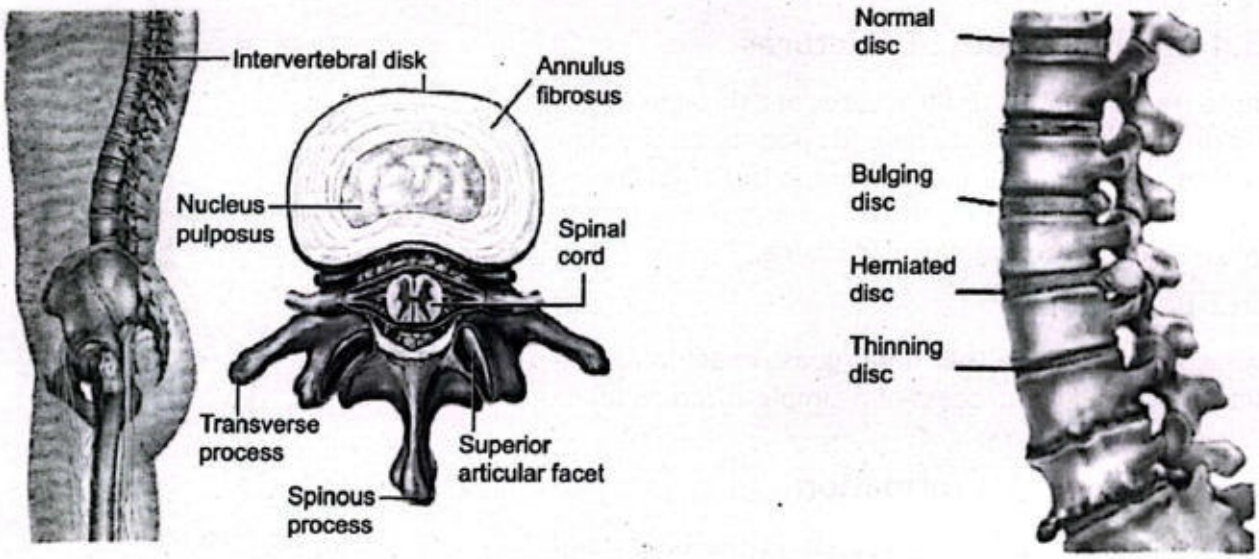


Fig. 7.11: Structure of (a) intervertebral disc (b) slipped disk

7.4.3 Sciatica

Sciatica refers to pain, weakness, numbness, or tingling in the leg. It is caused by injury to or pressure on the sciatic nerve. Common causes of sciatica include: Slipped disk, pelvic injury or fracture and tumors.

7.4.4 Arthritis

It is the inflammation of joints. The typical **symptoms** of arthritis include pain after walking which may later occur even at rest, creaking sounds in joint, difficulty in getting up from a chair and pain on walking up and down stairs. There are different types of arthritis. **Osteoarthritis** is a progressive disease in which the articular cartilages gradually soften and disintegrate. It affects knee, hip and intervertebral joints.

Rheumatoid arthritis is the result of an autoimmune disorder in which synovial membrane becomes inflamed due to faulty immune system. **Gouty arthritis** results from a metabolic disorder in which an abnormal amount of uric acid is retained in the blood and sodium urate crystals are deposited in the joints. The most common joint affected is the joint of the big toe.

7.4.5 Osteoporosis

Osteoporosis, is a common disease characterised by reduced bone mass and an increased risk of fracture. In normal individuals, bone mass increases during skeletal growth to reach a peak between the ages of 20 and 25 but falls thereafter in both sexes. Osteoporosis, occurs because in

the bone resorption exceeds bone deposition. The increased calcium is used to increase bone mass. The greater the bones mass before the onset of osteoporosis, the greater the tolerance for bone loss later in life. For this reason, it is important for adults, especially women in their twenties and thirties, to ingest adequate amounts of calcium.

7.5 BONE FRACTURES

A fracture is the medical term for a broken bone. They occur when the physical force exerted on the bone is stronger than the bone itself. So bones break when they cannot withstand a force or trauma applied to them.

7.5.1 Common types of fractures

Simple fracture or **closed fractures** are those in which the skin is intact. If the bone ends penetrate the skin and form a wound are called **compound fracture** or **open fracture**. When a fracture damages the adjacent organs it is called **complicated fracture**.

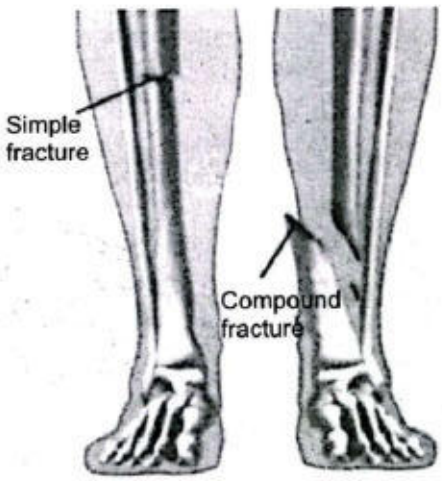


Fig. 7.12: Bone fractures

7.5.2 Bone Repair

Bone is a living tissue that undergoes repair following fracture. The repair process of a simple fracture takes place in four major steps.

Haematoma or clot formation

When a bone breaks, blood vessels in the bone, and perhaps in surrounding tissues, are torn and haemorrhage. As a result, a haematoma, a mass of clotted blood, forms at the fracture site. Soon, bone cells deprived of nutrition die, and the tissue at the site becomes swollen, painful, and inflamed.

Fibrocartilaginous callus formation

Within a few days, several events lead to the formation of fibrocartilaginous or soft callus. Capillaries grow into the haematoma and phagocytic cells invade the area and begin cleaning up the debris. A fracture ruptures the periosteum and stimulates the production and release of the numerous osteoblasts. These osteoblasts in conjunction with cartilage forming cells secrete a porous mass of bone and cartilage called callus (or cartilaginous callus) surrounding the break. The callus replaces the original blood clot and holds the ends of the bones together. This process takes 3-4 weeks.

Bony callus formation or callus ossification

Within a week, after the formation of soft callus, it is gradually converted into a hard **bony callus** of spongy bone. Bony callus formation continues until a firm union is formed about two months later. Osteoclasts breakdown the cartilage while osteoblasts replace it with bone.

Bone remodelling

It takes place when a compact bone is formed across the fracture line to connect both sides. Usually, more bone is produced at the site of a healing fracture than needed to replace the

damaged tissue. However, osteoclasts eventually remove the excess and the final result of the repair is bone shaped very much like the original. The final structure of the remodeled area resembles that of the original unbroken bony region because it responds to the same set of mechanical stressors.

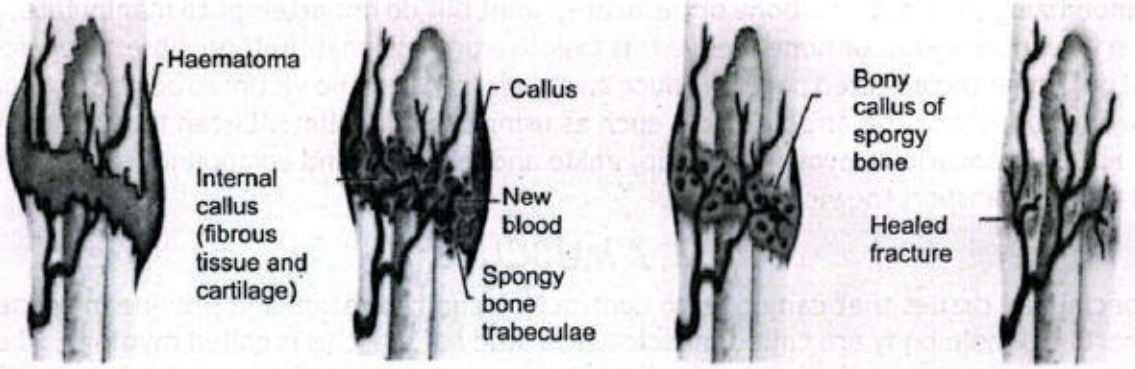


Fig. 7.13: Bone repair

Science, Technology and Society Connections

Relate improper posture to bone/joint problems

Improper posture causes increased stress on joints and their supporting structures resulting in injury, pain and early degeneration of bones and joints.

7.6 INJURIES TO JOINTS

Torsion or sudden impact to the side of a joint can be devastating. We will discuss here dislocation and sprain.

7.6.1 Dislocation of joints

A dislocated joint is a joint that slips out of place. It occurs when the ends of bones are forced from their normal positions. A severe dislocation can cause tearing of the muscles, ligaments and tendons that support the joint. Symptoms include; swelling, intense pain, and immobility of the affected joint. The most common causes are a blow, fall, or other trauma to the joint. In some cases, dislocations are caused by a disease or a defective ligament. **Rheumatoid arthritis** can also cause joint dislocation. A dislocated joint usually can only be successfully *'reduced' into its* normal position by a trained medical professional. Surgery may be needed to repair or tighten stretched ligaments.

7.6.2 Sprain

A sprain is an injury to a ligament. Commonly injured ligaments are in the ankle, knee and wrist. The ligaments can be injured by being stretched too far from their normal position. The sprain should be rested. Sprains can usually be treated conservatively with treatments such as icing and physical therapy. Dressings, bandages, or ace-wraps should be used to immobilize the sprain and provide support.

7.6.3 First Aid Treatment for Disorders of Skeleton

Prompt and proper first aid increases the chances of a complete recovery. Usually, the severity of the bone fracture and dislocation of joints depend on its cause and the affected part. If you suspect someone has dislocated a joint or fractured bone, you can help by: (a) immobilizing the fractured bone or dislocated joint but do not attempt to manipulate, pull or re-align the injured joint or bone. Leave this task to a professional (b) If possible; apply ice pack or cold pack over the affected part to reduce swelling. (c) Assist the victim to position of comfort. (d) Provide support to the affected area such as using sling or splints. Listen to what the victim tells you. (e) Dislocations involving the hip, ankle and leg joints and compound fractures require ambulance to transport the victim.

7.7 MUSCLES

The specialized tissues that can undergo contraction and relaxation and provide movements of body parts or whole body are called **muscles**. The study of muscles is called **myology**. They also function to hold body parts in postural positions, movement of body fluids and heat production.

7.7.1 Types of Muscles

There are three types of muscle tissues: smooth, cardiac and skeletal.

Smooth muscles

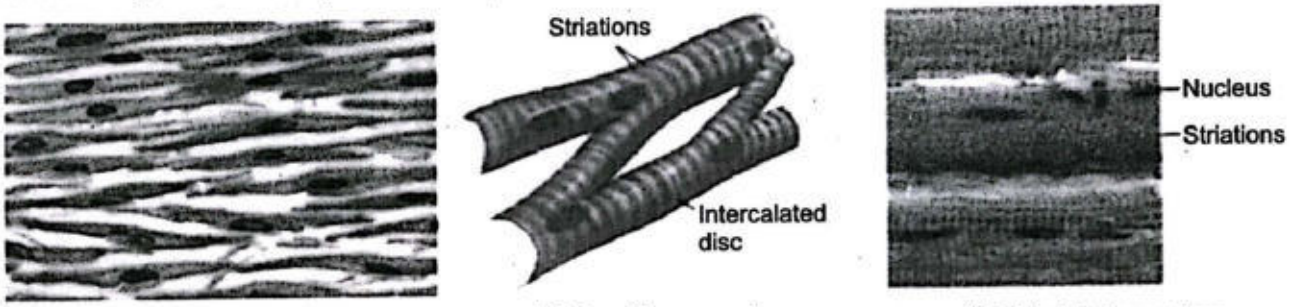
These are distributed widely throughout the body and are more variable in function than other muscle types. The smooth muscle cells are spindle shaped, with a single nucleus located in the middle of the cell. **Myofilaments** are not organised into sarcomeres. Consequently, smooth muscle does not have a striated appearance. Smooth muscle cells contain noncontractile intermediate filaments. Smooth muscles are involuntary in function. They are found in digestive, reproductive, urinary tract, blood vessels etc.

Cardiac muscles

These are found only in heart. They branch extensively. Cardiac muscles are striated like skeletal muscle, but each cell usually contains one nucleus located near the centre. Adjacent cells join together to form branching fibres by specialised cell-to-cell attachments called **intercalated discs**, which have gap like junctions that allow action potentials to pass from cell to cell.

Skeletal muscles

These muscles are attached to the bone and are responsible for movements of body parts and whole body movements (locomotion).



(a) Smooth muscles (c) Cardiac muscles (b) Skeletal muscles

Fig. 7.14: Types of muscles

Table 7.2 Comparison of three types of muscle tissues

Property	Smooth Muscles	Cardiac Muscles	Skeletal Muscles
Muscle appearance	Unstriped	Irregular striped	Regular striped
Cell shape	Spindle	Branched	Spindle or cylindrical
Number of nuclei	One per cell	One per cell	Many per cell
Speed of contraction	Slow	Intermediate	Slow to rapid
Contraction caused by	Nervous system	Spontaneous	Nervous system
Function	Controls movement of substances through hollow organs	Pumps blood	Move skeleton
Voluntary control	Usually no control	Usually no control	Have control

7.8 STRUCTURE OF SKELETAL MUSCLES

Skeletal muscles or striated muscles show alternate light and dark regions under microscope. Skeletal muscles are composed of muscle fibres or muscle cells. Bundles of muscle fibres are enclosed by collagen fibres and connective tissue. At the ends of the muscle the collagen and connective tissue forms **tendons** which attach the muscle to skeletal elements. Each skeletal muscle fibre is a single cylindrical cell, enclosed by a plasma membrane like structure called sarcolemma and has several nuclei. The sarcolemma of muscle fibre cell penetrates deep into the cell to form a hollow elongated tube, the **transverse tubule (T-tubule)**. The cytoplasm of the muscle fiber is called **sarcoplasm**. It contains **sarcoplasmic reticulum**. Within the muscle fibres are numerous thin **myofibrils** which possess characteristic cross striations.

The myofibrils are 1-2 μm in diameter that run in parallel fashion and extend the entire length of the cell. Each myofibril is composed of two types of myofilaments **thin myofilaments** and **thick myofilaments**.

7.8.1 Ultra - structure of skeletal muscles

Under a light microscope only the striated nature of the myofibrils can be observed. This is seen as a regular alternation of light and dark bands called the **I bands** and **A bands** respectively, transversed by thin, dark lines. Electron microscope studies clearly indicate that the bands are due to regular arrangement of thin and thick myofilaments. Transversing the middle of each I band is a dark line called the **Z line**. The section of myofibril between two Z lines is called a **sarcomere**, which is a contractile unit. From the Z line thin myofilaments extend in both directions, while in the centre of the sarcomere are found thick myofilaments.

In certain regions of the sarcomere, thin and thick myofilaments overlap. Transverse sections in these regions indicate that six thin myofilaments surround each thick myofilament. This arrangement of thin and thick myofilaments results in a number of other bands being recognizable in the sarcomere. The entire length of thick myofilaments constitute the **A band** because they are **anisotropic** that can polarize visible light. Thin myofilaments alone constitute **I band**, which is **isotropic** or nonpolarizing. The centre of the A band is lighter than the outer regions in a relaxed sarcomere as there are no overlap between the thin and thick myofilament in this region. It is called the **H zone** (H stands for 'hele' means bright). The H zone itself may be bisected by a dark line, the **M line**. The M line joins adjacent myosin filaments together at a point halfway along their length.

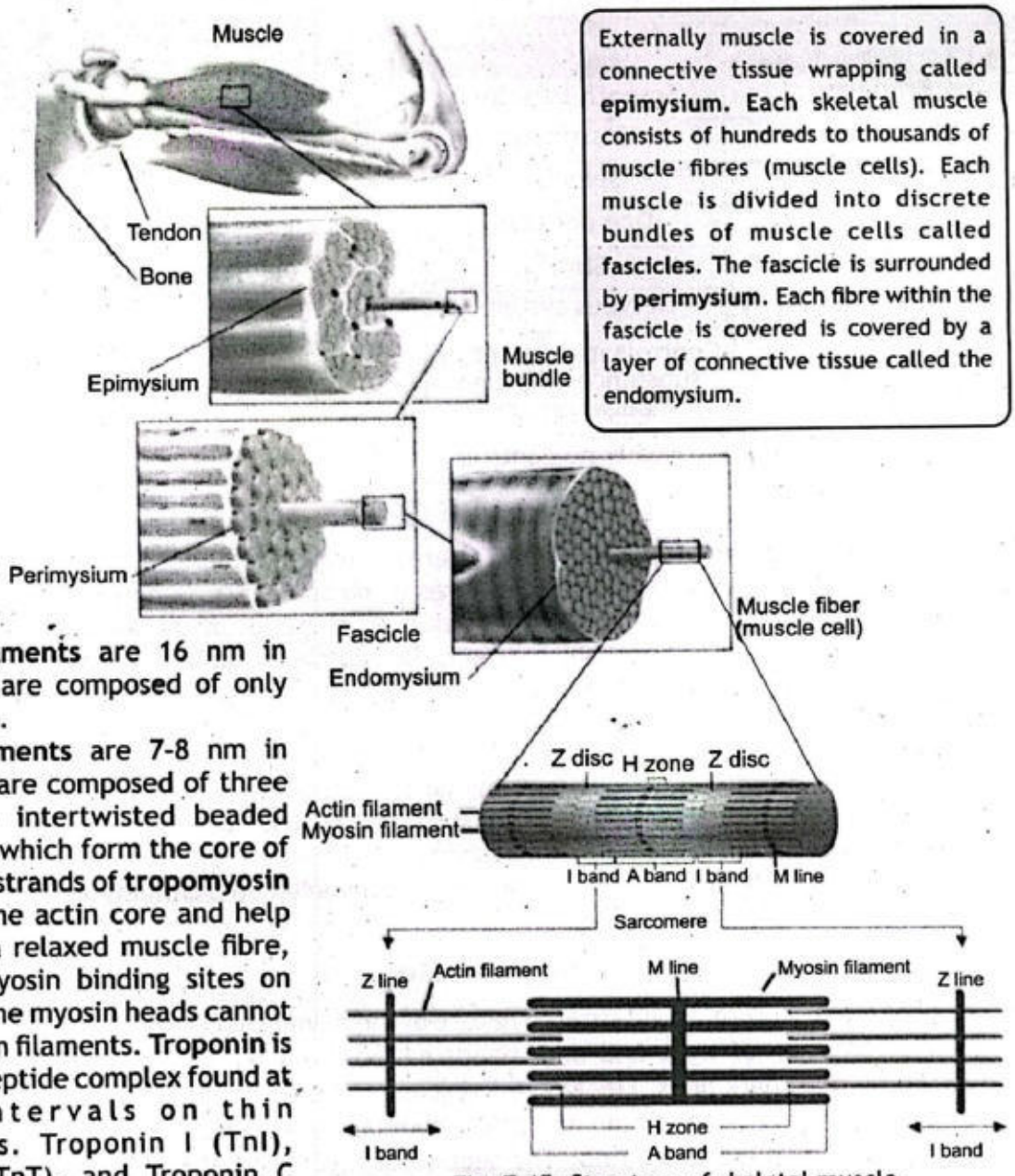


Fig. 7.15: Structure of skeletal muscle

Externally muscle is covered in a connective tissue wrapping called **epimysium.** Each skeletal muscle consists of hundreds to thousands of muscle fibres (muscle cells). Each muscle is divided into discrete bundles of muscle cells called **fascicles.** The fascicle is surrounded by **perimysium.** Each fibre within the fascicle is covered is covered by a layer of connective tissue called the endomysium.

Thick myofilaments are 16 nm in diameter and are composed of only myosin protein.

The **thin filaments** are 7-8 nm in diameter and are composed of three proteins. Two intertwisted beaded chain of **actin** which form the core of filament. Two strands of **tropomyosin** spiral about the actin core and help stiffen it. In a relaxed muscle fibre, they block myosin binding sites on actin so that the myosin heads cannot bind to the thin filaments. **Troponin** is a three-polypeptide complex found at regular intervals on thin myofilaments. Troponin I (TnI), Troponin T (TnT), and Troponin C (TnC). These proteins are crucial for regulating muscle contraction in both skeletal and cardiac muscles. TnI and TnT: are primarily found in cardiac muscle, with small amounts of TnT also present in skeletal muscle. TnC: is found in both cardiac and skeletal muscle. TnI is an inhibitory subunit that binds to actin. TnT binds to tropomysin and helps position it on actin. TnC binds calcium ions. Both troponin and tropomyosin help control the myosin-actin interactions involved in contraction.

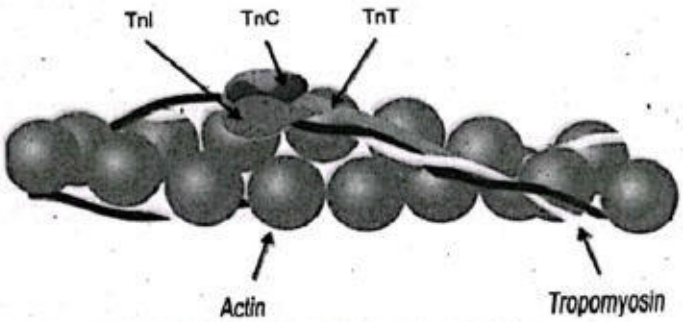
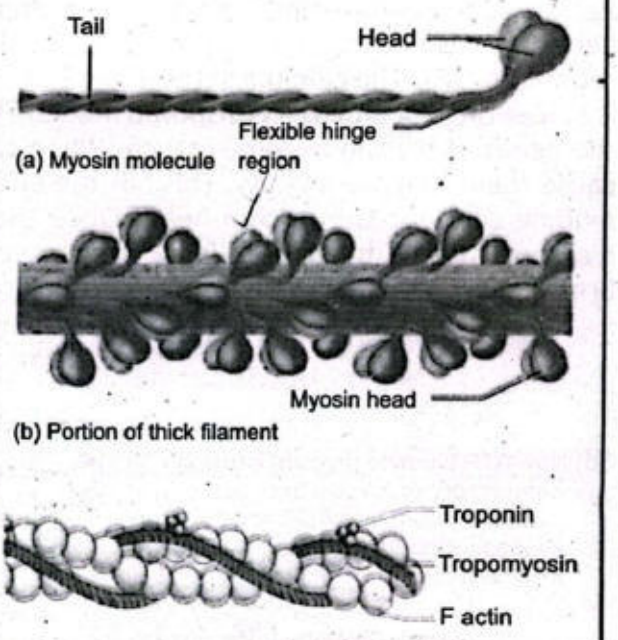


Fig. 7.16: The troponin complex

SCIENCE TITBIT

Each myosin molecule consists of six polypeptides which are arranged in such a way that each myosin molecule possesses a tail and two globular heads. Each thick filament contains about 300 myosin molecules bundled together with their tails forming the central part of the thick filament and their heads facing outward and in opposite directions at each end.

The kidney-shaped polypeptide subunits of actin, called globular actin or **G actin**, bear the active sites to which the myosin heads attach during contraction. G actin monomers are polymerized into long actin filaments called **fibrous, or F actin**. The backbone of each thin filament appears to be formed by two intertwined actin filaments that look like a twisted double strand of pearls.



7.9 MUSCLE CONTRACTION - SLIDING FILAMENT MODEL

The sliding filament theory of contraction states that during contraction the thin myofilaments slide past the thick ones so that they overlap to a greater degree. In a relaxed muscle fibre, the thick and thin myofilaments overlap only at the ends of the A band. But when muscle fibres are stimulated by the nervous system, the myosin heads are attached on to myosin binding sites on actin in the thin myofilaments, and the sliding begins. These links are called **cross bridges** which are formed and broken several times during a contraction, acting like tiny ratchets to generate tension and propel the thin myofilaments toward the centre of the sarcomere.

As this event occurs simultaneously in sarcomeres throughout the cell, the muscle cell shortens. The I bands shorten, the distance between successive Z discs is reduced, the H zone disappears, and the contiguous A bands move closer together but do not change in length.

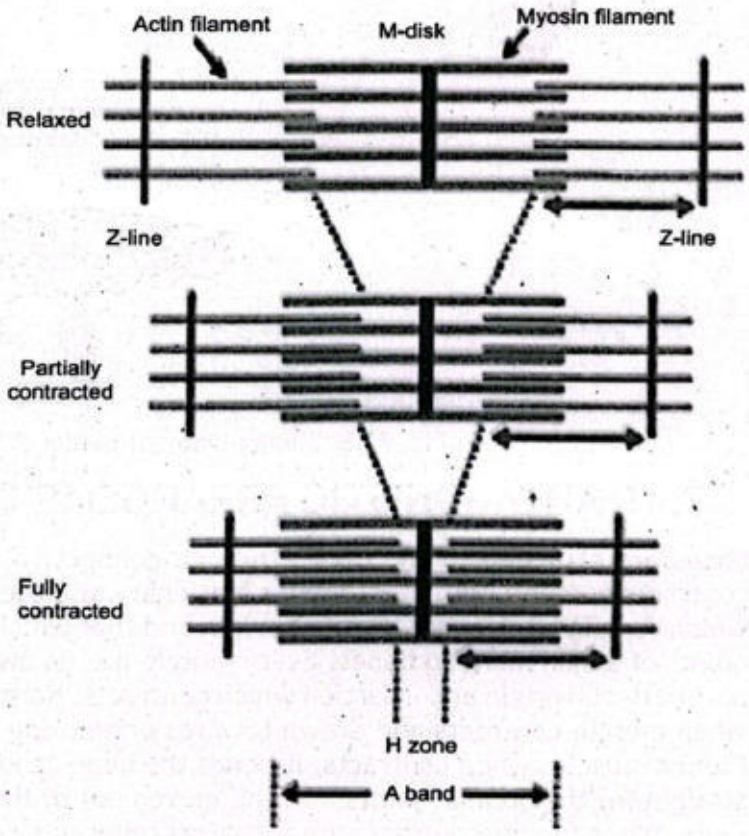


Fig. 7.17: Sliding filament model of muscle contraction

Control of cross bridges

Muscle contraction is initiated by nerve impulse arriving at the neuromuscular junction. The nerve impulse is carried through the sarcolemma to the T tubule then to the sarcoplasmic reticulum (SR). The calcium gates of the SR open releasing calcium into the cytosol. When muscle is at rest the tropomyosin is disposed in such a way that it covers the sites on the actin chain where the heads of myosin become attach. When calcium ions bind with the troponin molecules they cause them to move slightly. This has the effect of displacing the tropomyosin and exposing the binding sites for the myosin head. Once the myosin head has become attached to the actin filament, ATP is hydrolysed and the crossed bridges are broken down. The formation and breakdown of cross bridges occur again and again during the sliding of the filament.

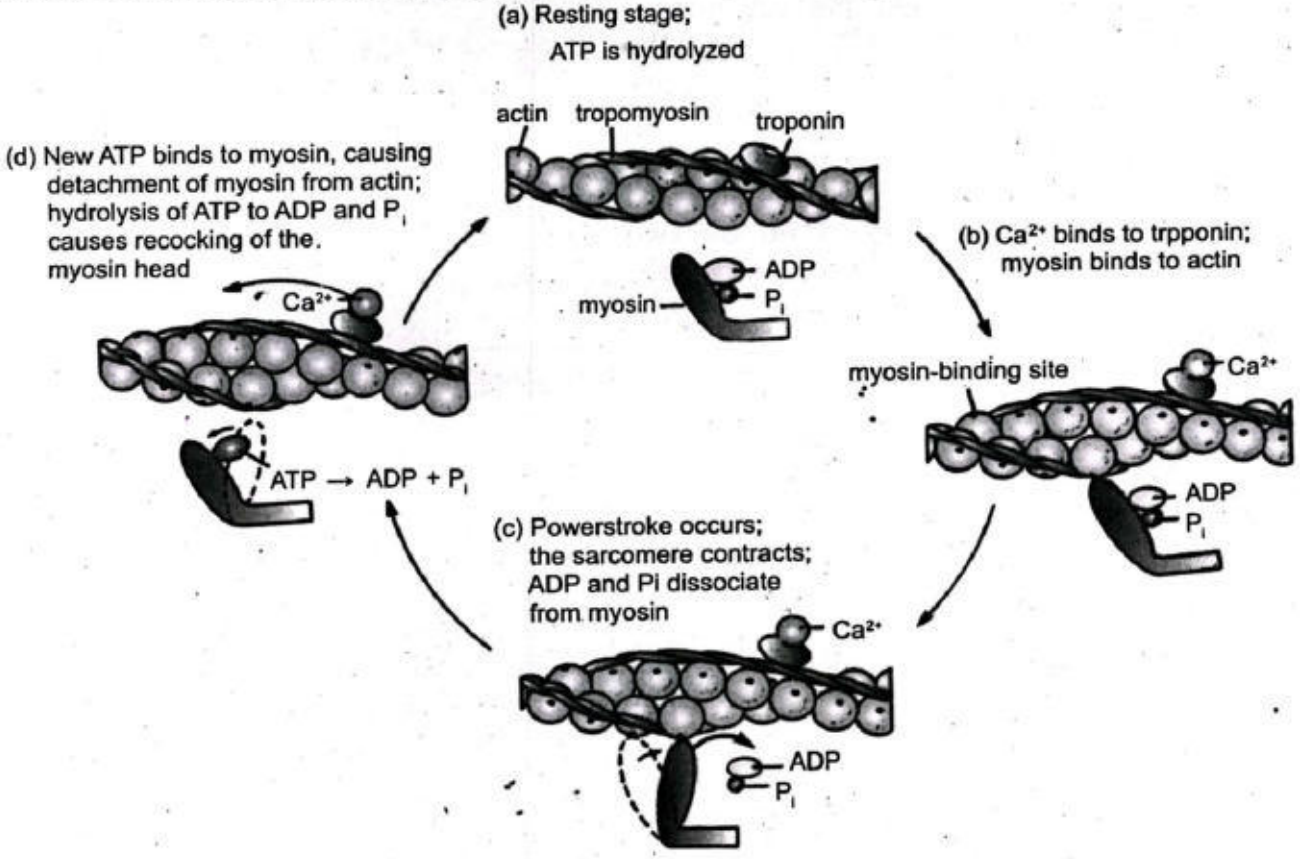


Fig. 7.18: Sliding filament model of muscle contraction

7.10 ANTAGONISTIC ARRANGEMENT OF SKELETAL MUSCLES

Bones are attached to the bones through connective tissue called **ligament**. When a muscle contracts one end normally remains stationary and the other end is drawn towards it. The end which remains stationary is called **origin** and that which moves is called **insertion**. Both are the points of attachment to bones. Every muscle has its own origin and insertion. **Belly** is the thick part between origin and insertion which contracts. Normally the bones of insertion is pulled upon when muscle contracts and drawn towards origin, one bone moving on the other at the joints. **Flexor muscle**, when contracts, it bends the bone at joint. **Extensor muscle**, when contracts it straightens the bone at joints. For the movement of the bone in two directions muscles work in pairs. When flexors contract, the extensors relax and vice versa. Such arrangement of muscles is called **antagonistic arrangement**.

Movement in knee joint

Knee or **tibio-femoral joint** is located between the femur and tibia. It is a complex hinge joint that permits limited rolling and gliding movements in addition to flexion and extensions. The flexion is carried out by the flexor muscles. These are **hamstring muscles** present at the back of the upper part of the leg (thigh). The major hamstring muscle is **biceps femoris.** It has two origins, one from pelvic girdle and other from the top of the femur. At its insertion the tendon divides into two portions to attach at the upper part of the tibia and fibula.

The extension is carried out by the extensor muscles which are present in the front of the thigh. The main extensor muscles are quadriceps femoris. They originate at the ilium and femur, come together in a tendon surrounding the patella (kneecap), and insert at the tibia. These extend the leg at the knee joint and are important for standing, walking, and almost all activities involving the legs. A fusiform muscle located in the posterior compartment of the thigh is called **semitendinosus.** One of the hamstring muscles located in the posterior (back) compartment of the thigh is called **semimembranosus.**

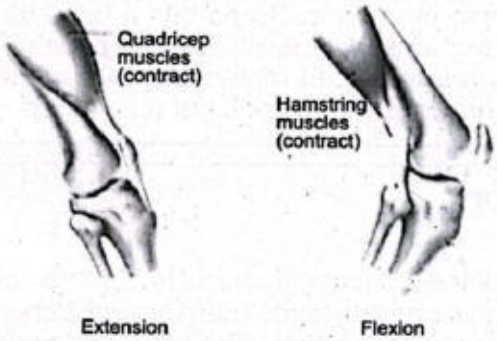


Fig. 7.19: Movement at knee joint

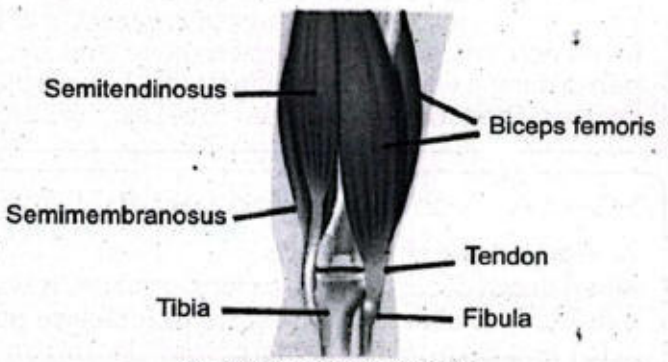


Fig. 7.20: Biceps femoris

7.11 MUSCLE DISORDERS

There are many problems related to muscle which are generally called muscle disorder. Some common muscle disorders e.g., muscle fatigue, cramp and tetany are discussed here.

Muscle fatigue

When the muscles lose the ability to contract, the physiological state of muscles is called **muscle fatigue.** The other factors which contribute to muscle fatigue are accumulation of lactic acid and ionic imbalance. The cause of extreme fatigue is lactic acid which causes muscle pH to drop and the muscle to ache.

Cramp

It is also known as **tetanic contraction** of entire muscle. It lasts for just few seconds to several hours, causing the muscle to become taut (tightly drawn) and painful. It is most common in thigh and hip muscles. It usually occurs at night or after exercise. It reflects low blood sugar level, electrolyte depletion, dehydration, irritability of spinal cord and neurons.

Tetany

In tetany the body shakes from continuous muscle contraction and convulsion occur due to calcium imbalance. It results in the excitability of neurons and results in loss of sensation. If untreated the symptoms progress to spasm of larynx, paralysis and ultimately death occurs.

Table 7.3 Difference between tetany and tetanus

Feature	Tetany	Tetanus
Cause	Electrolyte imbalance (e.g., low calcium)	Bacterial infection (Clostridium tetani)
Mechanism	Overly stimulated peripheral nerves and muscles	Toxin blocking nerve signals
Symptoms	Muscle spasms, cramps, potential larynx spasms	Muscle stiffness, spasms, especially in jaw ("lockjaw")
Treatment	Address electrolyte imbalance	Tetanus immune globulin, supportive care

Science, Technology and Society Connections

Justify why do the muscles pull but do not push.

Bones act as the levers, while joints perform as living fulcrums. Muscle, attached to bones by tendons and other connective tissue, exerts force by converting chemical energy into tension and contraction. When a muscle contracts, it shortens, in many cases pulling a bone like a lever across its hinge. Muscles move and by their motions we move. We are capable of performing a wide variety of actions, but despite this, muscle itself moves only by becoming shorter. They shorten and then they rest - in other words, a muscle can pull but it cannot push.

Science, Technology and Society Connections

Reason out the rigor mortis.

When death occurs, ATP is no longer made. It is a short-lived chemical and so it runs out fairly quickly. This causes the muscles to lock into position as cross-bridges that formed between actin and myosin filaments before death can no longer be broken. The skeletal muscles undergo a partial contraction that causes the joints to become fixed. This condition, rigor mortis (rigidity of death), happens in all body muscles. It appears about four hours after death and lasts about 34 hours. After this time, muscles proteins are destroyed by enzymes within the cells and so rigor mortis disappears.

STEAM ACTIVITY 7.1

1. Identification of the bones of the pelvic girdles, pectoral girdle, arms and legs by using the model of human skeleton
2. Comparison of the structure of skeletal, smooth and cardiac muscles with the help of prepared slides

EXERCISE

Section I: Multiple Choice Questions

Select the correct answer:

1. Ribs originate from vertebral column at:

A. lumbar region
B. cervical region
C. thoracic region
D. pelvic region

2. Skeletal muscles contain dark band, which are anisotropoic, are called
   A. A band
   B. I band
   C. Z band
   D. M line
3. The acetabulum provides the articular surface for the
   A. humerus
   B. femur
   C. pelvis
   D. fibula
4. Scapula is connected with sternum by
   A. ribs
   B. carpals
   C. clavicle
   D. atlas
5. Which statement correctly describes the smooth muscles?
   A. Unstriated involuntary with spindle shape cells
   B. Unstriated involuntary with multinucleate cells
   C. Unstriated voluntary with uninucleate cells
   D. Striated involuntary with spindle shape cell
6. Thin myofilaments consist of
   A. actin, myosin, troponin
   B. actin, tropomyosin, troponin
   C. actin, tropomyosin, fibrin
   D. actin, myoglobin, troponin
7. Which of the following changes occur when skeletal muscle contracts?
   A. The A- bands shorten
   B. The I- bands shorten
   C. The Z- lines move further apart
   D. The H- zone becomes more visible
8. A human internal organs are protected mainly by the
   A. hydrostatic skeleton
   B. axial skeleton
   C. exoskeleton
   D. appendicular skeleton
9. Arm and leg muscles are arranged in antagonistic pairs. How does this affect their functioning
   A. it provides a backup if one of the muscles is injured
   B. one muscle of the pair pushes while the other pulls
   C. it allows the muscles to produce opposing movements
   D. it doubles the strength of contraction
10. Which of the following bones in the human arm would correspond to the femur in the leg?
   A. radius
   B. ulna
   C. tibia
   D. humerus
11. The deep infolding of the muscle fibre membrane is called
   A. sarcoplasmic reticula
   B. Z lines
   C. T-tubules
   D. sarcomeres
12. Bone dissolving cells are called
   A. chondrocytes
   B. osteoblasts
   C. osteoclasts
   D. osteocytes

13. Which of the following cartilage is found at the end of long bones?
    A. calcified B. fibrous
    C. elastic D. hyaline
14. At times ligaments are overstretched or torn. It is called
    A. sprain B. dislocation
    C. fracture D. tension
15. Which ion is essential for muscle contraction?
    A. Na B. K
    C. Ca D. Cl
16. The tough layer of connective tissue surrounding each bone is called
    A. tendon B. ligament
    C. periosteum D. cartilage
17. The network of tubes that run through compact bone is called the
    A. periosteum B. joint
    C. Haversian canals D. marrow
18. Strips of tough connective tissue that hold bones together are known as
    A. tendon B. smooth muscles
    C. Striated muscles D. ligaments
19. Joints that allow circular movements are
    A. gliding joints B. ball-and-socket joints
    C. hinge joints D. pivot joints
20. Two proteins that are involved in the contraction of muscles are
    A. sarcomere and microfibril B. actin and myosin
    C. periosteum and cartilage D. ATP and acetylcholine

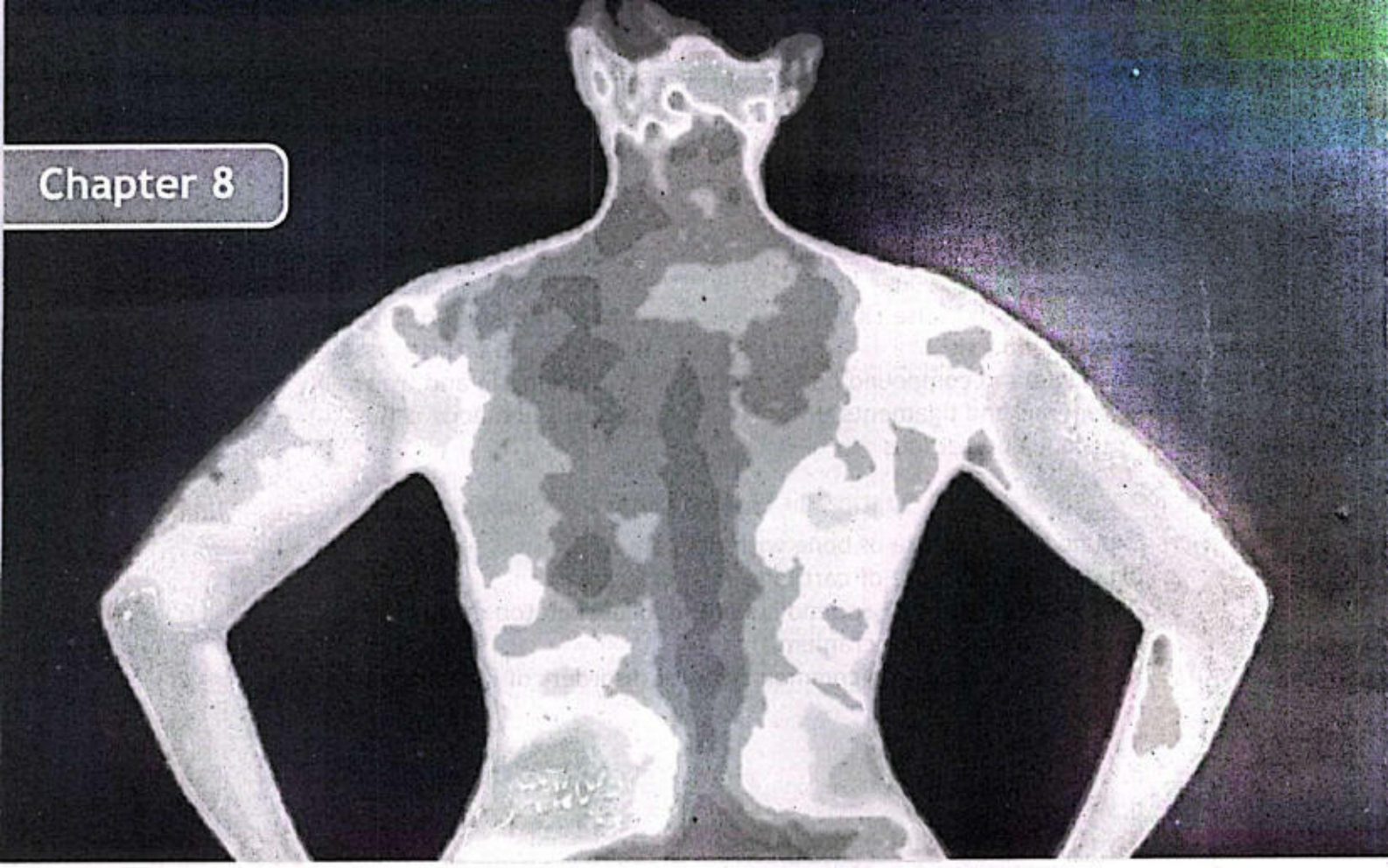
Section II: Short Answer Questions

1. How do compact bone and spongy bone differ in structure?
2. Name three types of cells associated with bone and write their functions.
3. Compare structure of bone with that of cartilage.
4. Name the bones of axial and appendicular skeleton.
5. Name the bones of cranium.
6. Describe the five groups of vertebrae.
7. What is the structure of the human rib cage.
8. Name the bones that form the (a) pectoral girdle (b) pelvic girdle.
9. Name the bones of upper and lower limbs.
10. What are the main types of joints found in bones?
11. What is fibrous joint?
12. What are the four steps required for bone fracture repair?
13. What skeletal structures are affected from the osteoarthritis?
14. List the major parts of skeletal muscle fibre and write the function of each part.
15. What is Z line and M line and what are their functions?
16. How the arrangement of actin filaments and myosin filaments produce I band, A band and H zone?

17. Describe the antagonistic arrangement of skeletal muscles.
18. Why are ligaments elastic and why does the tendon need to be inelastic?
19. Draw a diagram of sarcomere and label its parts.
20. Write the difference between:
    a. epiphysium and diaphysium
    b. periosteum and endosteum
    c. compact and spongy bone
    d. axial skeleton and appendicuar skeleton
    e. true ribs and false ribs
    f. false ribs and floating ribs
    g. atlas and axis
    h. rheumatid arthritis and gouty arthritis
    I. simple and compound bone fracture
    j. tropomysin and troponin
    k. tendons and ligaments
    l. callus and bony callus
    m. tetany and tetanus

Section III: Extensive Answer Questions

1. Explain the structure of bone with diagram.
2. Explain the structure of cartilage with diagram.
3. Describe the bones of appendicular and axial skeleton of man.
4. Describe the bones of cranium.
5. What are the following common types of disorders of human skeleton:
    a. Slipped disc
    b. Spondylosis
    c. Sciatica
    d. Arthritis
6. Give a detail account of bone repair.
7. Give an account of the following related to injuries to bones:
    a. Dislocation of joints
    b. Sprain
    c. First aid treatment for disorders of skeleton
8. Describe three types of muscle tissues in man.
9. Explain the ultra structure of skeletal muscle.
10. Explain the sliding filament model of muscle contraction.
11. Explain the action of antagonistic muscles in the movement of knee joint in man.
12. Give explanation of the following statement:
    a. Pregnant women should be encouraged to drink milk
    b. The sutures of the skull are fixed joint.
    c. The human femur is stronger than humerus.
13. Describe the following muscle disorders:
    a. Muscle fatigue
    b. Cramp
    c. Tetany



Chapter 8

THERMOREGULATION HOMEOSTASIS

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-R-74] Define thermoregulation and explain its needs.
2. [B-12-R-75] Classify animals on the basis of the source of body heat i.e., ectotherms and endotherms.
3. [B-12-R-76] Classify the animals on the basis of the ability to thermoregulate i.e., poikilotherms and homeotherms.
4. [B-12-R-77] Describe the regulatory strategies in man for thermoregulation.
5. [B-12-R-78] Describe three elements i.e., receptors, control center and effectors which operate homeostatic mechanisms.
6. [B-12-R-79] Relate the homeostatic mechanisms with the negative and positive feedback systems.
7. [B-12-R-80] Differentiate between osmoconformers and osmoregulators.
8. [B-12-R-81] Define osmoregulation.
9. [B-12-R-82] Explain the problems faced by osmoregulators.
10. [B-12-R-83] Explain the different methods of osmoregulation found in freshwater, marine water and terrestrial.

Humans, like most mammals can maintain a constant body temperature, despite changes in the surroundings. The core temperature of the human body remains reasonably constant at 37 °C. It can fluctuate by a degree or so, more during fever, but it is generally very stable.

8.1 THERMOREGULATION

Heat is produced inside the body as a byproduct of metabolic reactions. Heat production occurs more generally in the organs of the body. Since heat is a byproduct of metabolism, the amount of heat produced depends on metabolic rate.

8.1.1 Thermoregulation and its needs

Thermoregulation is **defined** as the maintenance of internal temperature within a range that allows cells to function efficiently. The body works to maintain a stable internal temperature. Temperature colder or warmer than the enzymes optimum range, changes the shape of the active site and chemical reactions to stop. The main purpose of thermoregulation is to keep the enzyme systems of the body working properly.

8.1.2 Classification of Animals on the Basis of Temperature

Animals can be classified on the basis of the ability to thermoregulate and the source of body heat.

a. Classification of the animals on the basis of the ability to thermoregulate.

Animals can be classified based upon ability to maintain constant body temperature as poikilotherms and homeotherms.

Poikilotherms are all non-vertebrates, fishes, amphibians and reptiles. These are unable to maintain their body temperature within the narrow limits using physiological mechanisms.

Homeotherms are birds and mammals which are able to maintain a fairly constant body temperature by using physiological mechanisms.

b. Classification of animals on the basis of the source of body heat

Animals are also classified on the basis of source of body's heat a ectotherms and endotherms.

Ectotherms animals produce metabolic heat at low level that is also exchanged quickly with environment. They rely more on heat derived from the environment to raise their body temperature. Examples are most invertebrates, fishes, amphibians and reptiles.

Endotherms animals produce their own body heat through heat production as byproduct during metabolism in muscles or by the action of hormones that increase metabolic rate. The examples of endotherms are birds and mammals.

8.1.3 Thermoregulatory Strategies in Man

Thermoregulatory center in human body is located in the **hypothalamus** which acts as a thermostat. It can detect the temperature of the blood that passes through it and if the temperature increases or decreases even slightly, the hypothalamus initiates corrective responses such as sweating or shivering. When we encounter a particularly warm or cold environment, temperature receptors in the skin inform the hypothalamus. They also stimulate the higher, voluntary centers of the brain. This means that we 'feel' changing our clothing or turning the heating up or down. Often, this behavioral response corrects the situation without the need for any physiological response.

I. Physiological Responses to Heat

There are two main physiological responses when hypothalamus detects an increase in blood temperature: a. Vasodilation, b. Sweating

a. Vasodilation

One way to **increase heat loss** is to supply the capillaries in the skin with a **greater volume of blood**, which then loses heat to the environment via radiation. **Arterioles** have muscles in their walls that can relax or contract to allow more or less blood to flow through them. During vasodilation these **muscles relax**, causing the arterioles near the skin to **dilate** and allowing more blood to flow through capillaries.

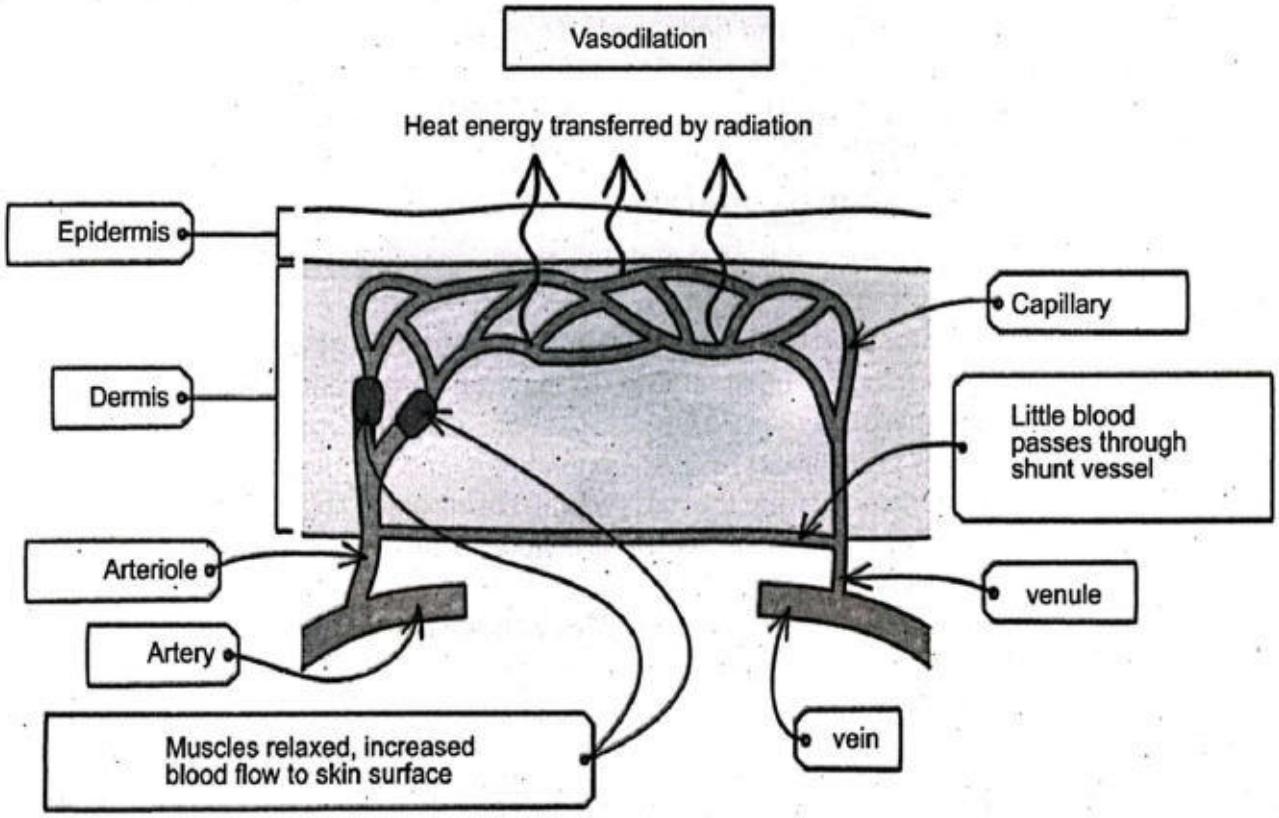


Fig. 8.1: Mechanisms of vasodilation

b. Sweating

Sweat is a salty solution made by sweat glands. Evaporation of sweat from the skin's surface leads to cooling. As the sweat evaporates, it absorbs heat from the body, thereby cooling the skin and helping to regulate internal body temperature. The efficiency of sweating depends on humidity. In dry air, humans can tolerate temperature of 65°C for several hours. In humid air, however, when the sweat cannot evaporate, temperatures of only 56°C cause overheating.

II. Physiological Responses to Cold

There are four main physiological responses when hypothalamus detects a drop in blood temperature: a. Shivering, b. Vasoconstriction, c. Piloerection, d. Increased metabolic rate

a. Shivering

We shiver when muscles contract and relax rapidly. Shivering muscles give out four or five times as much heat as resting muscles.

b. Vasoconstriction

One way to decrease heat loss is to supply the capillaries in the skin with a smaller volume of blood, minimizing the loss of heat to the environment via radiation. During vasoconstriction the muscles in the arteriole walls contract, causing the arterioles near the skin to constrict and allowing less blood to flow through capillaries the blood is diverted through shunt vessels, which are further down in the skin and therefore do not lose heat to the environment. Vasoconstriction reduces heat loss from the blood as it flows through the skin

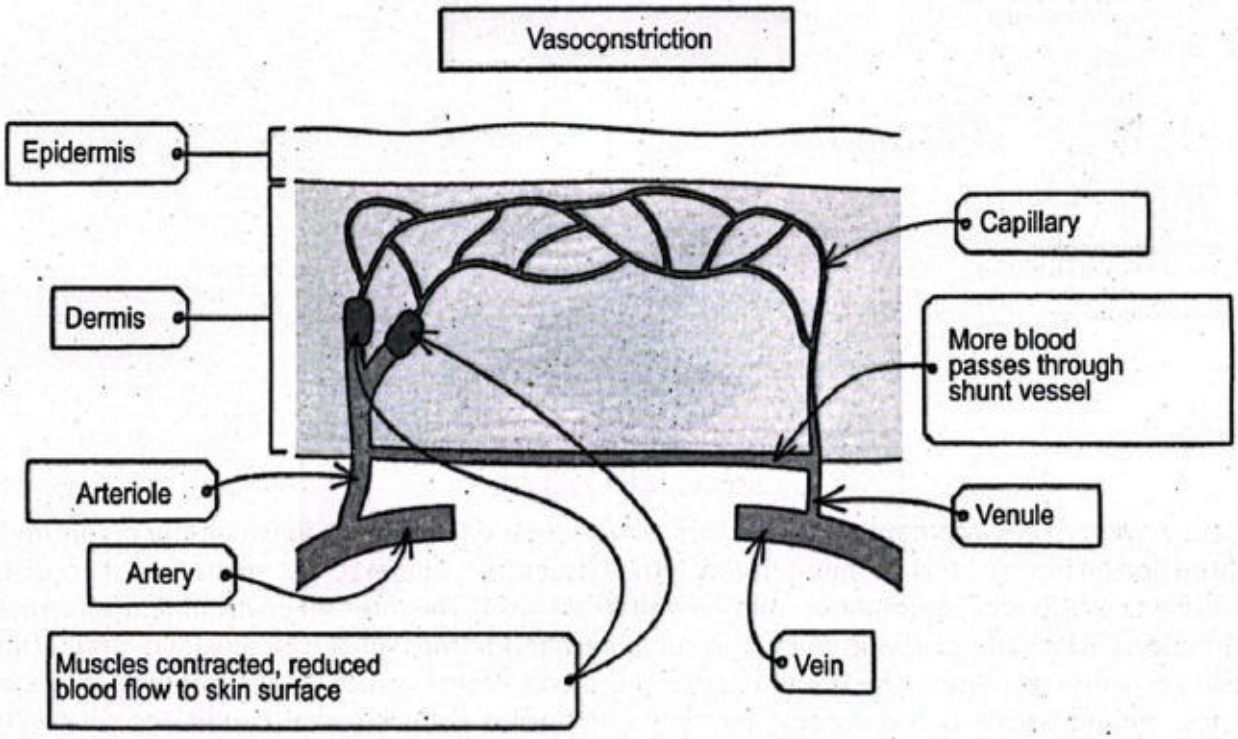


Fig. 8.2: Mechanisms of vasoconstriction

c. Piloerection

It means literally 'erection of hairs' and involves a reflex. In most mammals, piloerection makes the fur 'thicker', so that it traps more air to provide extra insulation. In humans, the **erector pili** muscles in the skin pull the tiny hairs upright, and succeed in creating goose bumps.

d. Increased metabolic rate

The body secretes the hormone adrenaline in response to cold. This raises metabolic rate and therefore increases heat production.

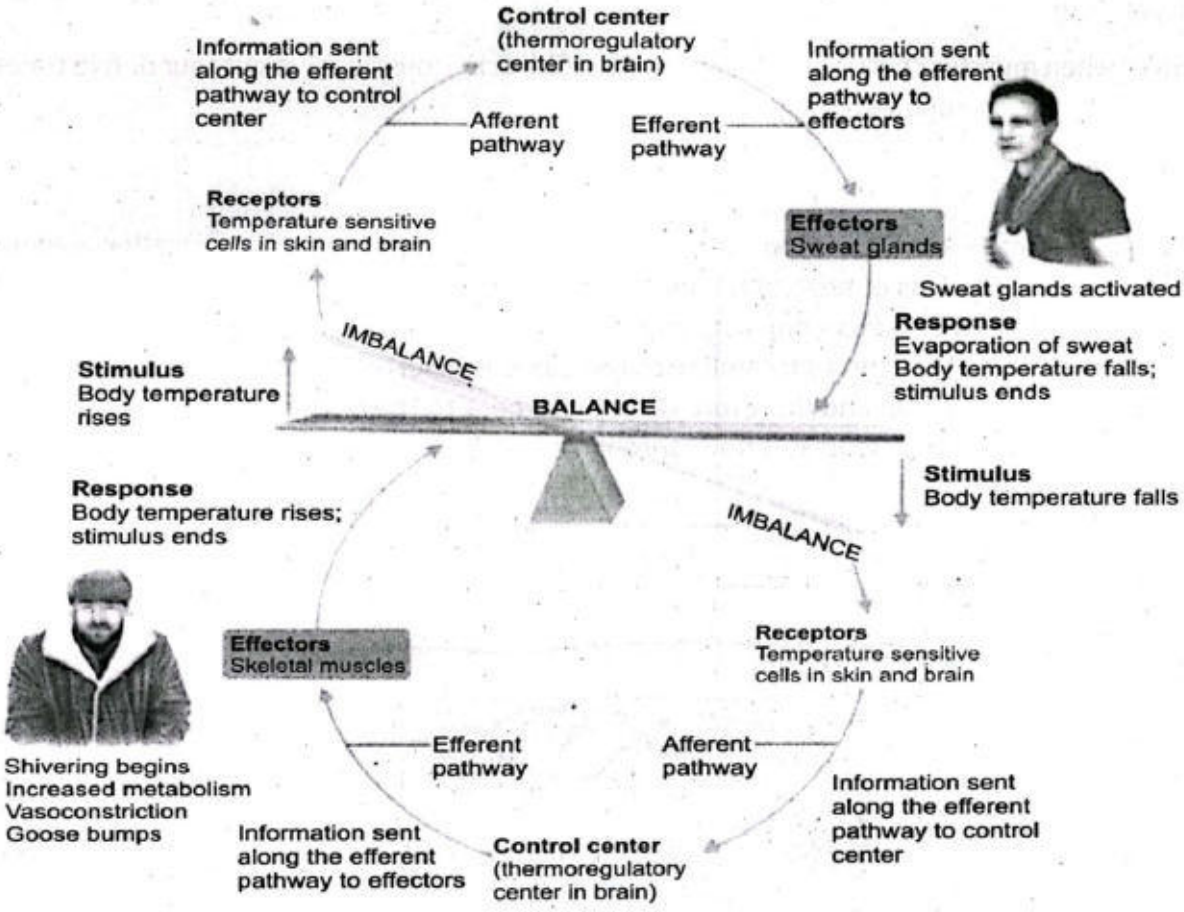


Fig. 8.3: Thermoregulation in human

8.2 HOMEOSTASIS

Animals have two environments in their lives, an external environment in which the organism is situated and an internal environment in which the tissues live. The external environment consists of varying conditions of atmosphere, marine and freshwater. The internal environment is formed by the interstitial fluid or tissue fluid that surrounds and bathes all the tissues and circulating fluids like lymph or plasma the liquid part of the blood. Homeostasis means 'keeping things in balance'. **Homeostasis** is the process by which organisms keep internal conditions relatively constant despite changes in external environment.

The human organ systems are working constantly to maintain a controlled, stable environment. The digestive system takes in and digests food, providing nutrient molecules that enter the blood and replace the nutrients that are constantly being used by the body cells. The respiratory system adds oxygen to the blood and removes carbon dioxide. The amount of oxygen taken in and carbon dioxide given off can be increased to meet the body needs. The liver and kidneys contribute greatly to homeostasis. For example, immediately after glucose enters the blood, it can be removed by the liver and stored as glycogen. Later glycogen is broken down to replace the glucose used by the blood cells. In this way, the glucose composition of the blood remains the same. The hormone insulin, secreted by the pancreas, regulates glycogen storage. The kidneys are also under hormonal influence as they excrete wastes and salts, substances that can affect the pH level of the blood.

8.2.1 Components of homeostatic mechanisms

Adjustment of physiological systems within the body is called homeostatic regulation. It involves three parts or mechanisms: (1) the receptor, (2) the control center, and (3) the effector.

Receptor

The receptor receives information that something in the environment is changing. It responds to changes in the environment, either external or internal. Receptors include thermoreceptors and mechanoreceptors etc.

Control Center

The control center or integration center receives and processes information from the receptor. The control centers include the the renin-angiotensin system (RA).

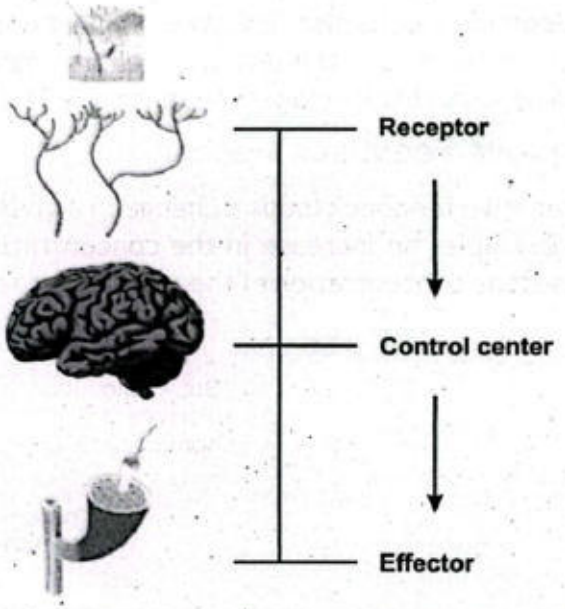
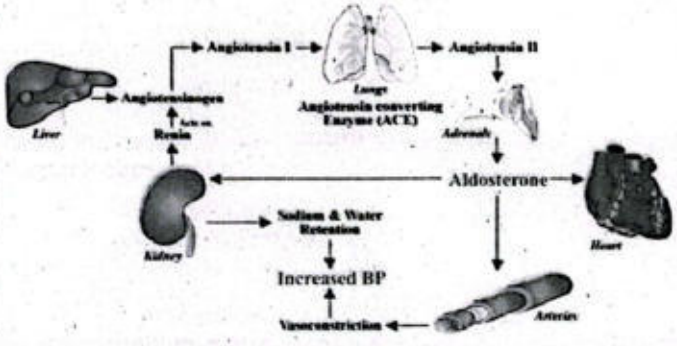


Fig. 8.4: Components of homeostatic mechanisms

For your information

The renin-angiotensin system (RAS), also known as the renin-angiotensin-aldosterone system (RAAS), is a critical hormonal system that regulates blood pressure and fluid balance. It is the system of hormones, proteins, enzymes and reactions. It regulates your blood pressure by increasing sodium (salt) reabsorption, water reabsorption (retention) and vascular tone (the degree to which your blood vessels constrict, or narrow). The RAAS consists of three major substances, including Renin (an enzyme), Angiotensin II (a hormone), and Aldosterone (a hormone).



Effector

The effector responds to the commands of the control center by either opposing or enhancing the stimulus. This ongoing process continually works to restore and maintain homeostasis. For example, during body temperature regulation, temperature receptors in the skin communicate information to the brain (the control center) which signals the effectors: blood vessels and sweat glands in the skin. As the internal and external environments of the body are constantly changing, adjustments must be made continuously to stay at or near a specific value: the set point.

8.2.2 Control of homeostatic mechanism

Homeostasis is maintained by negative feedback loops within the organism. In contrast, positive feedback loops push the organism further out of homeostasis, but may be necessary for life to occur. Homeostasis is controlled by the nervous and endocrine systems in mammals.

Feedback

A **feedback mechanism** is a physiological regulation system in a living body that works to return the body to its normal internal state, or commonly known as homeostasis. In a living system, the feedback mechanism takes the shape of a loop, which aids in maintaining homeostasis.

Negative Feedback Mechanism

In negative feedback loops a change in a given direction causes change in the opposite direction. For example, an increase in the concentration of a substance causes feedback that ultimately causes the concentration of the substance to decrease.

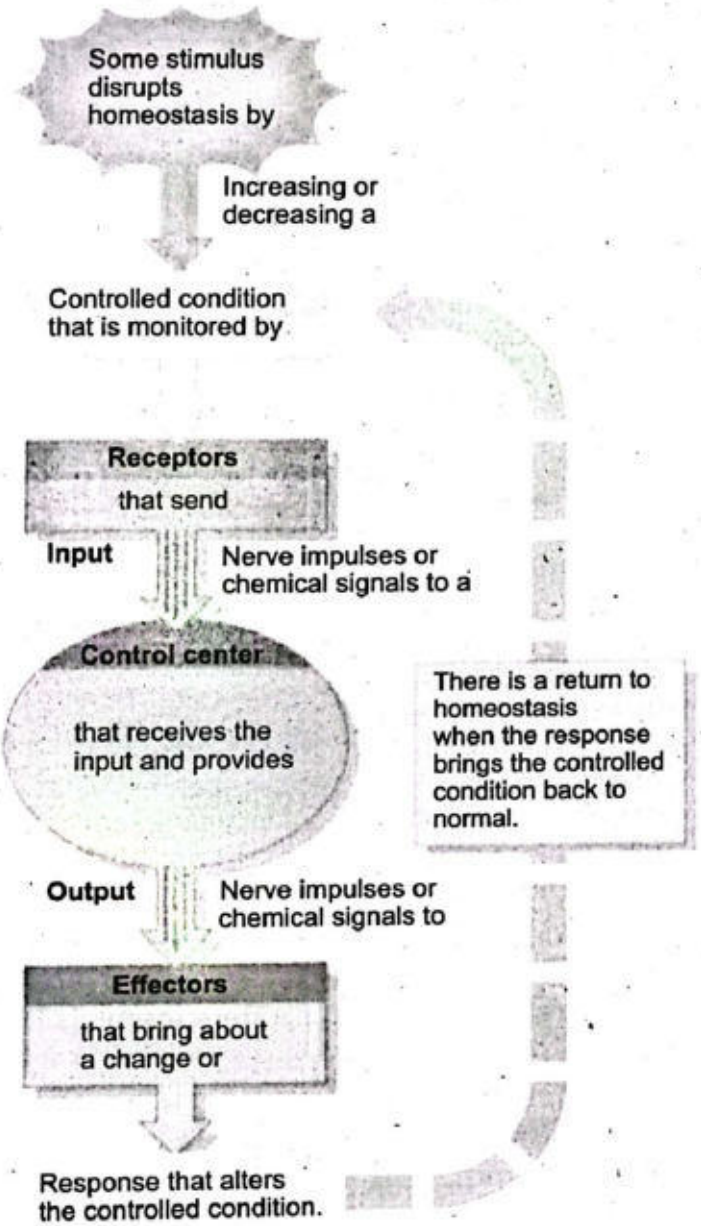


Fig. 8.5: Negative feedback flowsheet

Any homeostatic process that changes the direction of the stimulus is a negative feedback loop. It may either increase or decrease the stimulus, but the stimulus is not allowed to continue as it did before the receptor sensed it. In other words, if a level is too high, the body does something to bring it down; conversely, if a level is too low, the body does something to raise it; hence, the term: negative feedback.

An example of negative feedback is the maintenance of blood glucose levels. When an animal has eaten, blood glucose levels rises, which is sensed by the nervous system. Specialized cells in the pancreas (part of the endocrine system) sense the increase, releasing the hormone insulin. Insulin causes blood glucose levels to decrease, as would be expected in a negative feedback system. However, if an animal has not eaten and blood glucose levels decrease, this is sensed in a different group of cells in the pancreas: the hormone **glucagon** is released, causing glucose levels to increase. This is still a negative feedback loop, but not in the direction expected by the use of the term "negative."

Another example of an increase as a result of a feedback loop is the control of blood calcium. If calcium levels decrease, specialized cells in the parathyroid gland sense this and release parathyroid hormone (PTH), causing an increased absorption of calcium through the intestines and kidneys. The effects of PTH are to raise blood levels of calcium. Negative feedback loops are the predominant mechanism used in homeostasis.

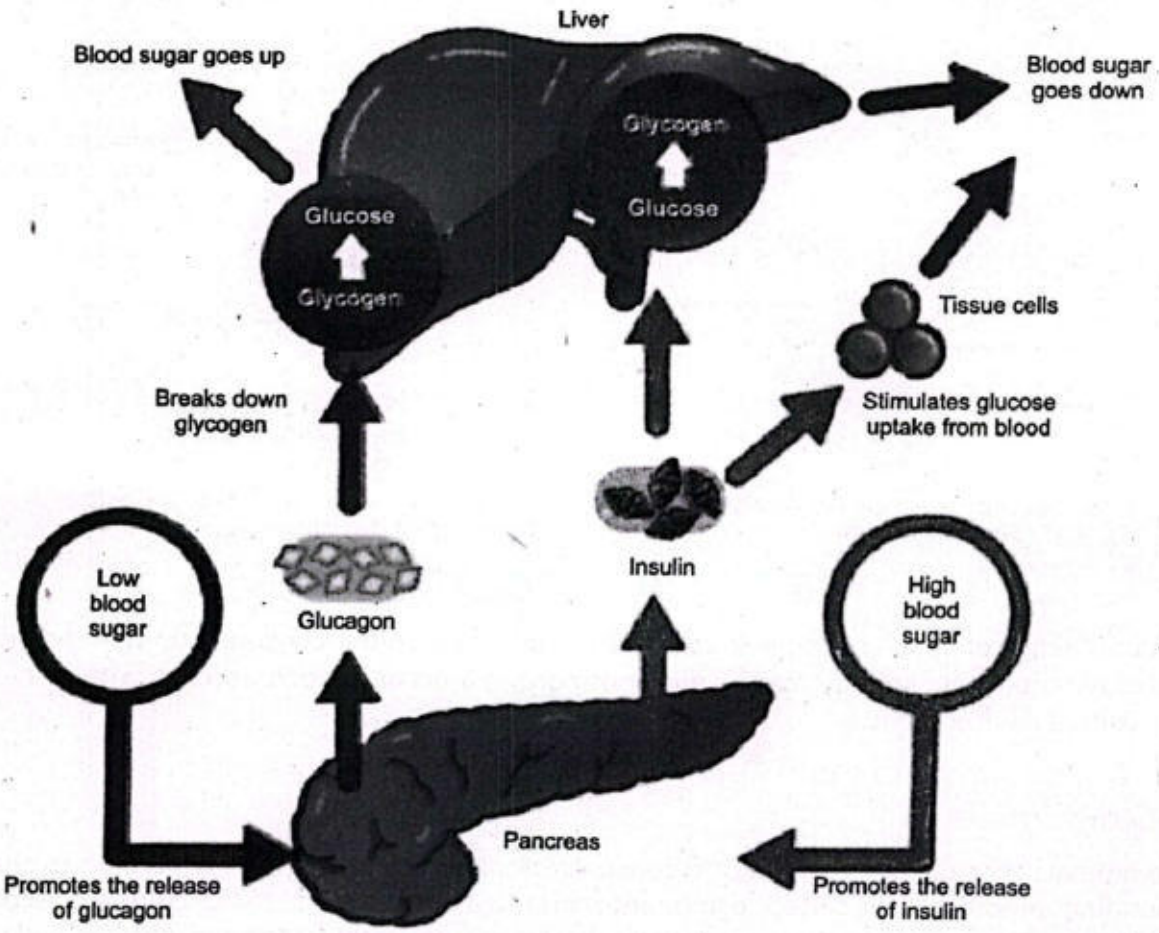


Fig. 8.6: Blood sugar levels are controlled by a negative feedback flowsheet

Positive Feedback Mechanism

In positive feedback loops, a change in a given direction causes additional change in the same direction. An increase in the concentration of a substance causes feedback that produces continued increases in concentration.

When a wound creates bleeding, the body responds by **clotting the blood** and preventing blood loss through a positive feedback loop. The wounded blood vessel wall releases substances that start the clotting process. Platelets in the blood begin to adhere to the wounded area and produce substances that attract more platelets. As the platelets continue to accumulate, more chemicals are released, and more platelets are drawn to the clot location. The clotting process is accelerated by the positive feedback until the clot is large enough to halt the bleeding.

Another example of positive feedback is uterine contractions during childbirth. The hormone oxytocin, made by the endocrine system, stimulates the contraction of the uterus. This produces pain sensed by the nervous system. Instead of lowering the oxytocin and causing the pain to subside, more oxytocin is produced until the contractions are powerful enough to produce childbirth.

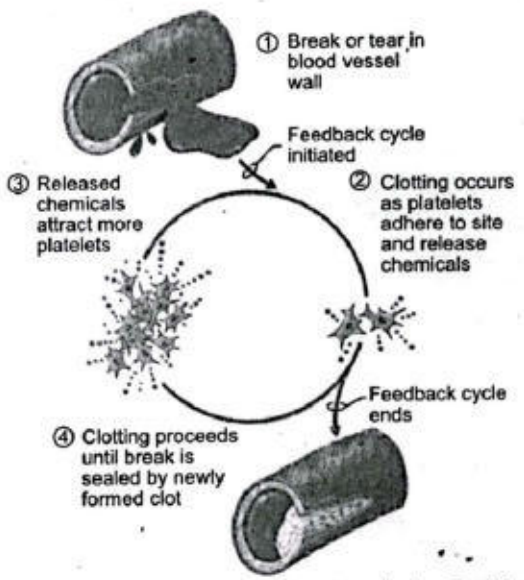


Fig. 8.7: Blood Clotting Mechanism during Positive feedback system.

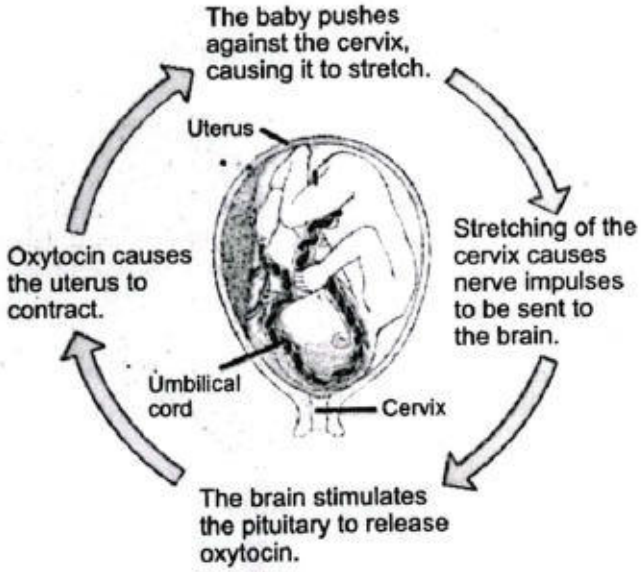


Fig. 8.8: Positive feedback loop: The birth of a human infant is the result of positive feedback

8.3 OSMOREGULATION

The maintenance of constant osmotic conditions (water and solute concentration) in the body is called osmoregulation. Animals may be either osmoregulators or osmoconformers with respect to their external environment.

8.3.1 Osmoconformers and Osmoregulators

Osmoconformers

Those animals that change the osmotic concentrations of the body fluids according to that of surrounding medium are called **osmoconformers**. These are isotonic to their external environment. These include all marine invertebrates, some freshwater invertebrates and some marine vertebrates like Myxine (hag fishes) and elasmobranches (sharks and rays).

Osmoregulators

Those animals that can maintain internal osmotic concentrations different from the surrounding medium are called **osmoregulators**. Such animals are hypotonic or hypertonic to their environment. Almost all of the freshwater animals and most of the marine vertebrates are osmoregulators.

The unusual higher osmotic concentration than other vertebrates of marine habitat is maintained by high levels of urea and trimethylamine oxide (TMAO) in the blood. These organic substances are called **osmolytes** because they increase the osmotic (solutes) concentration.

SCIENCE TITBITS

In most vertebrates, the level of urea to this high concentration would damage the proteins because it is chaotropic (denaturing) agent that disrupts non-covalent and ionic bonds between amino acids residues, but the presence of TMAO helps to stabilize these protein molecules against the adverse effects of urea.

8.3.2 Problems faced by Osmoregulators

Since, freshwater animals live in hypotonic environment, therefore, water constantly enters the body and they also face deficiency of salts, so they have to lose excess water and maintain higher salt concentration than their environment.

On the other hand, most of the **marine teleosts** (bony fishes) are hypotonic to sea water. So these fishes have problem to lose water to the environment, especially across the gill epithelium. They also have problem of excess of salts in the body due to drinking of sea water.

Terrestrial animals are also hypotonic to the outer environment. Evaporation of water that leads to the dehydration is the major problem faced by these animals.

8.3.3 Osmoregulatory Adaptations in Animals

Freshwater animals

Almost all of the freshwater animals are osmoregulators. These animals are generally hypertonic to their outer environment. These animals deal with these problems by producing large volume of diluted urine. Their kidney reabsorbs the salts that are required. Salts are also obtained from the

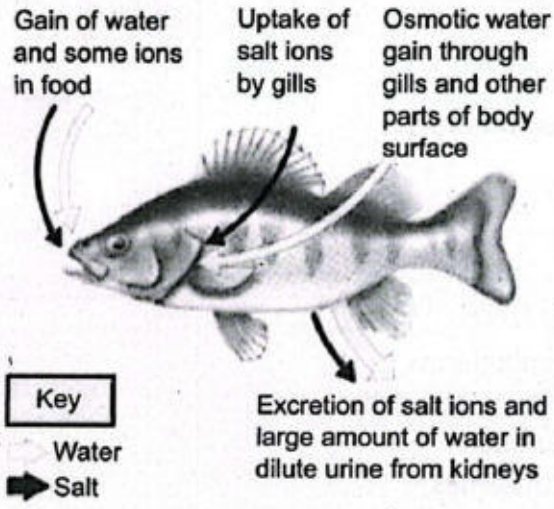


Fig. 8.9: Osmoregulation in freshwater animals

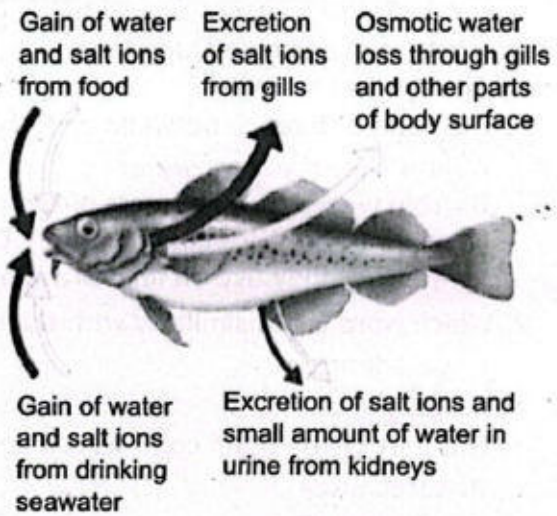


Fig. 8.10: Osmoregulation in marine animals

food they eat. These animals also actively transport salts from the external dilute medium with the help of special salt cells called **ionocytes.** Ionocytes are found in the amphibian skin and gills of fishes.

Marine animals

Teleosts (*bony fishes*) are osmoregulators in marine environment which are hypotonic to their environment. So these fishes have tendency to lose water to the environment, especially across the gill epithelium. In order to replace the water loss, these fishes usually drink large amount of water unlike freshwater fishes.

They also have problem of excess of salts in the body due to drinking of sea water. Among the excess salts, Na^+, Cl^- and some amount of K^+ are removed across the gill epithelium while divalent ions like Mg^{++}, Ca^{++} are excreted by the kidney. Some fishes also have special salt secreting glands in the wall of rectum called **rectal glands** that remove salts into the digestive tract which are then eliminated from the body during egestion.

Terrestrial animals

The successful groups of land animals are arthropods among the invertebrates and reptile, birds and mammals among the vertebrates. The presence of chitinous exoskeleton in arthropods and dead keratinized skin in vertebrates are adaptation to reduce water loss by their bodies.
Desert mammals are very much resistant in this regard. They can tolerate against strong degree of dehydration by special metabolic and behavioural adaptation. This characteristic is called **anhydrobiosis.** Actually, these animals feed upon seeds of desert plants in which large amount of carbohydrate are stored. During the breakdown of these compounds; water is produced as by-product that is utilized by these animals. Best example of such animals is kangaroo rat. They avoid day time heat and emerge at night. Ninety percent of the water that they use is metabolic water derived from cellular oxidation.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. The main difference between endotherms and ectotherms is
   A. how they conserve water
   B. from where they get most of their body heat
   C. whether they are cold or warm blooded
   D. whether they live on land or water
2. Which word is not similarly with the others?
   A. ectoderms B. endoderms
   C. homeothermic D. warm-blooded
3. This part of the brain controls temperature regulation.
   A. cerebellum B. thalamus
   C. hypothalamus D. hippocampus

4. If body temperature decreases, which one of the following is incorrect?
   A. vasoconstriction
   B. hair raised
   C. increase metabolic rate
   D. sweating
5. The body's ability to maintain a constant body temperature is called what:
   A. thermoregulation
   B. modification
   C. adaptation
   D. lucky
6. The liver's functions are required for
   A. thermoregulation
   B. osmoregulation
   C. homeostasis
   D. all of these
7. The mechanism of regulation, generally between organism and its environment, of solutes and the gain and the loss of water is called
   A. homeostasis
   B. hemostasis
   C. osmoregualtion
   D. thermoregulation
8. In a hot summer after noon, if your body's homeostatic machinery keep your internal temperature quite lower than that of external than this is an example of
   A. positive feed back
   B. negative feed back
   C. feed back
   D. osmoregulation
9. The characteristic which enable animals to tolerate dehydration is called
   A. osmoconformation
   B. osmoregulaton
   C. anhydrobiosis
   D. anhydrosis
10. Homeostasis
   A. must always be restored using negative feedback mechanisms
   B. provides for the tight regulation of all physiological variables
   C. is the sum of all chemical reactions in the body
   D. is a combination of positive and negative feedback mechanisms
11. A negative feedback mechanism comprise
   A. detectors, comparators, a fixed set point and effectors
   B. detectors, amplifiers, comparators, a set point and effectors
   C. detectors, attenuators, comparators, a set point and effectors
   D. detectors, comparators, a variable set point and effectors
12. Positive feedback
   A. does not exist in physiological systems
   B. is seen in the initiation of an action potential when sodium entry causes depolarization which in turn leads to potassium exit
   C. is unstable and requires some mechanism to break the feedback loop
   D. is switched off by negative feedback mechanisms
13. Which of the following is an example of a positive feedback mechanism?
   A. the control of blood sugar by insulin
   B. blood clotting
   C. the control of blood pressure
   D. the regulation of body temperature

14. Which of the following components of a homeostatic regulatory mechanism is responsible for detecting a stimulus?

A. an effector
B. a control center
C. a receptor
D. an afferent pathway

15. Which of the following phrases most correctly defines homeostasis? Homeostasis involves the maintenance of internal conditions within _____.

A. specific set-points.
B. specific normal ranges.
C. ranges higher than external conditions.
D. ranges equal to external conditions.

16. Homeostasis is best conceived as a state of:

A. negative feedback
B. dynamic consistency
C. positive feedback
D. hormone regulation

17. Insulin is a hormone that acts to:

A. stimulate metabolism in the body
B. increase blood sugar levels
C. decrease blood sugar levels
D. stimulate the formation of blood clots

18. A setpoint is usually:

A. the top of a normal range
B. the bottom of a normal range
C. in the middle of a normal range
D. the point at which changes can no longer occur

Section II: Short Answer Questions

1. Define or describe very briefly the following.

a. osmoregulation
b. osmoregulators
c. osmoconformers
d. vasodilation
e. vasoconstri
f. thermoregulation
g. poikilotherms
h. homeotherms
I. ectotherms
j. endotherms
k. homeostasis

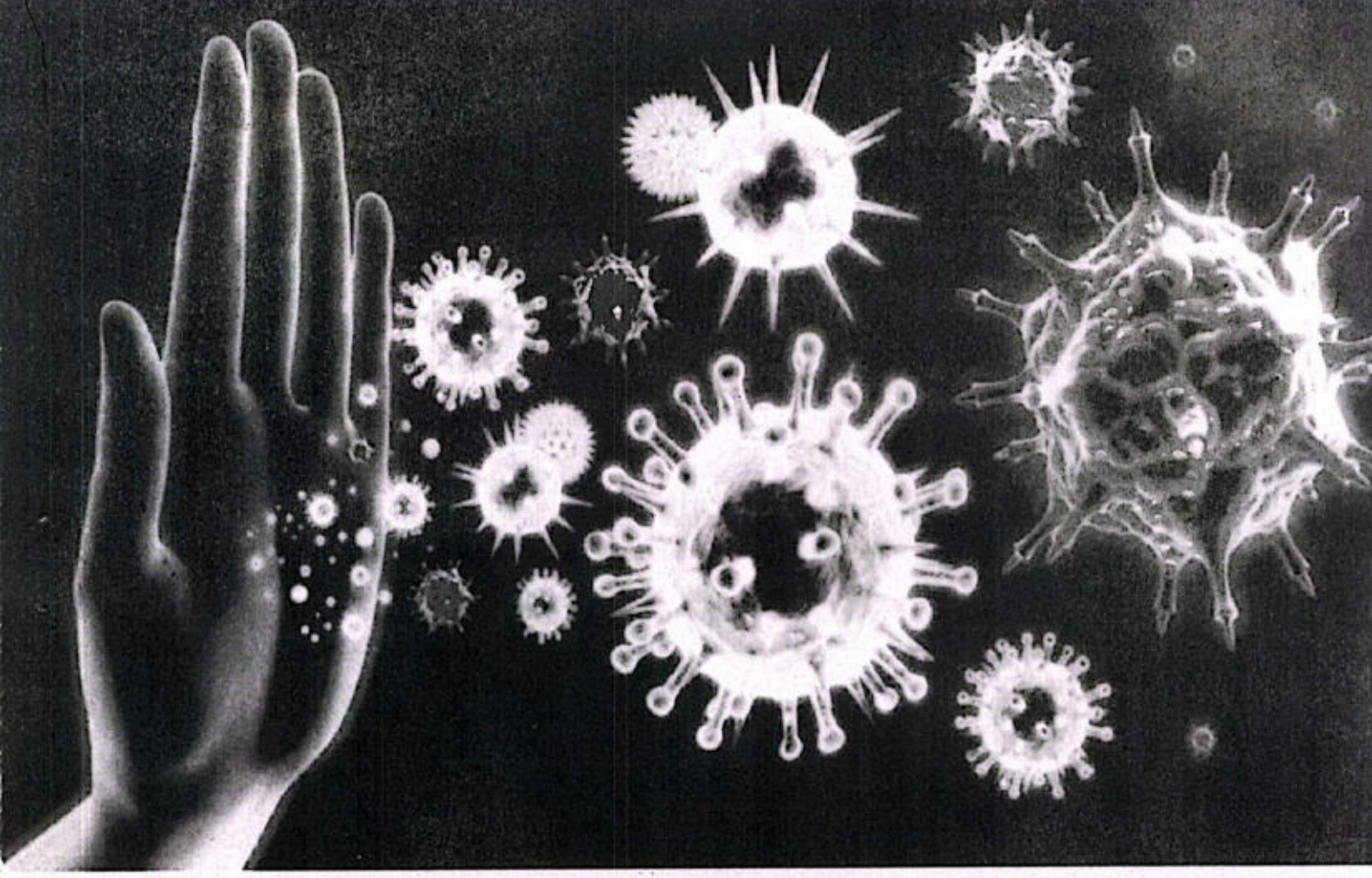
2. What are the problems faced by osmoregulators?
3. Describe the osmoregulatory adaptations in :

a. Freshwater animals
b. Marine animals
c. Terrestrial animals

4. What are the needs of thermoregulation?
5. What is a feedback mechanism?
6. Identify and define the four interacting components that maintain homeostasis in feedback loops.
7. Give two examples of physiological processes that are controlled by positive feedback loops.

Section III: Extensive Answer Questions

1. Classify animals on the basis of temperature.
2. What are the thermoregulatory strategies in man?
3. How various human organs system to maintain controlled stable environment.
4. Explain components of homeostatic mechanism.
5. Describe with example the negative feedback mechanism with relation to homeostasis.
6. Describe with example the positive feedback mechanism with relation to homeostasis.
7. Compare and contrast negative and positive feedback loops.
8. Explain how negative feedback controls body temperature.



IMMUNITY

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-1-01] List the structural features of human skin that make it an impenetrable barrier against invasion by microbes. (1st line of defence).
2. [B-12-1-02] Explain how oil and sweat glands within the epidermis inhibit the growth and also kill microorganisms. (1st line of defence).
3. [B-12-1-03] Recognize the role of the acids of the digestive tract as killing bacteria present in food.
4. [B-12-1-04] State the role of the ciliated epithelium of the nasal cavity and the mucous of the bronchi and bronchioles in trapping airborne microorganisms.
5. [B-12-1-05] Describe the role of macrophages and neutrophils in killing bacteria.
6. [B-12-1-06] Explain how Natural Killer (NK) cells kill cells infected by microbes and cancer cells.
7. [B-12-1-07] State the way proteins of the complement system kill bacteria and that interferons inhibit viruses from infecting cells.
8. [B-12-1-08] State the events of the inflammatory response as a generalized, nonspecific defence.
9. [B-12-1-09] Outline the release of pyrogens by microbes and their effect on the hypothalamus to boost the body's temperature.
10. [B-12-1-10] List the ways that fever affects microbes.
11. [B-12-1-11] Define the specific immune system as providing specific defence and acting as the most powerful means of resisting infection.

12. [B-12-1-12] Identify monocytes, T cells, and B-cells as components of the immune system.
13. [B-12-1-13] State inborn and acquired immunity as the two basic types of immunity.
14. [B-12-1-14] Differentiate between active and passive immunity as the two types of acquired immunity.
15. [B-12-1-15] Describe the role of T-cells in cell-mediated immunity.
16. [B-12-I-16] Describe the role of B-cells in antibody-mediated immunity.
17. [B-12-1-17] Discuss the role of T-cells and B-cells in transplant rejections.
18. [B-12-1-18] Evaluate the discovery of monoclonal antibodies and justify how this accomplishment revolutionized many aspects of biological research.
19. [B-12-I-19] Identify the process of vaccination as a means to develop active acquired immunity.
20. [B-12-1-20] Draw the structural model of an antibody molecule.
21. [B-12-I-21] Explain the role of memory cells in long term immunity.
22. [B-12-1-22] Define allergies and correlate the symptoms of allergies with the release of histamines.
23. [B-12-1-23] Describe the autoimmune diseases with examples.

You have already learnt about immunity in previous classes. In this chapter we will learn about the body's defence and more emphasis would be on the immune system. The body's response to foreign particles, such as the production of antibodies directed against a specific antigen, is called an **immune response. Immunity** is the ability to resist damage from foreign substances such as microorganisms and harmful chemicals, e.g., toxins released by microorganisms. **Immunology** is the study of foreign particles that can affect the living body and the defence mechanisms, which are taken by the body to eliminate these particles. The human body has three lines of defence against microbial attack. First line of defence comprises **external barriers** that keep microbes out of the body. Second line of defence consists of **nonspecific internal defence** that combats all invading microbes. First line and second line of defence together make **innate immunity.** Third line of defence includes the **specific internal defence** also called **adaptive/ acquired immunity.**

9.1 FIRST LINE OF DEFENCE

The first and obviously best, defence is to keep microbes out in the first place. The human body has two surfaces exposed to the environment: the skin and the mucous membranes of the digestive and respiratory tracts. These surfaces are external barriers to microbial invasion. Since these barriers inhibit generally all kind of microbial invasion thus, first line of defence is supposed to be a non-specific defence.

9.1.1 Skin: An Impenetrable Barrier Against Microbial Invasion

The skin is made up of two layers i.e., **epidermis** and **dermis.** Epidermis is outermost layer of the skin, composed of tightly packed cells that provide a physical barrier. Most cells of epidermis contain keratin protein that strengthens skin cells, making them resistant to abrasion and water loss. The outer surface of the skin also consists of dry dead cells. Consequently, most microbes that land on the skin cannot obtain the water and nutrients they need. The skin surface has a slightly **acidic pH (around 5.5),** which inhibits the growth of many pathogens. **Desquamation** is the process of shedding dead skin cells. This helps in removing attached microbes. Dermis is inner, comparatively thick layer containing glands, hair follicles, receptors, nerves and blood vessels. **Sebaceous glands** produce **sebum,** an oily substance. Sebum contains fatty acids that lower skin

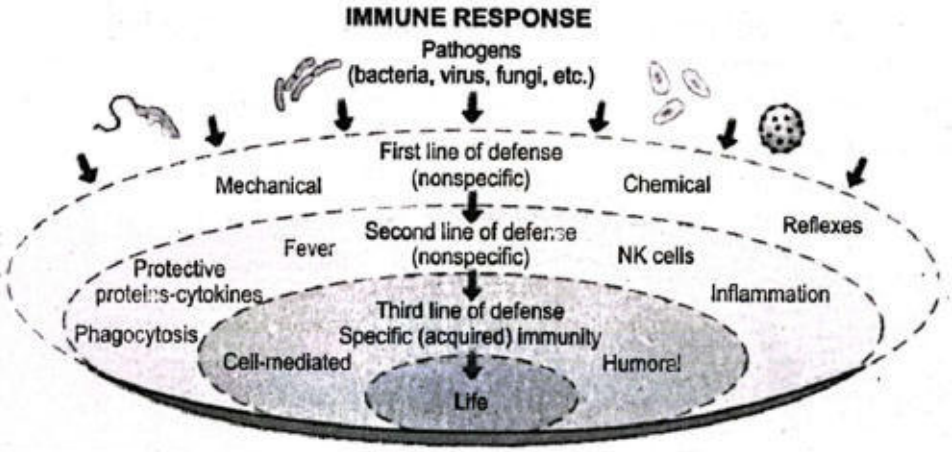


Fig. 9.1: The five drug development phases

pH and possess antimicrobial properties. Sweat glands secrete sweat, a salty fluid that generally provides cooling effect to the body. Sweat contains lysozyme, an enzyme that breaks down bacterial cell walls, and has a high salt concentration that can dehydrate bacteria. Secretion from sweat glands and sebaceous glands usually cover the skin. These secretions contain natural antibiotics such as lactic acid that inhibit the growth of bacteria and fungi. These multiple defences including chemical, physical and immune barriers make the unbroken skin an extremely effective block against microbial invasion.

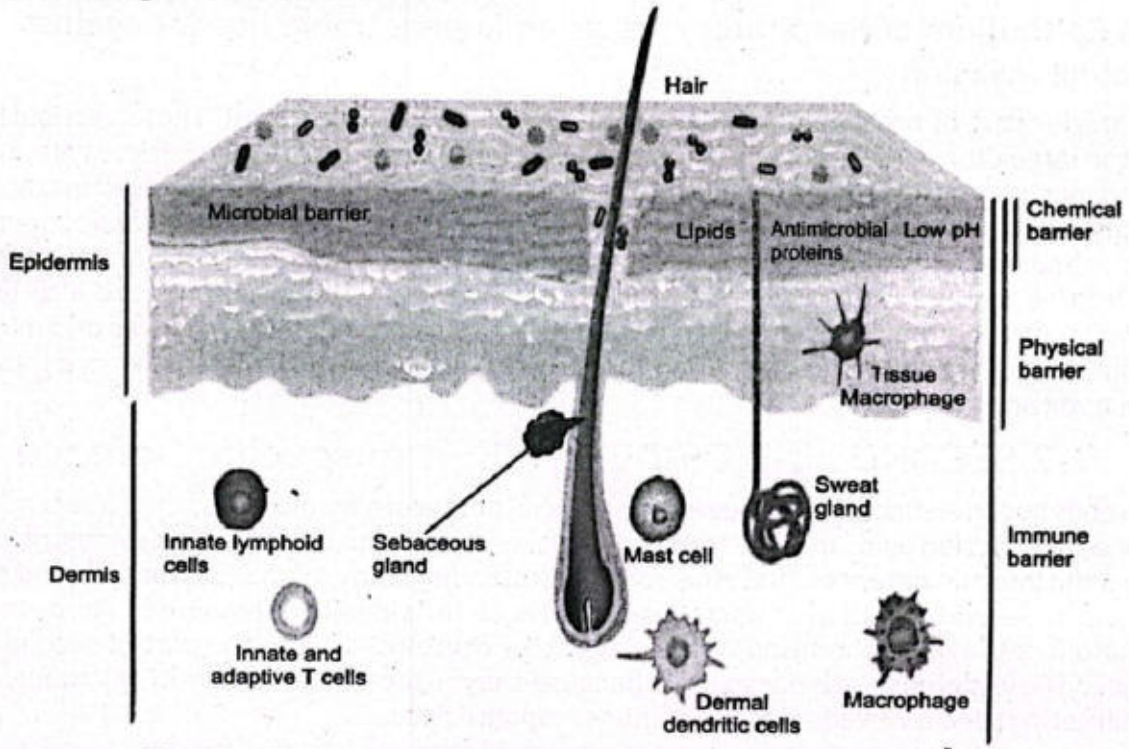


Fig. 9.2: Skin as an impenetrable barrier against microbial invasion

9.1.2 Epithelium of Digestive Tract: An Impenetrable Barrier Against Microbial Invasion

The gastrointestinal tract (GIT), is covered by mucous membrane, which protects the G1T against

microbial invasion by means of its various kind of secretions. Such as **hydrochloric acid** in the stomach is secreted by oxyntic or parietal cells that kills the bacteria present in food. In addition, various **digestive enzymes** present in gastric juice, intestinal juice and pancreatic juice also digest the bacteria present in food.

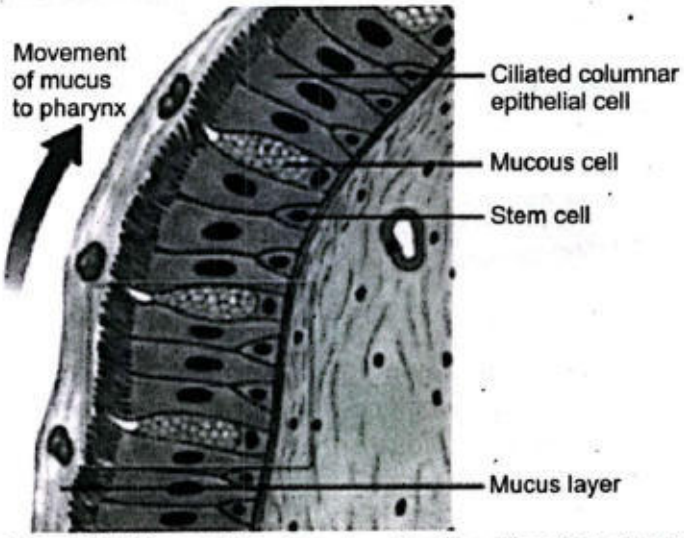


Fig. 9.3: Respiratory epithelium of trachea showing the direction of movement of mucous containing trapped particles towards pharynx

9.1.3 Epithelium of Respiratory Tract: an impenetrable barrier against microbial invasion

The anterior part of nasal cavities that contain hairs is called **vestibule**. These vestibular hairs filter the large dust particles of the inhaled air. The inner surface of nasal cavities is also lined by ciliated mucous epithelium. The mucus secreted by this epithelium is also involved in trapping of fine dust particles and microbes. The cilia of the epithelium sweep the trapped, fine dust particles and microbes posterior to the pharynx, where they are swallowed and are eliminated by the digestive system. The trachea and the air passageways within the lungs are also lined by ciliated mucous epithelium that is also involved in trapping of fine dust particles and microbes. The cilia in this region propel mucus and foreign particles towards the larynx, where they enter the pharynx and are swallowed.

9.2 SECOND LINE OF DEFENCE - Nonspecific Defence

If microbes become successful to penetrate the skin or mucous membranes, then a second line of defence takes action against these foreign invaders. The second line of defence comprises three nonspecific internal defence. First, the body has a standing army of **phagocytic cells** and **natural killer cells**. Second, invasion of microbes provokes an **inflammatory response**. Third, the body often produces **fever**. In addition, some **protective proteins** are also the part of second line of defence. These defence are nonspecific because they attack wide variety of microbes, rather than targeting specific invaders as the immune response does.

9.2.1 Killing Cells of Blood

There are white blood cells in the body called phagocytes. A phagocyte is a cell that destroys other abnormal body cells (cancerous cells) or invaded microorganisms by engulfing. This process is called phagocytosis. Main types of phagocytic white blood cells are: macrophages, dendritic cells, and neutrophils.

Macrophages and Dendritic cells

Monocytes are formed in bone marrow. From bone marrow. Monocytes typically circulate in the blood for 1-3 days before migrating into tissues, where they become macrophages or dendritic cells. Through blood, macrophages and dendritic cells are transported to the areas of the body where they are needed.

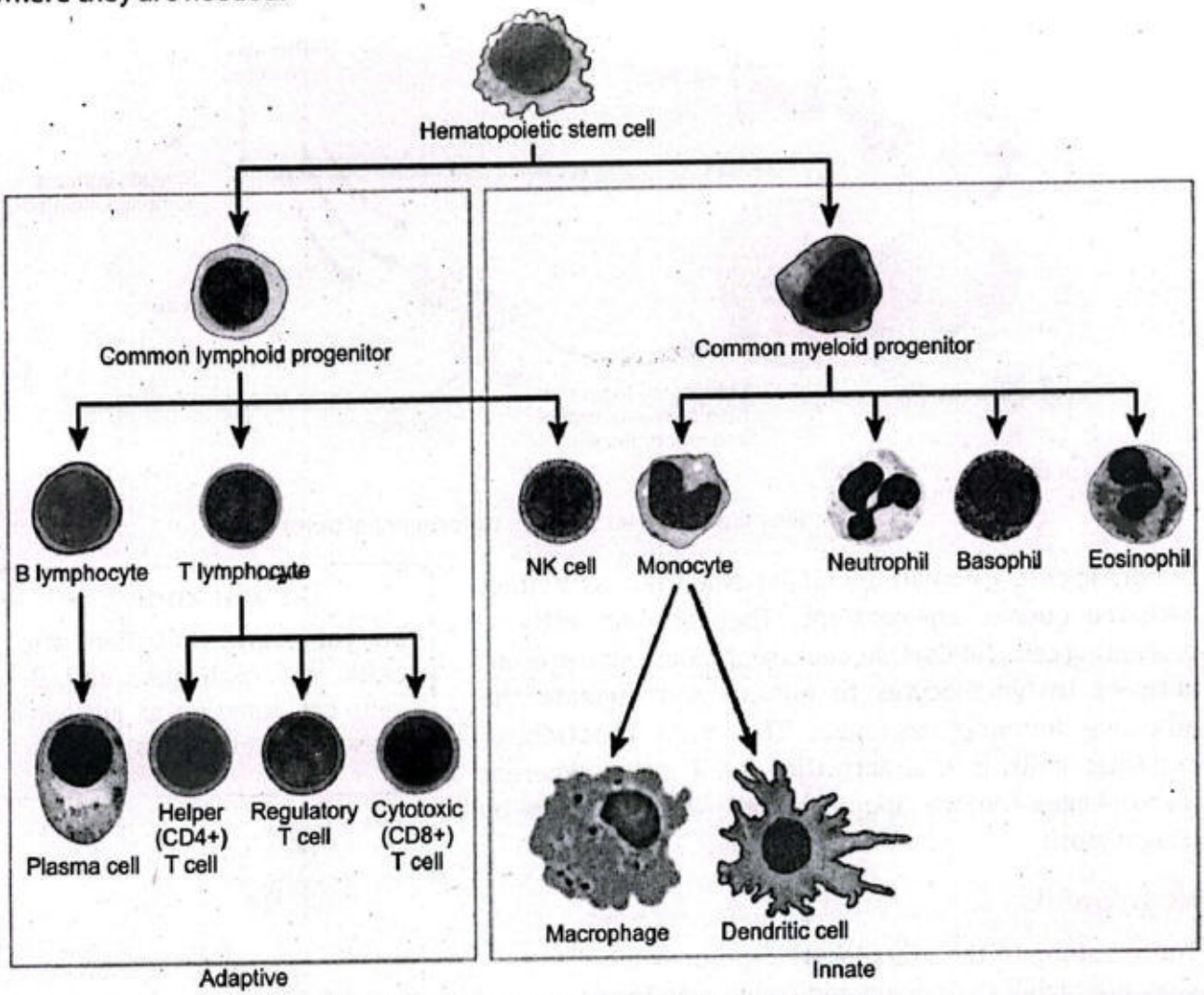


Fig. 9.4: Cells of Innate and Adaptive Immunity

Macrophages are generally found in the organs such as the lungs, liver, spleen, kidney and lymph nodes, rather than remaining in the blood. In these organs, they patrol within the free spaces among the cells and provide protection by trapping and destroying microorganisms entering the tissue. As macrophages interact with microbes, they not only engulf and destroy them; they also display some parts of microbes on their surface so that other body cells may also be informed. Such cells are called **Antigen Presenting Cells (APCs)**. The macrophages also secrete many different proteins when they perform phagocytosis of the microbes. Some of these proteins trigger the maturation of monocytes into macrophages, thereby increasing their numbers. Another protein interleukin-I signals the brain to raise the body temperature, producing fever. Some other proteins also stimulate the specific immune response. Macrophages also play an essential role in wound healing and tissue repair by removing dead cells and debris.

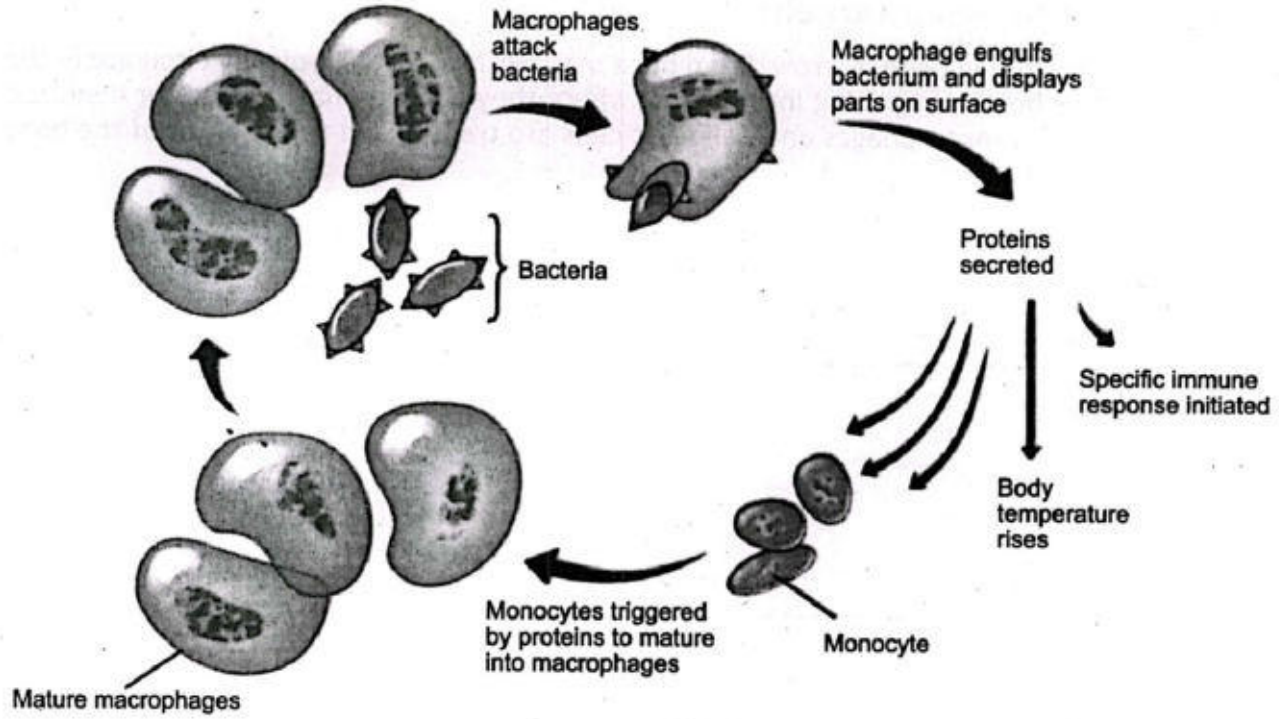


Fig. 9.5: Response of macrophages to foreign particles

Dendritic cells (DCs) are found in tissue that has contact with the outside environment. They become antigen-presenting cells (APCs) that capture, process, and present antigens to lymphocytes to initiate and regulate the adaptive immune response. The main function of dendritic cells is the activation of T cells, whereas macrophages remove apoptotic cells and microbes by phagocytosis

Do you know?

Do you know that Dendritic cells, macrophages, and B-cells can function as antigen-presenting cells (APCs)?

Neutrophils

These belong to the granulocyte type of WBCs. They are highly short-lived and highly mobile as they squeeze between cells of capillary walls and can enter parts of tissue where other cells would not be able to enter otherwise. They move like Amoeba forming pseudopodia. They proceed rapidly to infected area to perform their duty and they often die after a single phagocytic event. Neutrophils also release lysosomal enzymes by extracellular degranulation that kill microorganisms and cause inflammation. Neutrophils can release Neutrophil extracellular trap to kill microbes.

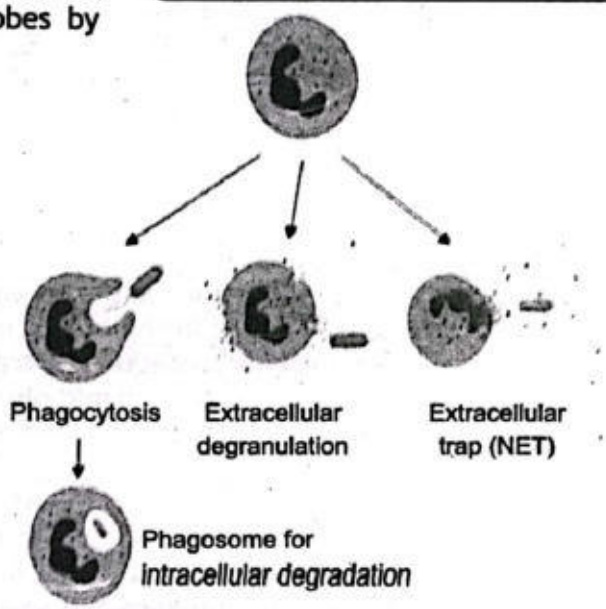


Fig. 9.6: Neutrophils immune response

Natural killer cells

Natural killer (NK) cells are a type of lymphocytes which provide innate immunity. In general, natural killer cells do not directly attack invading microbes. Instead, natural killer cells attack the cancerous cells or viruses infected body cells. NK cells kill their target by releasing proteins called **perforins**, which punch holes through the membranes of the infected cells. The pores formed by these proteins allow for the passive diffusion of certain apoptotic proteases, known as the **granzymes**, into the target cell. The cell dies by apoptosis. Macrophage engulfs and digests that dying cell.

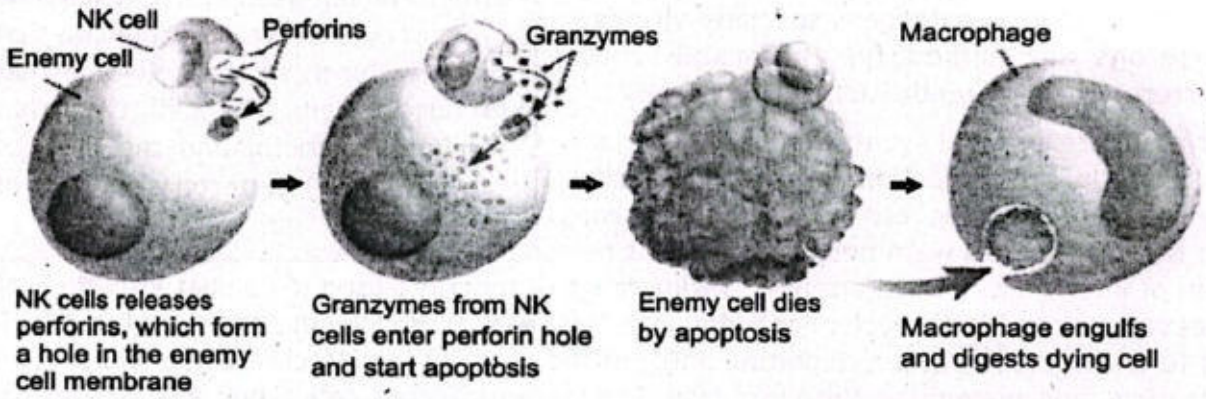


Fig. 9.7: NK cells attack on enemy cells (Cancerous cell/ Virus infected cell)

9.2.2 Protective Proteins of Complement System

The complement system consists over fifty types of small proteins found in the blood, synthesized by the liver, and normally circulating in inactive state. They are activated on the entry of foreign particles. Once a complement protein is activated, it activates another protein, which further activates other proteins of the system and so on. As a result, phagocytes clear foreign and damaged material. Development of inflammation to attract additional phagocytes at the site of infection. This activates cell killing membrane attack complexes. The complement system is an important supporter of the immune system that enhances (complements) the ability of antibodies and phagocytic cells to clear microbes and damaged cells from the body, promotes inflammation, and attacks the pathogen's plasma membrane.

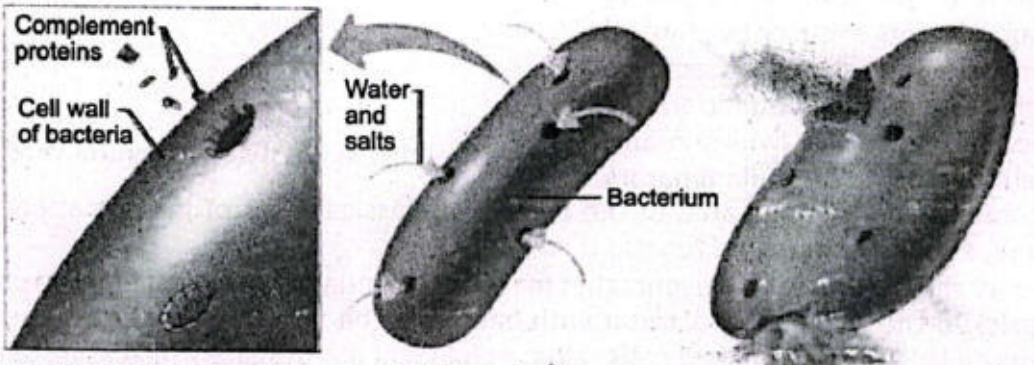


Fig. 9.8: Action of the complement system against a bacterium

An example of protective proteins of complement system is **membrane attack complex (MAC)** that produces holes in the bacterial cell walls and plasma membranes of pathogens. The holes allow fluids and salts to enter the bacterial cell, thus, bacterial cell swells and eventually burst.

Interferons

Interferons belong to the large class of proteins known as **cytokines**, molecules used for communication between cells during infection. They are released by host cells in response to the presence of several pathogens specially viruses. Interferons are named for their ability to "**interfere**" with viral replication.

Do you know?

A **cytokine** is a chemical messenger that regulates cell differentiation, production, and gene expression to affect immune responses. At least 40 types of cytokines exist in humans that differ in terms of the cell type that produces them, the cell type that responds to them, and the changes they produce. Interferon is one type of cytokine.

Interferons are antiviral agents produced by virus-infected cells. Upon infection, virus infected cells mount an innate immune response to protect them from the virus and to warn neighbouring cells by means of interferon. Interferons have a wide range of functions used to combat infection at all stages of a pathogen's life cycle. For a viral infection, examples include: signalling virus infected cells to undergo apoptosis, prohibiting entry of the virus into uninfected cells, stopping viral replication, and preventing the virus from leaving an infected cell. They also activate the immune cells to generate immune response.

The many forms of interferon are rapidly produced to defend against viruses. Interferons can also combat bacterial and parasitic infections, inhibit cell division, and promote or slow down the differentiation of cells.

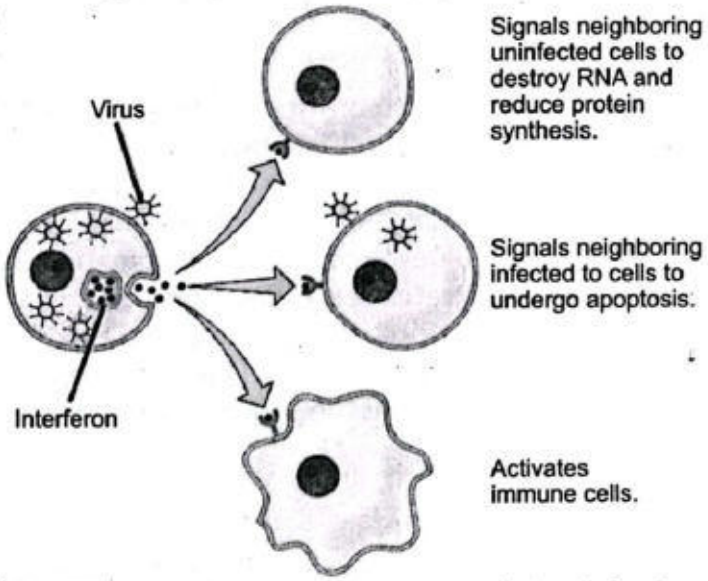


Fig. 9.9: Action of interferon to control virus infection

9.2.3 Inflammatory Response

The inflammatory response is a major component of the non-specific defence. Any damage to tissue, whether caused by an infectious microorganism or by physical injury, even just a scratch or an insect bite triggers this response. Inflammation can be localized or systemic (widespread). Local inflammation is an inflammatory response confined to a specific area of the body. The classical signs of inflammation are heat, pain, redness, swelling, and loss of function.

The figure 9.10 shows the chain of events that make up the inflammatory response, in case where a pin has pricked the skin and infected it with bacteria. The first thing that happened when a tissue is injured is that the damaged cells release chemical alarm signals such as histamine. The chemical sparks the mobilization of various defence. Histamine for instance induces neighbouring blood vessels to dilate and blood vessels start leaking. Blood supply to the damaged area increases, and blood plasma passes out of the leaky vessels into the interstitial fluid of the affected tissues causing inlammation.

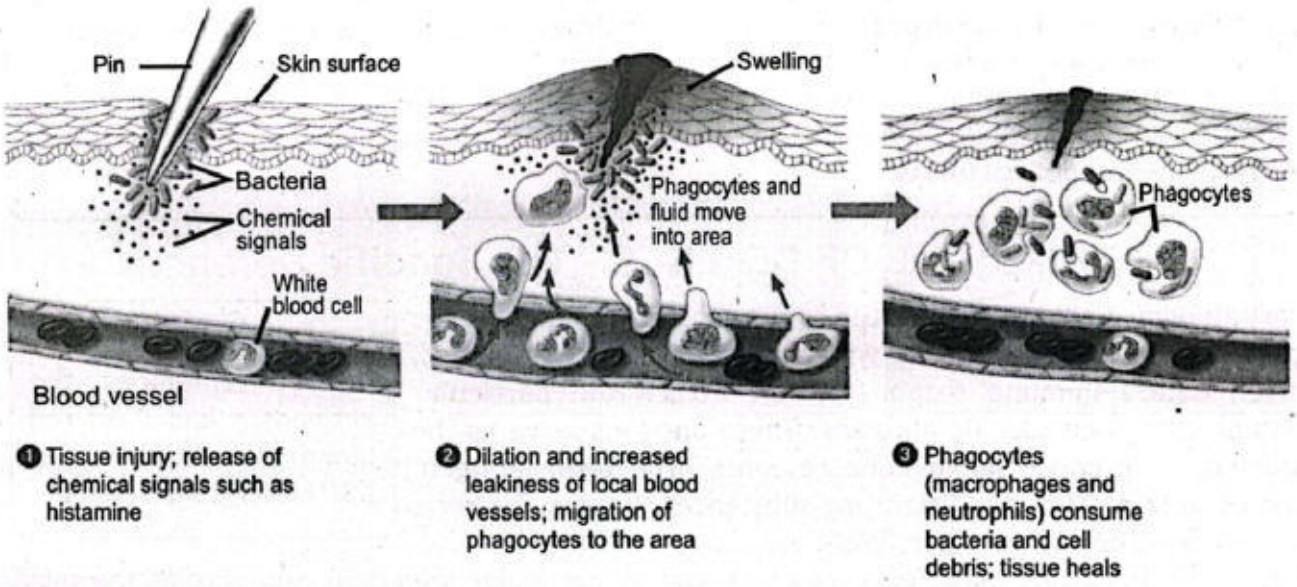


Fig. 9.10: The Inflammatory response

The function of inflammation is to eliminate the initial cause of cell injury, clear out necrotic cells and tissues damaged from the original insult (to attack physically) and the inflammatory process, and to initiate tissue repair. The inflammatory response also helps to prevent the spread of infection to the surrounding tissues.

9.2.4 Temperature Response

Fever or **pyrexia** is the raised body temperature than normal. The invaded microorganisms often release certain chemicals, which are generally termed as **pyrogens**. These pyrogens cause the temperature set point of the **hypothalamic thermostat** of the body to rise; as a result, all the mechanisms for raising the body temperature are brought into play, such as heat conservation and increased heat production. Since, higher body temperature than normal facilitates the microbial growth in the body, this is the reason why invaded microorganisms want to increase the host's body temperature.

On the other hand, certain white blood cells in response to the infection, also release hormones collectively called **endogenous pyrogens** that further increase the temperature set point of hypothalamus because higher body temperature than normal increases the activity of phagocytic white blood cells that attack upon bacteria. The endogenous pyrogens also cause other cells to reduce the concentration of iron in the blood because many bacteria require more iron to reproduce at temperature of 38°C or 39°C than at 37°C, so fever and reduced iron in the blood combine to slow down their rate of reproduction. Fever also increases the production of interferons that travel to other cells and increase their resistance to viral attack. The higher body temperature may directly inactivate the virus particles, particularly enveloped viruses, which are more heat-sensitive than non-enveloped viruses. Replication of some viruses is reduced at higher temperatures, therefore fever may inhibit replication.

However, fever is nonspecific defence against microbial infections, but often, high degree fever becomes destructive for body's own metabolic system and ultimately body is collapsed. Therefore, physicians use to prescribe antipyretic drugs to the patients of high degree fever.

Justify why the physician prescribe antipyretic drugs, when fever is a nonspecific defence against microbial infections

Antipyretic drugs create their effects by inhibiting prostaglandin production in the hypothalamus, which has the effect of blocking set point elevation and maintaining the set point at nearer normal levels.

9.3 THIRD LINE OF DEFENCE - The Specific Defences

Do you know?

Do you remember, the antigens A and B on red blood cells, you learned in ABO blood group system?

If a pathogen is able to get past the body's nonspecific defence, the third line of defence interferes with a series of defence responses, often called immune responses that attack the particular pathogens having specific antigens. These antigens serve as the stimulus to produce an immune response. The term "antigen" comes from ANTI-body GENerating substances. Viruses, bacteria and other pathogen have specific antigens on their surface.

Since, the third line of defence respond against particular infections and acts as the most powerful means of resisting infections therefore, it is also called **specific defence**. Its response can be of two types: **Humoral immune response** and **cell-mediated immune response.** These immune responses are particularly carried out by two components: B-lymphocytes or B cells and T-lymphocytes or T cells. However, third line of defence also involves role of monocytes (macrophages) that participate in activation of these lymphocytes.

9.3.1 Role of Monocytes in Third Line of Defence

As already described in second line of defence that monocytes are kind of WBCs, which are produced by lymphoid tissues. The monocytes circulate in blood for one to three days and ultimately they leave the blood and come into the intercellular space of tissues. In the tissues, they swell and attain a larger size to become tissue **macrophages** or **dendritic cells** which are irregular in shape with many projections. When these cells perform phagocytosis of invaded microorganisms, after digesting them they not only display microbial antigens on their surfaces. Macrophages begin to secrete about 100 different compounds including various enzymes, interferons and a protein called **interleukin-1**. The interleukin-1 secreted by macrophages activates the T cells that in turn begin to secrete **interleukin-2**, which then activates the B cells. Interleukin-1 also promotes a general response to injury, causing fever and activating other mechanisms that defend the body against invasion. While dendritic cells after phagocytosis become antigen presenting cells for T cell activation.

9.3.2 Role of T Cells in Third Line of Defence (Cell mediated immune response)

T cells originate from stem cells in the bone marrow. After early embryonic development, the newly forming T cells migrate to **thymus gland** for processing. The thymus makes T cells immunocompetent that is capable of immunological response. The immune response provided by T cells is called **cell mediated immune response.**

Activations of T cells

In case of infection, macrophages perform phagocytosis of invaded microorganism and detect

particular **antigens (nonself molecules)** of the organism. Macrophages isolate and display these antigens on their surface with the help of their own proteins (self-protein) called **major histocompatibility complex (MHC)**. In this way, macrophages become **antigen-presenting cells (APCs)**. Macrophages also secrete **interleukin-1** that stimulates and attracts helper T cells towards the displayed antigen. Helper T cells have specific receptor on their surface called **T cell receptor (TCR)** by which they bind with a particular antigen displayed on APC. Interleukin-1 also stimulates the helper T cells to secrete another protein, the interleukin-2 that not only compel the helper T cells to divide but also causes the proliferation of certain cytotoxic T cells and B cells. The activation of T-cells by a specific antigen is called **cell-mediated immunity**. The body contains millions of different T-cells, each able to respond to one specific antigen.

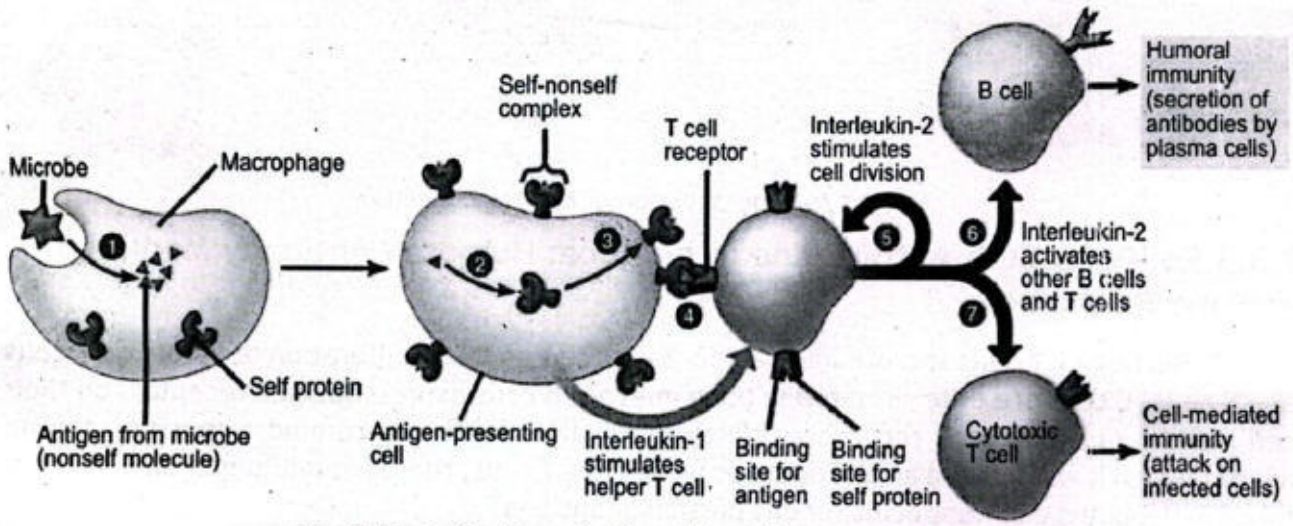


Fig. 9.11: Activation of cell mediated immune response

Types of T cells

Two main categories of T cells have been identified. The first group, known as **CD8** cells because they have surface marker designated **CD8**, include cytotoxic T cells and suppressor T cells. The second group i.e., **helper T cells** also known as **CD4** cells because they have a surface marker designated **CD4**.

When T cells are activated, they divide and produce four types of cells which have specific role in cell-mediated immune response.

(i) Cytotoxic T cells: These cells secrete cytotoxin which triggers destruction of the pathogen's DNA or perforin which is a protein that creates holes in the pathogens plasma membrane. The holes cause the pathogen to lyse (rupture).

(ii) Helper T cells: These cells secrete interleukin 2 which stimulates cell division of T cells and B cells. In other words, these cells recruit even more cells to help fight the pathogen.

(iii) Suppressor T cells: When infection is successfully removed, these cells begin to secrete certain proteins that inhibit further proliferation of T cell. Therefore, they shut down the immune response.

(iv) Memory T cells: These cells remain dormant after the initial exposure to an antigen. If the same antigen presents itself again, even if it is years later, the memory cells are stimulated to convert themselves into helper T cells and help fight the pathogen.

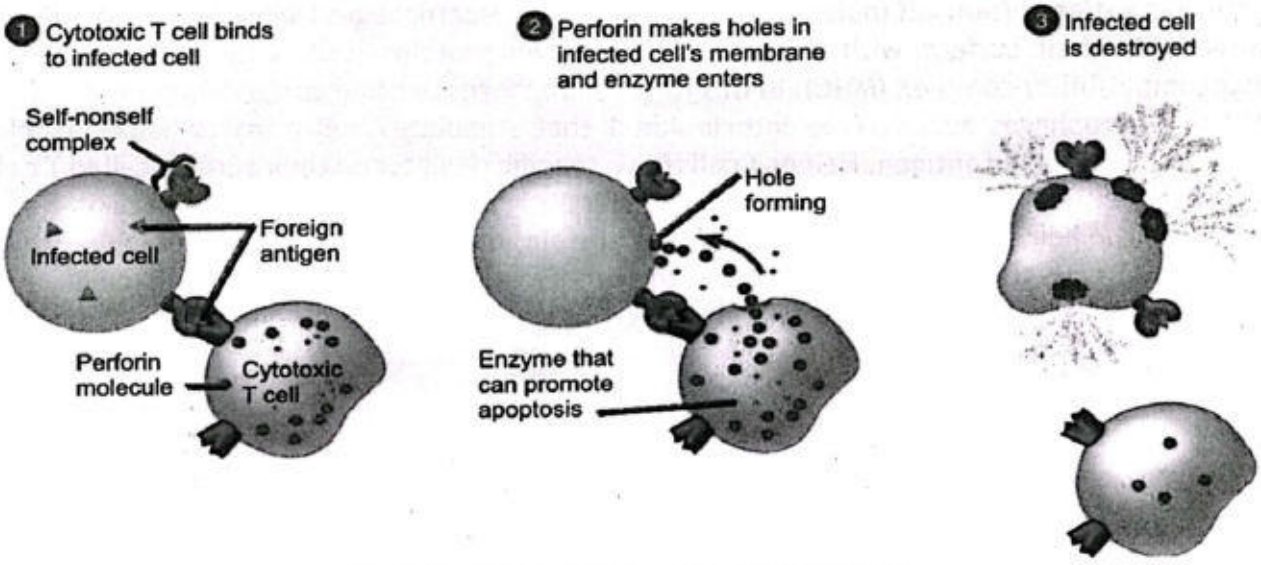


Fig. 9.12: Mode of action of cytotoxic T cells

9.3.3 Role of B Cells in third line of defence: Humoral/ Antibody Mediated Immune Response

Stimulated helper T cells secrete interleukin-2 that causes the proliferation of cytotoxic T cells and B cells. B cells are differentiated in bone marrow. B cells express specific receptors on their cell membrane, the B cell receptors (BCRs). BCRs allow the B cell to bind a specific antigen, against which it will initiate an antibody response. Like T cells, there are millions of B cells types, found in the body; each is specific for one particular antigen.

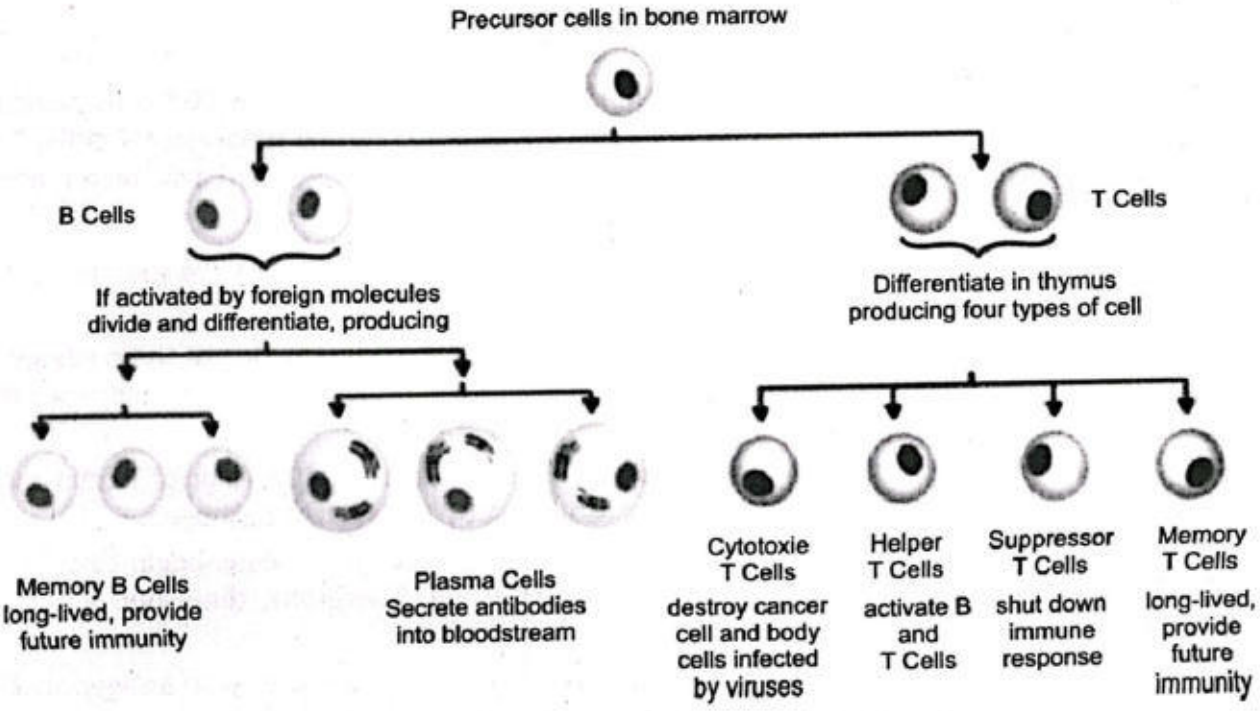


Fig. 9.13: The major cells of Adaptive Immunity and their roles in the immune system

Activation of B cells

B cell activation begins when the B cell binds to an antigen via its BCR. Actually, B cells are stimulated to bind with specific antigen by interleukin-2 proteins, which are secreted by helper T cells. After binding with specific type of antigen the B cells divide to produce two type of cells: **plasma clone cells** and **memory B cells**. The plasma clone cells are specialized to secrete bulk quantity of antibodies. After B cells become plasma cells they live only for a few days but secrete a great deal of antibody during the time. A **plasma cell** can produce more than 10 million molecules of antibody per hour. If the same antigen enters the body later, the **memory B cells** divide to make more plasma cells and memory cells that can protect against future attacks by the same antigen. The stimulation of B cells to divide into plasma clone cells and memory B cells and the secretion of antibodies by plasma clone cells is called **humoral mediated immune response.**

Structure of an antibody

Antibodies (also called immunoglobulins or Ig's) are Y-shaped proteins that circulate through the blood stream and bind to specific antigens, thereby attacking microbes. The antibodies are transported through the blood and the lymph to the pathogen invasion site.

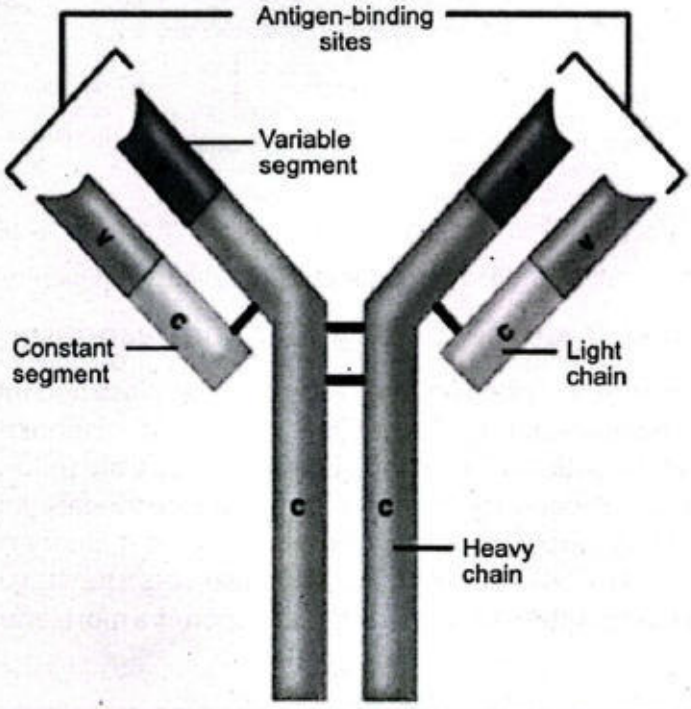


Fig. 9.14: Structure of an antibody

A typical antibody is a Y-shaped molecule, which consists of four polypeptide chains: two identical long chains called heavy chains, and two identical short chains called light chains. Each chain has a constant segment, a functional segment, and a variable segment. In the constant segment, (C) of the heavy chains, the amino acid sequence is constant within a particular immunoglobulin class. On the other hand, the variable segments (V) consist of different amino acid sequences in every antibody. Therefore, they act as antigen-binding site. Each antibody has two antigen-binding sites.

Mode of action of an antibody

Antibodies work in different ways:

1. Antibodies can combine with virus and toxins to neutralize them. This prevents binding o pathogens with host cells.
2. The antibody can bind to an antigen, forming an antigen-antibody complex thus promote phagocytosis by macrophages. This mode of action is called **opsonization.**
3. They can activate complement system to form **membrane attack complex.** As a result, target *cell either bursts* or undergoes phagocytosis.
4. Antibodies can attach with virus infected cells or tumour cells to start **antibody dependent cell mediated cytotoxicity.** NK cells attach with target cell and induce apoptosis to kill that cell.

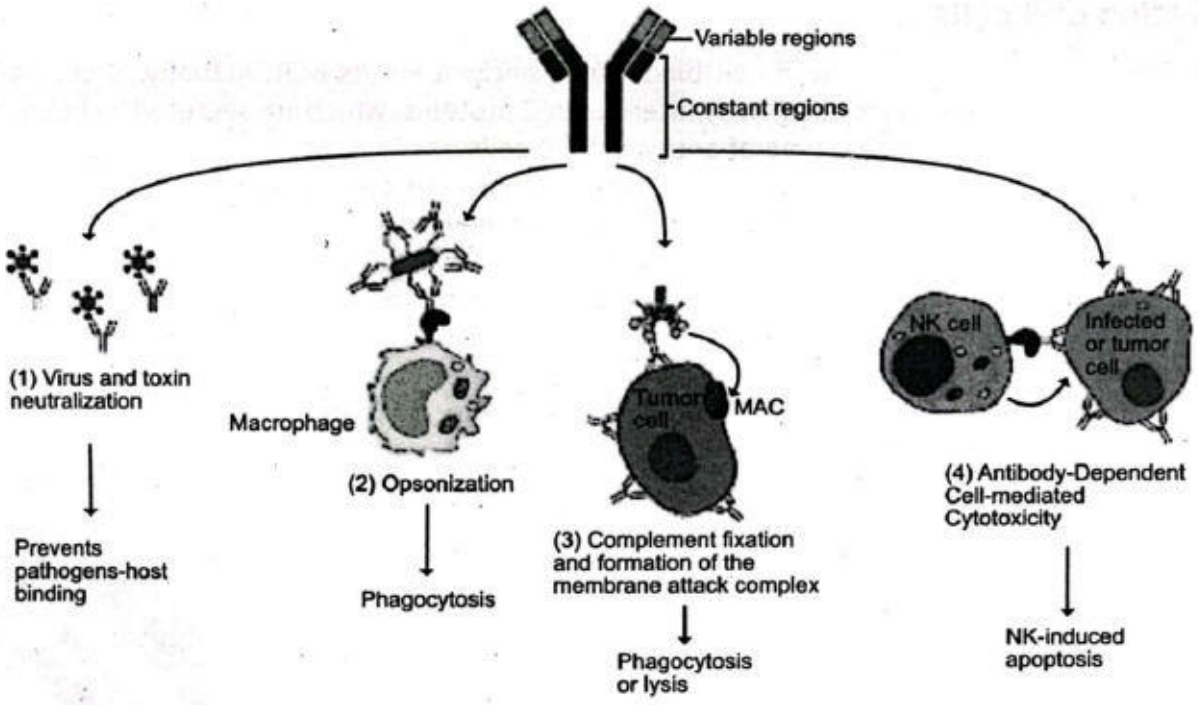


Fig. 9.15: The major cells of Adaptive Immunity and their roles in the immune system

Primary and secondary immune response

The action of the immune system can be classified into two parts: the primary and the secondary immune response. The **primary immune response** displays the first contact of the immune system with an infectious agent whereas all following contacts with the same pathogen are named **secondary immune response**. Secondary immune response is faster and stronger than primary response. Primary response forms memory cells, while secondary response uses existing memory cells. The primary response sets the stage for the secondary response, allowing the immune system to "remember" and mount a more effective defence against future infections.

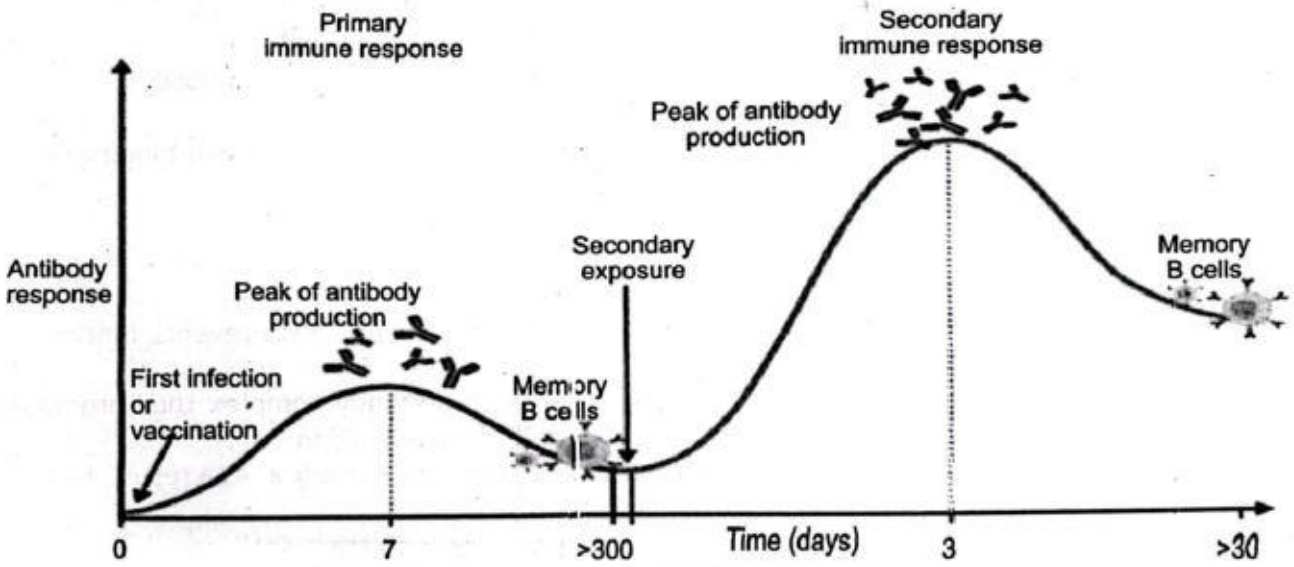


Fig. 9.16: Primary vs Secondary immune response

Monoclonal antibody

Whenever a person falls ill, the body responds by producing antibodies to counteract the antigens of pathogens. These antibodies are specific to a particular antigen. Scientists can replicate these antibodies and help in the treatment of a disease. Monoclonal antibodies (mAbs) are artificially engineered in laboratories by scientists as a form of medication.

This is because they are characterized by their ability to help human body combat diseases better. These can target only one specific type of antigen.

The discovery of mAbs by Köhler and Milstein in 1975 revolutionized various aspects of biological research, diagnostics, and therapy. mAbs are a single type of antibody that are produced by identical immune cells (clones). These mAbs specifically bind to a particular antigen. This uniqueness allows for precise targeting and recognition of specific molecules.

Impact on biological research

1. **Specificity and sensitivity:** mAbs enabled researchers to detect and quantify specific molecules with precision. This helped in the study of complex biological processes.
2. **Immunological research:** mAbs helped explain immune responses, cell signaling, and antigen-antibody interactions.
3. **Cancer research:** mAbs aided in understanding cancer cell biology. As a result, targeted therapies and diagnostic tools are developed.
4. **Protein analysis:** mAbs facilitated the detection and characterization of specific proteins. It increased our understanding of protein function and expression.
5. **Drug development:** mAbs are responsible for the creation of new targeted therapies of cancer and autoimmune diseases.

Impact on diagnostics

1. **ELISA (Enzyme Linked Immunosorbent Assay) and Western blot:** mAbs enabled the development of sensitive and specific diagnostic tests, like ELISA and Western blot.
2. **Imaging agents:** mAbs combined with radioactive or fluorescent labels help imaging techniques like PET and fluorescence microscopy. Positron Emission Tomography (PET) is a medical imaging technique that uses radioactive tracers to creat 3D images of metabolic and physiological processes in the body.PET helps doctors diagnose and monitor various diseases, such as cancer, neurological disorders, and cardiovascular conditions

Impact on therapy

1. **Targeted therapies:** mAbs have revolutionized disease treatment. It is used to treat cancer, COVID-19, cardiovascular disease and autoimmune diseases.
2. **Immunotherapy:** mAbs can make use of immune system to combat cancer.

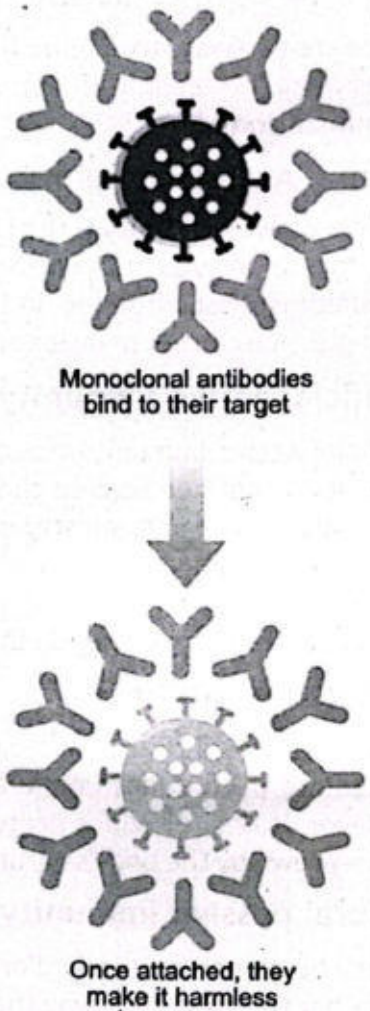


Fig. 9.17: Action of mAbs onCOVID-19 virus to control the disease

9.3.4 Inborn and Acquired Immunity

The two basic types of immunity are (a) inborn or innate immunity (b) acquired immunity. The ability of the innate immune system to kill microorganisms is not specific. First and second line of defence that you have already studied in this chapter are the part of **innate or inborn immunity.** Highly specific protection is provided by the **acquired (adaptive) part** of the immune system, but it takes several days for this system to become fully functional. The two components of the acquired immune system are **cell-mediated immunity and antibody mediated (humoral) immunity.**

Adaptive immunity is unique to vertebrates, while innate immunity is found in all multicellular organisms.

SCIENCE TITBITS

In 1717 Mary Montagu, the wife of an English ambassador to the Ottoman Empire, observed local women inoculating their children against smallpox. **Edward Jenner** observed and studied Miss Sarah a milkmaid who had previously caught cowpox and was found to be immune to smallpox.

9.4 TYPES OF ACQUIRED IMMUNITY

There are two ways to acquire adaptive immunity: (a) Active Immunity (b) Passive Immunity. Both types may be acquired naturally or artificially. Providing immunity artificially is called **immunization.**

Natural Active Immunity

Natural active Immunity is the kind of immunity, which is obtained as a result of an infection. The body manufactures its own antibodies when exposed to an infectious agent. This type of immunity is most effective and generally persists for a long time, sometimes even for life. For example, you can get measles only once in your life, as it gives lifelong natural active immunity.

Artificial active immunity

Artificial Active Immunity (vaccination) is achieved by injecting (or administering orally) small amounts of antigen, called the vaccine, into the body of an individual. The process is called **vaccination.** The antigen stimulates the body to manufacture antibodies against other antigen. Often a second, booster is given and this stimulates a much quicker production of antibody which is long lasting and which protects the individual from the disease for a considerable time. Several types of vaccine are currently in use.

Passive immunity

In passive immunity antibodies from one individual are passed into another individual. They give immediate protection, unlike active immunity, which takes a few days or weeks to build up. However, it only provides protection against infection for a few weeks, for the antibodies are broken down by the body's natural processes, so their number slowly fall and protection is lost.

Natural passive immunity

It may be gained naturally. For example, antibodies from a mother can cross the placenta and enter her foetus. In this way they provide protection for the baby until its own immune system is fully functional. Passive immunity may also be provided by **colostrum**, the first secretion of the mammary glands. The baby absorbs the antibodies through its gut.

Artificial passive immunity

> **Do you know?**
> The first antibody-based therapies were used to treat snake bites and were called antivenoms!

Antibodies which have been formed in one individual are extracted and then injected into the blood of another individual which may or may not be of the same species. They can be used for immediate protection if a person has been; or is likely to be, exposed to a particular disease. For example, specific antibodies used for combating tetanus and diphtheria used to be cultured in horses and injected into humans. Only antibodies of human origin are now used for humans. Antibodies against rabies and some snake venoms are also available. Antibodies against the human rhesus blood group antigen are used.

9.3.5 Disorders of Immune System

Some conditions that stimulate a defective immune response or destroy immune system are called disorders of immune system.

Allergies

Allergies are defective immune responses leading to chronic health conditions like Hay fever, eczema, asthma and food allergy. The immune system of allergy patients overreacts when allergens (like pollen, dust or mold) are inhaled or ingested or enter through skin. The body starts producing large quantity of special antibodies IgE (Immunoglobulin E). This IgE binds with basophils to release inflammatory chemicals like histamine. Histamine increases capillary leakiness, swelling, mucus secretion, inflammation and other allergic responses. Antihistamine drugs block some of the effects of histamine, relieving the symptoms of allergies. Vaccination can be effective treatment of allergy specially for asthma.

Autoimmune disease

In autoimmune disease, the immune system attacks the healthy cells of body's organs and tissues by mistake. The antibodies are produced against body's own components and begin to destroy them. There are more than 80 types of autoimmune diseases. They can affect almost any part of your body. For example:

a. Some types of anaemias are caused by antibodies that destroy a person's red blood cells.
b. Many cases of insulin-dependent (juvenile-onset) diabetes occur because the insulin-secreting cells of the pancreas are the victims of a misdirected immune response.
c. Vitiligo is a chronic autoimmune disorder that causes patches of skin to lose pigment or colour.

Unfortunately, at present there is no way to cure autoimmune diseases. The autoimmune response can be suppressed with drugs.

Fig. 9.18: Vitiligo causes pigment-less patches on skin

Transplant rejections

It is occasionally desirable to transplant some tissue or an organ such as the skin, kidney, heart, or liver, from one person to another to replace a non-functional damaged or lost body part. In such

cases, there is a danger that the recipient cells may recognize the donor's organ or tissue as being foreign.
This triggers the recipient's immune mechanisms, which may act to destroy the donor tissue. Such a response is called **transplant rejection.**

Do you know?
The first successful kidney transplant was performed in 1954 between identical twins.

Role of T cells in transplant rejection

Although the mechanism of rejection probably varies with the nature of the tissue and the degree of incompatibility, all the mechanisms require that the host helper T cells come into contact with the graft tissue's major histocompatibility complex (MHC) antigens. This contact is probably mediated by the dendritic cells of the graft tissue itself. At this point, three different possibilities exist. In the first, **antigen-specific TH cells** stimulate the activation and proliferation of appropriate T cells, which then enhance a focused attack on the transplant tissue. In the second, **responsive** antigen-specific TH cells move to the graft site, where they release **lymphokines.** These recruit monocyte/macrophages and T cells to the graft site and maintain them at the scene while they destroy the tissue.

Lymphokines are signaling molecules released by immune cells (like lymphocytes) that help communicate with other immune cells to fight infections. They act like messengers, coordinating the immune response to eliminate pathogens.

Role of B cells in transplant rejection

There is a third mechanism in which antibodies plays a role. The responsive helper T cell interacts with the appropriate B cell clone, producing a shower of antibodies to the implanted tissue's MHC antigens. These can trigger either complement-mediated graft damage or facilitating the phagocytosis of the grafted tissue by macrophages.
The immune system is a highly complex and dynamic network of organs, cells, and molecules that work in concert to defend the body against a wide array of threats. The interplay between innate and adaptive immunity ensures a robust and efficient response to both common and novel pathogens. Understanding the mechanisms of immunity not only helps in appreciating how our body protects us but also underscores the importance of vaccinations and the impact of allergies.

Explain why a transplant recipient is given immune suppressant drugs and determine what implications does this has on his life.

Organ transplantation has become a routine procedure due to improvement of surgical techniques, better tissue typing and the availability of drugs that more selectively inhibit rejection of transplanted tissues and prevent the patient from becoming immunologically *compromised.* Transplant rejection occurs as a delayed hypersensitivity reaction as a function of lymphocytes and not due to antibodies. Administration of immunosuppressive drugs enhances tolerance. People receiving immunosuppressive drugs have side effects like pain, diarrhoea, leukopenia, sepsis, lymphoma, thrombocytopenia, skin rashes, anaphylactic reaction, hypertension, hyperkalemia and neurotoxicity (tremors, seizures, hallucination). Hence, each system is affected, so the person starts to feel weakness and gets fatigue easily.

STEAM ACTIVITY 9.1

Recognizing phagocytes and lymphocytes while observing prepared slides

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Plasma cells are
   A. the same as memory cells
   B. formed from blood plasma
   C. B cells that are actively secreting antibody
   D. inactive T cells carried in the plasma

2. Antibodies combine with antigens
   A. at variable regions
   B. at constant region
   C. only if macrophages are present
   D. both A and C are correct

3. In addition to the immune system, we are protected from disease by
   A. normal body temperature
   B. hormones
   C. antigens
   D. mucous membrane and cilia

4. Fever decrease the
   A. interferon production
   B. concentration of iron in the blood
   C. activity of phagocytes
   D. inflammation

5. T and B cells are
   A. lymphocytes B. macrophages C. natural killer cells D. red blood cells

6. When B-cells are presented with antigen they differentiate into
   A. T-cells B. helper T-cells C. plasma cells D. bursa cells

7. When one receives a booster shot for polio which type of cell is most directly stimulated?
   A. killer T-cells B. memory cells C. phagocytes D. suppressor cells

8. Natural killer cells kill virus infected and cancerous cells by:
   A. phagocytosis B. complement proteins C. perforins and granzymes D. antibodies

9. Colostrum provides
   A. natural active immunity
   B. artificial active immunity
   C. natural passive immunity
   D. artificial passive immunity

10. mAbs can help to combat diseases like:
   A. measles B. cancer C. anorexia D. haemophilia

11. A patient has a severe burn injury, compromising their skin barrier. Which of the following is most likely to occur?
    A. Increased risk of infection due to loss of chemical and physical barriers
    B. Decreased risk of infection due to increased immune response
    C. No change in infection risk
    D. Increased risk of autoimmune disease

12. Dendritic cells are crucial for initiating an adaptive immune response. What would happen if dendritic cells were unable to present antigens?
    A. The adaptive immune response would be enhanced
    B. The innate immune response would be impaired
    C. The adaptive immune response would be impaired
    D. There would be no impact on the immune response

13. Neutrophils use extracellular traps to kill pathogens. What is the primary advantage of this mechanism?
    A. Targeted killing of specific pathogens
    B. Ability to phagocytose large pathogens
    C. Immobilization of pathogens in a localized area
    D. Activation of complement system

14. NK cells play a crucial role in controlling viral infections and cancer. What would happen if NK cell function was impaired?
    A. Increased risk of bacterial infections
    B. Increased risk of viral infections and cancer
    C. Decreased risk of autoimmune disease
    D. No impact on immune function

15. Interferons released by virus-infected cells trigger a response in neighboring cells. What is the primary purpose of this response?
    A. To induce apoptosis in uninfected cells
    B. To destroy RNA in infected cells
    C. To activate the adaptive immune response
    D. To prevent viral replication in neighboring cells

16. Antibodies can bind to an antigen, forming an antigen-antibody complex. What would be the most likely outcome if antibodies were unable to opsonize bacteria?
    A. Increased phagocytosis of bacteria
    B. Decreased phagocytosis of bacteria
    C. Increased activation of complement system
    D. Decreased activation of NK cells

17. Monoclonal antibodies have revolutionized the field of immunotherapy. What is a potential benefit of using monoclonal antibodies in cancer treatment?
    A. Increased killing of virus infected cells
    B. Targeted killing of cancer cells
    C. Enhanced tumor growth
    D. Increased risk of infection

18. Vitiligo is an autoimmune disease characterized by skin depigmentation. What would be a potential consequence of vitiligo, in majority of patients, if left untreated?
    A. Increased risk of skin cancer
    B. Decreased risk of autoimmune disease
    C. Increased risk of infection
    D. Emotional distress due to cosmetic impact
19. Transplant rejection occurs due to the immune system's ability to recognize foreign antigens. What would happen if a patient received a transplant from an identical twin?
    A. Increased risk of graft-versus-host disease
    B. Decreased risk of transplant rejection
    C. Increased risk of autoimmune disease
    D. No impact on immune function
20. Lymphokines, such as interleukins, play a crucial role in coordinating the immune response. What would be the consequence of impaired lymphokine production?
    A. Enhanced activation of cytotoxic T-cells
    B. Reduced activation of immune cells
    C. Increased production of antibodies
    D. Enhanced phagocytic activity of neutrophils

Section II: Short Answer Questions

1. What is immune response?
2. Name the three lines of defence against microbial attack.
3. How oil and sweat glands take part in defence against microorganisms?
4. Name the parts of antibody molecule.
5. How interferons control spread of virus in the body?
6. How do antibodies kill pathogens?
7. Why does each antibody bind only to a specific antigen?
8. Why is passive immunity temporary?
9. Name the disorders of immune system.
10. What are the autoimmune diseases?
11. Write the differences between:
    a. sebaceous gland and sweat gland
    b. macrophages and neutrophils
    c. antibody-mediated immune response and a cell-mediated immune response.
    d. cytotoxic T cells and suppressor T cell
    e. plasma cells and memory cells
    f. antibody and antigen
    g. inborn immunity and acquired immunity
    h. primary and secondary immune response

Section III: Extensive Answer Questions

1. Describe the human skin as an impenetrable barrier against invasion by microbes.
2. What is the role of macrophages and neutrophils in killing bacteria?
3. Explain the protective proteins of complementary system with diagram.
4. Explain in detail inflammatory response with diagram.
5. Explain temperature response against infection.
6. What are the ways fever kills microbes?
7. Describe the role of monocytes in immune system.
8. What is the role of T cells in cell mediated response.
9. Describe the role of B cells in humoral antibody mediated immune response.
10. Describe the types of acquired immunity.
11. Describe the role of T cells and B cells in transplant rejection.
12. Explain why a transplant recipient is given immune suppressant drugs and determine what implications this has on his life.
13. Evaluate the discovery of monoclonal antibodies and justify how this accomplishment revolutionized many aspects of biological research.

Chapter 10

BIOTECHNOLOGY

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-J-01] Introduce genetic engineering.
2. [B-12-J-02] Explain polymerase chain reaction (PCR).
3. [B-12-J-03] Outline the Function of Restriction Enzymes.
4. [B-12-J-04] Describe plasmid as vector prokaryotes and Explain how recombinant plasmids can be formed.
5. [B-12-J-05] Define Genetically modified organism.
6. [B-12-J-06] Explain the formation of human insulin protein in bacteria.
7. [B-12-J-07] Describe how vertical food farms (soil free) work.
8. [B-12-J-08] Compare and contrast the advantages of vertical food farms with general agricultural practices prevalent in Pakistan.

The history of biotechnology is as old as the civilization history of man. Knowledge and use of biotechnology is traced back to earliest human society, when they realized to plant their own crops, breed and domesticate their own animals, for continuous supply of good food. But the term biotechnology was introduced by the end of 20th century. Biotechnology can be defined as **"use of living organisms especially microorganisms or their processes and products for the welfare of mankind"**. Use of biotechnology led human to produce yogurt and cheese from fermented milk, wine or beer from fermented juices of fruit, sugarcane or malted barley. Since early civilizations, people have been preparing the leather by tanning process which involves the use of multiple bacteria.

10.1 INTRODUCTION TO GENETIC ENGINEERING

Needs of rapidly growing human population, led the human to develop new animals with modified characteristics. Biologists imagined the possibility of growing more nutritive and naturally pest-resistant crops. Biotechnology is so vast field but this chapter touches a brief part of biotechnology, called **Genetic engineering**. Basis of genetic engineering lies on the technique called **Recombinant DNA Technology** which involves the combining DNA (genes) from different sources to create new genetic combinations. It deals with manipulation or alteration in genetic material of an organism to modify its characteristics or capabilities for human welfare. Genetic engineering of any organism can be done by adding, removing or editing specific genes within its genome. Thus the goal to give new traits to the organism, improve its existing traits or eliminate undesirable traits is achieved by genetic engineering. Human hope to develop unlimited and useful medicines and vaccines by modifying genome of microorganisms. Bacteria have been used to clean up environmental pollutants, increase the fertility of the soil and kill insect pest. Applications of genetic engineering are greatly helpful to humans in the following major fields:

Agriculture: Genetically modified (GM) crops are being produced that are resistant to pests, diseases or adverse environmental stresses.

Medicine: Research is being carried out to develop gene therapies for the treatment of genetic disorders and to find innovative and effective ways to combat fatal diseases like hepatitis and cancer. Improved biopharmaceuticals like insulin, antibiotics and vaccines are synthesized by genetic engineering.

Industry: Genetic engineering of microorganisms help in the production of biofuels, biodegradation of industrial and sewerage waste and development of environment friendly chemicals.

Genetic engineering is now one of the fastest growing areas of science, hence great genetic engineer **Craig Venter** rightly said that the 21st century is the **"Century of Biology"**. Biotechnology has been included among the six priority areas of Science and Technology by the National Commission of Science and Technology of Pakistan.

10.1.1 Recombinant DNA Technology

Recombinant DNA technology is the foundation of genetic engineering, which involves a series of steps to join DNA segments from different sources. This is an ***in-vivo*** (in living cells) method which is used for the synthesis of product of gene beside copies of desired gene (gene of interest) at industrial scale. It involves the selection and isolation of gene of interest, inserting it in a suitable vector and the transformation into suitable host by the recombinant DNA (rDNA). Components or requirements of recombinant DNA technology include:

i. Gene of interest
ii. Molecular scissors
iii. Molecular carrier or vector
iv. Molecular glue
v. Expression system

Gene of Interest

The gene of interest is the gene which is to be cloned. It can be obtained by one of the three possible ways:

a. Artificial gene synthesis is the process of synthesizing a gene ***in-vitro*** (Latin: "in glassware" means "outside the living cell") without template DNA samples with the help of DNA synthesizer machine.
b. Gene of interest can also be obtained by synthesizing it from its mRNA. Synthesis of gene from mRNA is carried out by **reverse transcriptase enzyme** which is naturally found in retroviruses. The DNA formed by this process is called complementary DNA (cDNA).
c. In most of the cases the gene of interest is directly cleaved from a chromosomal DNA by using particular DNA scissors called restriction endonucleases.

10.2 MOLECULAR SCISSORS (RESTRICTION ENDONUCLEASE)

Restriction endonucleases are enzymes that cleave the phosphodiester bonds of both strands of DNA duplex at specific sequences. They are used to cut the gene of interest during genetic recombination. Restriction endonucleases are host-defense system in bacterial cell against infecting viruses. Name of the enzyme "restriction endonuclease" is given because they are naturally found inside the bacterial cell to "restrict" the growth of the infecting viruses by digesting (chopping-up) DNA/RNA of viruses at specific sequences called restriction sites or recognition sites. Bacteria protect their own DNA by modifying their own restriction sites, generally by adding methyl (CH_3) group to the nucleotides in their recognition sequences. Methyl groups at restriction sites block the endonuclease enzymes and protect the host (Bacterial) DNA from being cleaved by its own restriction endonucleases. Thus bacterial endonucleases can recognize and cleave only viral restriction sequences, which are usually un-methylated.

In 1970, the first restriction enzyme was isolated. Many different restriction endonucleases have been isolated so far. Generally, endonucleases are *named after* the name of the genus, species and strain of the bacteria from which it was initially

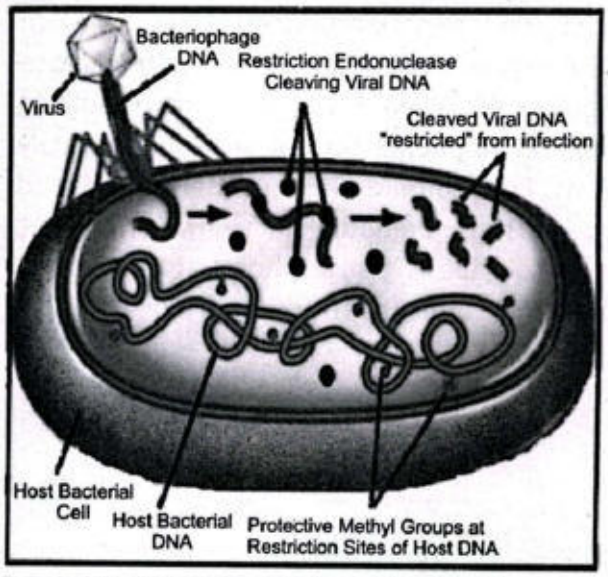


Fig. 10.1: Functioning of Restriction Endonucleases in Bacterial Cell

CRITICAL THINKING

- If restriction endonuclease enzymes are capable of destroying the DNA of bacteriophage, then why they *do not* break down the genomic DNA of host cell i.e. bacteria?
- The restriction enzymes that form sticky ends are more useful in genetic engineering. Why?

isolated. For example, *EcoRI* was isolated from *Escherichia coli*, *Hind-II* and *Hind-III* from *Haemophilus influenzae* and *XhoI* from *Xanthomonas holcicola*.

Restriction sites are recognized by endonuclease enzymes due the presence of specific palindromic sequences. A **palindromic sequence** is a four to eight base pairs in DNA in which nucleotides are arranged symmetrically in reverse order in both complementary DNA strands. Restriction enzymes either make staggered or blunt cut. A staggered cut is one in which the resulting duplex fragments show single stranded projected ends called **sticky ends**.

Sticky ends may be produced at 5' ends of the both DNA strands (by endonuclease *EcoR1*) or sticky ends may be produced at 3' end of both DNA strands (by Restriction endonuclease Kpn1). While in blunt cut the resulting duplex fragments do not show such sticky ends. For example, Blunt ends are produced by restriction endonuclease *HaeIII*, target sites for cleaving sugarphosphate backbone of DNA are indicated by green triangles.

SCIENCE TITBITS

Bacteria methylate their DNA shortly after synthesis during binary fission, by adding methyl (CH_3) groups to the nucleotides in the recognition sequences. This process is called **methylation** and is carried out by the modifying enzyme methyltransferase present in the bacterial cell.

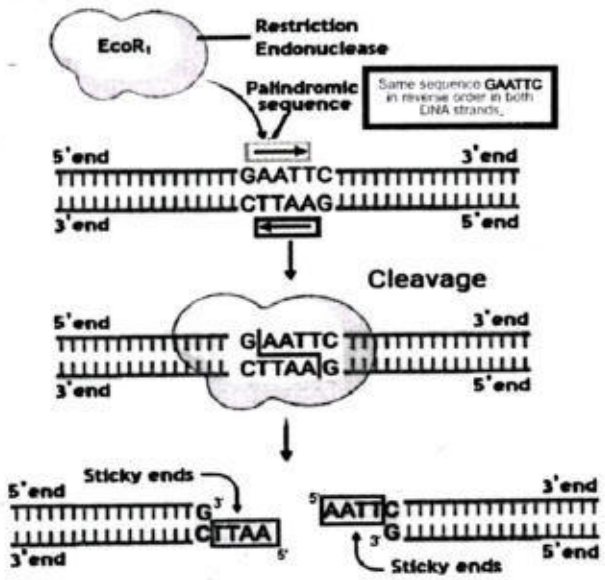


Fig. 10.2: Recognition of palindromic sequence by restriction endonuclease *EcoR1* and production of sticky ends at 5'end in both complementary DNA strands

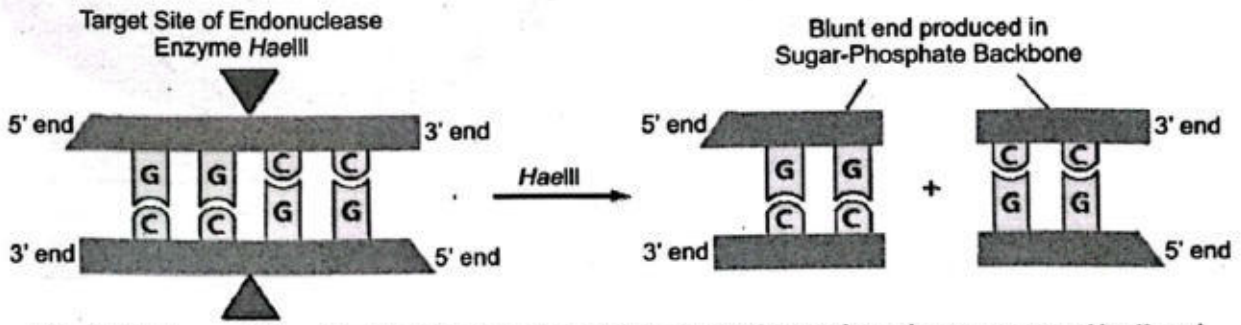


Fig. 10.3: Recognition of palindromic sequence by restriction endonuclease enzyme *HaeII* and production of blunt ends in Sugar-Phosphate backbone of double stranded DNA

10.3 MOLECULAR CARRIERS OR VECTORS

For the synthesis of recombinant DNA (rDNA), a molecular vector is needed to transfer recombinant DNA into a host cell. Vectors act as a vehicle for carrying foreign DNA (gene of interest) into a host cell for multiplication and its expression for the production of specific protein e.g. insulin. One common type of vector is a plasmid. Plasmids are small circular DNA

molecules naturally found in bacterial cells. Example of vectors other than plasmids are: lambda phage DNA, Cosmid (combination of plasmid and phage DNA), Yeast artificial chromosomes (YACs) and bacterial artificial chromosomes (BACs) etc.

Plasmids were discovered by investigators studying the sex life of the intestinal bacterium *Escherichia coli*. Plasmids are primarily found in bacterial cells but can also be found in some eukaryotes e.g. Yeast and some higher plants. They are separate from the chromosomal DNA so called extra chromosomal and can replicate independently. Plasmids carry genes for antibiotic resistance and fertility etc. One of the common plasmids discovered earlier *pSC-101* has antibiotic resistance gene for tetracycline, whereas *pBR-322* has antibiotic resistance genes for both tetracycline and ampicillin.

Plasmids are commonly used as vectors in genetic engineering due to many characteristics essentially needed as vector:

i. **Origin of Replication site:** Plasmids contain an origin of replication (Ori) site which is required for self-regulated replication of the plasmid in the host cell. Plasmids are ideal vector for producing multiple copies of a gene inserted in it.

ii. **Antibiotics resistant genes as selectable Marker:** Markers help in the selecting of cells (bacteria) that have successfully taken up the recombinant plasmids. The markers used for selection are the antibiotic resistance genes. Plasmids usually contain antibiotic resistance genes (e.g. genes for ampicillin or tetracycline resistance). When these genes are present in a bacteria it will be resistant to the specific antibiotic.

iii. **Restriction sites of different enzymes:** A vector should have a restriction site for the commonly used endonucleases. The plasmid which has at least one restriction site is required for the insertion of foreign DNA fragment. Presence of unique restriction sites provide flexibility in the choice of endonucleases for the easy insertion of foreign DNA.

iv. **Promoter regions for gene expression:** Plasmids may contain promoter sequences that enable the transcription of inserted genes in the host cell, thus facilitating the expression of the gene of interest.

v. **Small Size:** Plasmids are much smaller than chromosomal DNA, so they are easily purified as intact molecular vector and easily inserted into host cells.

vi. **High Copy Number:** Some plasmids are found in high copy numbers inside the host cell, resulting in large amounts of the cloned DNA.

10.3.1 *pBR322* as an example of Plasmids

It is the first and most common, purpose built plasmid vector, artificially developed in the laboratory by Bolivar and Rodriguez in 1977. ***pBR322*** is modified from natural bacterial plasmid. This vector has the origin of replication (ori), restriction site and also antibiotic-resistant genes. Here are the key features of the *pBR322* plasmid:

i. **Origin of replication:** It carries a fragment of the plasmid *pMB1* that acts as an origin for DNA replication to ensure the multiplication of the vector.

ii. **Size:** It is relatively small plasmid having 4,361 bps. Small size is important, as transformation efficiency is inversely proportional to size of plasmid. Transformation efficiency become very low if plasmid size is above 10 kbp, thus DNA segment up to 6 kbp can possibly be inserted in *pBR322* plasmid to form it recombinant.

iii. **Copy number:** It has relatively high copy number (~15 copies per cell)

iv. **Cloning sites:** It carries a number of unique restriction sites. Some of these are located in one of the antibiotic resistance genes (e.g., sites for *PstI*, *PvuI*, and *Sac I* are found in Ampicillin and *BamHI* and *HindIII* in Tetracycline).

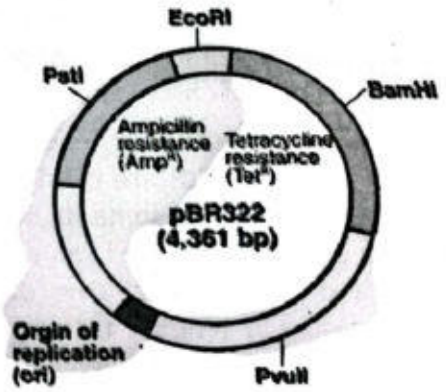


Fig. 10.4: *E. coli* cloning vector (*pBR 322* plasmid) having origin of replication (ori), restriction site and antibiotic-resistant genes

SCIENCE TITBITS

Types of Plasmids as Vectors

1. **Cloning Vectors:** These are used for the cloning of DNA fragments. They contain essential elements like Ori, selectable markers, and cloning sites.
2. **Expression Vectors:** These are designed for the expression of a gene in a host organism. They include promoters, ribosome binding sites, and termination sequences.
3. **Shuttle Vectors:** Plasmids that can replicate in multiple host species, such as in both prokaryotic and eukaryotic cells, are known as shuttle vectors. These are useful for gene transfer between different biological systems.

SCIENCE TITBITS

Applications of Plasmids

Gene Cloning: Plasmids are extensively used for cloning of genes of interest for further study and manipulation.

Protein Production: Expression vectors are used for the production of proteins by expressing inserted genes.

Gene Therapy: Plasmids are used to deliver therapeutic genes into cells of organisms with a genetic disease.

Vaccine Development: Most of the DNA vaccines are Plasmid based and are effectively used to prevent diseases.

10.3.2 Mechanism of formation of recombinant Plasmid in recombinant DNA technology

Cloning of the desired gene through recombinant DNA technology involves the formation of recombinant DNA (gene of interest + vector DNA), transformation into suitable expression system by the recombinant DNA and the identification of transformed clones.

Formation of recombinant Plasmid

The first step in the construction of a recombinant DNA, is the isolation and purification of gene of interest and relevant vectors. The gene of interest is cleaved directly from genome by specific restriction endonucleases with specific sticky ends or it may be synthesized from mRNA by reverse transcription using reverse transcriptase. Then specific vector DNA (plasmid) having same restriction site is also cleaved with same restriction enzyme by which gene of interest is cleaved so that compatible sticky ends can be produced. Next both, vector and gene of interest are incubated together in the presence of DNA ligase which connects them by forming phosphodiester linkage. When gene of interest is ligated to plasmid at the complementary sticky ends the

resultant plasmid is now called recombinant plasmid (vector).

Molecular glue (DNA Ligase) is responsible for the formation of the phosphodiester linkage between two adjacent nucleotides and thus joins two double-stranded DNA fragments; therefore it is called molecular glue. In rDNA experiments, **DNA ligase** is used to join two different DNA fragments (plasmid/vector and the foreign DNA) that are annealed by the sticky ends.

Products of recombinant DNA technology can be produced by using suitable expression system. Plasmids are usually made recombinant for the production of specific protein as a result of expression of gene of interest in natural expression system.

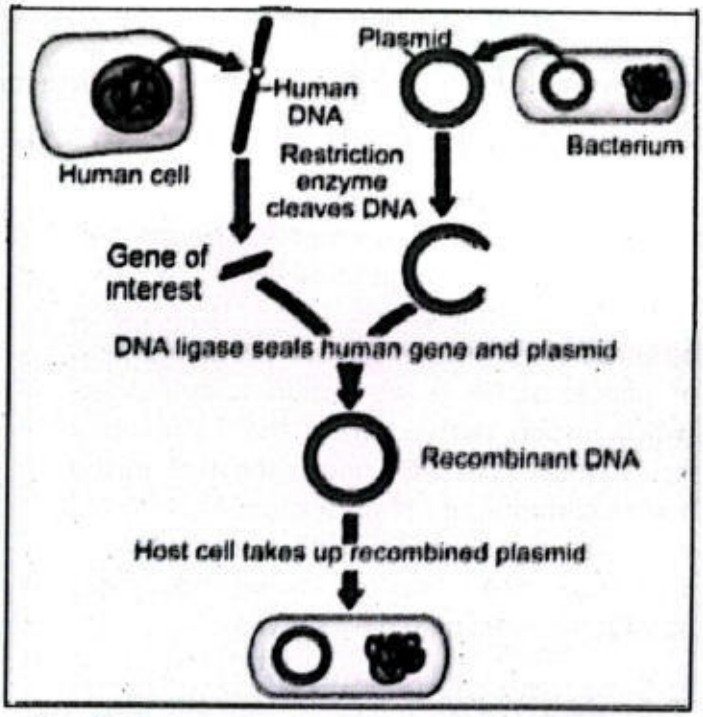


Fig. 10.5: Steps for the formation of recombinant plasmid

Expression system

Expression system may be a suitable cell or organism that can act as host for the recombinant vector for its cloning (multiplication) or expression. Therefore, the selection of suitable expression system always depends upon the type of vector which is being used while making recombinant DNA. The most important character of an ideal expression system is its short generation time and simplicity of its cellular and genetic system. So bacterial cells can act as an ideal expression system.

Transformation of expression system

Here transformation refers to the insertion of recombinant DNA into the expression system which can be performed by putting the expression system (bacterial cells that already contain no plasmids) and recombinant plasmids into the same medium. Bacterial cells take up recombinant plasmid, especially, if they are treated with calcium chloride which make them more permeable. Thereafter, as the cell reproduces, a bacterial clone forms and each new cell contains at least one plasmid. Therefore, each of the bacterial cell contains the gene of interest, which will express itself and make its product.

Identification of transformed clone

The transformed clone can be identified by adding a particular antibiotic (for which resistant gene is found in plasmid) into the medium. As the transformed clone has got resistance against the antibiotic, so it remains alive and continues to grow, whereas all the untransformed clones are killed by the antibiotic. From this transformed bacterial clone, the cloned gene can be isolated for further analysis or its protein product can be separated and used for various purposes.

10.4 FORMATION OF HUMAN INSULIN PROTEIN IN BACTERIA

Human Insulin is produced by recombinant DNA technology, which involves the following steps:

1. Identification and Isolation of the Insulin Gene

The insulin gene, which produces human insulin, is isolated from a human DNA sample. Insulin consists of two peptide chains (α and β) linked by disulfide bonds. Insulin is produced by endocrine β-cells in the islets of Langerhans of pancreas. Gene for insulin is called INS (word insulin derived from the Latin word insula, means "island") and is located on the human chromosome 11 at position 11p15.5 (on short arm (p), region 11, band 15 and sub band 5). The gene is 1.5 Kbp long having about 1,425 bp with three exons and two introns.

SCIENCE TITBITS

Insulin was discovered by Edward S. Schafer in 1916. It is the major regulator of blood sugar in the body. Fredrick Sanger and his team in 1954 first time described the complete structure of insulin. Initially, β-cells synthesize pre-pro-insulin polypeptide, having 109 amino acids. Out of 109 amino acids, 23 amino acids act as signal molecules needed for entry of the pre-pro-insulin through cell membrane. When inside the cell, it become inactive pro-insulin with 86 amino acids, that finally converted to active insulin with 51 amino acids by some proteolytic enzymes. Active insulin consists of two polypeptide chains, chain α has 21 amino acids and chain β has 30 amino acids, both linked together by disulphide bonds.

2. Selection of suitable plasmid for insertion of insulin gene

The production of human insulin by recombinant DNA technology involves plasmids that are specifically engineered to efficiently transfer insulin gene in host cells e.g. *Escherichia coli*. Two commonly used plasmids in the production of insulin are:

1. ***pBR322*** is one of the most widely used plasmids in genetic engineering. It contains antibiotic resistant genes for ampicillin and tetracycline.
2. ***pUC18/pUC19:*** These plasmids are derivatives of *pBR322* that have been modified for efficient transformation. They include a gene for ampicillin resistance.

Both above mentioned plasmids have smaller size, origin of replication, higher copy number and multiple unique restriction sites, which simplifies the insertion of the insulin gene. Human genes for chain α and β of insulin may be inserted into these plasmid, for expression in bacterial cells to synthesize insulin chains.

3. Creation of Recombinant DNA

Bacteria e.g. *E. coli* are not so advanced cells so cannot directly produce eukaryotic proteins like insulin, so two separate synthetic genes are created for the α and β chains of insulin. These genes for both chains (α and β) of insulin and separately inserted into two separate bacterial plasmid vectors i.e. *pBR322* plasmid. These genes are inserted into the plasmid by the side of β-galactosidase gene. The plasmids are engineered with a promoter sequence that helps to initiate the auto- production of insulin chains when inside the bacterial cells.

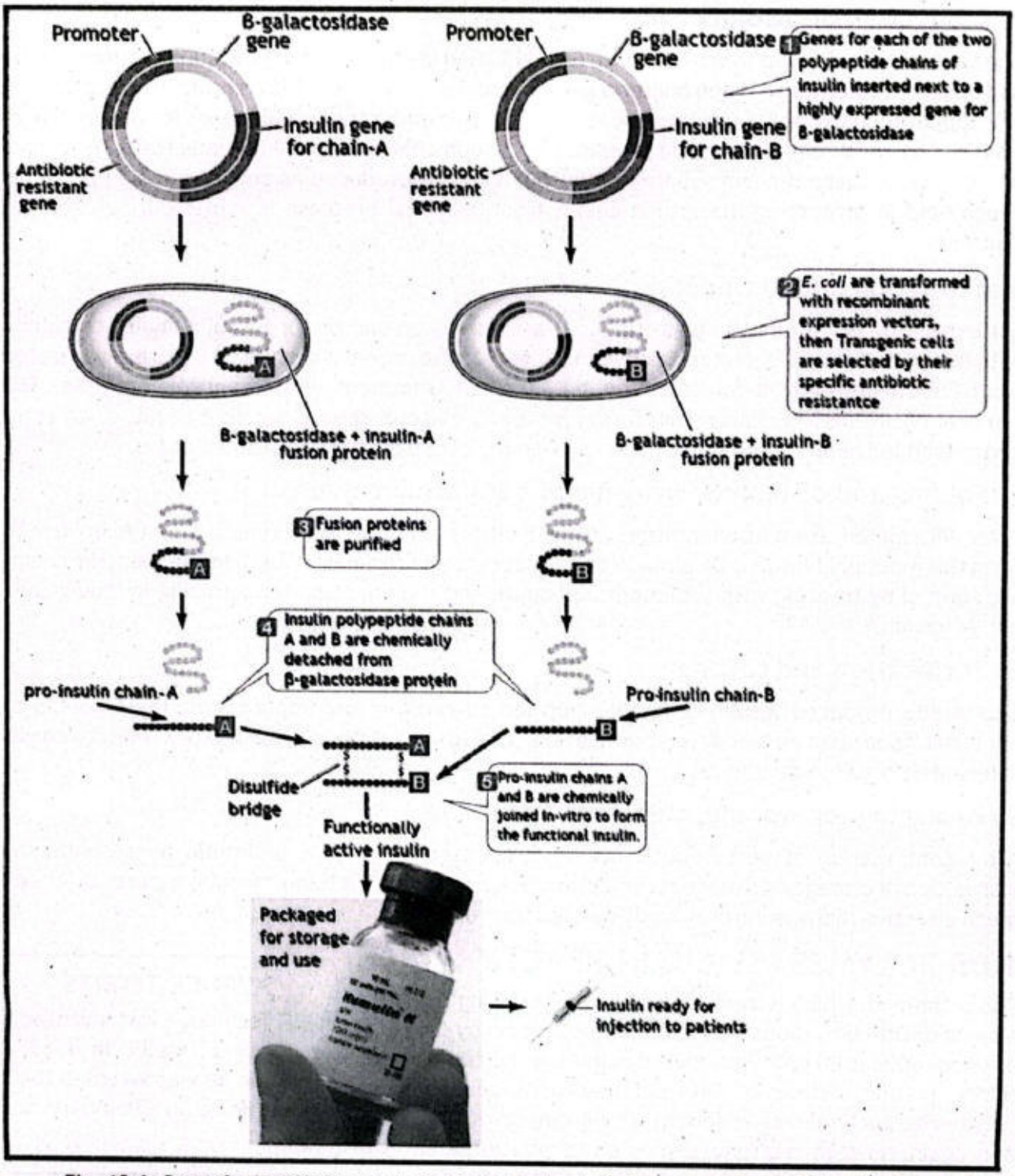


Fig. 10.6: Steps for synthesis of human insulin in bacteria by recombinant DNA technology

4. Insertion of recombinant plasmids into host Cells

The recombinant plasmids are then separately inserted into *E. coli* (or another bacterial strain) through a process called transformation. The bacteria take up the recombinant plasmids and become recombinant bacteria.

5. Production of insulin chains

The bacteria are allowed to grow in large fermentation tanks containing suitable culture medium and optimum conditions. When bacteria grow, recombinant plasmid DNA is replicated resulting in multiplication (cloning) of insulin gene. Bacteria also express the insulin genes for production of insulin. The recombinant bacteria produce pro-insulin chains i.e. fused β-galactosidase-A chain and β-galactosidase-B-chain separately. Both chains are produced as part of a fusion proteins, which help in protecting the insulin chains from bacterial protease enzymes during bacterial synthesis.

6. Extraction and Purification

For extraction of insulin, the bacterial cells are harvested and the pro-insulin chains combined with fusion proteins (β-galactosidase) are isolated. These pro-insulin chains A and B are separated from Fusion proteins, β-galactosidase by chemical treatment with cyanogen bromide. The removal of pro-insulin chains from fusion protein β-galactosidase is possible because, an extra codon is added before methionine codon at N-terminal of each gene for A and B-chain.

7. Folding and disulphide bridging of both insulin chains

After detachment from fusion proteins, A and B chains of insulin are chemically joined in-vitro to form the functional insulin. Disulphide bridges at cysteine residues of both insulin peptide chains are formed by treating with sodium disulphonate and sodium sulphite, resulting in biologically active insulin.

8. Purification and testing

The finally produced insulin is further purified to remove any impurities or by-products of bacterial gene expression. After purification, the insulin is tested for quality, effectiveness, safety and possible side effects.

9. Packaging for storage, shipment and usage

After confirmation of best quality, insulin is packaged into vials or insulin pens containing instruction of storage and usage for injection. Thus recombinant human insulin is pure, safer and much effective than insulin previously derived from animals.

10.5 POLYMERASE CHAIN REACTION (PCR)

SCIENCE TITBITS

PCR Technique was invented by Kary B. Mullis in 1983; later on he was awarded the Nobel Prize in Chemistry in 1993.

The technique, which is used to amplify (clone) a single gene or a piece of DNA into thousands to millions of copies by means of *in-vitro* replication process is called polymerase chain reaction (PCR). In this technique, DNA polymerase is compelled to polymerize (polymerase reaction) a given piece of DNA again and again, so that multiple copies are produced, thus, the technique is known as **polymerase chain reaction (PCR).**

A special DNA polymerase, the ***Taq polymerase*** is used in PCR technique, which is specialized temperature-tolerant enzyme isolated from *Thermus aquaticus*, a bacterium found in hot springs. This enzyme is stable and active at near-boiling temperatures. In order to perform PCR, template DNA (DNA to be amplified), free nucleotides (deoxyribo-nucleoside triphosphates or dNTPs), primers and *Taq polymerase* are diluted in a suitable buffer to make PCR

reaction mixture. The PCR mixture is placed in an instrument called thermocycler or PCR machine. Thermocycler regulates the temperature during various steps of PCR reaction according to the need.

Fig. 10.7: PCR machine (Thermocycler)

Mechanism of PCR Reaction

PCR cycle consists of three steps: **denaturation, primer annealing** and **extension** or **polymerization**. Each step requires a specific temperature. The time duration, temperature and sequence of the steps have to be programmed in the thermocycler.

Denaturation

Initial Denaturation

This step is performed only once before the start of cyclic steps of PCR process.

Purpose: To completely denature the DNA template and ensure all strands are separated before cycling begins. Temperature and time (typically) set at 94-95°C for 4-5 minutes.

Reason: Some DNA templates, especially GC-rich regions or complex secondary structures, require a longer initial denaturation to break hydrogen bonds fully, allowing proper primer binding.

Cyclic Denaturation

Cyclic denaturation step is performed in each cycle of the PCR process. The template DNA is heated to 94°C for one minute. At this high temperature the DNA undergoes complete denaturation and the double-stranded DNA (dsDNA) becomes single-stranded DNA (ssDNA). Each single ssDNA can act as the template for the in vitro DNA synthesis.

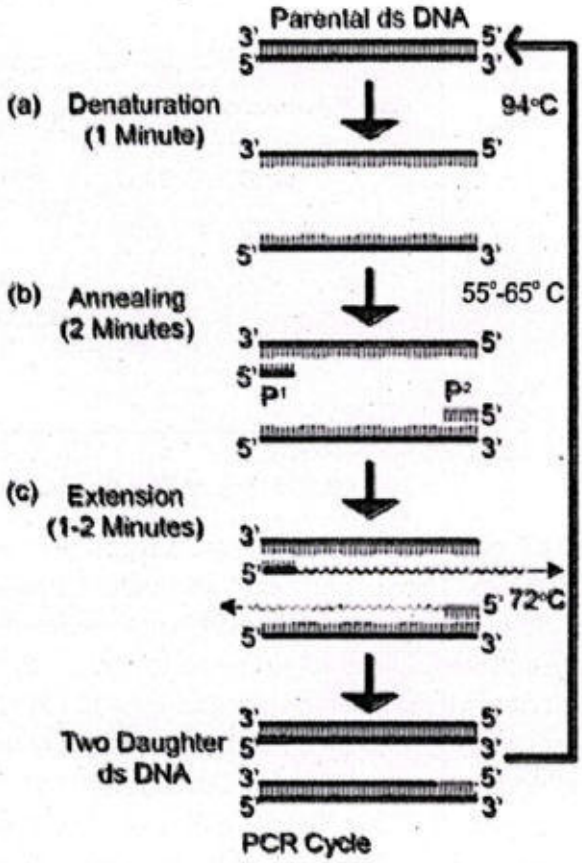


Fig. 10.8: Mechanism of PCR reaction P1 is forward primer and P2 is reverse primer

Primer annealing

The next step is the primer annealing. In this step the two primers, the forward primers and the revese primers, anneal or hybridize to the single-stranded template DNA at its complementary regions. Annealing is usually carried out at a lower temperature depending on the length and sequence of the primers. In standard cases temperature is between 55°-65°C depending upon size of the primer and the length of the gene. Approximate time required for this step is 2 minutes.

Extension or Polymerization

Cyclic Extension

Cyclic Extension is performed in each cycle of the PCR process. This is final step in each cycle of primer extension or polymerization in which the Taq polymerase synthesizes new DNA strands to the 3' ends of primers using dNTPs. The optimum temperature for carrying out the primer extension reaction or polymerization of dNTPs is standardized at 72°C. This step takes just one minute to be completed in each cycle.

Final Extension

On the completion of cyclic steps of PCR process final extension is performed only once.

Purpose: For complete synthesis of all PCR products by Taq DNA polymerase. Temperature and time is usually 72°C for 5-7 minutes.

Reason: The final extension ensures that any incomplete remaining DNA strands during cyclic extension, are fully extended resulting in complete double-stranded products.

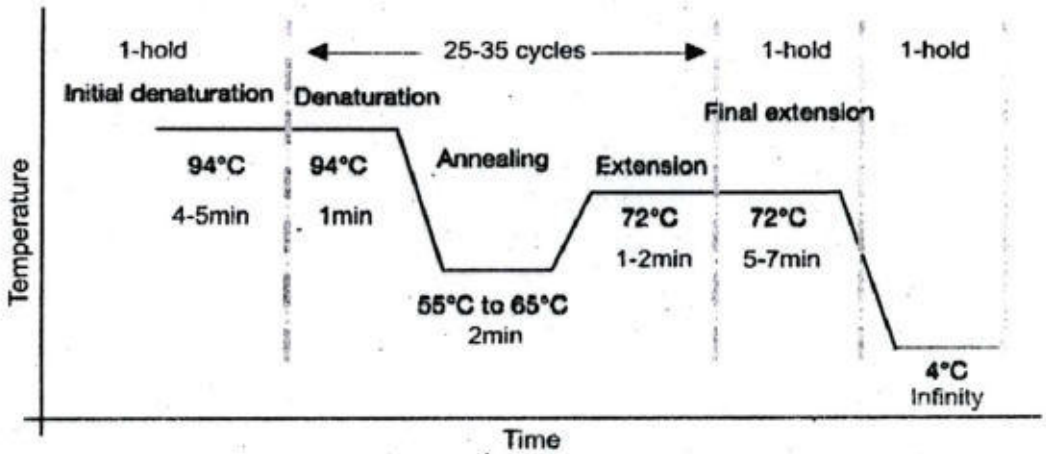


Fig. 10.9: Steps of PCR mechanism as set in thermocycler (PCR machine)

At the end of first cycle, one target dsDNA molecule is converted into two daughter dsDNA molecules. The second cycle immediately starts with the denaturation by heating at 94°C, so that all the newly synthesized dsDNA molecules are also denatured to single strands, which again act as templates. It will again be followed by the primer annealing and extension and thus the cycle of denaturation, primer annealing, and extension continues resulting in the amplification of the selected DNA sequence at an exponential rate i.e., the number of existing DNA molecules become doubled after each cycle. Both non cyclic steps i.e. initial denaturation and final extension contribute to the efficiency and accuracy of PCR, leading to better yields and more reliable results.

Storage: At the end of the extension, temperature is set at 4°C for longer time to safely store the PCR products (i.e. replicated DNA copies) until it is not shifted to refrigerator.

SCIENCE TITBITS

- Why heat is used in PCR technique to denature the target DNA instead of using DNA helicase and DNA gyrase enzymes?
- Why human DNA polymerase cannot be used in PCR technique? Why already synthesized primers are used in PCR technique instead of using primase enzyme?

Science, Technology and Society Connections

The application of polymerase chain reaction.

PCR has application in almost all areas of molecular biology, genetics, and in clinical areas.

1. PCR is an efficient diagnostic technique used for the detection of specific genotypes of infectious agents.
2. Reactions for DNA sequencing are also simplified by introducing the PCR method.
3. DNA fingerprinting is also made simple by PCR.
4. The genetic mutations responsible for certain genetic diseases and cancers can be detected using PCR tools. Early detection of genetic disease is even possible in embryonic conditions or even in sex cells—sperm and egg.

10.6 GENETICALLY MODIFIED ORGANISMS (GMOs)

"Genetically Modified Organisms (GMOs)" are the organisms (e.g. Bacteria) whose genetic material (DNA) has been altered in a way that does not occur naturally through fertilization or natural recombination. Techniques of genetic engineering are used to insert foreign genes, remove existing genes or modify specific genes in naturally free living organisms to convert them into genetically modified organisms with desirable traits. GMOs have improved nutritional content, enhanced growth rates and are resistant to pests, diseases and environmental conditions. Genetically modified organisms are being widely used in agriculture, animal husbandry, medicine and research. Many transgenic organisms such as animals, plants, and bacteria have been produced.

SCIENCE TITBITS

Both strains of *Pseudomonas syringae* occur naturally, but recombinant DNA technology has allowed for the synthetic removal or alteration of specific genes, enabling the creation of the ice- minus strain. Modifying *P. syringae* may have unexpected consequences for climate. A study has shown that its ice nucleating proteins may play an important part in causing ice crystals to form in clouds. If humans increase the frequency of bacteria lacking these proteins then it could potentially affect rainfall.

10.6.1 Transgenic Bacteria

Unlike other organisms bacteria can be easily transformed due to their simple genetics. The first example of this occurred in 1978 when a version of the human insulin gene was inserted into the bacterium *Escherichia coli* to produce synthetic "human" insulin. The transgenic bacteria are not only being used to produce different human proteins, they are also being used in improvement of plant growth, removal of environmental pollutants and extraction of metals from low grade ores.

10.6.2 Transgenic Plants

The first field trials of genetically engineered plants occurred in France and USA in 1986, when tobacco plants were engineered to be resistant to herbicides. In most cases the aim of developing transgenic plant is to introduce a new trait to the plant which does not occur naturally in this species. Examples include resistance to certain pests, diseases or environmental conditions or the production of a certain nutrient or pharmaceutical agent.

10.6.3 Transgenic Animals

A transgenic animal is one that carries a foreign gene that has been deliberately inserted into its genome. Genetic engineering has also been used to improve the traits of farm animals. In addition these animals are also used to produce drugs. Such transgenic animals which also produce human proteins or drugs are called **transpharmer animals.**

SCIENCE TITBITS

The first genes available for genetic engineering of crop plants for pest resistance were known as Bt genes from a bacterium ***Bacillus thuringiensis***. These are specific to particular group of insect pests and are not harmful to other useful insects like butter flies and silk worms. Transgenic crops with *Bt* genes (e.g. cotton, rice, maize, potato, tomato, brinjal, cauliflower, cabbage, etc.) have been developed. This has proved to be an effective way of controlling the insect pests and has reduced the pesticide use.

SCIENCE TITBITS

Concerns about the Genetically Modified Organisms (GMOS)

The main areas of consideration for safety aspects in biotechnology are the following:

a. How to dispose-off spent microbial biomass and purify the effluents from biotechnological processes?
b. The toxicity of the allergy associated with microbial production.
c. How to deal with the increase in the number of antibiotic resistant pathogenic microorganisms?
d. How to evaluate the pathogenicity of the genetically engineered microorganisms to infect humans, plants and animals?
e. How to prevent contamination, infection or mutation of the processed strains?

Science, Technology and Society Connections

Global Transgenic Crops

Since 1996, the cultivation of transgenic crops has expanded rapidly. In 2005, transgenic crops were planted globally on 90 million hectares, which increased to 190.4 million hectares by 2019. Major GM crops include herbicide tolerance and insect resistance soybean, maize, cotton, and canola. Leading producers are the United States, Brazil, Argentina and Canada.

Transgenic Crops in Pakistan

Pakistan commercially adopted Bt cotton in 2010, which is now grown over 2.3 million hectares (95% of the cotton area). New triple gene cotton varieties, resistant to pests and herbicides, have been introduced in 2023. GM maize production increased sharply, from 1 million metric tons in 2013 to 10.5 million metric tons in 2023. Recently, GM varieties of sugarcane has also been approved for cultivation. (Discourse: 2024, PIDE, Islamabad)

SCIENCE TITBITS

Most of the countries of the world are signatories to the Biological Weapons Conventions of 1972. As a signatory, it is a voluntary pledge by a nation "never to produce microbial or other biological agents or toxins, whatever may be their method of production, for use in wars. However, many people have expressed their concerns about the possible use of genetic manipulations for military purposes in the near future.

Science, Technology and Society Connections

· Justify the need of genetic counselling.

Genetic counselling is a service that provides information and advice about genetic conditions. Counselling is conducted by healthcare professionals who have been specially trained in the science of human genetics (a genetic counsellor or a clinical geneticist). The counsellor will discuss the risks, benefits and limitations of genetic testing with you. They will also explain how the information found as a result of genetic testing could have implications for both you and your family.

·Investigate careers that require an understanding of biotechnology and genetic engineering.

Many careers require an understanding of biotechnology and genetic engineering. Such as: Healthcare professionals, Teachers of biological sciences, biomedical engineers, crime lab analyst, crime scene investigator, environmental impact analyst, forensic scientist, genetic engineer, molecular biologist etc.

· Describe briefly the accomplishments of the renowned genetic engineers working in private and public sector institutions in her or his province.

It is advised to the administration that they should arrange study tour of student to public and privet sector institutions of genetic engineering so that students can meet with renowned genetic engineers and can directly ask about their accomplishments.

· Suggest measure she/he would take to solve related problems by using knowledge gained in this chapter.

Students should evaluate themselves to know what they have learnt in this chapter and should apply this knowledge to solve related problems under the guidance of their class teacher.

· Describe the role of genetic screening.

Genetic screening includes all those diagnostics tests which are used to determine whether a person or a new born baby is at risk of genetic diseases or not. Generally there are two types of genetic screening, screening of children and adults, and screening of unborn children. Genetic screening of children and adults has two purposes: first it can confirm whether the person has a mutated gene of certain disease or characteristics. The second purpose is to test adults to see if their children will be at risk of certain disease. Knowing that one or both parents carries a dominant allele for a genetic disease might affect the decision of parents about having birth of affected children. Now a days, genetic screening is used for approval of marriage licenses in some countries, like Denmark.

10.7 WORKING OF VERTICAL (SOIL-FREE) FOOD FARMS

Vertical farming is the soil free agriculture farming by growing plants in vertically stacked layers or towers, allowing food production in urban areas or places with limited land. Vertical farming is a common practice in densely populated areas and can be perfectly done in small spaces including greenhouses, warehouses or empty spaces in offices and houses.

Vertical farming or soil free farming is typically growing plants without the use of soil. As soil is heavy that may weigh down the vertical stacking system for growing plants so, farmers use air and water to create a suitable artificial environment needed for plant growth. On the basis of technique and plant growing medium soil free farms are called hydroponics, aeroponics or aquaponics.

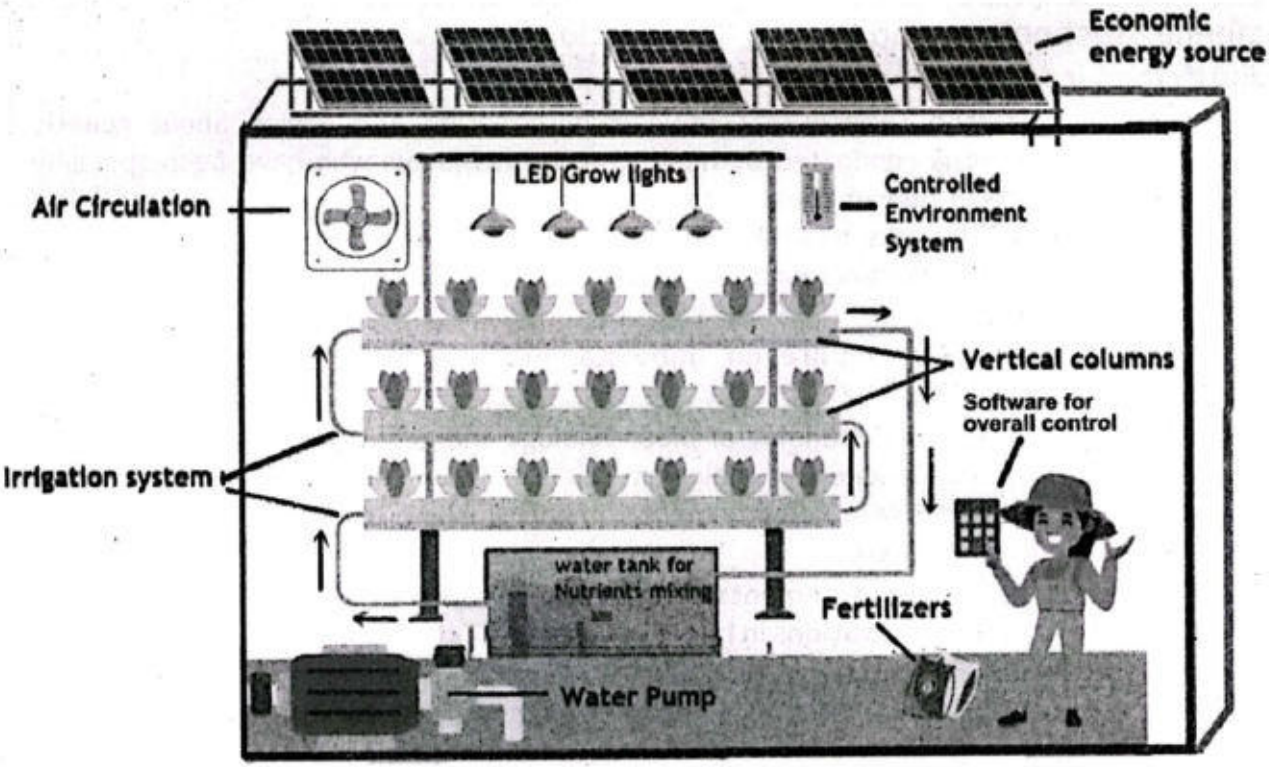


Fig. 10.10: Working of vertical (Soil-free) food farms

1. Hydroponics

Plants are grown with their roots submerged in nutrient rich water solution instead of soil. Water is efficiently used and set to flow through channels providing nutrients directly to the plants and then recycled to conserve the resources up to 90% less than traditional farming.

Fig. 10.11: Harvesting of fruits from vertical (Soil-free) food farms

2. Aeroponics

In aeroponics, plant roots are suspended in the air, instead of being submerged in water. Nutrient rich water is sprayed directly onto the roots after specific intervals for efficient absorption of moisture and nutrients by roots. Aeroponics are economical to hydroponics for even less water usage, better oxygenation for the roots and higher crop yields.

3. Aquaponics

Sometimes fish farming in combination with hydroponics: is carried out and called aquaponics. Water from fish tanks is circulated

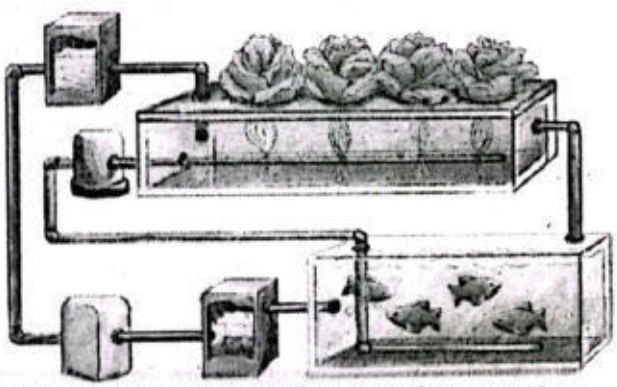


Fig. 10.12: Schematic diagram of Aquaponics: Vertical (Soil-free) food farming with fish farming

Fig. 10.13: well established large scale vertical (Soil-free) food farm

through plant beds where plants absorb the nutrients. Fish excreta provides natural nutrients to the plants and in return plants filter the water for the fish. This creates a self-sustaining ecosystem and reduces the need for synthetic fertilizers.

Vertical farming uses controlled environment agriculture (CEA) technology to maintain an optimal growing environment around the year. CEA includes vertically placed LED grow lights with inbuilt timers to ensure light spectrum necessary for photosynthesis in plants, temperature regulators to ensure the optimal farm climate and various sensors for the continual monitoring of growth. Thus soil free farming provide faster growth and year round production with limited resources. Vertical farming is also sustainable, compared to traditional farming because it uses less water and land, releases less CO_2 and produces higher crop yields per square foot.

Now a days, vertical farms are equipped with automated systems of sensors and AI support, to monitor plant growth, adjust climatic conditions, water and nutrient supply and optimized production.

10.8: COMPARISON OF VERTICAL FOOD FARMS WITH GENERAL AGRICULTURAL PRACTICES IN PAKISTAN

Agriculture is the major contributor to Pakistan's economy. Agriculture provide employment to a large population especially in rural areas and act as of major labour force in Pakistan. It provides raw materials for tèxtile, sugar, food and dairy industry of Pakistan. Main aspects of agriculture in Pakistan are:

i. Pakistan has 47% agricultural land, which is higher than the global average of 38%. About 82% of

cultivated land is irrigated through well planned canal system and 18% is arid land.

ii. The major crops in Pakistan are wheat, rice, sugarcane and potatoes as staple crops and cotton and maize as main cash crops. Pakistan has two main crop seasons i.e. Kharif and Rabi.

iii. Livestock is complementary to agriculture and is a major contributor to economy. Pakistan is the 5th largest in dairy products and 4th largest exporter of leather item in world.

iv. Organic farming is also common by using recycled remainder of crop and animal manure, using no or minimum pesticides and relying on crop rotation, thus minimizing the environmental impact.

Vertical food farms and traditional agricultural practices as prevalent in Pakistan have some advantages and challenges.

Table 10.1 Comparison between vertical food farming and general agricultural practices

Vertical food farming	General agricultural practices
1. Space Utilization	
Advantage: Utilize less horizontal space by stacking plants in vertical layers. This is ideal for urban environments where land is limited or expensive. In big cities, vertical farming is ideal due to insufficient land.	Disadvantage: Requires large horizontal fields for crop cultivation, making it less feasible in urban or densely populated areas. Crops like wheat, rice and sugarcane need vast fields, as grown in rural areas of Punjab and Sindh.
2. Water Usage	
Advantage: Use 90-95% less water compared to traditional farming. Hydroponic systems recycle water and aeroponics uses water spray, minimizing water wastage. This is crucially relevant in regions facing severe water shortages, like Thar and Baluchistan.	Disadvantage: Traditional farming methods consume large amounts of water, especially rice and sugarcane which consume huge water. Pakistan frequently faces drought and wastage of water due to floods in traditional irrigation systems.
3. Yield and Productivity	
Advantage: Crops grow faster due to optimized nutrient delivery systems. It is possible to achieve higher yields per square foot by using controlled environments (temperature, light, humidity and fertilizers) for stacked plants. Leafy greens vegetables, herbs and small fruits like strawberry are grown throughout the year with higher production.	Disadvantage: Mainly depends on seasonal cycles, weather conditions and unpredictable factors like floods and droughts. Annual productivity per unit of land, remains inconsistent and lower as a crop failures due to possible adverse climatic conditions. Wheat production is limited to winter seasons and monsoons may damage cotton and rice crops.
4. Labour and Automation	
Advantage: May be easily managed by automatic and AI systems to monitor and control plant health, watering times and light durations. Thus need for manual labour is	Disadvantage: Mainly depends upon manual labour and mostly uses outdated tools and techniques. Less use of modern and efficient machinery lead to low productivity.

minimal. Perhaps, high cost for automation may be a barrier for making it common especially in rural areas of Pakistan.	
5. Crop Varieties	
Disadvantage: It is suited for only short-cycle crops like leafy green vegetables, herbs and small fruit plants like strawberries. Hence, large scale growing staple crops (wheat, rice, maize) in Pakistan may not be easily grown in vertical systems due to land usage challenges.	Advantage: It can produce a wide range of crops, including grains (wheat, rice, maize), fruits (mangoes, apples, oranges) and vegetables like potatoes. Traditional agriculture methods provide food security.
6. Pesticide and Chemical Usage	
Advantage: There are rare chances of insects and pest in controlled environments so it has minimal need for pesticides and herbicides, resulting in pesticide and toxin free food products. Thus, it may improve food quality and safety by avoiding pesticide contamination in agricultural zones.	Disadvantage: Frequent and extensive use of pesticides and fertilizers is needed pests in traditional agriculture farming to avoid loss of food by insects and other. Improper handling of toxins may harm to human health and lead to environmental degradation.
7. Environmental Impact	
Advantage: As they are usually located in cities, so negative impacts on environment is rare. It is sustainable because of less usage of water and land sources, minimal need of transportation, negligible fossil fuel emissions and no soil erosion since. However, demand of energy usage for LED grow lights and climate control may be managed by using renewable energy like solar electricity.	Disadvantage: This agriculture practice is greatly at risk to be affected by environmental hazards like soil degradation, salinity, floods and drought. Another issue is deforestation which is due to desire for expanding agricultural land. Extreme climate changes have often deteriorated the traditional agriculture and resulted in loss of agriculture land.
8. Accessibility and Investment	
Disadvantage: Vertical farming require higher initial investment to establish infrastructure for lighting, climate control and automation. Thus it is less accessible to small farmers in Pakistan. However, it may be ideal for agriculture farming business in urban areas.	Advantage: Lower initial investment in many cases, particularly for small-scale farmers who rely on simple tools and natural resources. Disadvantage: Yields are generally lower, and dependence on natural weather cycles makes it unpredictable.

STEAM ACTIVITY 10.1

Make a model of DNA probe and restriction enzymes.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Which tool of recombinant DNA technology is incorrectly paired with its use?
   A. Restriction enzyme – RFLP production
   B. DNA ligase – cuts DNA
   C. Reverse transcriptase – makes cDNA
   D. Electrophoresis – separates DNA

2. Which of the following is a key difference between vertical farming and traditional agriculture?
   A. Vertical farming uses more horizontal space, suitable for rural areas.
   B. Vertical farming is not ideal for crops like wheat, rice, and sugarcane.
   C. Vertical farming is ideal for urban areas; traditional farming needs large fields.
   D. Traditional farming grows crops in vertical layers; vertical farming requires vast fields.

3. A paleontologist finds tissue from a 400-year-old extinct bird and wants to compare its DNA with living birds. Which method would best increase the bird DNA for testing?
   A. a RFLP analysis
   B. polymerase chain reaction (PCR)
   C. electroporation
   D. Southern hybridization

4. Which of the following sequences in double-stranded DNA is mostly likely to be recognized as a cutting site for a restriction enzyme?

A.	B.	C.	D.
AAGG	AGTC	GGCC	ACCA
TTCC	TCAG	CCGG	TGGT

5. A plasmid
   A. is used as DNA vector
   B. is a type of bacteriophage
   C. is a type of cDNA
   D. is a retrovirus

6. DNA molecules with complementary sticky ends associate by
   A. covalent bond
   B. hydrogen bond
   C. ionic bond
   D. disulphide bond

7. Which technique rapidly replicates specific DNA fragments without cloning?
   A. gel electrophoresis
   B. cDNA libraries
   C. genetic probe
   D. polymerase chain reaction

8. The PCR technique uses
   A. heat resistant DNA polymerase
   B. reverse transcriptase
   C. DNA ligase
   D. restriction enzymes

9. If eukaryotic DNA contains five cleavage sites for a particular restriction enzyme, how many fragments will be produced upon complete digestion of the DNA with that enzyme:
   A. 2 B. 4 C. 6 D. None

10. The dideoxynucleotides (ddATP, ddTTP, ddGTP and ddCTP) are important in DNA sequencing because they:
    A. cause premature termination of growing DNA strand
    B. are used as prime
    C. cause the DNA fragments that contain them to migrate more slowly through the gel
    D. are not affected by high temperatures

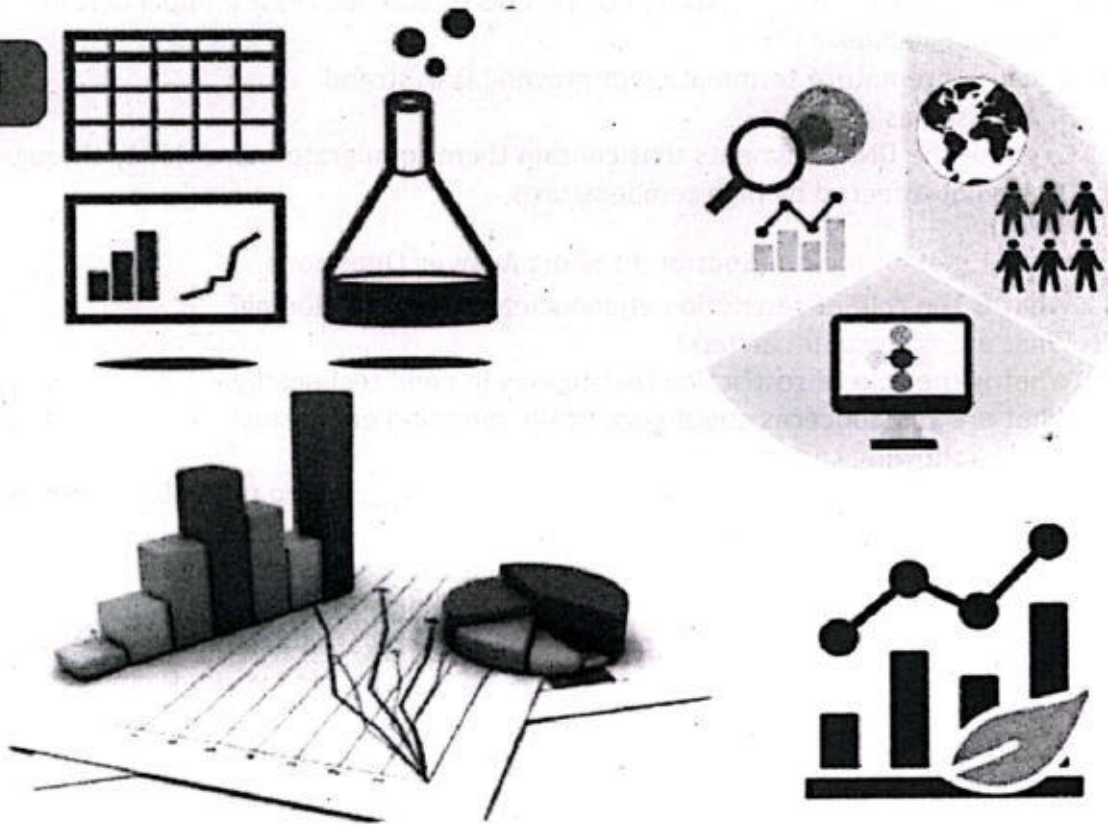
Section II: Short Answer Questions

1. What is the role of restriction endonucleases in gene cloning?
2. What are molecular carriers?
3. What is the role of restriction DNA ligases in gene technology?
4. What are the concerns about genetically modified organisms?
5. Define following terms:
   (i) Biotechnology (ii) genetic engineering (iii) gene cloning (iv) palindromic sequence (v) recombinant DNA technology (vi) DNA ligase (vii) polymerase chain reaction (viii) primers(ix) Taq polymerase (x) genome (xi) transgenic organisms
6. Write the difference between:
   (a) biotechnology and genetic engineering (b) staggered and blunt cut restriction enzymes (c) genome and chromosome(d) trangenic organisms and hybrid organisms (e) biotechnology and nanotechnology
7. Shortly suggest, which type of farming is better from vertical farming and traditional agriculture farming in Pakistan.
8. Explain the role of restriction endonucleases and DNA ligases in gene cloning.
9. Describe the selection and isolation of the gene of interest.
10. Explain the properties and the role of vectors in recombinant DNA technology.
11. State the steps for the integration of DNA insert into the vector.
12. Briefly state the technique applied for the selection of the vectors that take up the DNA insert.
13. Describe the steps involved in gene amplification through polymerase chain reaction.
14. State the objectives of the production of transgenic bacteria, transgenic plants and transgenic animals.
15. Explain the scope and importance of biotechnology in promoting human welfare.
16. List the hazards of using genetically modified organisms.

Section III: Extensive Answer Questions

1. Describe the components of recombinant DNA technology under the following heads:
   (a) Gene of interest (b) Molecular scissors (c) Molecular carriers (d) Molecular glue (e) Expression system
2. Describe the mechanism or procedure of recombinant DNA technology.
3. What is polymerase chain reaction? Discuss its components and mechanism?
4. Describe vertical agriculture farming. Explain hydroponics, aeroponics and aquaponics.
5. Discuss the scope and importance of biotechnology in promoting human welfare.
6. What are the ethical, legal and social implications of using biotechnology?
7. Compare vertical farming and traditional agriculture farming in Pakistan to clear advantages and disadvantages of both.

Chapter 11



BIOSTATISTICS AND DATA HANDLING

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-K-01] Define biostatistics and its use.
2. [B-12-K-02] Define mean, median, mode, standard deviation, range, percentile.
3. [B-12-K-03] Calculate mean, median, mode, standard deviation, range, percentile from a given set of data.
4. [B-12-K-04] Sketch a bar chart for a given set of data.
5. [B-12-K-05] Sketch error bars based off of range or standard deviation for a given set of data on a bar chart.
6. [B-12-K-06] Evaluate the appropriate type of figure or chart for a given set of data and/or experiment (bar chart, pie chart, xy axis data figure etc).
7. [B-12-K-07] Make the appropriate chart with proper title, labeled axes, legend, axes units.
8. [B-12-K-08] Design an appropriate experiment with control group and dependent, independent and control variables.

11.1 BIOSTATISTICS AND ITS USES

11.1.1 Biostatistics

Biostatistics is the application of statistical principles and techniques to analyse, interpret and present the findings of research in the fields of biology, medicine and health sciences. Biostatistics mainly deals with the data associated with living organisms and then presentation of findings in an appropriate way for possible plans or solutions.

Biostatistics is the application of statistical principles and techniques to analyze, interpret, and present research findings in the fields of biological, medical, and health sciences. It primarily deals with data associated with living organisms, presenting findings to support effective plans or solutions. Biostatistics is applicable to various fields, including medicine, public health, and agriculture. It helps in calculating and assessing agricultural, poultry, and dairy farming outcomes, such as crop yields and livestock growth. Biostatistics is an essential part of modern health sciences and is frequently used in areas like medicine, epidemiology, and clinical research. It plays a key role in understanding disease outbreaks, health trends, possible preventive measures, and the effectiveness of specific disease treatments.

Data

In biostatistics, data refers to the facts, measurements or observations related to living organisms collected to analyze and draw conclusions about biological phenomena. It includes the values such as heights, weights, enzyme activity levels, population counts or rate of any disease.

Data set

Data set is a collection of related data values, usually organized systematically for analysis. It usually includes multiple measurements or observations, organized in a table. Each row typically represents a subject or experimental unit and each column represents a variable. Each entry in a data set represents an individual sample and each variable describes a particular characteristic being measured.

Example: A table recording the heights and weights of 100 plants grown under different availability of light or moisture conditions is a data set.

Components of Biostatistics studies

For effective application of biostatistics, following components (steps) are followed:

Identification of problem: It is first ever requirement to solve any problem affecting the living organisms especially human.

Collecting and analyzing data: Data collected before experiments and then outcome of the experiments is analyzed thoroughly.

Designing experiments: For the solution of any problem associated to living organisms, biologist use biostatistics to plan biological experiments specifically the requirements and durations.

Interpreting results: After experiments, the results are used to interpret the reasons and then possible future effects of biological problem are estimated.

Developing new tools: Interpretations of experimental results lead to creating new predictive tools and plans for effectively dealing the problem e.g. health related issues.

It is highly recommended for every biologist to have basic learning or understanding of biostatistics for effective dealing to biological problems.

11.1.2 Uses of Biostatistics

1. Need Assessments of Agriculture and Cattle Farming for Growing Population

Biostatistics is involved in the assessment of demands of agriculture and dairy farming according

to the rate of population growth. Furthermore it also help the government to assess the need for import or export of food items as per growing population.

2. Evaluation of Efficacy of Medical Instruments and Pharmacological Drugs

Biostatistics helps to design clinical trials and controlled studies to assess the efficacy and safety of newly designed drugs, treatment plan or medical instrument. Findings of medical research guide whether treatment resulted to improvements or side effects. Assessment of the effectiveness and safety of new drugs and deciding optimal doses for any new pharmacological drug.

3. Monitoring of Epidemiological Studies and Policy Development

Biostatistics help in monitoring and analysis of data collected from population about the spread of any epidemic disease. Researchers can identify the risk factors, pattern and rate of disease. Epidemiological studies by using biostatic tools help to control and prevent future outbreaks (e.g., prevalence of Hepatitis and Polio, spread of COVID-19 etc.). Biostatistics evidence helps governments and public organizations to make decisions about population management, healthcare plans and funding sources.

4. Management of Public Health and Population Growth

Each country conduct biostatics studies to estimate health trends within its population. Routine studies include data about birth rates, death rates and prevalence of different disease. It guides the government in planning health initiatives and allocation of resources for public. Biostatistics is useful to monitors and optimize the hospital performance by calculating patient number, availability of doctors and medicine and effectiveness of treatment.

5. Genetic Diseases

Biostatistics is also useful to analyse the data about inheritance patterns of genetic diseases in any population. For example, number of thalassemia and muscular dystrophy patients. It helps in guessing risk factors and behaviour of genetic disorders.

6. Pollution Indicators and Environmental Protection

Biostatistics is used to analyse the pollution level, its causes and impact on population health. Different biostatic tools are designed to monitor the pollution level and associated potential health risks. It helps in designing policies to reduce health risks from environmental hazards. On the basis of findings, multiple steps are taken to protect the environment. For example, causes of smog, identification of affected areas, possible solution like plantation derives in Punjab especially in Lahore.

7. Survival Analysis

Biostatistics is used to predict and then note the survival rate of patients after a particular treatment in any specific disease. It helps to estimate life expectancy and the chances of success for medical treatments. For example, five years survival after the treatment of cancer is considered a successful treatment. Data of survival rate indicate the effectiveness of health plans.

11.2 DEFINITION AND CALCULATION OF MEAN, MEDIAN, MODE, STANDARD DEVIATION, RANGE AND PERCENTILE

In our daily life routine, we commonly hear the statements like:

i. Heartbeat of human is 72 beats per minute

ii. Death rate due to cancer in Pakistan is 25 per thousand patients.

iii. Production of wheat in Punjab is 2000 Kg per acer.

iv. The price of the bananas in the market is Rs. 120 per dozen.

v. Food consumption of a human is 1kg per day.

vi. The rain fall in Islamabad is 1500mm per year.

If we think on about above mentioned statements, none of them is found exactly correct. In statement no. "i", our heart may not be same 72 in each minute of the day. During running it may be 90 per minute and during sleep it may be 60 per minute. Our heartbeat is approximately 72 in each minute. As given in statement "ii" It is quite possible that in one hospital only 5 cancer patient died out of 1000 visited for treatment and in other hospital 60 patients died out of 1000 patients gone through treatment. The death rate of cancer patients is about 25 per 1000, may not be same all the year and in every hospital. The production of wheat in one district of Punjab may be 1500 Kg from an acer and it may be 2400 Kg from one acer in another district. Although above statements are not exactly true but still they are very important. Actually, these are approximate statements in specific situations. In terms of statistics, we call such statements as average statements.

In our daily conversation, we make many statements which have some meaning only on average basis. In different fields of life like agriculture, health, poultry, the idea of average is very important. Many experts at national and international level discuss the findings of studies in averages. The average is also called measure of central tendency.

Calculation of Average

Average is a single value which is calculated to represent the whole data. It may be calculated for a data sample of patients or a population of migrating birds etc. The average is a value which expresses the central idea of the observations. There are different ways to represent average of a data in different situations. For representation of a specific data, proper type of average is used by the expert who is calculating the average.

Types of averages

The following types of averages are commonly used:

(i) Arithmetic Mean (ii) Median (iii) Mode (iv) Geometric mean (v) Harmonic mean

Here in this chapter we will study only first three types of averages in detail.

11.2.1 Arithmetic Mean or simply Mean:

Definition

Mean is the sum of all the values of data set divided by the total number of values in the data set. It is the single value which is calculated to represent the whole set of data. The symbol "$\bar{x}$" (read as "x bar") represent the sample mean. The bar above the letter x represents the mean of a set of values.

$$\text{Mean } (\bar{x}) = \frac{\textit{Some of values}}{\textit{Total Number of values}} = \frac{(\sum X)}{(n)}$$

Formula

Direct method for un-group data	Direct method for group data
$\bar{X} = \frac{\sum x}{n}$ where, x = *Value of data set*	$\bar{X} = \frac{\sum fx}{\sum f}$ (where, x = *Value of data set and* is calculated as $x = \frac{\textit{lower limit + upper limit}}{2}$ and f= frequency distribution)

In biostatistics, data can be categorized as **grouped data** or **ungrouped data**, depending on how it's organized:

Ungrouped Data: Raw data in the form of individual values that has not been organized into groups or categories. It is suitable for small datasets.

Example: Individual blood pressure readings from 10 patients:

120, 125, 130, 122, 118, 135, 128, 124, 129, 121

Grouped Data: Data that has been organized into classes or intervals with their frequencies. It makes large datasets easier to summarize and analyze.

Example: Blood pressure ranges with number of patients:

110-119 mm/Hg: 2 patients 120-129 mm/Hg: 5 patients 130-139 mm/Hg: 3 patients

Frequency distribution: It is a way of organizing and summarizing data in the form of table or graph to display the number of occurrences (frequencies) of different outcomes or data values in a dataset. A frequency distribution makes it easier to understand and interpret the data by showing how often values occur. It is useful to summarize large data sets, Identify patterns, constructing histograms and other statistical charts

There are two types of Frequency Distributions:

1. Ungrouped Frequency Distribution: Lists each individual value and its frequency.
2. Grouped Frequency Distribution: Groups data into intervals (classes) and shows the frequency for each class.

Example 1(un-group data)

Dataset: Team of world health organization (WHO) planned to assess the prevalence of polio disease in Pakistan. Study to record the polio cases in Pakistan continued for consecutive two years. Number of confirmed Polio patients detected each month of 2022 and 2023 are given in table below. Calculate the mean polio patients per month in each year. Also compare the prevalence of Polio disease in both years.

Sr. no.	Month of sampling	Number of Polio patients in year 2022	Number of Polio patients in year 2023
1	January	9	7
2	February	13	9
3	March	15	13
4	April	19	17
5	May	22	18
6	June	25	17
7	July	20	15
8	August	22	14
9	September	18	11
10	October	13	9
11	November	10	8
12	December	6	6
Total	**12 months**	**192**	**144**

Mean number of Polio patients per month in 2022 = $\frac{\text{Sum of Polio cases in complete year}}{\text{Total number of Months}} = \frac{192}{12} = 16$

Mean number of Polio patients per month in 2023 = $\frac{\text{Sum of Polio cases in complete year}}{\text{Total number of Months}} = \frac{144}{12} = 12$

Difference of Polio patients per month detected in 2022 and 2023= 16 - 12 = 04

Prevalence of Polio disease decreased in 2023 compared to 2022 by 04 patients per month.

Example 2 (Group data)

Data set: United Nation-World Food Programme (UN-WFP) conducted a research to assess the impact of food quality on body mass of 100 students of different age groups. Find the arithmetic mean for the Frequency distribution of body mass of 100 students as shown in table given below.

Mass of student groups before the start of experiment				
Sr. No.	Mass (Lbs)	Frequency (f)	$X = \frac{\text{Lower limit + Upper limit}}{2}$	Frequency x mean of limits (fx)
1	35-39	13	$\frac{35 + 39}{2} = 37$	13 X 37 = 481
2	40-44	15	$\frac{40 + 44}{2} = 42$	15 X 42 = 630
3	45-49	28	$\frac{45 + 49}{2} = 47$	28 X 47 = 1316
4	50-54	17	$\frac{50 + 54}{2} = 52$	17 X 52 = 884
5	55-59	12	$\frac{55 + 59}{2} = 57$	12 X 57 = 684

6	60- 64	10	$\frac{60 + 64}{2} = 62$	10 X 62 = 620
7	65- 69	05	$\frac{65 + 69}{2}$ = 67	05 X 67 = 335
	Total	100		4950

Calculations $= \frac{\sum fx}{\sum f} = \frac{4950}{100}$ = 49.5 Lbs

49.5 Lbs is the mean mass of 100 students of different groups before the start of experiment

11.2.2. Median

Definition

The median is the middle value in a dataset that are arranged in ascending or descending order of magnitude. Median divides the data set into two equal parts. One part of the dataset have the values less than the middle value and the other part of the dataset have values greater than the middle item. It is denoted by $\tilde{x}$, (read as "x tilde" or "x snake"). It is necessary to arrange the values of dataset in ascending or descending order.

The methods of calculating the median are simple and the value of median is not affected by change in extreme values of dataset.

Median for un-group data

- If the number of values is odd, the median is the middle value.

  Median ($\tilde{x}$) = The value of $(\frac{n+1}{2})^{th}$ item in the dataset (where n = number of items or data)
- If the number of values is even, the median is the average of the two middle values.

Example 1: (For the dataset with odd number of values)

Dataset: In an experiment to check the effect of specific fertilizer on the growth of the plants, heights of the plants in the experimental dataset was recorded. The heights (in cm) of 13 plants are given below.

58, 67, 65, 70, 68, 62, 63, 46, 64, 49, 55, 66, 72

Find out the Median value of height

Solution: The median is calculated as follows

The measured heights of plants after arranging in ascending order is as given below:

46, 49, 55, 58, 62, 63, **64**, 65, 66, 67, 68, 70, 72

Number of values in the dataset of observed heights= 13

Median ($\tilde{x}$) = $\frac{n+1}{2} = \frac{13+1}{2} = \frac{14}{2}$= 7 (i.e. value of 7th value in datasheet)

Median ($\tilde{x}$) = 64

Example 1: (For the dataset with odd number of values)

Median ($\tilde{x}$) = $\frac{\left(\frac{n}{2}th\ value\right) + \left(\frac{n}{2}+1\right)}{2}$

Dataset: The number of fruits produced on each of the 16 plants of experimental group are recorded as below:

3, 5, 18, 21, 15, 10, 8, 12, 13, 7, 11, 14, 9, 16, 20, 24

Find out the median value of fruits produced per plant.

Solution

The numbers of fruits produced on 16 plants after arranging the values of dataset in ascending order are given below:

3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 20, 21, 24

Total number of values in the above given dataset n = 16 (even number)

$$\text{Median } (\bar{x}) = \frac{\left(\frac{n}{2}th\ value\right) + \left(\frac{n}{2}+1\right)}{2} \qquad = \frac{\left(\frac{16}{2}\right) + \left(\frac{16}{2}+1\right)}{2}$$

$$\text{Median } (\bar{x}) = \frac{(8th\ value) + (8th\ value+1)}{2} \qquad = \frac{(12) + (12+1)}{2}$$

$$\text{Median } (\bar{x}) = \frac{12+13}{2} = \frac{25}{2} = 12.5 \text{ fruits per plant}$$

Activity: (to be solved by the students)

Calculate the median of the following values of data set obtained by measuring the heights of 22 plants in an experimental group to assess the effects of less water availability:

8, 9, 10, 18, 10, 8, 9, 7, 8, 11, 23, 19, 17, 15, 7, 12, 14, 12, 11, 14, 15, 13.

2. Median for grouped data

(i) Discontinuous or Unconnected values in dataset

To calculate the value of median for discontinuous grouped data, first of all the cumulative frequency (cf) of complete dataset is obtained.

The value of data against n+1/2 the cumulative frequency will be the median for odd number of data.

- Median for dataset with odd number of values will be:

  Median $(\bar{x})$ = *value of data against* $\left(\frac{n+1}{2}th\right)$ *cumulative frequency*
- Median for dataset with even number of values will be:

  $$\text{Median } (\bar{x}) = \left(\frac{Class\ values\ against\ \frac{n}{2}^{th} + \frac{n}{2}+1^{th}\ \ cumulative\ frequencies}{2}\right)$$

Example for odd number dataset:

Calculate the median of the following dataset obtained by counting the number of flowers on 21 rose plants.

Class (no. of flowers/plant)	1	2	3	4	5
Frequency (no. of plants)	3	5	6	4	3

Calculations:

Class (no. of flowers/plant)	Frequency (no. of plants = n)	Cumulative frequency
1	3	3
2	5	8
3	6	14
4	4	18
5	3	21

Number of plants (n) = 21

Median $(\tilde{x}) = (\frac{n+1}{2}th)$ cumulative frequency

Median $(\tilde{x}) = \left(\frac{21+1}{2}\right) = \frac{22}{2} = 11$

Since cumulative frequency 11 is included in 13 which represents the class value 3, therefore, for cumulative frequency 11, the class value will be 3 which is the median.

Example for even number dataset

Calculate the median for the following data recorded for height (in cm) of 80 plants.

Class (plant height in cm)	119	120	121	122	123	124	125
Frequency (no. of plants)	4	9	14	18	15	13	7

Calculations

Calculate the median for the following data recorded for height (in cm) of 80 plants.

Class (plant height in cm)	Frequency (no. of plants = n)	Cumulative frequency
119	4	4
120	9	13
121	14	27
122	18	45
123	15	60
124	13	73
125	7	80

Number of plants (n) = 80

Median $(\tilde{x}) = \left(\frac{Class\ values\ against\ \frac{n}{2}th + \frac{n}{2}+1th\ \text{cumulative frequencies}}{2}\right)$

Median $(\bar{x}) = \left(\frac{\frac{80}{2}th + \frac{80}{2}+1th \text{ cumulative frequencies}}{2}\right)$

Median $(\bar{x}) = \left(\frac{\text{Class values against cumulative frequencies } 40 \& 41}{2}\right)$

The class values for cumulative frequencies 40 and 41 are included in the class value of cumulative frequency 45 which is 122. Therefore, **Median $(\bar{x})$ = 122+122/2 = 122.**

Advantages of Median

1. It is easy to calculate and is located exactly.
2. It is not affected by abnormally large and small values in dataset.
3. It can be used in quantitative measurements.

Disadvantages of Median

1. The median of two or more datasets cannot be calculated by using/adding the median of the individual datasets.
2. Median value may not be necessarily represented in central data.
3. It cannot be used where specific values e.g. weight & age used.

11.2.3. Mode

Definition: The mode is the value in a dataset that appears maximum number of times. A dataset may have one mode (unimodal), more than one mode (bimodal or multimodal) or no mode at all (amodal) i.e. all values occur in same number of times. It may be denoted by "$\hat{X}$ "(read as x-hat or x cap).

Mode = the most frequent or repeated value occurring in a given dataset.

Formula for calculating Mode for Group data is given below

Mode $(\hat{X})$ = $l + \left[\frac{(fm-f1) \times h}{(fm-f1)+(fm-f2)}\right]$

Where, l= lowercase boundary of model group

f_m= maximum frequency of a group

f_1= previous frequency of fm

f_2= next frequency of fm

h= class interval of model group

Class interval and Modal Group (Modal Class)

1. **Class Interval:** A class interval is a range of values into which data is grouped in a frequency distribution table. Each interval includes a lower and an upper boundary (e.g., 120-129). All intervals are typically of equal width.

Example:

Blood Pressure (mm/Hg)	Frequency (f)
110-119	2
120-129	5
130-139	3

Here, 110-119, 120-129, and 130-139 are class intervals.

2. **Modal Group (Modal Class)** The modal group is the class interval with the highest frequency in a grouped frequency distribution. It indicates the most common range of values in the dataset. Using the table above: The class interval 120-129 has the highest frequency (5). So, 120-129 is the modal group.

Examples for calculating Mode

Example #01: Find the mode from the word "BIOLOGY".

Mode ($\hat{X}$) = the most repeated value of the data

Mode ($\hat{X}$) = "O"

Example #02: Find mode from the following data; 3, 5, 6, 6, 9, 10, 9, 6, 6

Mode ($\hat{X}$) = the most repeated value of the data

Mode ($\hat{X}$) =6

Example #03: Find the mode from the following data; 3, 5, 5, 6, 9, 9, 10, 12

Mode ($\hat{X}$) = the most repeated value of the data

Mode ($\hat{X}$) =5, 9

Example #04: Find the mode from the following frequency distribution;

Groups	Frequency (f)	Class Boundary (CB)	
10-19	5	9.5-19.5	
20-29	25 (f_1)	19.5-29.5	
30-39	40 (f_m)	29.5-39.5	(model group)
40-49	20 (f_2)	39.5-49.5	
50-59	10	49.5-59.5	

Mode ($\hat{X}$) = $l + \left[\frac{(fm-f1) \times h}{(fm-f1)+(fm-f2)}\right]$

l=29.5, f_m=40, f_1=25, f_2=20, h=10

Mode ($\hat{X}$) = $29.5 + \frac{(40-25) \times 10}{(40-25)+(40-20)}$

Mode ($\hat{X}$) = 33.786

11.2.4. Standard deviation (SD)

Standard deviation (SD) is a fundamental concept in statistics that measures the dispersion of data points. It states the extent to which data values in a dataset deviate from the mean. It provides a clear sense of the variability within the data. It is used to find the deviation of any data value from the mean value in a data set. **"Standard deviation is a measure of the spread of data values around the mean in a normal curve. It measures that how much a set of data varies from its mean value."**

Standard deviation is sometimes referred to as the "mean of the mean". For any given situation, the standard deviation measures how close the data values are to the mean. If most of the data values are clustered around the mean, then the standard deviation is small. Thus, a lower value of standard deviation means the data values are tightly grouped around the mean. Conversely, if most of the data values are widely spread and are not grouped around the mean, then the standard deviation is large. Thus a higher value of standard deviation means the data values are more spread out. In other words, the more the data values differ from the mean, the greater the standard deviation, and vice-versa. Examples of data values for a biologist may be height of each individual in the sample population or number of hepatitis infected patients in each city of Pakistan or number of fruits on each plant in a garden being investigated for fruit production etc.

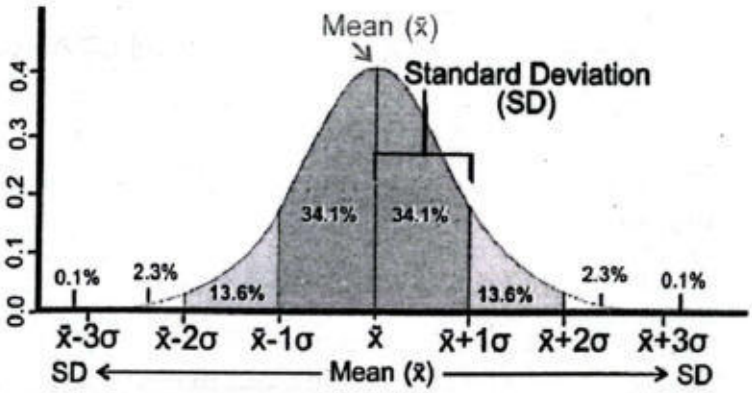


Fig. 11.1: Normal Curve showing Mean (x) and Standard Deviation (SD)

The standard deviation is represented by the lowercase Greek letter sigma (σ) for a population and the Latin letter (s) for a sample. Thus, sigma (σ) value describes how far a specific data value is from its mean. A higher sigma value means the data point is further from the mean. SD and variance are related, because standard deviation is the square root of the variance. Standard deviation is easier to interpret because it is expressed in the same units as the data. The variance is sigma square $(\sigma)^2$.

To clarify the concept of SD, let's consider the quiz results of biology subject in a class. Each of the 40 students scored 77 marks and same grade, so the mean score is also 77. As, all of the scores are equal to the mean, so there is no arithmetic difference between the scores and the mean. Therefore, the standard deviation in this scenario would be zero. But, if a few students have scored 75 marks, then standard deviation would not be zero, and it would be very small and much less than one sigma (σ).

Calculation of standard deviation

The calculation of standard deviation is quite simple, but there are two slightly different ways to do it depending on the context. First, consider the steps below:

i. Determine the mean (arithmetic average)

ii. Subtract the mean from each score

iii. Square the result for each score

iv. Add the results together

v. Divide this result by either the number of scores (biased) or the number of scores minus 1 (unbiased), as explained below.

vi. Determine the square root of this number which is what we call the biased standard deviation

Let's calculate the SD for prevalence of COVID in 2021. Number of confirmed COVID cases in four major cities of Pakistan were recorded:

Cities	Number of confirmed COVID cases	Mean of COVID cases
Karachi	90	60
Lahore	80	
Peshawar	40	
Quetta	30	

1. **Determine the mean:** The mean is 60.
2. **Subtract the mean cases from cases of each city:** Karachi = (90-60) = 30;
   Lahore = (80-60) = 20; Peshawar = (40-60) = -20; Quetta = (30-60) = -30
3. **Square the result for each city:**
   Karachi = (30)2 = 900; **Lahore** = (20)2 = 400; **Peshawar** = (-20)2 = 400; **Quetta** = (-30) = 900
4. **Add the results of all cities together:** 900 + 400 + 400 + 900 = 2600
5. **Divide this result by the number of scores minus 1 (unbiased),** because we are interested in considering these cities as a sample from the entire Pakistan: 2600/3= 866.7
6. **Determine the square root of this number which is the standard deviation (SD):**

The square root of 866.7 = 29.45, Hence, Standard deviation (SD): 29.45

As a general rule large standard deviation means that data is well dispersed away from the mean. A small standard deviation indicates a tight cluster of data points near the mean.

Standard deviation (SD) of a population or sample can be calculated by using following formulas:

Population	Sample
$\sigma = \sqrt{\frac{\Sigma(X - \mu)^2}{N}}$	$S = \sqrt{\frac{\Sigma(X - \bar{x})^2}{n - 1}}$
X - The Value in the data distribution μ - The population mean N - Total number of observations	X - The value in the data distribution $\bar{x}$ - The sample mean n - Total number of observations

As calculations of SD are complex and there's a high risk of error, so statisticians don't usually calculate standard deviation by hand. We can use a calculator or computer software to find the SD.

11.2.5. Range

In biostatistics, the range helps researchers to understand the variability within data obtained from some experiment or variation in a population. Range is defined as **"the difference between the highest and lowest values in a set of data"**. The range can also be defined as **"the difference between the highest observation and lowest observation"**.

The obtained result is called the **"range of data values"** or **"range of observation"**. It is the measure of spread or variability of a dataset or observations obtained from experiment.

Calculation of Range

To find or calculate the range first step is to arrange the given values of data set or set of

observations in an ascending order. This means, firstly we have to arrange the values or observations from the lowest to the highest sequence. Then, we can use the formula to find the range of values or observations.

Formula for Range

The formula of the range in statistics can simply be given as follows:

Range = Highest or Maximum Value - Lowest or Minimum Value

Or

Range = Highest observation - Lowest observation

During biological studies, we can use range to find the variation in population or findings of biological research.

Example: Imagine a student studying the heights of a sample of plants in a garden after the treatment of fertilizers. Student collected the following data set of plant heights (in centimetres) from sampled plant population:

1. **Raw data Set:**

10cm, 15cm, 18cm, 21cm, and 25cm, 32cm, 41cm, 28cm, 54cm, 35cm, 26cm, 23cm, 33cm, 38cm, 40cm, 19cm, 33cm, 43cm, 08cm, 13cm

2. **Arranged data set (ascending order):**

   08cm, 10cm, 13cm, 15cm, 18cm, 19cm , 21cm, 23cm, 25cm, 26cm, 28cm, 32cm, 33cm, 33cm, 35cm, 38cm, 40cm, 41cm, 43cm, 54cm

3. **Identify the highest value:** 54cm
4. **Identify the lowest value:** 08cm
5. **Calculate the range:** Range = Highest or Maximum Value - Lowest or Minimum Value

   Range = 54cm - 08cm = 46cm

   The range here is 46cm, meaning there is a 46 cm difference between the smallest and tallest plants in the sample.

Importance of Range in Biology

In biology, the range helps scientists understand the variability within a population. This can be useful in studies of genetics, ecology and physiology where variability may indicate environmental influences or adaptations or organisms in a given population.

A small range would mean that the organisms in sampled population responding to the treatment in about the same level. A small range indicates that the individuals are more similar. A small range is generally good news for the researcher because it indicates that the treatment is almost equally effective for all organisms. A small range is best when the low range is also at a high effectivity level.

The middle range is often the most difficult for the researcher because no clear-cut information can be derived from the data. The researcher must re-plan to proceed the experiment when intermediate range of results are observed.

A large range suggests a high level of variation among individuals.

Limitations of Range

Before planning for the future study on the basis of range, the researcher must consider another factor regarding range. The range statistic may be deceiving. The range only accounts for the

highest and lowest values. For example, if the almost all the plants responded well to the fertilizer treatment with greater productivity and only one or two plants showed lowest productivity. In this situation we can conclude that looking at the range alone may be misleading.

11.2.6. Percentile

A percentile is a value that indicates the percentage of data in a set that is below a certain value. For example, the 25th percentile is the value below which 25% of the data points lie. Percentiles are used to interpret and understand data and are often used to report test scores and biometric measurements.

Percentiles divide the ordered data into 100 separate units. For instance, it is possible to have a data point at any number between 0 and 100 such as the 99 percentile, 44 percentile or 9th percentile. A percentile is the value or score on the ordered array of data that indicates the percentage of the scores that fall at or below that value.

For example, the 25th percentile of the number of fruits on the plants in the garden is number of 39 fruits on a plant. This would mean that 25% of the plants from that garden produced fruits below 39.

The 25th percentile is also known as the first quartile; the 50th percentile is also the median. The desired 99th percentile is that location point where no scores are above it. A plant which produced number of fruits in the 99th percentile has produced very well in comparison to the rest of the plants who were included in the pool total fruits produced in the garden. For research and biometry purposes, percentile ranks are used to interpret an individual's raw value by comparing it with the value of other individual in the study group. For example, if a student's height measured 77cm and that height is translated to a percentile rank of 89, then 89% of the students in that population have a height of 77cm or less.

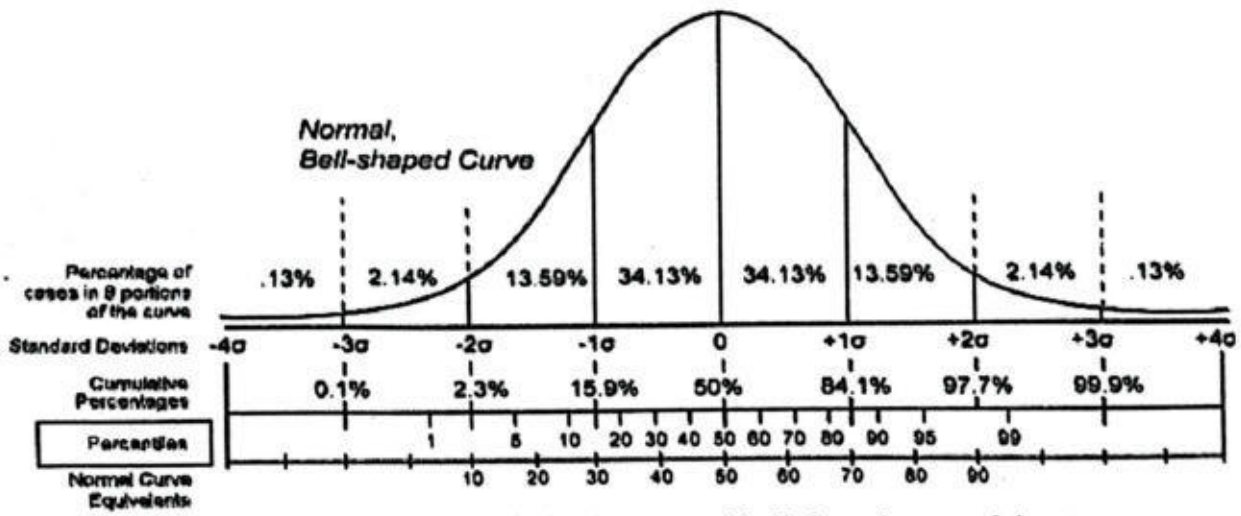


Fig. 11.2: Percentile calculation in a normal bell shaped curve of data

Further helping material to understand Percentile:

Quartiles

A quartile is a special type of percentile. A quartile is any of the three values which divide the sorted data set into four equal parts so that each part represents one-fourth of the population. Each quartile defines a specific section of the ordered data distribution.

The first quartile (Q.) or lower quartile is that point on the ordered array where 75% of the values are above it and 25% of the values are below it. The range of the first quartile accounts for the bottom one-fourth of the data, or the lowest 25% of whatever is being measured. Thus, the lowest quartile is also known as the 25th percentile.

The second quartile (Q.) would identify the midpoint of the data where 50% of the values are above and 50% are below. The second quartile is also called the median and the 50th percentile.

The third quartile (Q) establishes that point where 25% of the values are located above it and 75% below it.

The interquartile range (IQR) is the difference between the upper and lower quartiles. The interquartile range is often used to characterize the bulk of the population.

The quartiles labelled in the data given below are collected as the number of fruits on the orange trees in a small garden.

Quartile	Number of fruits on each plant
	11
	13
	14
First Quartile	15
	18
	18
	19
Second Quartile= (21)	19
	23
	23
	23
	24
Third Quartile	24
	25
	25
	26

Quartiles divide the data so the researcher can analyze the results by an ordered grouping rather than by focusing on the entire data pool.

Steps to calculate percentile

1. Arrange Data: Sort the data values in ascending order.
2. Calculate Position: Use the formula for the position of the P^{th} percentile:

Position = $\frac{P}{100} X(N+1)$

P is the desired percentile (e.g., 25 for the 25th percentile).
N is the number of observations.
Percentile can be calculated by using the data by formula:

P = $\frac{n}{N} X\ 100\%$

Where P is the percentile,
n is the number of data points below the data point of interest, and
N is the total number of data points in the data set.

11.3 SKETCHING A BAR CHART FOR A GIVEN SET OF BIOLOGICAL DATA

11.3.1 Graphic presentation of scientific data: Need and its importance

Biostatistical values (data) are documented in the form figures and are usually recorded in the form of tables. But numerical or arithmetical figures are usually not attractive. Large number of figures in tables are not easily understandable. It seems difficult to get a clear picture from the numerical data. Diagrams and graphs are comparatively more attractive way of presenting the clear and complete picture of data. Moreover, data information presented in the form of diagrams, pictures, charts and graphs leave long lasting impression on the mind of the observer. Multiple types of graphs, pictures and diagrams are used in representing data including bar-chart, rectangles and pie-chart.

11.3.2 Simple bar diagram or simple bar chart

Simple bar chart have bars which are drawn to represent a single data without further classification of the characteristics. Bar chart represent only one characteristic of the data. One bar represents only one value or figure and there may be multiple bars representing many values or figures. In a simple bar chart, bars of equal width are drawn, but their lengths are variable. Heights of length of the bars represent the magnitude of a quantity or degree of value in the data.

11.4. SKETCHING OR CONSTRUCTION OF BAR CHARTS AND PIE CHARTS WITH PROPER TITLE, LABELLED AXES, LEGEND, AXES UNITS

Some basic steps in sketching of bar charts are:

1. Take a graph paper with suitable sizes and scales as per requirement and type of data.
2. Draw two lines on the graph, perpendicular to each other and intersecting at zero.
3. Label the axis of the graph, horizontal line is X-axis and vertical line is Y-axis.
4. Choose uniform width of bars and uniform gap between the bars along the horizontal axis (X-axis).
5. Label X-axis with the names of the data items whose values are to be presented.
6. Choose a suitable scale to determine and specify the heights of the bars for the given values along the vertical axis (Y-axis).
7. Label the Y-axis scale with specific unit of data value to grade the length of bars.
8. Calculate the heights of the bars according to the scale chosen and mark as dots.
9. Draw the bars carefully and recheck all the entries.

Bars in the graph may be drawn vertically or horizontally but normally vertical bars are used.

Some basic steps to make a pie chart manually, follow these steps

1. **Gather Your Data:** You'll need a list of categories and their values.
   Example: Category A: 20, Category B: 30, Category C: 50
2. **Calculate Total and Percentages:** Add up the values to get the total. Then, for each category, divide its value by the total and multiply by 100 to get its percentage.

Example: Total = 20 + 30 + 50 = 100, Category A: (20 / 100) × 100 = 20%, Category B: (30 / 100) × 100 = 30%, Category C: (50 / 100) × 100 = 50%

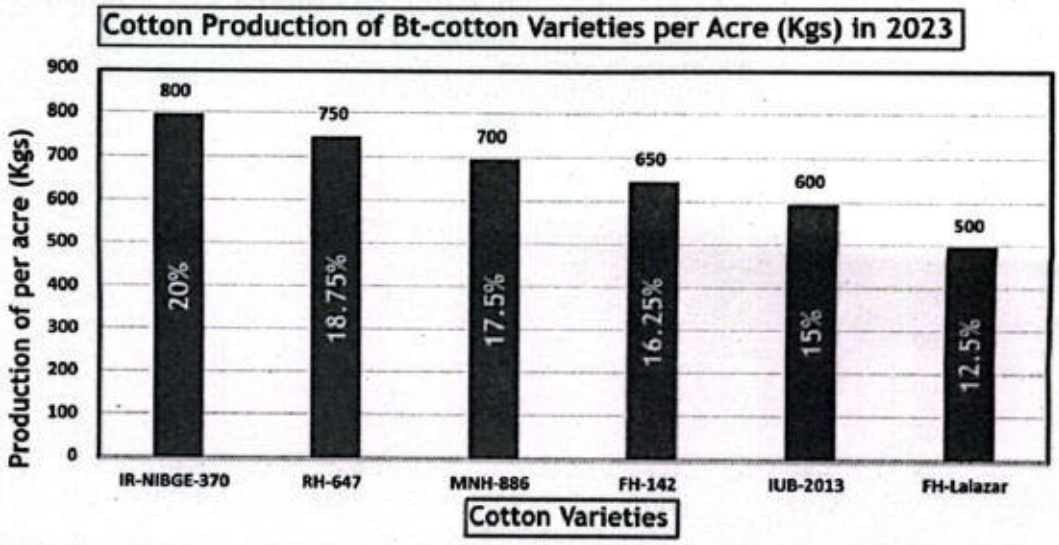
3. **Convert Percentages to Degrees:** Since a circle is 360 degrees, multiply each percentage by 3.6 (because 100% × 3.6 = 360°) to get each angle.
   Example: Category A: 20% × 3.6 = 72°, Category B: 30% × 3.6 = 108°, Category C: 50% × 3.6 = 180°
4. **Draw a Circle:** Use a compass to draw a circle on your paper. Mark the center.
5. **Measure and Draw Each Segment:** Start at the top of the circle (12 o'clock position).Use a protractor to measure each angle from the center, marking each section. Draw lines from the center to the edge of the circle at each angle to divide the circle into sections.
6. **Label Each Segment:** Write each category name and percentage inside or near each section.
7. **Add Color (Optional):** You can color each segment differently for clarity.

Bar chart and pie chart can be constructed by using computer software.

Example 1: Draw simple bar graph/chart to represent the cotton (weight in Kgs) of produced per acer of land from five Bt cotton varieties (IR-NIBGE-370, RH-647, MNH-886, FH-142, IUB-2013 and FH-Lalazar) in year 2023.

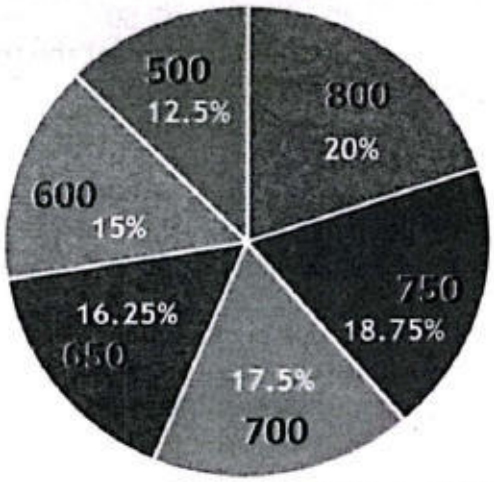
Cotton Varieties	IR-NIBGE-370	RH-647	MNH-886	FH-142	IUB-2013	FH-Lalazar
Production per acre (Kgs)	800	750	700	650	600	500
Production per acre (%age)	20%	18.75%	17.5%	16.25%	15%	12.5%

Simple bar chart using above data



Simple pie chart using above data

Pie chart to show Cotton Production of Bt-cotton Varieties per Acre (Kgs) in 2023



Trend Line and it's purpose

A trend line shows the overall direction or pattern in the data over time or across categories. In bar graphs, trend lines are usually drawn as a dotted line across the tops of the bars to show increasing, decreasing or constant trends. Trend line explains that

"There is an increasing trend...

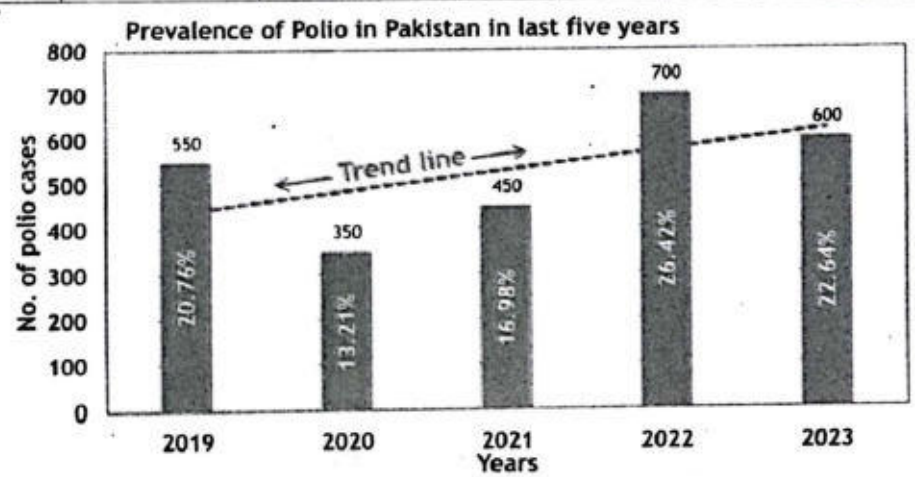
""The trend line shows a gradual decline...

""The trend remains fairly constant...

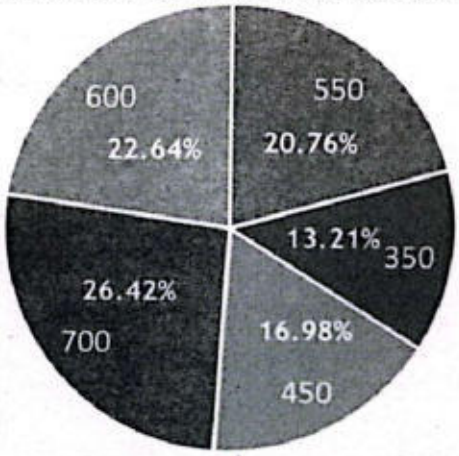
""There is a sharp rise/drop between..." etc.

Example 2: Draw simple bar graph/chart to represent the prevalence of polio, showing number of confirm polio cases in Pakistan in last five years (2019-2023)

Years	2019	2020	2021	2022	2023
No. of polio cases	550	350	450	700	600
%age of polio cases	20.76%	13.21%	16.98%	26.42%	22.64%



Pie chart for Prevalence of Polio in Pakistan in last five years



11.5 SKETCHING ERROR BARS BASED ON RANGE OR STANDARD DEVIATION ON A BAR CHART

To sketch error bars on a bar chart, representing variability such as range or standard deviation, follow these steps:

1. Calculate Error Values

Range-Based Error Bars: For each data point or category, first determine the minimum and maximum values to get the range. The error bar's length will be half of the range, extending above and below the mean or median value.

Standard Deviation (SD) Error Bars: For each data point or category, calculate the standard deviation. Error bars will extend above and below the mean by one standard deviation.

2. Draw the Bar Chart

Create a bar chart with the values representing the mean (or other central tendency) of each category.

3. Add Error Bars

Vertical Error Bars: Draw a line centered on each bar, extending upward and downward by the calculated range or standard deviation. Use caps on the ends of each line for a clean representation.

Error bar Length:

For range, set the error bar to $\frac{(\text{Max value} - \text{Min value})}{2}$

For standard deviation, set it equal to the standard deviation.

Calculation for Standard Deviation

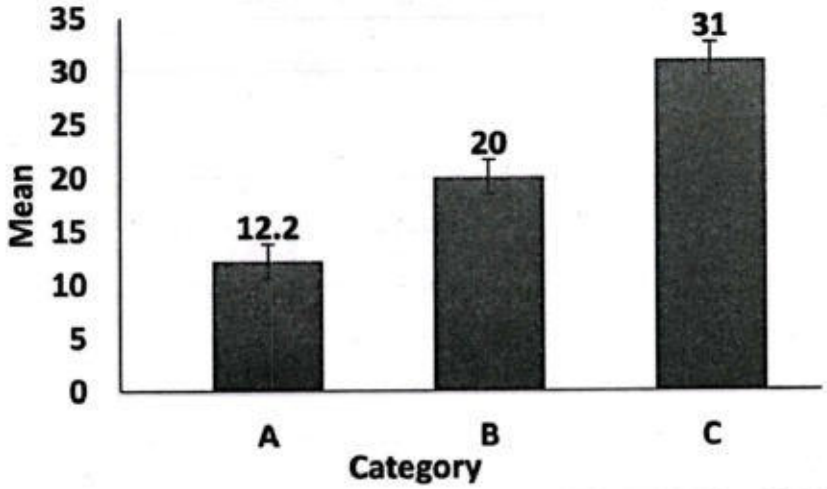
Suppose we have the following data points for three categories in a biological experiment:

1. Calculate the mean and standard deviation for each category.
2. For each bar representing the mean of each category, add error bars with lengths based on the calculated standard deviations.

Here are the data points, mean values, ranges and standard deviation (SD) and error bar lengths for each category:

Category	Data Points	Mean	Range $\frac{(\text{Max value} - \text{Min})}{2}$	Standard deviation (SD)	lengths of error bars (±SD)
A	(10,12,15,11,13)	12.2	2.5	1.92	±1.92
B	(20, 21, 22, 19, 18)	20.0	2	1.58	±1.58
C	(30, 33, 32, 31,29)	31.0	2	1.58	±1.58

Graph showing error bars



11.6. EXPERIMENTAL DESIGN WITH CONTROL GROUP AND DEPENDENT, INDEPENDENT AND CONTROL VARIABLES

While designing experiments, two main types of groups are used to get better and clear outcome of any experiment. Control and experimental groups are used in experiments to compare results and evaluate acceptance of the findings of experiments.

11.6.1. Experimental Group

This group is to test and experience a change in a specific variable that is being tested. The experimental group is also known as the treatment group because in this group, scientist apply a specific change or treatment to observe the effects of that treatment. For example, if students of class 12 are testing the effect of a fertilizer on the plant growth, plants in the experimental group would receive the fertilizer.

11.6.2. Control Group

This group is kept under unchanged normal conditions without any specific treatment as applied in the experimental group. It serves as a standard or reference to compare the effects of treatment in experimental group. In example of effects of fertilizer on plant growth, the control group would consist of plants grown without any added fertilizer.

Independent, Dependent and Controlled Variables

There are three main types of variables in scientific investigations: *independent, dependent, and* controlled variables.

11.6.3. Independent Variables

The variable that the experimenter (researcher) changes or manipulates in the experiment. This is the variable that scientist think, will cause an effect during experiment. That is why, they are also known as the **"input variables"** or the **"cause variables"** because they are the factors that cause changes in the dependent variable. In case of fertilizer experiment, the independent variable would be the presence or absence of fertilizer.

11.6.4. Dependent variables

These variables depend on the independent variable or affected by the independent variable in an experiment. The dependent variables are what researcher measure or observe to determine the effect of the independent variable that is why they are also known as the **outcome variables** or the **effect variables.** In the plant fertilizer experiment, the dependent variable might be plant height, number of leaves or overall growth rate.

11.6.5. Controlled variables

These are factors that must be kept constant during an experiment across both the experimental and control groups to ensure that they do not influence the results. These variables are also known as **constant variables** or the **controlled factors.** The purpose of controlling these variables is to ensure that any changes observed in the dependent variable are due to changes in the independent variable and not due to other factors. These elements are essential for designing a fair and effective experiment, allowing you to clearly see the impact of the independent variable on the dependent variable. For example, control variables in the fertilizer experiment might include the amount of sunlight, temperature, water, type of plant and soil quality.

Further examples of independent, dependent and control variables:

Independent variable: If a researcher is investigating the effect of temperature on the rate of photosynthesis in plants, temperature would be the independent variable. Researcher would manipulate the temperature to see how it affects the rate of photosynthesis. It is essential to note that an experiment should have only one independent variable at a time. This is because if researcher changes more than one variable in the same experiment, he would not know which variable caused the change in the dependent variable. Therefore, by controlling the independent variable, researcher can determine the effect of that variable on the dependent variable.

Dependent variable: If a researcher is experimenting to know the effect of temperature on photosynthesis, the dependent variable would be the rate of photosynthesis, which is affected by changes in temperature. It is crucial to keep the record of dependent variables continuously during an experiment to ensure the clear observation of any effect as a result of changes in the independent variable. Additionally, the dependent variables should be measurable quantitatively so that it can be expressed and compared in numerical values.

Controlled variable: If a researcher is investigating the effect of temperature on the rate of photosynthesis in plants, the controlled variables would include factors such as the type of plant, the duration and intensity of light and the amount of CO_2. By keeping these variables constant, researcher can ensure that any changes in the rate of photosynthesis are surly due to changes in temperature and not due to any other relevant factors.

11.6.6. Experimental design

Let's consider a scenario where we want to investigate the effect of light intensity on plant growth and effect of different amounts of water on plant growth. For this purpose we design two separate experiments:

Experiment 1: Effect of Light Intensity on Plant Growth

Objective: To investigate how different light intensities affect the growth of a specific plant (e.g., bean plants).

Hypothesis: Plants exposed to higher light intensities will grow more compared to plants under lower light intensities.

Materials required: 20 potted bean plants (similar age and size), light source with adjustable intensity, ruler, water and watering can, soil with same composition, thermometers

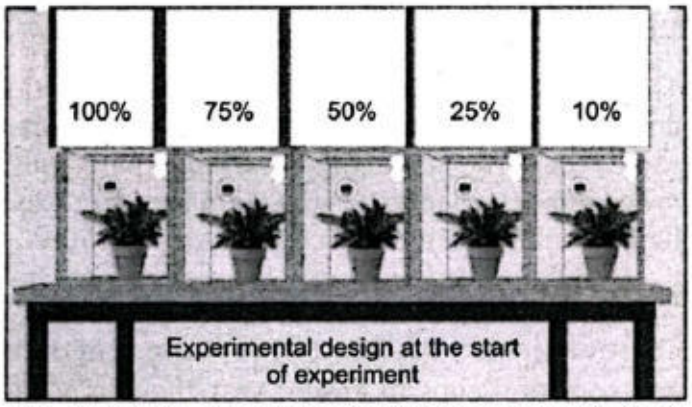


Fig. 11.3: Experimental design to check the effect of light intensity on plant growth

Procedure:

1. Divide the 20 potted plants into five groups of four plants each.
2. Place each group under different light intensities (e.g., 100%, 75%, 50% and 25%).
3. Ensure all groups receive the same amount of water and are kept at a constant temperature.
4. Measure the height of the plants every three days continuously for four weeks.
5. Record and analyze the growth data.

Variables:

Independent Variable: Light intensity (100%, 75%, 50%, 25% and 10%)

Dependent Variable: Plant growth; which we could be measured by tracking the height of the plants (in cm) and number of leaves of the plants.

Control Variables: Type of plant, type of soil, amount of water, temperature, duration of light, amount of CO_2, pot size and initial plant size.

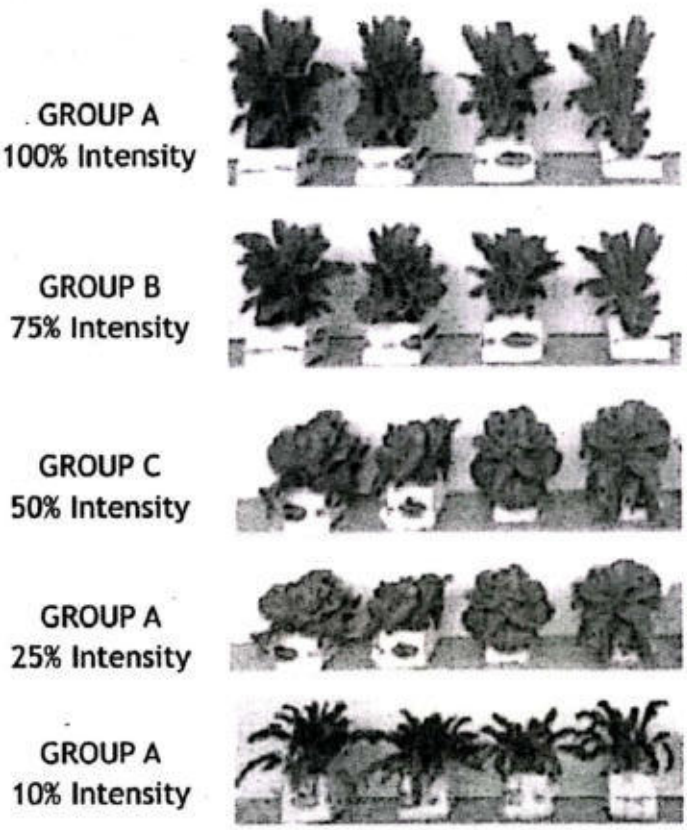


Fig. 11.4: Experimental results showing the effect of light intensity on plant growth

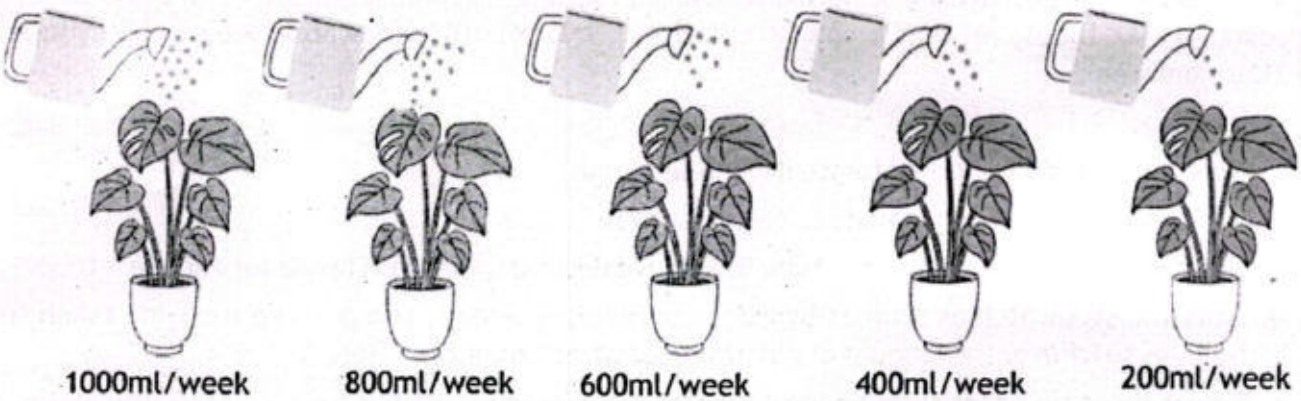
Control Group: Plants grown under the normal light intensity (e.g., 100%)

Experiment 2: Effect of different amounts of water on plant growth

Objective: To investigate how different amounts of watering, affects the growth of a specific plant (e.g., potato plants).

Hypothesis: Plants given more amount of water (1000ml per week) will grow more compared to plants given lower amount of water.

Materials required: 20 potato plants (similar age and size) in lager pots, water and graduated watering can, Light source with same intensity for all plants, ruler, soil with same composition, Thermometer.



Experimental Design at the start of experiment

Fig. 11.5: Experimental design to check the effect of amount of water on plant growth

Procedure:

1. Divide the 20 potato plants potted in larger but same size pots into five groups of four plants each.
2. Place all five groups under light of same higher intensity (100%) and at a constant temperature (30°C).
3. Give different amount of water per week to each group of plants (1000ml, 800ml, 600ml, 400ml and 200ml).
4. Measure the height (in cm) of the plants and number of leaves on each group of plants after every three days continuously for six weeks.
5. Record and analyze the data of plant growth.

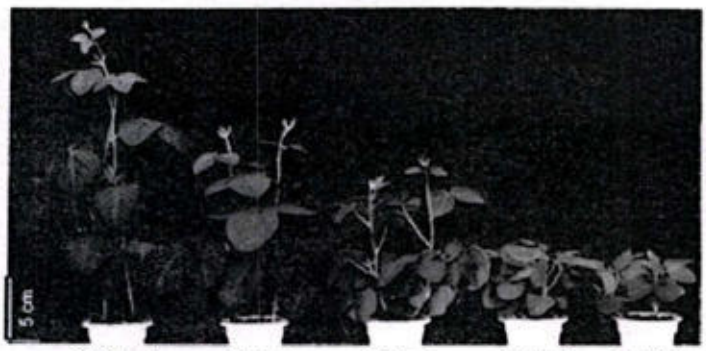


Fig. 11.6: Experimental results showing the effect of amount of water on plant growth

Variables:

Independent Variable: Amount of water given per week to each group of plants (1000ml, 800ml, 600ml, 400ml and 200ml)

Dependent Variable: Plant growth; which we could be measured by tracking the height of the plants (in cm) and number of leaves of the plants.

Control Variables: Type and species of plant, type of soil, duration and intensity of light,

temperature, amount of CO_2, pot size and initial plant size

Control Group: Plants watered 1000ml per week

Experiment 3: Effect of Different pH Levels on Enzyme Activity

Objective: To examine how pH levels affect the activity of the enzyme catalase in breaking down hydrogen peroxide.

Hypothesis: Catalase will have the highest activity at a neutral pH and will be less active in acidic or alkaline conditions.

Materials required: Hydrogen peroxide solution, catalase (can use potato or liver tissue as a source), Test tubes, pH buffer solutions (pH 4, pH 7, pH 10), Stopwatch, Measuring cylinder, Thermometer

Procedure:

1. Place an equal amount of catalase in each test tube.
2. Add 10 mL of hydrogen peroxide to each test tube.
3. Add different pH buffers to each tube to achieve desired specific pH levels for each test tube.
4. Start the stopwatch as soon as hydrogen peroxide is added, and observe the time taken for bubbles to form or the amount of gas produced after 1 minute.
5. Repeat three times for each pH and calculate the average.

Variables:

Independent Variable: pH level (pH 4, pH 7, pH 10)

Dependent Variable: Enzyme activity (rate of reaction measured by gas produced or reaction time)

Control Variables: Amount of hydrogen peroxide, amount of catalase, temperature, and test tube size

Control Group: Reaction at neutral pH (pH 7)

Above mentioned experiments, will give a hands-on and easily observable understanding to students of scientific methods and the effects of variables on biological processes.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. In experiment examining the effects of pH levels on the activity of the enzyme, independent variable will be
   A. pH B. Temperature C. Substrate D. Reaction time
2. The variable that the experimenter changes in the experiment to check its effect during experiment is called.
   A. Dependant variable B. Independent variable
   C. Control variable D. Experimental variable

3. Variables that researcher measure to determine the effect of the independent variable is also known as:
   A. Outcome variables B. Input variables C. Cause variables D. Control variable
4. To which of the following fields of life sciences, biostatistics is not applicable?
   A. Health B. Chemical engineering C. Agriculture D. Medicine
5. 25th percentile is the value ---------- of the data points lie.
   A. Above which 25% B. Below which 25% C. ¾ th D. 25
6. Biostatistics is not involved in:
   A. Epidemiological studies B. Agriculture C. Petroleum industry D. Public Health
7. The factors that must be kept constant during an experiment across both the experimental and control groups are known as
   A. Control variables B. Outcome variables C. Input variables D. Cause variables
8. All of the followings are types of averages except:
   A. Arithmetic Mean B. Median C. Mode D. Product of data values
9. The symbol for mean is:
   A. "$\bar{x}$" (read as "x bar") B. $\tilde{x}$ (read as "x tilde")
   C. "$\hat{X}$" (read as x-hat) D. "h" ("read as highly stable")
10. Formula of "Mean" for un-group data is:
    A. $\frac{\Sigma x}{n}$ B. $\frac{\Sigma fx}{\Sigma f}$ C. $\frac{\Sigma f1}{\Sigma f2}$ D. $\frac{n+1}{2}$
11. Find the mode from this dataset given 46, 49, 55, 58, 62, 66, 64, 65, 66, 67, 68, 70, 72:
    A. 46 B. 62 C. 66 D. 72
12. The first step in genetic engineering is:
    A. Isolation of the gene of interest
    B. Insertion of the gene into a vector
    C. Transfer of recombinant DNA into the host organism
    D. Expression of the gene
13. Biostatistics is similar to maths because of:
    A. Calculations B. Counting birds
    C. Used of symbol pie D. It is also useful in engineering studies
14. If the numbers of diseased persons is greater in 2nd year of study than 1st year then
    A. Height of the bar will be greater in 1st year
    B. Width of the bar will be greater in 1st year
    C. Height of the bar will be smaller in 1st year
    D. Width of the bar will be greater in 2nd year
15. In a bar chart of number of deaths due to hepatitis in Pakistan in last 10 years what will we write at the x-axes of graph?
    A. Years B. Number of deaths
    C. Any of the value D. Causes of hepatitis

Section II: Short Answer Questions

1. How Standard Deviation is different from Range?
2. What are the demerits of relying on range to decide future plans in scientific experiments?
3. Why control group is important for scientific experiments?
4. Define mean, median and mode.
5. Write down the formulae of median and mode.
6. What is importance of mean calculation?
7. Why value of mean is not completely reliable to get the correct picture?
8. Write the formula for calculation of Mode.
9. How bar chart is different from pie-chart?
10. Write one similarity and one difference between rectangle graph and pie-graph.
11. How graphical representation of data is important that tabular representation?
12. Find out the standard deviation of the values in following dataset.
    33, 55, 66, 84, 91, 72, 68, 87, 78, 66, 82, 46, 71, 31, 38
13. Calculate the median of the values given in dataset of above question 13.

Section III: Extensive Answer Questions

1. What are advantages and disadvantages of Median?
2. Describe detailed procedure to add error bars in the graph.
3. Complete the following table by filling the values of Cumulative frequency.

Class (no. of flowers/plant)	Frequency (no. of plants = n)	Cumulative frequency
1	30	
2	50	
3	60	
4	40	
5	30	

4. Give details steps to construct the Bar-chart.
5. For what the letters l, fm, f1, f2 and h stands for in the given formula? For which calculation this formula is used? $l + \left[\frac{(fm-f1) \times h}{(fm-f1)+(fm-f2)}\right]$
6. Sketch and label the Pie-chart by using the data given in the table below about the deaths of vulture birds due to pollution in last five years? Also label the data values in the pie-chart.

Years	2019	2020	2021	2022	2023
No. of deaths	250	400	275	350	175

7. Draw a table and then sketch and label the bar-chart by using the data of height (in cm) collected from 200 students of 12th class of your college.
8. Compare and contrast control variables, dependant variables and independant variables.
9. Describe the usage of percentile along with its demerits.
10. Describe stepwise details to make the appropriate chart with proper title, labeled axes, legend, axes units from a fictitious data set.

STRUCTURAL AND COMPUTATIONAL BIOLOGY

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-L-01] Define structural biology.
2. [B-12-L-02] Explain that structure determination of biomolecules is important.
3. [B-12-L-03] Describe how X-ray crystallography works.
4. [B-12-L-04] Outline the online databases where biomolecule structures are available.
5. [B-12-L-05] Describe computational Biology.
6. [B-12-L-06] Define Sequence Homology.
7. [B-12-L-07] Define Structural Homology.

As you learned in biotechnology chapter, that it is an emerging and ever growing branch of biology. It has many subfields including genetic engineering, synthetic biology, structural biology, computational biology, bioinformatics and many others. Here we will learn about structural and computational biology.

12.1 STRUCTURAL BIOLOGY

The study of the 3D structure and organization of biological molecules, such as proteins, nucleic acids (DNA/RNA), lipids, and carbohydrates, to understand their function, interactions, and role in biological processes is known as structural biology.

The emphasis of structural biology includes determining molecular structure, understanding molecular function and macromolecular complex formations. The techniques used are X-ray crystallography, Nuclear Magnetic Resonance (NMR) spectroscopy, Cryo Electron Microscopy (Cryo-EM), molecular dynamics simulations, bioinformatics and computational modelling.

The aims of structural biology are explaining biological mechanisms, developing new treatments, designing novel biomolecules and understanding disease mechanisms.

The advances in structural biology are applied in drug discovery and development, vaccine design, enzyme engineering, cancer research and neurological disorder studies.

12.2 THE IMPORTANCE OF STRUCTURAL DETERMINATION OF BIOMOLECULES

Determining the three-dimensional (3D) structure of biomolecules, such as proteins, DNA, and RNA, is crucial for understanding how they function in our bodies. This information is essential for understanding biological processes, developing life-saving treatments, and advancing biotechnology. Continued research in this field will unlock new discoveries, improving human health and quality of life.

a. **Understanding Function and Mechanism:** The structure of a biomolecule reveals its function. Imagine a key and a lock - the structure of the key determines how it fits into the lock. Similarly, the structure of a biomolecule determines how it interacts with other molecules. Knowing the structure helps us understand how biomolecules perform specific tasks, such as enzyme catalysis or protein-protein recognition.

b. **Designing Life-Saving Treatments:** Accurate structural information enables the design of targeted therapies. By knowing the shape and chemical properties of a biomolecule, researchers can create drugs that specifically bind to and inhibit or activate it. This has led to breakthroughs in treating diseases like cancer, HIV, and Alzheimer's.

c. **Understanding Disease Mechanisms:** Structural biology helps us comprehend disease mechanisms. By studying the structure of disease-associated biomolecules, we can identify vulnerabilities to target with treatments. For example, understanding the structure of the influenza virus has informed vaccine development.

d. **Advancing Biotechnology:** Structural biology drives innovation in biotechnology. Knowing biomolecular structures enables the design of novel enzymes, biosensors, and biomaterials. This has led to advancements in biofuels, agriculture, and biomedical devices.

e. **Enabling Personalized Medicine:** Structural biology informs personalized medicine. By understanding individual variations in biomolecular structures, researchers can develop tailored treatments. This approach has shown promise in cancer treatment and genetic disorders.

12.3 X-RAY CRYSTALLOGRAPHY

X-ray crystallography is a powerful tool for determining the three-dimensional (3D) structure of biomolecules, such as proteins, DNA, and RNA. X-ray crystallography has revolutionized our understanding of biomolecular structure and function, enabling breakthroughs in medicine, biotechnology, and materials science. This technique uses X-rays to scatter off electrons in a crystallized biomolecule, producing a diffraction pattern that reveals the molecule's atomic structure. It has following steps:

Step 1: Crystallization

The process begins with crystallizing the biomolecule. This involves dissolving the molecule in a solution and slowly cooling or evaporating the solvent to form a crystal lattice. The crystal must be high-quality, with uniform orientation and minimal defects.

Step 2: X-Ray Diffraction

The crystal is then exposed to a beam of X-rays, which scatter off the electrons in the biomolecule. This scattering produces a diffraction pattern, consisting of intense spots or reflections. The diffraction pattern is captured on a detector, such as a CCD camera.

Step 3: Data Collection and Processing

The diffraction data are collected and processed using specialized software. The data are indexed, integrated, and scaled to produce a set of reflection intensities. These intensities represent the amplitude of the scattered X-rays. The reflection intensities are used to reconstruct the **3D electron density map** of the biomolecule. This is achieved through mathematical techniques. The electron density map reveals the arrangement of atoms within the molecule.

Step 4: Model Building and Refinement

A molecular model is built into the electron density map, using software. The final result is a precise 3D structure of the biomolecule, revealing its atomic arrangement, bond lengths, and angles. This information is essential for understanding biological mechanisms, designing drugs, and engineering biomolecules.

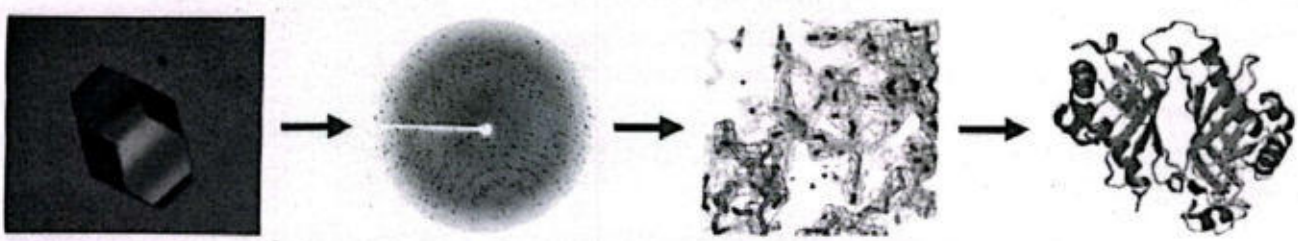


Fig. 12.1: X-ray crystallography

12.4 ONLINE DATABASE FOR BIOMOLECULE STRUCTURES THE PROTEIN DATA BANK (PDB)

The Protein Data Bank (PDB) is a freely accessible online database (www.wwpdb.org) that stores and provides three-dimensional (3D) structural information of biomolecules, including proteins,

nucleic acids, lipids, and carbohydrates. Established in 1971, the PDB is managed by the Worldwide Protein Data Bank (wwPDB) consortium, comprising leading research institutions and organizations. The database has grown exponentially, now containing over 180,000 biomolecule structures.

The PDB contains 3D atomic coordinates for biomolecules, structural information, experimental and functional data. The PDB serves as a cornerstone for biomolecular research, providing essential structural information to advance our understanding of biological processes and develop innovative treatments.

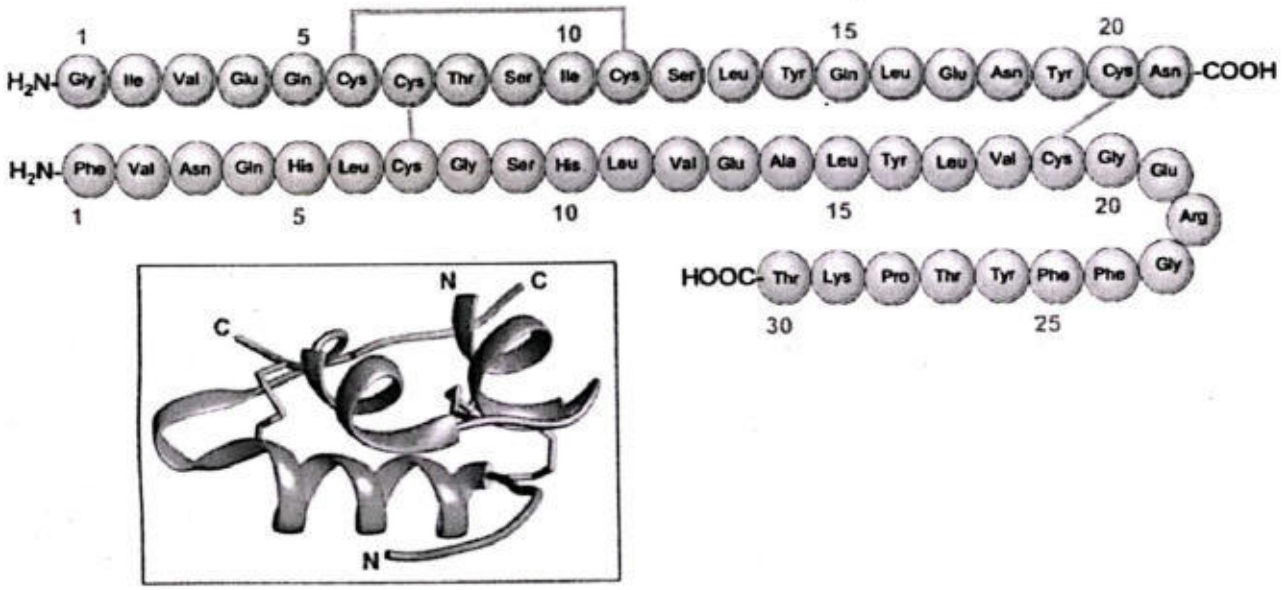


Fig. 12.2: Insulin structure details on PDB

12.5 COMPUTATIONAL BIOLOGY

Computational biology is an interdisciplinary field that combines computer science, mathematics, and biology to analyse and model biological systems. This field utilizes computational tools and methods to understand complex biological processes, interpret large datasets, and make predictions.

Computational biology is applied in personalized treatments based on individual genetic profiles, understanding gene regulation and function, modelling protein 3D structures, rapid analysis of large data, understanding of complex biological systems and disease mechanisms, phylogenetic and synthetic biology.

Tools and methods used in computational biology are algorithms, machine learning, database management and programming languages.

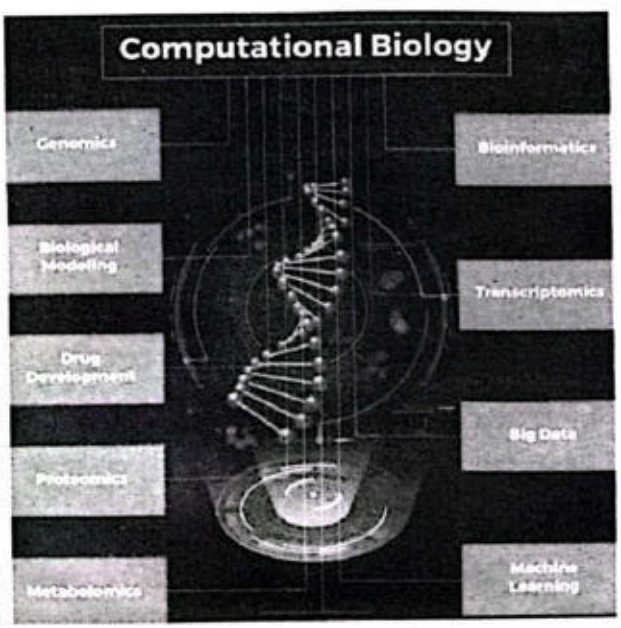


Fig. 12.3: Key areas of computational biology

By integrating computer science and biology, computational biology continues to advance our understanding of life and improve human health.

12.6 COMPUTATIONAL EVOLUTIONARY BIOLOGY

Computational evolutionary biology uses computational methods and algorithms to study evolution, particularly by analysing large data sets of genomics, transcriptomics and other related biological information.

Homology is the similarity of the structure, physiology, or development of different species of organisms based upon their descent from a common evolutionary ancestor. Here we will discuss sequence and structure homology.

12.7 SEQUENCE HOMOLOGY

Sequence homology is the study of similarities and relationships between biological sequences, such as DNA, RNA, or protein sequences. This concept is fundamental to understanding evolutionary relationships, functional conservation, and genetic diversity.

Sequence homology is the presence of shared sequences or structural features between two or more biological molecules, indicating a common ancestral origin.

Sequence homology provides a powerful tool for understanding the intricate relationships between biological sequences, shedding light on the complex history of life on Earth.

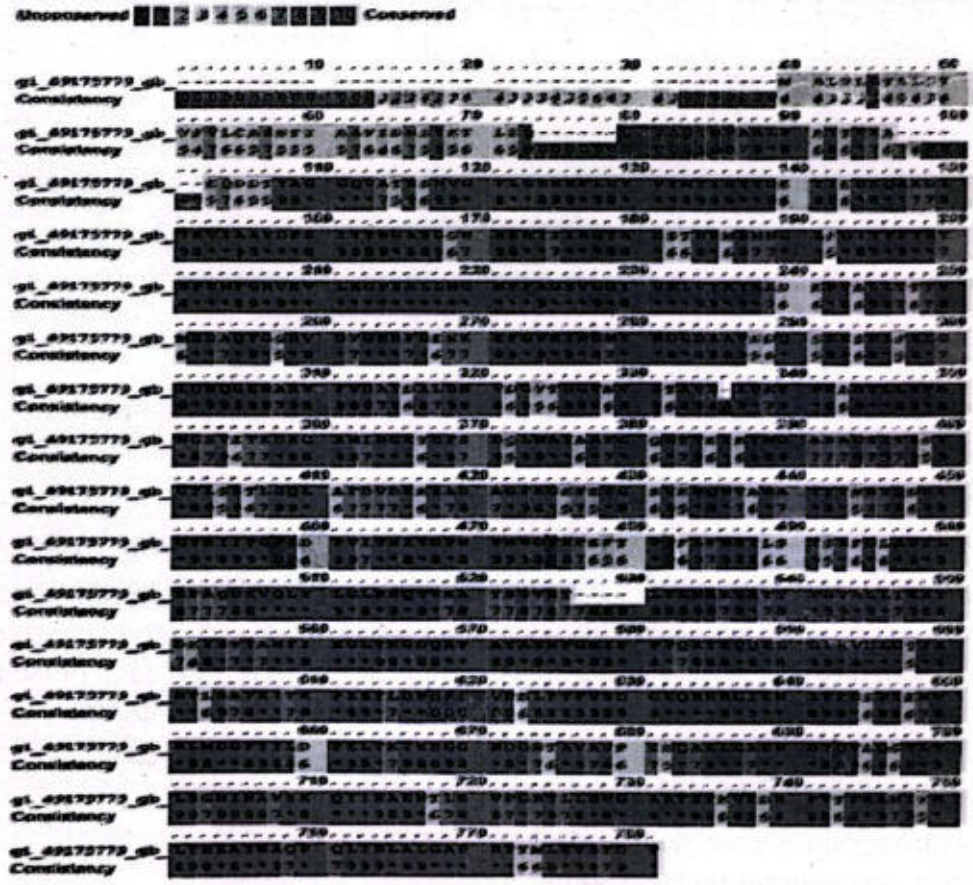


Fig. 12.4: BauA sequence homology shown in 25 samples. BauA is a protective antigen found in mice that is why it's sequence is conserved in most samples.

12.8 STRUCTURAL HOMOLOGY

Structural homology refers to similarities in three-dimensional (3D) structures among biological molecules, such as proteins, RNA, or DNA. This concept reveals shared architectural features, indicating evolutionary relationships or functional conservation.

Structural homology is the presence of similar 3D structures or substructures between two or more biological molecules, suggesting a common ancestral origin or functional analogy.

Structural homology provides valuable insights into the shared architectural features of biological molecules, illuminating the complex relationships between structure, function, and evolution.

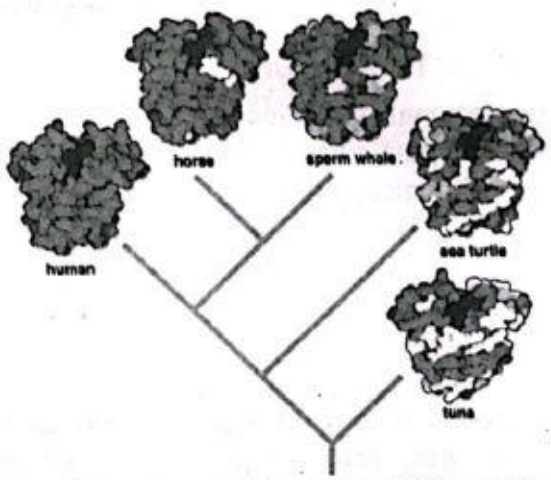


Fig. 12.5: Structural homology of Myoglobin molecule in different mammals

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. The function of protein is very much dependent on its:
   A. size B. number of amino acids C. 3D structure D. types of amino acids
2. Structure of biomolecules can be very helpful to understand the:
   A. spread of diseases B. mechanism of diseases
   C. cause of diseases D. symptoms of diseases
3. Lock and key model is applicable to:
   A. active site of enzyme and substrate B. hormones and their receptors
   C. antigens recognized by antibodies D. all of above
4. Targeted therapies can be more effective against:
   A. bacterial infections B. viral infections C. metabolic diseases D. syndromes
5. There are more than 200 types of cancers. Proper treatment of a specific cancer requires personalized medicines because each cancer has a:
   A. different name B. different effect on each person
   C. specific cell surface marker D. different set of symptoms
6. X-ray crystallography cannot be done on liquid or gaseous sample because:
   A. 3D electron maps are formed on solids
   B. X-ray diffraction is done on crystals
   C. solutions on evaporation form solids
   D. gases on slow cooling can form liquids

7. As a Pakistani student you can access the Protein Data Bank:
   A. by using VPN
   B. after paying require fee
   C. freely via internet
   D. if you get reference letter from concerned department
8. The rRNA sequence of all organisms has homology. It shows that all organisms:
   A. use ribosomes for protein
   B. have same size of ribosomes
   C. have evolved from common ancestor
   D. have same types of ribosomes
9. Structural homology of myoglobin in different mammals is helpful for these organisms as:
   A. it gives their meat red colour
   B. similar shapes are related with similar functions
   C. myoglobin can replace haemoglobin function when required
   D. different mammals eat each other so they can use it in their bodies
10. The Protein Data Bank provide information about:
   A. all molecules B. all proteins C. all enzymes D. all biomolecules

Section II: Short Answer Questions

1. How is the structure of molecule is related with its function?
2. How does structural biology give hope to cancer treatment research?
3. If you want to study the structure of pepsin enzyme, what will you do?
4. Which fields of science are related to computational biology?
5. Define structural biology, X-ray crystallography, computational biology, PDB, sequence homology and structural homology.

Section III: Extensive Answer Questions

1. Why is it necessary to determine the structure of biomolecules?
2. Describe the steps of X-ray crystallography.
3. Differentiate between sequence and structural homology.

CLIMATE CHANGE

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-U-01] Describe how climate change impacts flora and fauna.
2. [B-12-U-02] Describe how climate change can impact ocean biology in terms of its temperature and acidity as well as the resulting harmful effects.
3. [B-12-U-03] Name species that have gone extinct due to climate change.

Weather and **climate** are two closely linked terms often considered as synonyms by many people though these are quite different concepts. Weather is short term changes in environmental conditions such as temperature (hot and cold), water vapours in atmosphere (humid or dry air), precipitation (rain, snow, hails or dew), daylight (cloudy or sunny) and water availability (flooding or drought). On the other hand, climate is overall pattern of weather in an area that prevails over a period of few decades to even centuries. For example: ocean, forest, deserts and plains have all weathers, but each has distinct climate. In this chapter, you will learn about the concept of climate change, its causes and impacts on biotic and abiotic components of earth ecosystem.

13.1 CLIMATE CHANGE, ITS CAUSES AND IMPACTS ON BIODIVERSITY

Climate change refers to the long-term, gradual and apparently irreversible changes in climatic conditions of an area that may affect the whole world with passage of time. Major events of climate change include:

(i) Average rise in global air (atmospheric) temperature,
(ii) ocean acidification,
(iii) changes in the seasonal duration,
(iv) changes in the monsoon raining pattern,
(v) extreme hot and cold, and
(vi) extreme flooding and drought etc.

While climate naturally changes over thousands and millions of years due to factors like volcanic eruptions and variations in Earth's orbit, the term climate change today often refers to human-caused (**anthropogenic**) climate changes happening rapidly over the last century after industrial revolution.

13.1.1 Causes of Climate Change (Extra reading material)

The Earth's climate is driven by the balance of energy entering and leaving the atmosphere. This balance is disrupted by both natural and anthropogenic factors:

Natural Factors Causing Climate Change

Natural processes can influence Earth's climate over long periods of time, though their effects are often gradual and cyclical.

i. Volcanic Activity

Large volcanic eruptions release huge amounts of dust, ash and gases like sulfur dioxide into the atmosphere. These particles can block sunlight, causing temporary cooling of the Earth's surface. However, volcanic eruptions also release CO_2, contributing to the greenhouse effect over time.

ii. Solar Variability

The Sun's energy output is not constant and can vary over time due to solar cycles. Changes in solar radiation can influence Earth's climate. During periods of higher solar activity, more solar energy reaches the Earth, causing temporary warming.

Fig. 13.1: Volcanic eruption in 2018 near Antigua, Guatemala, Central America.

iii. Milankovitch Cycles

These are long-term changes in the Earth's orbit and axial tilt, affecting the amount of sunlight the planet receives. The shape of the Earth's orbit (eccentricity), the tilt of its axis (obliquity), and direction of its axis (precession) change slowly and periodically over time. These cycles cause variations in the amount of solar energy reaching the Earth.

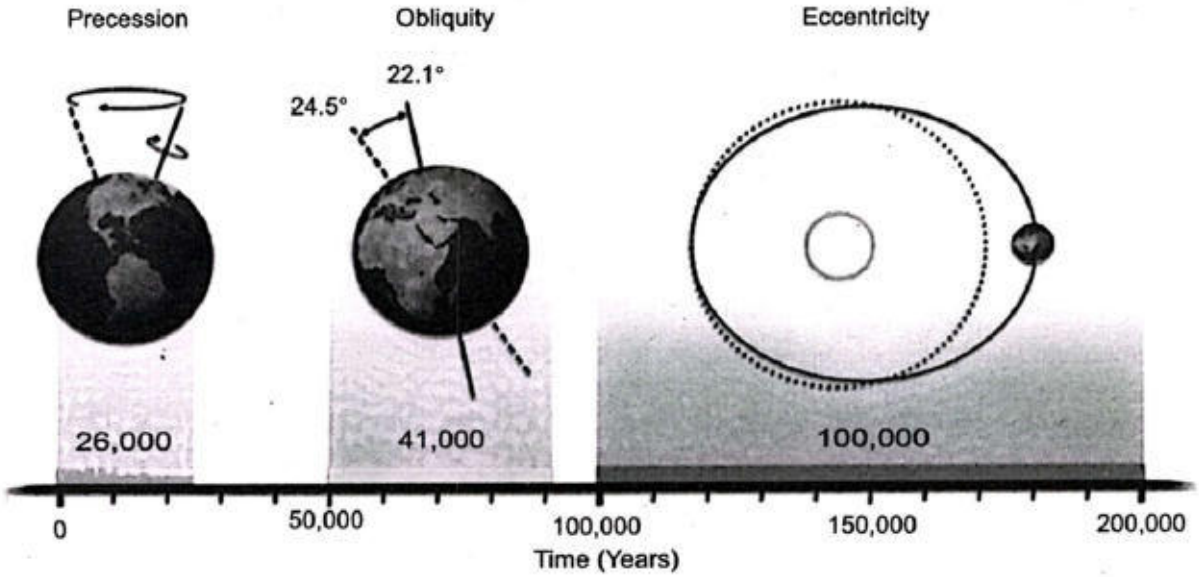


Fig. 13.2: Milankovitch Cycles

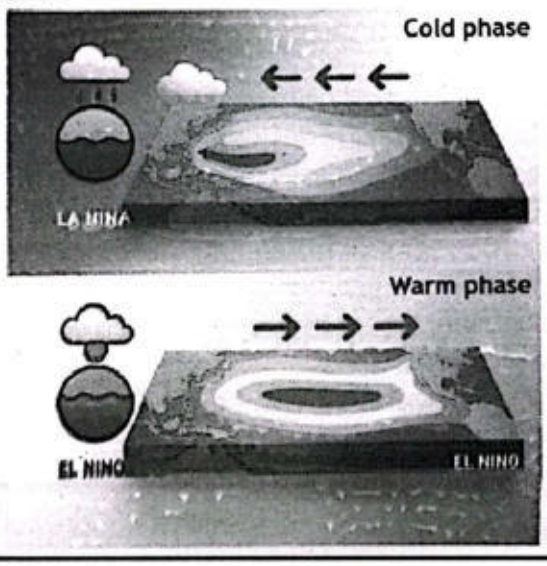
Eccentricity: This cycle affects the shape of the Earth's orbit around the Sun, alternating between more circular and more elliptical orbits. The cycle occurs over 100,000 years.

Axial Tilt (Obliquity): This cycle refers to changes in the angle of the Earth's tilt on its axis. The tilt varies between 22.1° and 24.5° over a period of about 41,000 years.

Precession: This is the wobble or change in the direction of the Earth's axis of rotation, like a spinning top. This cycle has a duration of about 26,000 years.

CONCEPT BUILDER

El Niño and La Niña are opposite phases of a climate pattern known as the **El Niño-Southern Oscillation (ENSO)**, which significantly influences global weather and climate conditions. **El Niño** brings warmer sea surface temperatures in the central/eastern Pacific, leading to wetter and warmer conditions in some regions and drought in others. **La Niña** brings cooler sea surface temperatures, leading to more rainfall in some areas (like Southeast Asia) and drier, cooler conditions in others (like South America). Both phenomena can last for several months and have widespread effects on weather, agriculture, ecosystems, and economies globally.



iv. Ocean Currents

The oceans store and transport heat around the world through currents. Changes in ocean circulation patterns, such as El Niño and La Niña events, can cause short-term climate changes, affecting weather patterns like rainfall and temperature distribution.

v. Natural Greenhouse Gas Emissions

Naturally occurring processes like the decay of organic matter, respiration of plants and animals, and wetlands release greenhouse gases like carbon dioxide (CO_2) and methane (CH_4) into the atmosphere. These gases trap heat, contributing to the natural greenhouse effect.

Anthropogenic (Human-Caused) Factors Causing Climate Change

Human activities since the Industrial Revolution have been the primary drivers of rapid climate change. These activities significantly increase the concentration of greenhouse gases in the atmosphere, accelerating global warming. Major anthropogenic factors include:

i. Deforestation and urbanization

Trees absorb CO_2 through photosynthesis, helping to regulate the Earth's climate, therefore called **environmental buffers.** Deforestation is the cutting of trees by man for various purposes. When forests are cut down for agriculture, logging, or urban development i.e., expansion of cities (urbanization), this carbon sink is lost (Fig. 13.3). Additionally, burning trees during deforestation releases stored CO_2 into the atmosphere.

Fig. 13.3: (a) Deforestation and (b) Urbanization contributing in climate change

ii. Burning of Fossil Fuels

The combustion of coal, oil, and natural gas for energy production, transportation, and industry is the largest source of CO_2 emissions. This leads to an enhanced greenhouse effect, where more heat i s trapped in the atmosphere, causing the planet to warm.

iii. Industrial Processes and Agriculture

Industrial activities like cement production and certain chemical processes release CO_2 and other gases. Agriculture is a significant source of methane (CH_4), especially from livestock (cows and sheep) and rice paddies, as well as nitrous oxide (N_2O) from fertilizers.

Fig. 13.4: Industrial processes releasing greenhouse gases contribute in climate change

iv. Land Use Changes

Beyond deforestation, other land use changes such as urbanization and soil degradation also contribute to climate change by reducing natural vegetation that absorbs carbon and increasing heat absorption by cities (urban heat islands).

v. Waste Management

Landfills produce methane (CH_4) as organic waste breaks down. Improperly managed waste, including food waste and discarded products, increases the release of greenhouse gases.

vi. Transportation

The global reliance on vehicles powered by gasoline and diesel engines emits significant amounts of CO_2. Air travel and shipping also contribute to greenhouse gas emissions.

vii. Aerosols and Chemicals

Human-made aerosols, such as those from industrial pollution, can have both cooling and warming effects on the climate. Some aerosols reflect sunlight (cooling effect), but others, such as black carbon (soot), absorb heat and contribute to warming. Additionally, chlorofluorocarbons (CFCs) and other chemicals not only damage the ozone layer but are also potent greenhouse gases.

13.1.2 Impact of Climate Change on Biodiversity (Flora and Fauna)

The flora (overall plants) and fauna (overall animals) in an area together referred to as biodiversity. Although, climate change has its impact on all environmental compartments, but biodiversity shows significant impact of climate change.

Impact of Climate Change on Flora (Plants)

Plants depend on specific conditions like temperature, rainfall, and soil quality to grow. Climate change alters these conditions, making it difficult for many plants to survive.

i. Changes in Growing Seasons

The growing season is the time of year when plants can grow due to favorable temperatures conditions. With climate change, growing seasons are becoming longer in some regions and shorter in others. This inconsistency affects when plants flower, produce fruit, or go dormant.

ii. Increased Stress from Extreme Weather

As climate change causes more frequent and intense storms, floods, or droughts, plants may struggle to survive. Droughts can dry out the soil, preventing plants from getting enough water, while floods can waterlog their roots.

iii. Migration of Plants

Plants can not move like animals, but seeds can spread to new areas through wind, water or animals. As climates change, plants that once thrived in a particular area may begin growing in new regions better suited to the altered climate, while others might disappear from their original habitats.

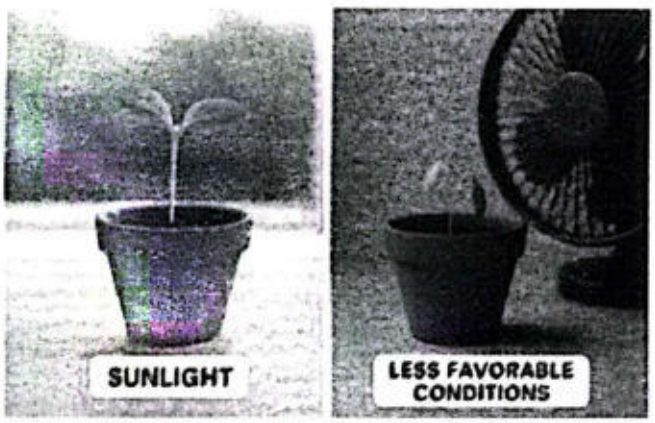


Fig. 13.5: Activity to demonstrate the impact of changes in growing seasons.

Plant two seeds in two small pots. Place one in normal sunlight and water it regularly. Place the other in a colder or less favorable environment (such as in a shaded area or near a fan to simulate a colder climate). Observe how differently the two plants grow. This demonstrates how environmental conditions affect plant growth.

Impact of Climate Change on Fauna (Animals)

Animals rely on stable ecosystems to find food, shelter, and mates. Climate change disrupts these ecosystems, causing a wide range of problems for wildlife.

i. Loss of Habitat

As temperatures rise, many animals lose their habitats. For example, polar bears rely on sea ice to hunt for seals. When the ice melts due to warming, they struggle to find food. This simulates the impact of climate change on animals' habitats.

Fig. 13.6: Impact of climate change on Polar Bear' habitat.

ii. Shifting Habitats

Just like plants, animals often need to move to new regions to find suitable climates. For example, birds that once migrated to warmer regions during winter may have to adjust their migration patterns as temperatures shift.

iii. Food Chain Disruption

Animals depend on specific plants and other animals for food. When climate change affects one species (e.g., a plant or prey animal), it also impacts the animals that rely on it. For example, if a type of plant that an insect feeds on goes extinct due to changing climate, the insect population will decline, which then affects animals that eat those insects.

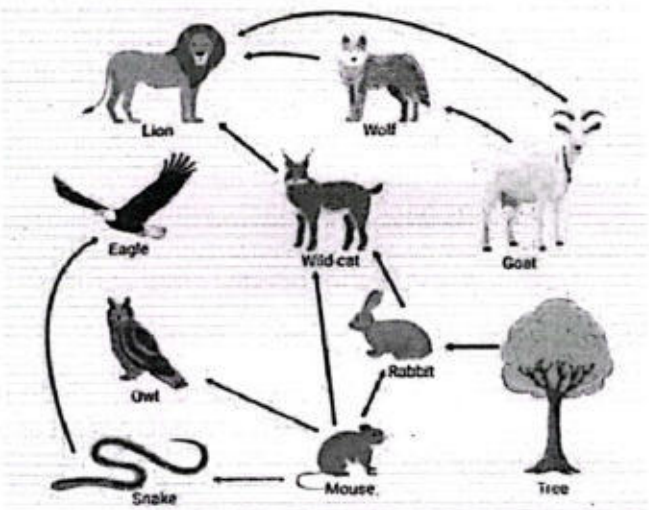


Fig. 13.7: Network of food chains (food web).

iv. Breeding and Hibernation Cycles

Many animals rely on specific temperature and weather conditions for breeding, hibernation, and migration. Climate change can throw off these cycles. For example, some animals hibernate in winter and wake up in spring when food is available. If spring comes too early or late, they may wake up at the wrong time, with no food around.

v. Ecosystem Balance and Extinction

Flora and fauna are part of an interconnected web. When one species struggles or disappears, it affects the whole system. If plants or animals can't adapt to the rapid changes in climate, they may go extinct, disrupting the balance of the ecosystem.

vi. Invasive Species

As some species move to new areas to escape changing climates, they may invade habitats where they don't naturally belong. These invasive species can outcompete native plants or animals for resources, which can harm the ecosystem.

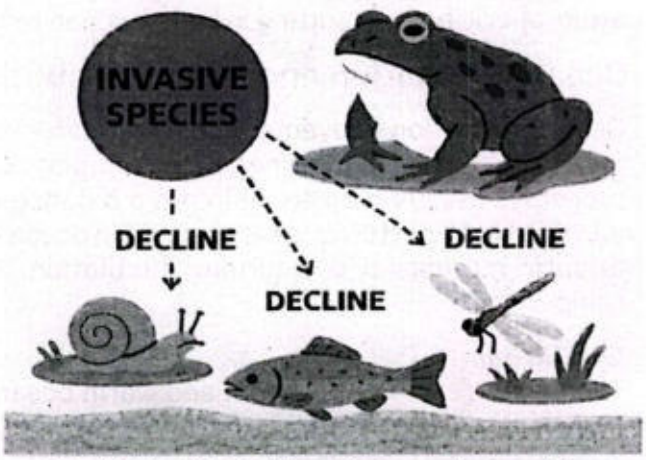


Fig. 13.8: Effect of invasive species on other species.

vii. Species Adaptation

Some species are better at adapting to new climates, but many can't keep up with the speed of climate change. Species that evolve quickly might survive, while others face extinction.

13.2 CLIMATE CHANGE IMPACTS ON OCEAN ECOSYSTEM

Climate change impacts on ocean ecosystem in three ways i.e., by causing:

i. Rise in ocean temperature
ii. Decrease in ocean pH (increased acidity)
iii. Effects on the growth of ocean biodiversity

13.2.1 Climate Change impacts Ocean Temperature

Climate change impacts ocean temperatures through several human and natural factors:

Global Warming and the Greenhouse Gasses

The process of **global warming**, primarily driven by the buildup of greenhouse gases (such as carbon dioxide, methane, and nitrous oxide) in the atmosphere. Human activities, particularly the burning of fossil fuels (coal, oil, gas), deforestation, and industrial processes, have increased the concentration of greenhouse gases in the atmosphere. These gases trap heat, preventing it from escaping back into space, which leads to global warming. The oceans absorb much of this excess heat, resulting in higher ocean temperatures.

SCIENTIFIC ENQUIRY

Warmer water expands, a process known as **thermal expansion**, which contributes to rising sea levels. This process occurs as water molecules move further apart when they are heated, leading to the expansion of the ocean's volume.

How can you prove thermal expansion in the laboratory.

High heat capacity of ocean

The oceans have a high heat capacity, which means they can absorb and store vast amounts of heat without experiencing a dramatic increase in temperature. This property also causes rise in ocean temperature.

Large surface area of oceans

Since the oceans cover more than 70% of the Earth's surface, they absorb about 90% of the atmospheric heat, resulting in higher ocean temperatures.

Ocean Circulation and Heat Distribution

Ocean circulation (movement of ocean water vertically or horizontally) and heat distribution play a critical role in regulating ocean temperatures across different regions of the world. These processes usually help to maintain a balance in ocean heat distribution, but climate change is altering these patterns, causing a rise in ocean temperatures in several ways, such as gulf stream, atlantic meridional overturning circulation, El Nino and La Nina Events, Sea Ice and ocean temperature.

Gulf Stream

The Gulf Stream is a powerful and warm ocean current that originates in the Gulf of Mexico and flows along the eastern coast of the United States before crossing the Atlantic Ocean toward Europe. It plays a key role in regulating the climate of the North Atlantic region and has a significant impact on weather patterns, especially in North America and Western Europe.

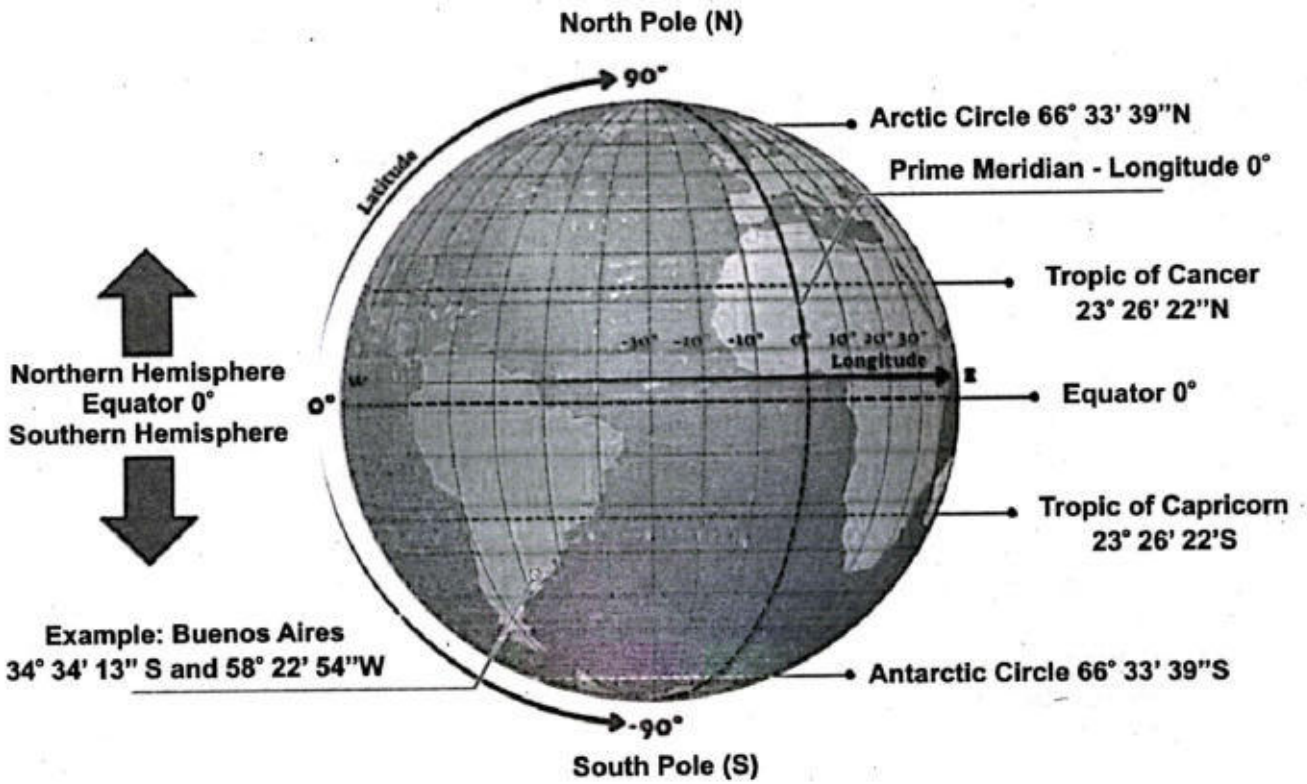


Fig. 13.9: Geographical distribution of earth. The numbers like 23° 26' 22" N, represent the geographic coordinates that specify the exact latitude. For example: 23° 26' 22" N is the precise position of the Tropic of Cancer, which is one of the major circles of latitude on Earth.

23°: This represents 23 degrees of latitude north of the equator.

26': The single apostrophe (') represents 26 minutes of latitude. There are 60 minutes in one degree.

22": The double apostrophe (") represents 22 seconds of latitude. There are 60 seconds in one minute.

N: Indicates that this latitude is in the Northern Hemisphere.

Meaning: The Tropic of Cancer is located at 23 degrees, 26 minutes, and 22 seconds north of the equator.

Normally, this heat is distributed more evenly across the globe. Climate change is causing these currents to weaken or shift, leading to an uneven distribution of heat. For example, some regions may experience a buildup of heat, causing ocean temperatures to rise more rapidly.

Atlantic Meridional Overturning Circulation (AMOC)

Atlantic Meridional Overturning Circulation (AMOC) is a type of ocean current, which carries warm surface water from the tropics to the North Atlantic, where it cools and sinks before flowing back toward the equator as cold, deep water.

As global temperatures rise due to climate change, polar ice melts, adding large amounts of freshwater into the North Atlantic. This reduces the water's salinity, making it less dense and preventing it from sinking as usual. When the AMOC slows down, less heat is transported to the poles, causing warmer ocean temperatures in tropical and subtropical regions. This warming further contributes to rising ocean temperatures and disrupts weather patterns globally.

El Niño and La Niña Events

El Niño and La Niña are climate phenomena that result from changes in ocean circulation in the Pacific Ocean, affecting global weather and ocean temperatures.

El Niño events occur when warm surface waters shift eastward toward the coast of South America, leading to warmer ocean temperatures in the central and eastern Pacific. This also affects weather patterns around the world, contributing to rising temperatures. La Niña is the opposite, where cooler waters dominate, but the later strong El Niño events often causes a significant increase in global ocean temperatures.

Sea Ice and Ocean Temperature

As ocean temperatures rise, sea ice and glaciers at the poles (particularly in the Arctic and Antarctic) are melting at an accelerated rate. Sea ice acts as a reflective shield, bouncing sunlight back into space. When it melts, darker ocean water is exposed, which absorbs more heat, further accelerating ocean warming.

CRITICAL THINKING

Climate change creates feedback loops that amplify ocean warming. For example, as ice melts and more heat is absorbed by the ocean, the ocean's ability to store carbon dioxide diminishes. This, in turn, increases atmospheric CO_2 levels, trapping more heat and further warming both the atmosphere and the oceans.

Is this feedback positive or negative?

CRITICAL THINKING

Even if greenhouse gas emissions were to stop today, the heat already absorbed by the oceans would continue to warm the planet for centuries. This is known as committed warming.

Why does this happen?

13.2.2 Climate Change impacts Ocean Acidification (Low pH)

Climate change is significantly contributing to ocean acidification, a process where the ocean becomes more acidic (lower pH) due to the absorption of increasing amounts of carbon dioxide (CO_2) from the atmosphere.

Ocean as a Carbon Sink

The ocean acts as a carbon sink, meaning it absorbs large quantities of CO_2 from the atmosphere. Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has increased dramatically due to human activities like burning fossil fuels (coal, oil, and gas), deforestation, and industrial processes. To balance the increased atmospheric CO_2, the ocean has absorbed about 30% of this excess CO_2.

CO_2 Dissolving in Ocean Water

When CO_2 dissolves in seawater, it undergoes a chemical reaction to form carbonic acid (H_2CO_3):

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Carbonic acid is unstable and dissociates into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+):

$$H_2CO_3 \rightarrow HCO_3^- + H^+$$

The increase in hydrogen ions (H^+) is what causes the pH of the ocean to decrease, making the ocean more acidic. Ocean acidification refers to this long-term lowering of pH levels due to the absorption of CO_2. Ocean acidification and climate change are interlinked. As climate change causes ocean temperatures to rise, it reduces the ability of the ocean to absorb CO_2. Warmer water holds less gas, meaning that in the future, more CO_2 will remain in the atmosphere,

accelerating global warming.

As the ocean becomes more acidic, it affects the delicate balance of ocean chemistry, which has serious consequences for marine life and ecosystems.

Regional Variations in Ocean acidification

Ocean acidification doesn't happen evenly across the globe. Some regions, like the polar oceans, are more vulnerable. Cold water absorbs more CO_2 than warm water, which means that areas like the Arctic and Southern Oceans are acidifying faster. This puts polar marine life, such as cold-water corals species that thrive in these environments, at greater risk.

13.2.3 Harmful Effects of High Ocean Temperature and Ocean Acidification on Marine Biology

High ocean temperatures and ocean acidification, both consequences of climate change, have profound and harmful effects on marine biology. These environmental changes threaten the survival of numerous marine species and ecosystems, disrupting food webs, biodiversity, and the services oceans provide to humanity.

Harmful Effects of High Ocean Temperature on Marine Biology

High Ocean Temperature affects marine life in several ways:

Coral bleaching

Coral reefs are among the most diverse ecosystems in the ocean, but they are extremely sensitive to temperature changes. When ocean temperatures rise, corals experience stress, which causes them to expel the symbiotic algae (called **zooxanthellae)** that live within their tissues and provide them with nutrients. This phenomenon where corals expel the symbiotic algae living in their tissues, causing the coral to turn completely white or pale is called **Coral bleaching.** The loss of the algae exposes coral's white calcium carbonate skeleton, giving the coral a "bleached" appearance. While bleached corals are not dead, they are more vulnerable to diseases and are unable to grow or reproduce efficiently.

Fig. 13.10: Bleaching was recorded in coral reefs of National Marine Sanctuary of American Samoa (a US territory located in the Polynesia region of the South Pacific Ocean) between 2014 and 2015.

Prolonged exposure to high temperatures leads to coral death, and the loss of coral reefs results in the destruction of habitats for many marine species, threatening the biodiversity and ecosystem services which reefs provide, such as coastal protection and fisheries.

Disruption of Marine Ecosystems

Temperature-sensitive species, such as certain types of fish and plankton, are particularly affected by rising temperatures. Many species must migrate to cooler waters, shifting the balance of ecosystems and affecting food chains.

Species that can't migrate quickly enough or that depend on specific habitats may face local or global extinction. For example, fish populations that live in cooler waters may decline, disrupting

the marine food web, from small plankton to large predators.

Impact on Fish Reproduction and Growth

Many fish species are cold-blooded, meaning their body temperatures are influenced by the surrounding water temperature. Warmer oceans can alter the metabolism, growth, and reproduction of these species.

Warmer waters can cause fish to grow smaller, affecting their reproductive success and survival rates. For example, certain fish species may produce fewer offspring or experience developmental problems in warmer environments.

Marine Heatwaves

Just like heatwaves on land, the ocean experiences periods of extreme heat called marine heatwaves. These events have intensified with climate change, causing mass die-offs of marine species, including fish, shellfish, and marine mammals.

Melting Polar Ice and Habitat Loss

In polar regions, rising ocean temperatures are causing sea ice to melt. Many species, such as polar bears, seals, and walruses, depend on sea ice for hunting and breeding. As the ice disappears, these species face habitat loss and are forced to migrate or adapt to unfamiliar environments, leading to population declines. The loss of sea ice also impacts the food chains in these regions, particularly affecting krill, an important food source for whales, seals, and penguins.

Fig. 13.11: Antarctic Krill (Genus: *Euphausia*) a Crustacean Arthropod.

Ocean Deoxygenation

Warmer ocean waters hold less oxygen, leading to areas of low oxygen concentration (**hypoxic zones**) or even dead zones (**anoxic zones**), where oxygen is so depleted that marine life cannot survive. Fish, crabs, and other marine species either die or move to other regions, further stressing marine ecosystems. Deoxygenation disrupts marine biodiversity and can lead to declines in fisheries.

Harmful Effects of Ocean Acidification on Marine Biology

Ocean acidification affects marine life in several ways:

Impact on Calcifying Organisms

Many marine organisms, such as corals, shellfish (oysters, clams), sea urchins and plankton rely on calcium carbonate ($CaCO_3$) to build their skeletons and shells. These are called calcifying organisms. As ocean acidification lowers the pH of seawater, it reduces the availability of carbonate ions (CO^{2-}_3), which these organisms need to form

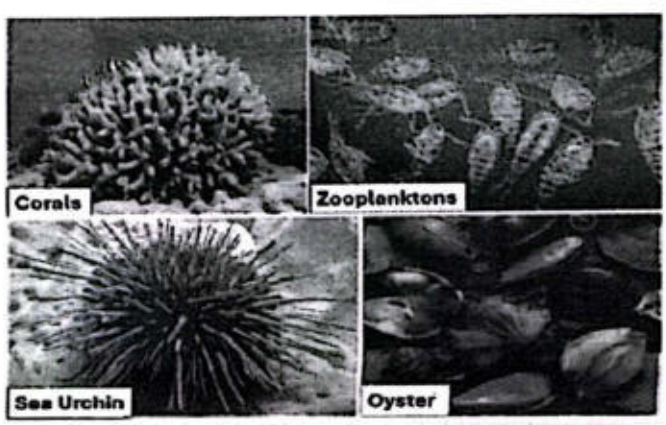


Fig. 13.12: Calcifying Organisms

calcium carbonate. This makes it harder for them to build and maintain their skeletons and shells. For example:

i. Oyster larvae struggle to form shells in acidic water,

ii. leading to high mortality rates in oyster populations.

iii. Coral reefs, which provide critical habitats for many marine species, are at risk of erosion and collapse as ocean acidification weakens their structures. The loss of coral reefs would have cascading effects throughout marine ecosystems.

Disruption of Food Chains

Plankton, particularly species like pteropods (tiny marine snails), are at the base of many marine food webs and are especially vulnerable to ocean acidification. Pteropods and other planktonic organisms struggle to form their shells in acidic water. As plankton populations decline, the species that depend on them for food, such as fish, whales, and seabirds, face reduced food availability, disrupting entire food webs.

Behavioural Changes in Marine Life

Ocean acidification can also affect the behaviour of marine animals. Studies show that elevated CO_2 levels can impair the ability of fish to smell, navigate, and avoid predators. Fish exposed to more acidic water may have trouble finding food, recognizing danger, or navigating their environments, making them more vulnerable to predators and less successful in finding mates or reproducing.

Do you know?

The Intergovernmental Panel on Climate Change (IPCC) is an international body established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). Its primary role is to assess scientific research related to climate change, including its causes, impacts, and potential strategies for adaptation and mitigation. The IPCC serves as a bridge between the scientific community and policymakers, ensuring that climate actions are based on the best available evidence.

13.3 SPECIES EXTINCTION DUE TO CLIMATE CHANGE

Climate change contributes to species extinction by drastically altering the habitats and ecosystems that species depend on for survival. The rapid changes in temperature, precipitation, and the frequency of extreme weather events caused by climate change can push species beyond their ability to adapt.

13.3.1 Species that have gone extinct due to climate change

There are many species that have gone extinct due to climate change. Some of them are:

Bramble Cay Melomys (*Melomys rubicola*)

This small rodent, native to the tiny island of Bramble Cay off the coast of Australia, is considered the first mammal to go extinct due to climate change. Rising sea levels and storm surges wiped out its habitat, leading to its extinction.

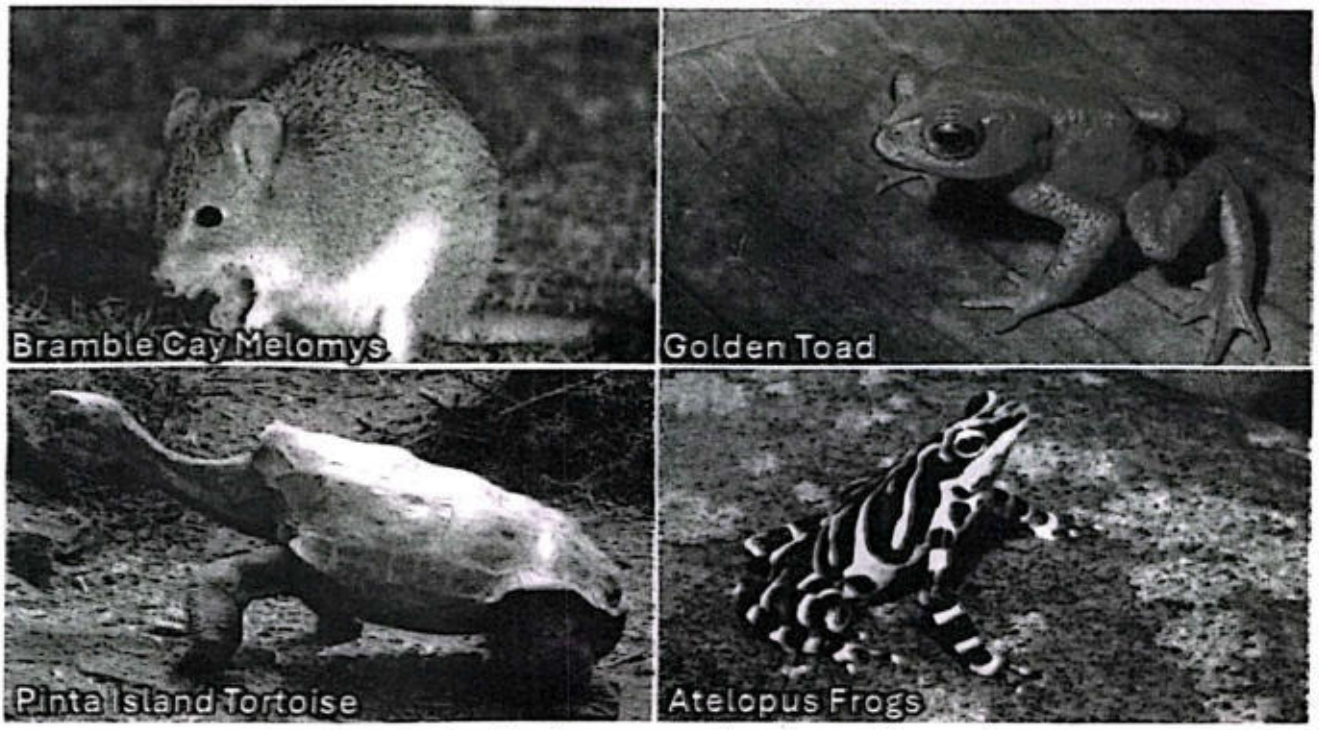


Fig. 13.13: Species that have gone extinct due to climate change

Golden Toad (*Incilius periglenes*)

The golden toad, once found in Costa Rica's Monteverde Cloud Forest, is believed to have gone extinct in the late 1980s due to climate change-induced drought and shifts in temperature. The changing climate made the forest less hospitable, and disease further decimated the population.

Pinta Island Tortoise (*Chelonoidis abingdonii*)

The last individual of this species, known as Lonesome George, died in 2012. While habitat loss and human activity contributed to its decline, climate change played a role by disrupting the ecosystem on the Galápagos Islands, particularly affecting the food and water availability for the tortoises.

Atelopus Frogs (Several species)

Many species of Atelopus, or harlequin frogs, have gone extinct in recent decades, largely due to the spread of the chytrid fungus (pathogenic fungus that affects amphibians worldwide), which is promoted by climate change. Rising temperatures and changes in humidity have helped the fungus spread in highland areas, leading to the collapse of amphibian populations.

13.3.2 Species that have gone endangered due to climate change (Extra Reading Material)

While several species have gone extinct, many species have become endangered due to the impacts of climate change. Here are some notable examples:

Polar Bears (*Ursus maritimus*)

Polar bears rely on sea ice to hunt for seals. As Arctic ice melts due to rising temperatures, their hunting grounds shrink, threatening their survival.

Adélie Penguins (*Pygoscelis adeliae*)

These penguins depend on Antarctic Sea ice for breeding and feeding. Warming temperatures and changing ice patterns are reducing their habitat.

Koalas (*Phascolarctos cinereus*)

Increased heatwaves and bushfires, exacerbated by climate change, along with habitat loss, have pushed koalas closer to endangerment.

Snow Leopards (*Panthera uncia*)

Rising temperatures are affecting the mountain ecosystems they inhabit, shrinking their prey base and increasing human-wildlife conflict.

Coral Species (e.g., Staghorn Coral)

Coral reefs are being devastated by ocean warming and acidification, leading to large-scale coral bleaching events that threaten the survival of many coral species.

Monarch Butterflies (*Danaus plexippus*)

Climate change is altering their migration patterns and reducing the availability of milkweed, their primary food source, pushing them toward endangerment.

Atlantic Cod (*Gadus morhua*)

Rising ocean temperatures are disrupting cod breeding grounds and food availability, causing declines in their population.

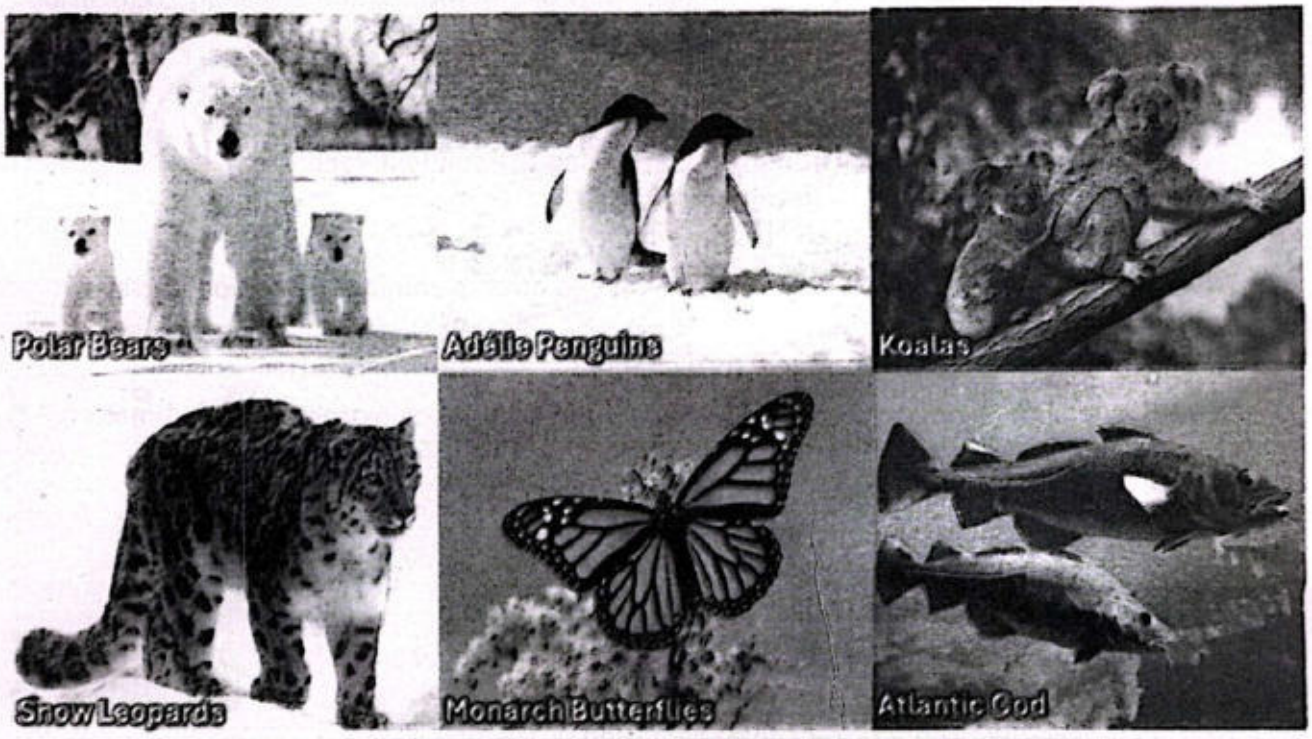


Fig. 13.14: Species that have gone endangered due to climate change

These species are just a few of the many that are struggling to adapt to the rapidly changing climate.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. What is the primary difference between weather and climate?
   A. Weather is long-term environment and climate is short-term environment.
   B. Weather is short-term changes, while climate is the long-term pattern of weather.
   C. Weather affects larger areas, while climate affects smaller regions.
   D. Climate changes daily, while weather remains constant.
2. Which of the following is an example of a natural factor that causes climate change?
   A. Deforestation
   B. Burning of fossil fuels
   C. Volcanic activity
   D. Urbanization
3. How does ocean acidification relate to climate change?
   A. It is caused by an increase in solar radiation.
   B. It results from increased levels of carbon dioxide in the atmosphere.
   C. It occurs due to the natural release of methane.
   D. It is caused by fluctuations in the Earth's orbit.
4. Which of the following best describes the term "anthropogenic climate change"?
   A. Climate change caused by natural factors such as volcanic eruptions.
   B. Climate change that occurs gradually over millions of years.
   C. Climate change results from human activities like deforestation and industrialization.
   D. Climate change due to changes in the Earth's orbit.
5. How do Milankovitch cycles affect Earth's climate?
   A. By increasing volcanic activity.
   B. By changing the Earth's orbit and tilt, affecting the sunlight received.
   C. By reducing the amount of greenhouse gases.
   D. By causing ocean currents to circulate heat.
6. Which of the following impacts of climate change affects animals' migration patterns?
   A) Increased volcanic eruptions
   B) Ocean acidification
   C) Shifting habitats due to temperature changes
   D) Urbanization
7. What happens to the ecosystem balance when a species goes extinct due to climate change?
   A. The balance remains unaffected.
   B. It strengthens the remaining species.
   C. It disrupts the entire ecosystem balance.
   D. It causes new species to evolve immediately.
8. Why is deforestation a major contributor to climate change?
   A. It releases sulfur dioxide, leading to global cooling.
   B. It increases the production of solar radiation.
   C. It reduces the Earth's capacity to absorb CO_2.
   D. It has no impact on climate change.

9. Which of the following factors directly contributes to the rise in ocean temperatures due to climate change?
   A. Increased ocean salinity
   B. Melting glaciers releasing fresh water
   C. Enhanced greenhouse effect trapping heat in the atmosphere
   D. Reduced marine biodiversity
10. Why does the ocean have a high heat capacity, affecting the global climate?
   A. It reflects sunlight back into space.
   B. It can store large amounts of heat without a significant temperature increase.
   C. It has a high salt content.
   D. It has a lower density than freshwater.
11. What role does the Atlantic Meridional Overturning Circulation (AMOC) play in ocean temperature regulation?
   A. It reduces ocean acidity.
   B. It transfers warm surface water to the North Atlantic and returns cold water to the tropics.
   C. It blocks the flow of ocean currents towards Europe.
   D. It increases the salinity of tropical waters.
12. What is coral bleaching, and why does it occur?
   A. It is the whitening of coral due to loss of algae, caused by higher ocean temperatures.
   B. It is the natural growth process of coral reefs in warmer waters.
   C. It is the formation of new coral structures due to ocean acidification.
   D. It is the process of corals adapting to cooler ocean temperatures.
13. Which oceanic region is more susceptible to ocean acidification?
   A. Equatorial regions
   B. Arctic and Southern Oceans
   C. Subtropical regions
   D. Mediterranean Sea
14. Which phenomenon is characterized by a significant increase in ocean temperatures due to shifts in warm water toward the coast of South America?
   A. La Niña
   B. Gulf Stream strengthening
   C. Ocean deoxygenation
   D. El Niño
15. Which of the following species is considered the first mammal to go extinct directly due to climate change?
   A. Pinta Island Tortoise
   B. Golden Toad
   C. Bramble Cay Melomys
   D. Adélie Penguin

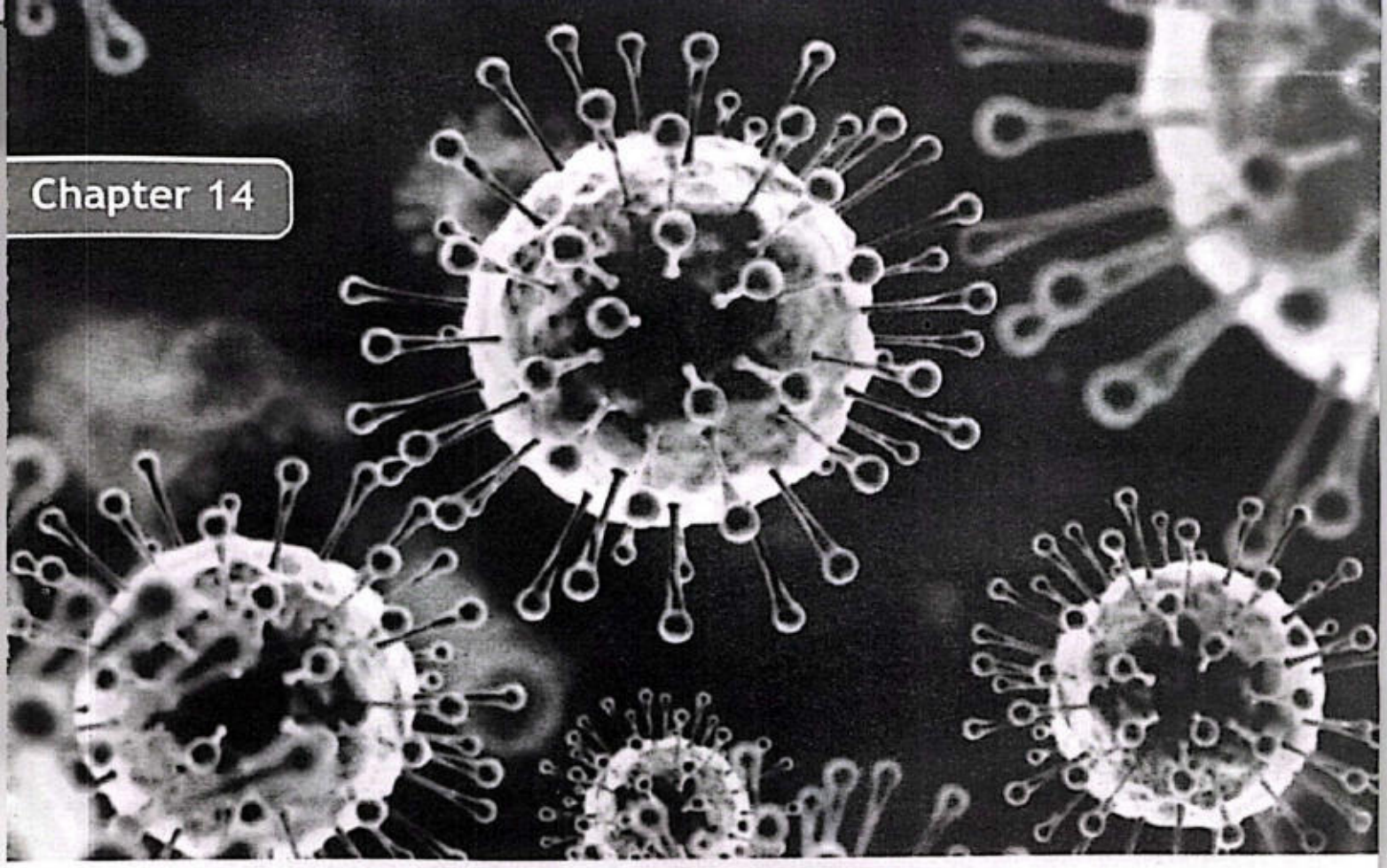
Section II: Short Answer Questions

1. How does climate change impact ocean temperature?
2. What is the role of the ocean's high heat capacity in climate change?
3. Name three animal species that went extinct due to climate change.
4. What phenomenon results in extreme ocean heat events, like heatwaves on land?
5. How does ocean acidification occur?
6. What is coral bleaching?

7. Which ocean current plays a critical role in regulating the climate of the North Atlantic region?
8. Why are polar bears threatened by climate change?
9. What impact does warmer ocean water have on oxygen levels?
10. How has climate change contributed to the spread of the chytrid fungus in amphibians?
11. What is the primary factor causing ocean warming?
12. Which species went extinct in Costa Rica due to climate change-induced drought?
13. What is the relationship between sea ice and ocean temperature?
14. How does ocean acidification affect calcifying organisms?
15. Differentiate between weather and climate

Section III: Extensive Answer Questions

1. Explain how global warming and greenhouse gases contribute to rising ocean temperatures.
2. Describe the process of ocean acidification and its impact on marine life.
3. How do El Niño and La Niña events influence ocean temperatures and global climate patterns?
4. What role does the Atlantic Meridional Overturning Circulation (AMOC) play in ocean heat distribution, and how is it affected by climate change?
5. Discuss the impact of high ocean temperatures on coral reefs and marine biodiversity.
6. How does climate change contribute to species extinction, and provide an example?
7. Describe how climate change has affected polar ecosystems and the species that inhabit them.
8. Explain the concept of marine heatwaves and their impact on ocean ecosystems.
9. What are the challenges faced by species that become endangered due to climate change, such as the snow leopard?
10. How does the melting of polar ice influence global climate patterns and ocean circulation?



Chapter 14

SELECTED TOPICS

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-V-01] Explain the role of biological warfare with examples.
2. [B-12-V-02] Describe how biodefense could work to protect from biological warfare with examples.
3. [B-12-V-03] Examine the hype behind the omics "genomics, transcriptomics, proteomics, metabolomics". To what extent is it valid or overblown?
4. [B-12-V-04] Explain synthetic biology with examples.

14.1 BIOLOGICAL WARFARE

Man has a long history of engaging in wars or conflicts to weaken or defeat his enemies. Wars occur in different ways and use different strategies and tools , such as traditional warfare by means of armies, guerrilla warfare using unconventional methods, and modern types like cyber warfare and biological warfare.

Biological warfare is the use of harmful biological agents like bacteria, viruses, or toxins to intentionally cause disease and death in humans, animals, or plants. These agents are used as weapons to attack and weaken enemies during conflicts or wars. The goal is to spread illness and fear, create disturbance in societies, and damage economies. Understanding the role of biological warfare is crucial for developing effective biodefense strategies and for recognizing its impact on society.

Historical Overview of Biological Warfare

The use of biological warfare goes back to ancient times when early civilizations used biological methods to spread disease among their enemies. For example, in 590 BC, the Assyrians, an ancient civilization in the region of Mesopotamia, which is present-day Iraq, used biological weapons in war. They were believed to have poisoned enemy water supplies with bread infected with Ergot, a fungus that caused hallucinations and paralysis. Another example was in 1347 when the Mongol army threw plague-infected bodies over the walls of Caffa, a city in Ethiopia. This act resulted in spread of the Black Death in Europe, killing millions and causing widespread social and economic chaos.

During the Spanish attempts to settle and take control of the Americas in the 16th Century, European colonizers purposely spread smallpox to indigenous people. The disease caused many deaths and weakened these communities, making it harder for them to resist control on their land and resources. In 1763, British forces deliberately gave blankets contaminated with smallpox to Native American tribes during the French and Indian War. This act of biological warfare led to severe outbreaks of the disease, causing significant suffering and loss of life.

In the 20th century, advancements in science and technology enabled more sophisticated forms of biological warfare. During World War I, Germany experimented with using anthrax and glanders to infect livestock and horses used by the Allied forces. Although these efforts had limited success, but they marked the beginning of the modern biological warfare. In World War II, Japan conducted horrific experiments, spreading diseases like plague, cholera, and anthrax in China. These experiments caused the deaths of thousands of people and highlighted the deadly potential of biological weapons. The Cold War period of geopolitical tension between the United States and the Soviet Union and their allies, witnessed development of huge biological weapon programs, including pathogens like smallpox and tularemia. In the Soviet Union, an accidental release of anthrax spores from a military facility led to an outbreak that killed many people. This incident underscored the dangers of biological weapons research and the potential for accidental release. In 2001, letters containing anthrax spores were mailed to several media outlets and government offices in the United States. The attacks killed five people and infected many, causing widespread fear and prompting a significant response from public health and law enforcement agencies.

Current State of Biological Warfare

Biological warfare remains a significant threat in today's world due to advancements in technology and biotechnology. Modern biotechnology allows for the genetic modification of pathogens to increase their virulence, resistance to treatments, and ability to spread.

A modern concern regarding biological warfare arose when researchers created a synthetic version of the polio virus in 2002, sparking worries about the possibility of developing synthetic pathogens that could be utilized as bioweapons. Another such example relates to controversial experiments that modified the H5N1 avian influenza virus to increase its transmission among mammals, thus initiating discussions on the dangers associated with dual-use research.

Governments around the world continue to research and develop measures to defend against biological attacks. International agreements, such as the Biological Weapons Convention (BWC), aim to prevent the development and use of biological weapons. However, the risk persists due to the dual-use nature of biological research, where scientific advancements can be used for both peaceful and military purposes.

Impacts of Biological Warfare

Biological warfare has profound and far-reaching impacts on society, causing severe health crisis, economic losses, social unrest, and political instability. The planned release of pathogens can lead to widespread illness and death, destroying healthcare systems and causing long-term public health challenges. Economically, biological attacks can damage industries, effect trade, and lead to significant financial losses, particularly in agriculture and livestock sectors. Socially, the fear and panic induced by biological warfare can lead to widespread anxiety, chaos and breakdowns in community trust. Politically, the use of biological weapons can cause tension in international relations, lead to conflicts, and demand increased security measures and regulatory responses. The societal impact of biological warfare requires urgent need for global cooperation in biosecurity and public health preparedness to prevent and mitigate these undesirable consequences.

Pathogens as Weapons of Biological Warfare

Biological agents used in warfare include bacteria, viruses, fungi, and toxins. These agents can be spread in various ways to infect large populations.

1. Bacteria: *Bacillus anthracis*, which causes anthrax, is a notable example. There are three forms of anthrax infection i.e., cutaneous (skin), inhalation (lungs) and gastrointestinal (stomach and intestine) that can cause severe illness and death . Anthrax can be easily spread through inhaling the spores, eating contaminated meat, or having the spores come in contact with the skin.

2. Viruses: The smallpox virus, which causes a highly spreadable and deadly disease, has been considered for use as a biological weapon due to its potential to cause widespread panic and mortality.

Fig. 14.1: Human skin infected with anthrax causing bacteria

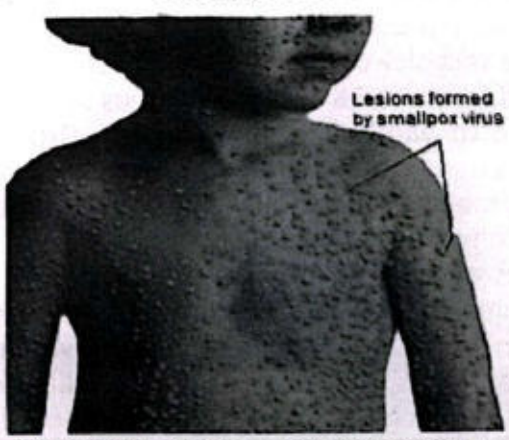


Fig. 14.2: Child effected with the smallpox virus

Delivery Methods

Biological agents can be delivered through various means, including aerosols, contaminated food or water, and infected vectors like insects. Some common methods are discussed below:

1. **Aerosols:** Aerosols can be used to infect large groups of people quickly. Aerosolization is a method where pathogens are dispersed in the air in tiny droplets. This allows them to be inhaled by people, leading to respiratory infections. The delivery vehicle in deliberate aerosolization could range from a cluster of small bombs to a simple leaf blower or nebulizer. A notable example is the accidental release of anthrax spores in Soviet Union in 1979, causing numerous deaths.
2. **Food and Water Contamination:** Deliberately contaminating food or water supplies can cause outbreaks of diseases like cholera or typhoid fever. This method spreads the infection when people consume the contaminated items. One example is *Salmonella* bacteria, which can be purposely introduced into food supplies, causing widespread illness among those who eat contaminated food.
3. **Infected Vectors:** Insects such as mosquitoes or fleas can be deliberately infected with disease-causing organisms like malaria parasites or plague bacteria which are then used to spread these diseases.
4. **Direct Contact:** Direct contact with infected individuals or contaminated surfaces can also be used to spread pathogens. For instance, during the 2014 *Ebola* outbreak in West Africa, the virus rapidly spread as people came into physical contact with infected patients or handled the bodies of those who had died from the disease without proper protective measures.

Types of Biological Weapons

Biotoxins

Biotoxins are toxic substances produced by living organisms. Examples include botulinum toxin, produced by the bacterium *Clostridium botulinum*, which is extremely potent and can cause paralysis and death.

Fig. 9.3: Gram positive bacterium Clostridium botulinum that produces botulinum toxin

Bioregulators

Bioregulators are chemicals that change how the body works. They can be used to mess up important processes in the body, making people very sick or even causing death. Some bioregulators can affect the nervous system, leading to paralysis or severe pain. Others might change the way the immune system works, making it hard for the body to fight off infections. These types of chemicals could be used as weapons to harm or disable people. An example of a bioregulator is ricin, a toxic protein from the castor bean plant. Even in small amounts, ricin can cause severe illness or death if inhaled, ingested, or injected, making it a potential bioweapon.

Fig. 9.4: Ricin is a highly toxic compound found in the castor bean seeds

Biovectors

Biovectors are living organisms, like insects or rodents, that can carry and spread diseases. For example, fleas can be used as bio vectors. If these fleas are infected with some pathogen e.g. plague causing bacteria Yersinia pestis, they can spread the disease to humans. This method has been used in biological warfare to intentionally make people sick by releasing these infected fleas into populations.

14.2 BIODEFENSE

Biodefense encompasses measures taken to protect people against the threat of biological warfare and bioterrorism. The principles of biodefense are guidelines and strategies designed to protect against biological threats, whether from natural outbreaks or intentional attacks. These principles ensure preparedness, prevention and effective response to biological warfare incidents. The main principles include:

Surveillance and Detection

Surveillance and detection are critical for early identification of biological threats. Effective surveillance systems help monitor and track the spread of infectious diseases. Monitoring disease outbreaks and unusual patterns can help detect a potential biological attack. For example, during the 2001 anthrax attacks in the United States, rapid identification of anthrax spores in mailrooms helped controlling the spread.

The detection technologies can be used to identify specific pathogens. Advanced biosensors can detect the presence of biological agents in the environment. For instance, tiny biosensors carried by soldiers on potential battlefields could reveal presence of threat molecules.

Prevention

Preventive measures aim to reduce the risk of biological attacks and limit their impact. Vaccines are a primary defense against biological agents. For example, the smallpox vaccine has been used to protect against potential smallpox outbreaks, and there are ongoing efforts to develop vaccines for other high-threat pathogens like anthrax and Ebola. Measures such as quarantine, travel restrictions, and sanitation can prevent the spread of infectious diseases. During the COVID-19 pandemic, these strategies were essential in controlling the spread of virus.

Fig. 9.5: Vaccination campaigns can help prevent the spread of infectious diseases among soldiers.

Preparedness

Preparedness involves setting up plans to respond to biological incidents with established protocols. Regular training for healthcare professionals and emergency responders is essential to effectively manage biological threats and ensure readiness during emergencies.

Research and Development

Research and development in biodefense focuses on creating medical countermeasures such as drugs, vaccines, and diagnostic tools to combat biological agents effectively. Innovations in biotechnology play a crucial role in enhancing detection, prevention, and treatment of biological threats, ensuring advancements in public health preparedness and response capabilities. Advances in synthetic biology enable the creation of new treatments and rapid vaccine development. For example, synthetic biology helped in developing mRNA vaccines for COVID-19.

Biosafety and Biosecurity

Biosafety and biosecurity are important for handling dangerous pathogens safely. Laboratories must follow strict safety rules to prevent accidents or the accidental release of pathogens. Also, oversight of research that could be used for both good and bad purposes help ensure safe and responsible practices.

14.3 OMICS

In recent years, the scientific fields of 'omics' including genomics, transcriptomics, proteomics, and metabolomics have generated significant interest in the scientific community and beyond. These fields promise to revolutionize our understanding of biology and medicine by providing comprehensive insights into the structure, function, and dynamics of biological systems. However, it's important to critically assess whether the claims about these technologies are valid or exaggerated. Although each field has advanced significantly with practical applications, it's important to keep a balanced perspective. The hype about these technologies should be balanced with a realistic view of their current abilities and challenges. Through ongoing research and addressing these challenges, we can fully realize the potential of the 'omics' fields, benefiting both science and society.

Genomics

Genomics is the study of the complete set of DNA of an organism, including all of its genes. Genomics involves sequencing, mapping, and analyzing genomes to understand genetic variations and their effects on health and disease. The most significant example and application of genomics is the Human Genome Project that was completed in 2003. This project mapped the complete human genome, identifying all the genes present in human DNA. It has paved the way for personalized medicine, where treatments can be tailored based on genetic makeup of an individual. Another example is genetic testing that provides information about ancestry, traits, and potential health risks based on genetic profile of an individual.

While genomics has certainly provided valuable insights and applications, some claims about its capabilities may be exaggerated. For instance, the promise of curing all genetic diseases solely through genomic information is still far from being realized. Ethical concerns, such as genetic privacy and discrimination, also need careful consideration.

Fig. 9.6: Commercially available genetic testing kits

Transcriptomics

Transcriptomics studies all RNA molecules in a cell or group of cells. It focuses on how these changes affect RNA, showing their effects. Transcriptomic analysis can reveal the expression levels of genes in cancer cells compared to normal cells, helping identify potential targets for treatment. In agriculture, transcriptomics can be used to study how plants respond to different environmental conditions or stresses, such as drought or disease. By analyzing which genes are activated or deactivated in response to these conditions, researchers can develop crops that are more resilient and productive in challenging environments. Transcriptomics provides a deeper understanding of gene function and regulation. However, it is important to recognize that gene expression is only one part of the complex regulatory networks within cells. The interpretation of transcriptomic data requires careful validation and integration with other 'omics' data.

Proteomics

Proteomics is the large-scale study of proteins, including their structures and functions. Since proteins are the main functional molecules in cells, proteomics provides insights into cellular processes and disease mechanisms. Proteomic studies have identified biomarkers for diseases such as Alzheimer's and cancer, which can aid in early diagnosis and monitoring. Understanding protein interactions and functions helps in the design of new drugs that can target specific proteins involved in diseases. Proteomics has made significant contributions to biomedical research. However, the complexity of the proteome, with its dynamic modifications and interactions, poses challenges. High costs and technical limitations also restrict the widespread application of proteomics in clinical settings.

Metabolomics

Metabolomics is the study of the complete set of small-molecule metabolites found within a biological sample. Metabolites are the end products of cellular processes, and their analysis can provide a picture of the physiological state of a cell or organism. Metabolomic studies can identify how different diets affect metabolism and health, leading to personalized nutrition plans. Metabolomics can be applied in disease diagnosis where metabolomic profiles can help diagnose metabolic disorders and monitor disease progression.

Metabolomics offers a comprehensive view of metabolism, but it also faces challenges such as the diversity of metabolites and the influence of external factors on metabolic profiles. While promising, the field requires further development to overcome these hurdles and fully realize its potential.

14.4 SYNTHETIC BIOLOGY

Synthetic biology is an interdisciplinary field that combines biology, engineering, and computer science to design and construct new biological parts, devices, and systems, or redesign existing biological systems for useful purposes. Synthetic biology involves the design and construction of new biological entities such as enzymes, genetic circuits, and cells. This rapidly advancing field holds the potential to revolutionize medicine, agriculture, and environmental management.

Synthetic biology operates on several key principles that guide the design and construction of new biological systems. One of the key principles of synthetic biology is the standardization of biological parts, known as BioBricks. These standardized genetic parts can be easily assembled in various combinations to create new biological systems. Other essential principles include modularity, orthogonality, abstraction and automation.

Applications of Synthetic Biology

Synthetic Microbes: Scientists have engineered microorganisms like bacteria and yeast to produce valuable chemicals, fuels, and pharmaceuticals. For instance, genetically modified bacteria can efficiently convert sugar into biofuels such as ethanol, offering a renewable alternative to fossil fuels. By inserting the human insulin gene into *E. coli*, bacteria can produce insulin that is harvested and purified for medical use. Similarly, engineered yeast strains are used to produce many important drugs more cost-effectively than traditional methods. Bioremediation is another application where engineered microorganisms can be used to clean up environmental pollutants. For example, bacteria can be modified to degrade oil spills or break down plastic waste.

Gene Editing: Gene editing involves precisely modifying DNA to correct genetic disorders in humans, enhance agricultural crops, improve livestock health, advance biomedical research, and aid conservation efforts for endangered species. Gene editing tools enable targeted changes to specific genes, offering potential treatments for diseases such as sickle cell anemia, enhancing crop resistance and nutrition, and creating disease-resistant livestock. For example, golden rice is engineered to produce beta-carotene which is essential for producing vitamin A, to combat vitamin A deficiency in developing countries. In biomedical research, gene editing helps study disease mechanisms and develop new therapies.

Bio-Sensing Devices: Synthetic biology has enabled the development of biological sensors that detect specific molecules or environmental conditions. These sensors often use genetically engineered cells that produce detectable signals in response to target substances. For example, biosensors are used to detect contaminants in water sources or to monitor glucose levels in diabetic patients, offering rapid and accurate diagnostic tools.

Biological Computers: Biological computers are devices that use biological components, like cells and proteins, to perform computations instead of traditional electronic circuits. These computers can mimic processes found in living organisms, such as communication between cells or the processing of biological signals. Researchers are exploring their potential for tasks like medical diagnostics, environmental monitoring, and even enhancing our understanding of biological systems. Biological computers offer distinct advantages such as requiring significantly less energy and operating efficiently in conditions where conventional computers may face limitations. For instance, they can be designed to function within biological environments, such as the human body, where they could assist in detecting diseases at the cellular level which is something traditional computers can not do.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. Which international treaty aims to prevent the development and use of biological weapons?
   A. Paris Agreement
   B. Kyoto Protocol
   C. Biological Weapons Convention
   D. All of above

2. How has modern biotechnology impacted biological warfare?
   A. It has facilitated the genetic modification of pathogens.
   B. It has promoted international cooperation in biodefense.
   C. It has decreased the lethality of biological agents.
   D. It has restricted the development of new bioweapons.
3. Aerosolization is the delivery method for spread of biological agents through.
   A. Dropping contaminated blankets
   B. Use of infected insects as vectors
   C. Dispersing pathogens in tiny droplets in the air
   D. Contaminating food and water supplies
4. Surveillance and detection are critical in biodefense because.
   A. They enable rapid identification and containment of biological threats.
   B. They ensure complete eradication of all biological agents.
   C. They eliminate the need for vaccination programs.
   D. They guarantee 100% accuracy in identifying bioterrorists.
5. The dual-use nature of biological research can be explained as
   A. It involves both peaceful and military applications
   B. It focuses on natural outbreaks only
   C. It is limited to genomic studies
   D. It excludes ethical concerns
6. What was the result of the accidental release of anthrax spores from a Soviet military facility in 1979?
   A. Outbreak of plague
   B. Widespread cholera
   C. Extensive smallpox cases
   D. Numerous deaths
7. Which principle of biodefense involves setting up plans and protocols to respond to biological incidents
   A. Surveillance and Detection
   B. Prevention
   C. Preparedness
   D. Research and Development
8. What is the role of synthetic biology in bioremediation?
   A. Producing biofuels from renewable sources
   B. Cleaning up environmental pollutants
   C. Enhancing crop resistance
   D. Improving livestock health
9. What sets metabolomics apart from genomics and transcriptomics?
   A. It studies the complete set of DNA of an organism
   B. It focuses on all RNA molecules in a cell
   C. It examines the complete set of small-molecule metabolites
   D. It analyzes the structures and functions of proteins
10. Which scientific field studies the complete set of DNA of an organism, including all of its genes?
   A. Proteomics
   B. Transcriptomics
   C. Genomics
   D. Metabolomics

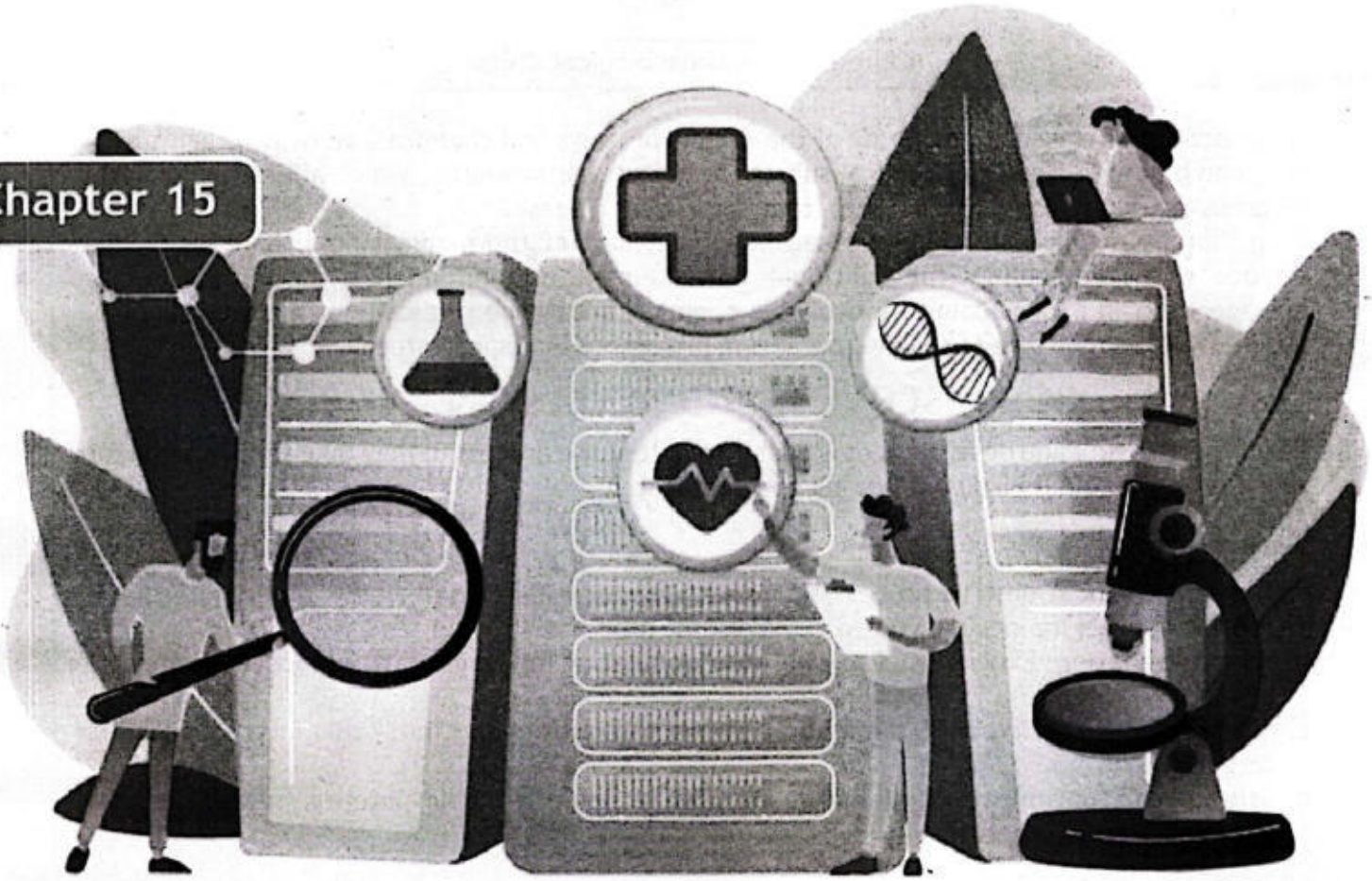
Section II: Short Answer Questions

1. What is biological warfare, and how does it utilize harmful biological agents?
2. Provide any two historical examples of biological warfare from ancient times to the 20th century.
3. Explain the impact of biological warfare on society, including health, economic, and political consequences.
4. Name three types of biological agents used in warfare and give examples of each.
5. How has modern biotechnology impacted biological warfare? Discuss with one example.
6. List the principles of biodefense. Why preparedness is considered a crucial principle of biodefense.
7. What are the main goals of international agreements like the Biological Weapons Convention?
8. Explain the concept of biosafety and biosecurity in the context of handling dangerous pathogens.
9. What is gene editing. How it contributes to both biodefense and potential biological threats?
10. What are genetic testing kits? Give any one application.

Section III: Extensive Answer Questions

1. Explain the concept of biological warfare and provide two historical examples where biological agents were used in conflicts.
2. Describe in detail different methods used to deliver biological agents during warfare. Give an example of each method.
3. Discuss the impact of biological warfare on societies, including its effects on health, economy, and politics. Provide examples to support your answer.
4. Critically analyze the ethical considerations surrounding the development and potential use of genetically modified pathogens as bioweapons, weighing the problem of dual-use of research and implications for global biosecurity.
5. What are bioregulators and biovectors in the context of biological weapons? Give examples of each and explain their role in warfare.
6. Explain how modern biotechnology has influenced the development and use of biological weapons. Provide two examples to illustrate your answer.
7. What are 'omics'? Briefly describe genomics, proteomics, and metabolomics, and explain their potential applications in understanding biological warfare agents.
8. Examine the role of surveillance and detection in biodefense. Why are these aspects crucial, and what technologies are used for early identification of biological threats?

Chapter 15



PHARMACOLOGICAL DRUGS

Students' learning outcomes
After studying this chapter, students will be able to:

1. [B-12-T-01] Explain the drug discovery and development process.
2. [B-12-T-02] Define 4 classes of antibiotics (Penecillins, Tetracyclins, Fluriquinolones and Sulfonamides) and describe their mode of action.
3. [B-12-T-04] Define antivirals and antiretrovirals.
4. [B-12-T-05] Describe advantages of monoclonal antibodies enjoy compared to other drug classes.

Pharmacology is the scientific study of the effects of drugs and chemicals on living organisms. A drug can be defined as any chemical substance, natural or synthetic, which affects a biological system. A drug used to diagnose, cure, treat, or prevent disease.
Drug therapy or pharmacotherapy is an important part of the medical field. It relies on the science of pharmacology for continual advancement and on pharmacy for appropriate management. In pharmacology, a drug is a chemical substance, typically of known structure, which, when administered to a living organism, produces a biological effect.

15.1 DRUG DISCOVERY AND DEVELOPMENT PROCESS

The drug discovery and development is complex multiphase process. It may take several years, or even upto a decade. It involves several important steps.

15.1.1 Drug discovery

a. **Target identification:** The process begins with the identification of a new target molecule, a protein or other molecule involved in the disease process.
b. **Target validation:** Experiments confirm that modulating the target can produce a therapeutic effect.
c. **Hit identification:** Screening large libraries of compounds to find "hits" that interact with the target.
d. **Hit-to lead optimization:** Refining the hits to improve their potency, selectivity and pharmacokinetic properties.

15.1.2 Preclinical Development

a. **In *Vitro* Studies:** Testing the lead compounds in laboratory setting to evaluate their effects on cells and biological systems.
b. **In *Vivo* Studies:** Conducting tests in animal models to assess the safety, efficacy (the ability to produce a desired or intended result), and pharmacokinetics of the compounds.
c. **Toxicology Studies:** Evaluating potential toxicology and side effects through rigorous testing.
d. **Formulation Development:** Developing the drug formulation for stability, delivery and dosage.

15.1.3 Clinical Development

Investigational new drug application: Submitting data from preclinical studies to regulatory authorities (like the FDA) to obtain permission to begin clinical trials.
Clinical Trials are composed of four phases: Phase 1, 2, 3 and 4.
a. **Phase 1 trials:** Testing the drug in a small group of healthy volunteers (20-100 to asses's safety, dosage and pharmacokinetics.
b. **Phase 2 trials:** Expanding the study to a larger group (100-500) of patients to evaluate efficacy and further assessment safety.
c. **Phase 3 trials:** Conducting large-scale studies (1000 -3000 participants) to confirms efficacy. Monitor side effects and compare with standard treatment.
d. **Phase 4 trials:** Post marketing surveillance monitors drug side effects.

15.1.4 Regulatory Review

a. **New drug application:** Submitting comprehensive data from all studies to regulatory authorities for approval to market the drug.

b. Review process: Regulatory agencies evaluate the data for safety, efficacy and quality before granting approval.

15.1.5 Post-Marketing Surveillance (Phase 4)

a. Monitoring: After approval, the drug is continuously monitored for long-term effects, rare side effects and overall effectiveness in the general population.

b. Additional studies: Conducting further studies to explore new uses, dosage adjustments or combinations with other drugs.

In the last we can say that throughout this process, collaboration across various disciplines, such as biology, chemistry, pharmacology and regulatory affairs is essential. The drug discovery and development process is expensive and time consuming, with a high rate of failure at each stage, but it ultimately aims to bring safe and effective medications to patients.

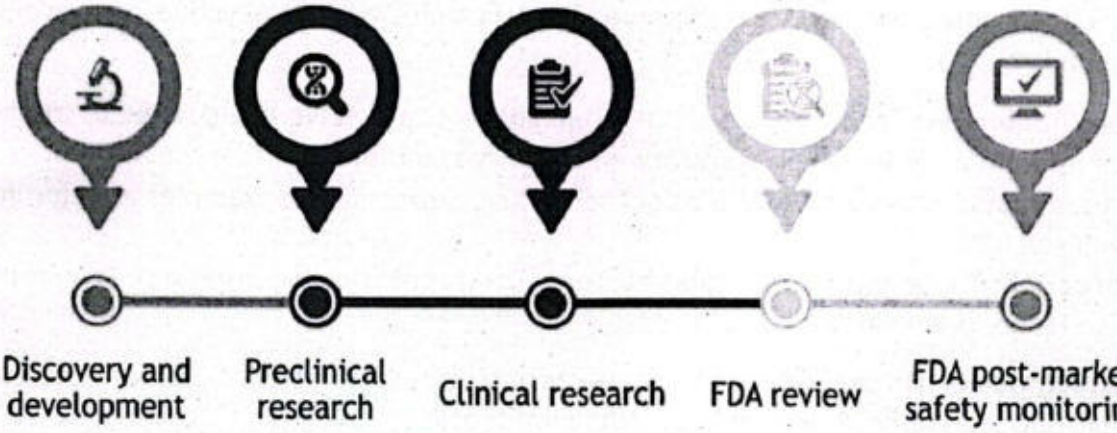


Fig. 15.1: The five drug development phases

15.2 ANTIBIOTICS AND THEIR MODE OF ACTION

Antibiotics are used to treat or prevent some types of bacterial infections.
Antibiotics are medicines that help stop infections caused by bacteria.
Antibiotics work by killing bacteria or stopping them from multiplying. For example, antibiotics can kill bacteria by destroying crucial parts they need to survive, like their cell walls or DNA. Antibiotics can stop the growth of bacteria by preventing them from making certain proteins they need to multiply. Antibiotics do not work for viral infections such as cold and flu and some coughs.

Antibiotic Resistance

Antibiotics are powerful germ-fighting tools when used carefully and safely. But up to half of all antibiotic use isn't necessary. Overuse has led to antibiotic resistance. Bacteria adapt over time and become "super bacteria" or "superbugs." Super bacteria cannot be killed by standard antibiotics because they have developed resistance through genetic mutations and natural selection, allowing them to survive and thrive despite the presence of drugs that would normally kill them.

Types of antibiotics

There are hundreds of different types of antibiotics, but most of them can be classified into four groups.

1. **Penicillins:** These are widely used to treat a variety of infections, including skin infections, chest infections and urinary tract infections. The examples are penicillin, amoxicillin, flucloxacillin etc.
Mode of action: They inhibit bacterial cell wall synthesis by binding to penicillin-binding proteins leading to cell lysis.

2. **Tetracyclines:** These can be used to treat a wide range of infections.
Mode of action: They inhibit protein synthesis by binding to 30S ribosomal subunit, blocking the attachment of aminoacyl-tRNA to ribosome. The examples are tetracycline, doxycycline and minocycline.

3. **Fluoroquinolones:** These are broad-spectrum antibiotics that were once used to treat a wide range of infections, especially respiratory and urinary tract infections; these antibiotics are no longer used routinely because of the risk of serious side effects. The examples are ciprofloxacin and levofloxacin.
Mode of action: These antibiotics inhibit bacterial DNA replication by targeting enzymes like DNA gyrase and topoisomerase IV.

4. **Sulfonamides:** These are synthetic bacteriostatic antibiotics. Sulfonamides include, Mafenide, Sulfacetamide, Sulfadiazine, Sulfanilamide etc.
Mode of action: These competitively inhibit conversion of p-aminobenzoic acid to dihydropteroate, which bacteria need for folate synthesis and ultimately purine and DNA synthesis. Humans do not synthesize folate but acquire it in their diet, so their DNA synthesis is less affected.

15.3 ANTIVIRALS AND ANTIRETROVIRALS

Antivirals and Antiretrovirals are a class of medication specifically used to treat viral and retroviral infections caused by viruses like HIV, herpes viruses, hepatitis B and C.
Antivirals: These are a class of drugs which are used to treat viral infections. They work by inhibiting the ability of viruses to multiply and spread within the body. The antiviral drugs target diverse group of viruses such as herpes, hepatitis, and influenza viruses.

Antiretrovirals: These are a subset of antivirals especially that are used to fight retrovirus infections which mainly include HIV (Human Immunodeficiency Virus). Different classes of antiretroviral drugs act on different stages of the HIV life cycle. Retroviruses are a type of virus that uses RNA as their genetic material and reverse transcriptase to replicate. Antiretrovirals inhibit the replication of retroviruses, helping to control HIV infection and reduce the risk of progression to AIDS.

Do you know?
All antiretrovirals are antivirals but not all antivirals are antiretrovirals.

15.4 ADVANTAGES OF MONOCLONAL ANTIBODIES

Monoclonal antibodies (also called moAbs or mAbs) are **proteins**. They are made in laboratories that act like proteins called **antibodies** in our bodies. Antibodies are parts of our immune system. They seek out the antigens (foreign materials) and stick to them in order to destroy them. Laboratory-made monoclonal antibodies help stimulate our own immune system. The word **"monoclonal"** refers to the fact that the antibodies created in the laboratory are clones. They are exact copies of one antibody. Monoclonal antibodies are used for diagnosis, disease treatment and research.

Do you know?

The difference between monoclonal antibodies and polyclonal antibodies is in the names. "Mono" refers to one and "poly" refers too many. Monoclonal antibodies are clones of just one antibody, and they bind to one antigen only.

SCIENCE TITBITS

Monoclonal antibodies have been used in treatment of Cancer, Organ transplant rejection, Inflammatory and autoimmune disorders, including allergies, Infections, including COVID-19, Osteoporosis, Eye disorders, Migraines, High cholesterol, Nervous system disorders. In most cases, monoclonal antibodies are given mostly as intravenous (IV) solution injected right into your vein (sometimes referred to as an infusion).

Advantages of using Monoclonal Antibodies

Monoclonal antibodies offer several advantages over traditional antibody therapies, including high specificity, consistent quality, and the ability to be produced in large quantities. They can be engineered to target specific antigens, making them effective for various applications like cancer diagnosis, therapy, and diagnostics.

Following are the advantages of using monoclonal antibiotics

1. **High Specificity**: Monoclonal antibodies are engineered to bind to a single, specific antigen or epitope, allowing for precise targeting and reducing off-target effects.
2. **Consistent Quality:** Monoclonal antibodies can be produced in large quantities with consistent quality across different batches, ensuring reproducibility and reliability.
3. **Renewable Production:** Once a hybridoma or recombinant cell line is established, monoclonal antibodies can be produced indefinitely.
4. **Versatile Applications:** Monoclonal antibodies are used in various fields, including:
    a. **Diagnostics:** Used in pregnancy tests, HIV testing and other diagnostic assays.
    b. **Therapy:** Used in cancer treatments, autoimmune disease therapies, and other drug development applications.
    c. **Research:** Used in molecular biology, biochemistry, and other research areas.
5. **Engineering Possibilities:** Monoclonal antibodies can be engineered in the lab to enhance their binding affinity or target specific molecules, allowing for tailored applications.
6. **Humanization:** Monoclonal antibodies can be humanized, minimizing the risk of immune reactions in patients.
7. **Large-Scale Production:** Recombinant DNA technology allows for the production of monoclonal antibodies in large quantities, making them accessible for various applications.

Monoclonal Antibodies Compared to Other Drug Classes

1. Monoclonal antibodies are clones of just one antibody, and they bind to one antigen only. Polyclonal antibodies come from several different types of immune cells and will bind to more than one antigen.
2. The advantages of using monoclonal antibodies to target specific cells compared to drug and radiotherapy treatments means that the drugs specifically target the cancer cells and can allow smaller doses of chemotherapy drugs to be used. This can reduce the side effects and reduce risk to healthy cells. Improving the immune system.
3. The difference between antibiotics and monoclonal antibodies is that mAbs have safety, high target-specificity, less susceptible to resistance mechanisms, longer half-lives (~21 days for IgG) compared to antibiotics.
4. The advantages of monoclonal antibodies over small molecules are that their advantage is exquisite specificity due to greater surface area for binding with antigen, resulting in decreased 'off-target' effects as compared with most small molecule drugs.

EXERCISE

Section I: Multiple Choice Questions
Select the correct answer:

1. What is the primary goal of target identification in drug discovery?
   A. To determine the chemical composition of a drug.
   B. To identify the biological origin of a disease and potential targets for intervention.
   C. To evaluate the safety and efficacy of a drug in animal models.
   D. To optimize the synthetic route for a drug's production.
2. Which clinical trial phase involves testing a drug on a small group of healthy volunteers to assess its safety and determine the appropriate dosage?
   A. Phase I B. Phase II C. Phase III D. Phase IV
3. The pharmacokinetic properties of a drug are mainly governed by the physicochemical properties of the drug such as it's:
   A. Solubility in aqueous solutions B. Size and structure
   C. Ability to form hydrogen bonds D. All of these
4. What is the main purpose of phase IV testing?
   A. Determine therapeutic window B. Determine unreported toxicity
   C. Determine variation in absorption D. Determine tolerability
5. Which among the following antibiotics function as protein synthesis inhibitors?
   A. penicillin B. tetracycline C. cefotaxime D. trimethoprim
6. Which of the following techniques is best for measuring the effectiveness of antibiotics on bacteria?
   A. Physical testing B. Chemical testing
   C. Biological testing D. Combined physical and chemical testing
7. Which point in the replication cycle appears most easily blocked by antivirals?
   A. Virus absorption B. Virus penetration
   C. Virus RNA and DNA replication D. Exit of viruses from the cell

8. Which is one of the main current goals of antiretroviral treatment?
   A. to suppress the viral load
   B. to cure HIV infection
   C. to allow the patient to have a pain-free death
   D. to prevent repeated infection with HIV

9. Which of the following is easily blocked by antivirals?
   A. Virus penetration
   B. Nucleic acid replication
   C. Virus absorption
   D. Removal of the virus from the cell

10. Which of the following is the primary reason why antiretroviral therapy (ART) cannot cure HIV?
   A. ART is not effective in reducing the viral load.
   B. HIV can hide within immune cells, forming latent reservoirs.
   C. ART drugs are toxic and cause severe side effects.
   D. HIV mutates too rapidly to be targeted by ART.

11. Which of the following cannot be treated by antiviral drugs?
   A. tuberculosis B. smallpox C. hepatitis D. warts

12. What is the main advantage of monoclonal antibodies over polyclonal antibodies?
   A. greater specificity and constancy.
   B. lower cost production.
   C. longer shelf life
   D. ability to target multiple antigens

13. How monoclonal antibodies are administered to patients?
   A. topically B. intravenously C. inhalation D. Orally

14. What is the main difference between Phase III and Phase IV clinical trials?
   A. Phase III tests the drug's efficacy, while Phase IV focuses on long-term safety.
   B. Phase III studies involve a small number of patients, while Phase IV studies involve a large number of patients.
   C. Phase III trials are conducted in animals, while Phase IV trials are conducted in humans.
   D. Phase III trials are conducted in one country, while Phase IV trials are conducted in multiple countries.

15. What is the purpose of a New Drug Application ?
   A. To obtain permission to conduct clinical trials on a new drug.
   B. To request a patent for a new drug.
   C. To seek regulatory approval to market a new drug.
   D. To conduct post-marketing surveillance on a new drug.

16. Antibodies are:
   A. prostaglandins B. steroids C. lipoproteins D. glycoproteins

17. What are monoclonal antibodies?
   A. Antibodies produced by a single type of immune cell.
   B. Antibodies derived from multiple individuals.
   C. Antibodies with multiple antigen-binding sites.
   D. Antibodies found in the blood of newborn

18. What is the main advantage of monoclonal antibodies over polyclonal antibodies?
    A. Greater specificity and consistency
    B. Low cost production
    C. Ability to target multiple antigens simultaneously
    D. Longer shelf life.

19. The science which deals with the drug and their action on human body is called:
    A. Physiology B. Pathology C. Pharmacology D. Microbiology

20. The study of absorption, distribution, metabolism and excretion of drug is known as:
    A. Pharmacy B. Pharmacokinetics C. Pharmacodynamics D. Pharmacopoeia

Section II: Short Answer Questions

1. Define the following:
    a. Pharmacology
    b. Drug
    c. Drug therapy
    d. Antibiotics
    e. Antivirals
    f. Antiretrovirus
    g. Monoclonal antibodies
2. What is a pharmacological drug?
3. Write the four steps of drug discovery.
4. What are the steps of preclinical development of drugs?
5. Describe clinical development of drugs.
6. Name the five drug development phases.
7. How do antibiotics work?
8. Why are monoclonal antibodies so specific?

Section III: Extensive Answer Questions

1. Explain drug discovery and development process.
2. Discuss the types antibiotics and their mode of action.
3. What are antivirus and antiretrovirus? Explain
4. What are the advantages of monoclonal antibodies?
5. Compare monoclonal antibodies to other drug classes.

GLOSSARY

Acetylcholine: One of the most common neurotransmitters, functions by binding to receptors and altering the permeability of the postsynaptic membrane to specific ions, either depolarizing or hyperpolarizing the membrane.

Actin: A globular protein which twist helically about each other, forming microfilaments in muscle and other contractile elements in the cells.

Action potential: A rapid change in the membrane potential of an excitable caused by stimulus-triggered, selective opening and closing voltage-sensitive gates in sodium and potassium ion channels.

Adaptive immunity: A type of specific immunity that develops when immune system responds to foreign substance or microorganism, such as after an infection or vaccination. It includes third line of defence

Adélie Penguins *(Pygoscelis adeliae)*: A species of penguin that depends on Antarctic sea ice for breeding and feeding, threatened by warming temperatures and changing ice patterns.

Adrenal gland: One of two endocrine glands located to the kidneys in mammals. Endocrine cells in the outer portion (cortex) respond to help maintain homeostasis during long term stress. Neurosecretory cells in the central portion (medulla) secrete epinephrine and norepinephrine in response to nervous inputs triggered by short-term stress.

Adrenocorticotropic hormone (ACTH): A tropic hormone produced and secreted by the anterior pituitary that stimulates the production and secretion of steroid hormones by the adrenal cortex.

Aldosterone: An adrenal hormone that acts on the distal tubules of the kidney to stimulate the reabsorption of sodium (Na+) and the passive flow of water from the filtrate.

Allergen: a substance that can cause an allergic reaction

Allergy: An overreaction of the immune system to any harmless substance

Alveolus: One of the dead-end, multi-lobed air sacs that constitute the gas exchange surface of the lungs.

Alzheimer's disease: An age related dementia (mental deterioration) characterized by confusion, memory loss and other symptoms.

Anaphylaxis: A severe, life-threatening allergic reaction

Androgen: Any steroid hormone, such as testosterone, that stimulates the development and maintenance of the male reproductive system and sex characteristics.

Anterior pituitary: Aso called the adenohypophysis, portion of the pituitary that develops from nonneural tissue, consists of endocrine cells that synthesize and secrete several tropic and nontropic hormone.

Anthrax: A bacterial disease caused by Bacillus anthracis, capable of infecting humans and animals and used as a biological weapon.

Antibiotics: These are medicines that work by killing bacteria and preventing them from multiplying.

Antidiuretic hormone (ADH): A hormone produced in the hypothalamus and released from the posterior pituitary. It promotes water retention by the kidneys as part of an elaborate feedback scheme that helps regulate the osmloarity of the blood.

Antigen: Any substance capable of stimulating an immune response; usually a protein or large carbohydrate that is foreign to the body.

Antiretroviral therapy (ART): The treatment for HIV is called antiretroviral therapy (ART). ART involves taking a combination of HIV medicines (called an HIV treatment regimen) every day. ART is recommended for everyone who has HIV. ART cannot cure HIV, but HIV medicines help people with HIV live longer, healthier lives.

Antiretroviral: A drug used to prevent a retrovirus, such as HIV, from replicating. The term primarily refers to antiretroviral (ARV) HIV drugs.

Antivirals: These are a class of drugs which are used to treat viral infections.

Atlantic Cod *(Gadus morhua)*: A species of fish in the North Atlantic Ocean whose population is affected by climate change, especially due to rising ocean temperatures that disrupt their breeding grounds and food availability.

Atlantic Meridional Overturning Circulation (AMOC): A large system of ocean currents in the

Atlantic Ocean that transports warm water from the tropics to the North Atlantic, influencing climate patterns in Europe and North America.

Autoimmune disease: The immune system attacks the healthy cells of body's organs and tissues by mistake

Axon: A typically long extension, or process, from a neuron that carries nerve impulses away from the cell body toward target cell.

B cells: A type of lymphocytes that participates in humoral immunity, gives rise to plasma cells that secrete antibodies into the circulatory system and to become memory cells.

Basophils: A type of WBCs that defend body from allergens, pathogens and parasites. It helps detect and destroy some early cancer cells

Bile: A liquid secretion of the liver stored in the gall bladder and released into the small intestine during digestion. Bile is a complex mixture of bile salts, water, other salts, and cholesterol.

Biodefense: Measures taken to protect against biological warfare and bioterrorism, including surveillance, detection, and response strategies.

Biological warfare: The deliberate use of biological agents (bacteria, viruses, toxins) to cause harm to humans, animals, or plants as part of warfare.

Biosafety measures: To ensure safe handling and containment of biological agents to prevent accidental release or exposure.

Biosecurity: Measures to prevent unauthorized access, theft, or deliberate misuse of dangerous biological agents or materials.

Biotechnology: The use of biological processes from microorganisms to make substance or to provide service to man.

Bipolar cell: A neuron that synapses with the axon of a rod or cone in the retina of the eye.

Body cavity: A fluid-containing space between the digestive tract and the body wall.

Bone marrow: The spongy interior of the bones with stem cells

Bone: A type of connective tissue, consisting of living cells held in a rigid matrix of collagen fibres embedded in calcium salts.

Bowman's capsule: A cup-shaped receptacle in the vertebrate kidney that is the initial, expanded segment of the nephron where filtrate enters from the blood.

Brainstem: Collection of structures in the adult brain, including the midbrain, the pons, and the medulla oblongata; functions in homeostasis, coordination of movement, and conduction of information to higher brain centres.

Bramble Cay Melomys: A small rodent native to Bramble Cay island in Australia, considered the first mammal to go extinct due to climate change, mainly because of rising sea levels.

Breathing control centre: A brain centre that directs the activity of organs involved in breathing.

Breathing: The process involving alternate inhalation and exhalation of air that ventilates the lungs.

Bronchiole: One of the fine branches of the bronchus that transport air to alveoli.

Bronchus: One of a pair of breathing tubes that branch from the trachea into the lungs.

Calcifying Organisms: Marine organisms, such as corals, mollusks, and some plankton, that use calcium carbonate to build their shells or skeletons, which are affected by ocean acidification.

Calcitonin: A hormone secreted by the thyroid gland that lowers blood calcium levels by promoting calcium deposition in bone and calcium excretion from the kidneys.

Cardiac cycle: One complete heart beat.

Cartilage: A type of flexible connective tissue with an abundance of collagenous fibres embedded in chondroitin sulphate.

Cell-mediated immunity: The immune response in which foreign cells or substances are destroyed by contact with T cells.

Cellular respiration: The most prevalent and efficient catabolic pathway for the production of ATP, in which oxygen is consumed as a reactant along with the organic fuel.

Central canal: The narrow cavity in the centre of the spinal cord that is continuous with the fluid-filled ventricles of the brain.

Central nervous system (CNS): In vertebrate animals, the brain and spinal cord.

Cerebellum: Part of the vertebrate hindbrain located dorsally; functions in unconscious coordination of movement and balance.

Cerebral cortex: The surface of the cerebrum; the

largest and most complex part of the mammalian brain, containing sensory and motor nerve cell bodies of the cerebrum; the part of the vertebrate brain most changed through evolution.

Cerebral hemisphere: The right or left side of the vertebrate brain.

Cerebrospinal fluid: Blood-derived fluid that surrounds, protects against infection, nourishes, and cushions the brain and spinal cord.

Cerebrum: The dorsal portion of the vertebrate forebrain, composed of right and left hemispheres; the integrating centre for memory, learning, emotions, and other highly complex functions of the central nervous system.

Chondrocyte: Cartilage cell that secretes collagen and chondroitin sulphate.

Chytrid fungus: A pathogenic fungus that affects amphibians worldwide, with its spread being facilitated by climate change through rising temperatures and changes in humidity.

Climate change: Long-term alteration of temperature and typical weather patterns in a place, primarily driven by human activities such as burning fossil fuels, deforestation, and industrial processes.

Complement system: Over fifty types of small proteins found in the blood which provide immunity.

Computational biology: An interdisciplinary field that combines computer science, mathematics, and biology to analyse and model biological systems.

Computational evolutionary biology: An interdisciplinary field that combines evolutionary and computational biology.

Coral bleaching: A phenomenon where corals expel the symbiotic algae living in their tissues due to stress from elevated temperatures, causing them to turn white and become more vulnerable to disease and death.

Corpus callosum: The thick band of nerve fibres that connect the right and left cerebral hemispheres in placental mammals, enabling the hemispheres to process information together.

Cortical nephron: Nephrons located almost entirely in the renal coertex. These nephrons have a reduced loop of Henle.

Corticosteroid: Any steroid hormone produced and secreted by the adrenal cortex.

Countercurrent multiplier system: A countercurrent system in which energy is expended in active transport to facilitate exchange of materials and create concentration gradients. For example, the loop of Henle actively transports NaCl from the filtrate in the upper part of the ascending limb of the loop, making the urine-concentrating function of the kidney more effective.

Cytotoxic T cells: Secrete cytotoxin which triggers destruction of the pathogen's DNA or perforin which is a protein that creates holes in the pathogens plasma membrane.

Decontamination: The process of removing or neutralizing biological agents from surfaces, equipment, or environments to prevent further spread or exposure.

Dendrite: One of usually numerous, short, highly branched processes of a neuron that convey nerve impulses toward the cell body.

Dendritic cells: A special type of WBCs that is found skin which boosts immune responses by becoming Antigen Presenting Cell (APC)

Depolarization: An electrical state in an excitable cell whereby the inside of the cell is made less negative relative to the outside than at the resting membrane potential. A neuron membrane is depolarized if a stimulus decreases its voltage from the resting potential of -70 mV in the direction of zero voltage.

Dermis: Inner, comparatively thick layer containing glands, hair follicles, receptors, nerves and blood vessels

Diabetes mellitus: An endocrine disorder marked by inability to maintain glucose homeostasis. The type I form results from autoimmune destruction of insulin-secreting cells; treatment usually requires insulin injections several times a day. The type II form most commonly results from reduced responsiveness of target cells to insulin; *obesity* and lack of exercise are risk factors.

Diaphragm: A sheet of muscle that forms the bottom wall of the thoracic cavity in mammals; active in ventilating the lungs.

Diastole (di-as'toh-lee): Phase of the cardiac cycle in which the heart is relaxed.

Dopamine: A biogenic amine closely related to

epinehhrine and norepinephrine.

Drug: any chemical substance, natural or synthetic, which affects a biological system.

Dual-Use Research: Scientific research that can be applied for both beneficial purposes (such as medicine) and harmful purposes (such as biological warfare).

Ecosystem: A community of living organisms and their physical environment interacting as a system, which can be significantly altered by climate change.

Electrocardiogram (ECG): A record of the electrical impulses that travel through cardiac muscle during the heart cycle.

Endangered species: Species that are at risk of extinction due to a declining population or threats from environmental changes, habitat loss, and climate change.

Endocrine gland: A ductless gland that secretes hormones directly into the interstitial fluid, from which they diffuse into the bloodstream.

Endocrine system: The internal system of chemical communication involving hormones, the ductless glands that secrete hormones, and the molecular receptors on or in target cells that respond to hormones; functions in concert with the nervous system to effect internal regulation and maintain homeostasis.

Endorphin: Any of several hormones produced in the brain and anterior pituitary that inhibits pain perception.

Eosinophils: A type of WBCs that protect body from parasites, allergens, foreign bacteria and organisms

Epidemiology: The study of the distribution and determinants of health-related states or events in populations, often used in tracking outbreaks caused by biological warfare agents.

Epidermis: outermost layer of the skin, composed of tightly packed cells that provide a physical barrier.

Erythropoietin: A hormone produced in the kidney when tissues of the body do not receive enough oxygen. This hormone stimulates the production of erythrocytes.

Estrogen: Any steroid hormone, such as estradiol, that stimulates the development and maintenance of the female reproductive system and secondary sex characteristics.

Excretion: The disposal of nitrogen-containing waste products of metabolism.

Extreme weather events: Severe weather phenomena like hurricanes, droughts, heatwaves, and heavy rainfall, which become more frequent and intense due to climate change, impacting ecosystems and human activities.

Feedback inhibition: A method of metabolic control in which the end product of a metabolic pathway acts as an inhibitor of an enzyme within that pathway.

Feedback loop: A process in which the output of a system amplifies or dampens its own production, such as how melting sea ice reduces reflectivity, leading to further warming and more ice melt.

Fever: Raised body temperature than normal

First line of defence: The external barriers of our body to stop entry of pathogens. It is nonspecific and includes skin and mucous membranes.

Fluoroquinolones: These are highly effective antibiotics with many advantageous pharmacokinetic properties including high oral bioavailability, large volume of distribution, and broad-spectrum antimicrobial activity.

Follicle-stimulating hormone (FSH): A tropic hormone produced and secreted by the anterior pituitary that stimulates the production of eggs by the ovaries and sperm by the testes.

Forebrain: One of three ancestral and embryonic regions of the vertebrate brain; develops into the thalamus, hypothalamus, and cerebrum.

Gastrin: A hormone released by the stomach mucosa; stimulates the gastric glands to secrete pepsinogen.

Genetic modification: Altering the genetic makeup of organisms, including pathogens, to enhance specific traits such as virulence or resistance.

Glial cells: Supporting cells that are essential for the structural integrity of the nervous system and for the normal functioning of neurons.

Global warming: The increase in Earth's average surface temperature due to rising levels of greenhouse gases, which is a major component of climate change.

Glomerulus: A ball of capillaries surrounded by Bowman's capsule in the nephron and serving as

the site of filtration in the vertebrate kidney.

Glucagon: A hormone secreted by pancreatic alpha cells that raises blood glucose levels. It promotes glycogen breakdown and release of glucose by the liver.

Glucocorticoid: A steroid hormone secreted by the adrenal cortex that influences glucose metabolism and immune function.

Golden Toad *(Incilius periglenes)*: A species of toad that lived in Costa Rica's Monteverde Cloud Forest, which went extinct in the late 1980s due to climate change-induced drought and shifts in temperature.

Gonadotropin: A hormone that stimulates the activities of the testes and ovaries. Follicle stimulating hormone and luteinizing hormone are gonadotropins.

Greenhouse Gases (GHGs): Gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that trap heat in the Earth's atmosphere, leading to global warming.

Grey matter: Regions of dendrites and clusters of neuron cell bodies within the CNS.

Growth hormone (GH): A hormone produced and secreted by the pituitary.

Gulf Stream: A warm and swift Atlantic Ocean current that originates in the Gulf of Mexico and flows along the eastern coastlines of the United States and Newfoundland before crossing the Atlantic Ocean.

Habitat Loss: The destruction or alteration of the natural environment where a species lives, often caused by human activities or climate change, leading to species becoming endangered or extinct.

Haemoglobin: the red, iron-containing protein pigment of erythrocytes that transports oxygen and carbon dioxide and aids in regulation of pH.

Helper T cell: T lymphocyte that facilitates the ability of B lymphocytes to form an antibody-producing clone in response to an antigen. Secrete interleukin 2 which stimulates cell division of T cells and B cells.

Hepatic: Pertaining to the liver.

Hindbrain: *One of* three ancestral and embryonic regions of the vertebrate brain; develops into the medulla oblongata, pons, and cerebellum.

Homeostasis: The steady-state physiological condition of the body.

Hormone: In multicellular organisms, one of many types of circulating chemical signals that are formed in specialized cells, travel in body fluids, and act on specific target cells to change their functioning.

Humoral mediated immune response: Immune response provided by antibodies

Hybridoma: It is a culture of hybrid cells that results from the fusion of B cells and myeloma cells. Hybridoma technology produces hybridomas. This technology was developed to produce mAbs. Hybridomas possess two important properties of B cells, production of antibodies, and immortalization of myeloma cells.

Hyperpolarization: An electrical state in which the inside of the cell is more negative relative to the outside than at the resting membrane potential. A neuron membrane is hyperpolarised if a stimulus increases its voltage from the resting potential of -70 mV, reducing the chance that neuron will transmit a nerve impulse.

Hypothalamus: The ventral part of the vertebrate forebrain; functions in maintaining homeostasis, especially in coordinating the endocrine and nervous systems; secretes hormones of the posterior pituitary and releasing factors that regulate the anterior pituitary.

Hypoxic zones: Areas in the ocean with low oxygen levels, often caused by increased water temperatures, nutrient pollution, or changes in circulation patterns, making it difficult for marine life to survive.

I band: The area near the edge of the sarcomere where there are only thin filaments.

Immune response: A specific response by the immune system to invasion of the body by particular foreign substance or microorganism, characterized by recognition of the foreign material by immune cells and its subsequent destruction by antibodies or cellular attack.

Immune system: An extensive network of tissues, organs, proteins, and cells

Immunity: The body's ability to resist or combat infections, diseases, and foreign substances

Incubation Period The time between exposure to a pathogen and the onset of symptoms.

Incubation Period The time between exposure to a

pathogen and the onset of symptoms.

Innate immunity: The body's first and second line of defence which prevents infection and attack of invading pathogens. It is present at birth and lasts a person's entire life

Insulin: It is a peptide hormone, produced by beta cells in the pancreas, and is central to regulating carbohydrate and fat metabolism in the body. It causes cells in the skeletal muscles, and fat tissue to absorb glucose from the blood.

Interferons: Antiviral agents produced by virus-infected cells.

International Biological Weapons Convention (BWC): An international treaty aimed at prohibiting the development, production, and stockpiling of biological weapons and promoting peaceful uses of biological research.

Juxtamedullary nephrons: Nephrons with well-developed loops of Henle that extend deeply into the renal medulla.

Koalas *(Phascolarctos cinereus)*: An arboreal marsupial native to Australia that faces threats from climate change due to increased heatwaves and bushfires, which are intensifying with rising temperatures.

Krause end bulbs: Nerve terminals in skin, mucosa of the oral cavity, conjunctiva, and other parts, consisting of a laminated capsule of connective tissue enclosing the terminal, branched, convoluted ending of an afferent nerve fiber; generally believed to be sensitive to touch and pressure. The end-bulbs of Krause were named after German anatomist Wilhelm Krause (1833-1910).

Lacteal: One of the many lymphatic vessels in the intestinal villi that absorb fat.

Leukopenia: It is a disease in number of white blood cells (leukocyte) found in blood, which places individuals at risk of infection.

Ligament: It comes from the Latin ligare meaning "to bind, tie," which is precisely what a ligament does. Ligaments only connect bones to bones. Ligaments allow for range of motion.

Limbic system: A group of nuclei (clusters of nerve cell bodies) in the lower part of the mammalian forebrain that interact with the cerebral cortex in determining emotions; includes the hippocampus and the amygdala.

Luteinizing hormone (LH): A tropic hormone produced and secreted by the anterior pituitary that stimulates ovulation in females and androgen production in males.

Lymph: The colourless fluid within the lymphatic vessels that is derived from blood plasma and resembles it closely in composition; contains white cells; ultimately, returns to the blood.

Lymph nodes: A mass of lymph tissue surrounded by a connective tissue capsule; manufactures lymphocytes and filters lymph. Small bean like structures that filter lymph to remove pathogens

Lymphatic system: A subsystem of the cardiovascular system; returns excess interstitial fluid to the circulation; defends the body against disease organisms.

Lymphocyte: A type of WBCs that is made in the bone marrow and is found in blood and lymph tissue

Macrophage: A type of WBCs that surrounds and kills microorganisms, removes dead cells, and stimulates the action of other immune system cells

Malpighian tubule: A unique excretory organ of insects that empties into the digestive tract, removes nitrogenous wastes from the hemolymph, and functions in osmoregulation.

Marine heatwaves: Periods of abnormally high ocean temperatures that can last for days or months, disrupting marine ecosystems and causing mass die-offs of sea life.

Medulla oblongata: The lowest part of the vertebrate brain, commonly called the medulla; a swelling of the hindbrain dorsal to the anterior spinal cord that controls autonomic, homeostatic functions, including breathing, heart and blood vessel activity, swallowing, digestion, and vomiting.

Memory B cells: On stimulation make more plasma cells and protect against future attacks by the same antigen.

Memory T cells: Provide long term immunity and are stimulated to convert into helper T cells and help fight the pathogen.

Midbrain: One of three ancestral and embryonic regions of the vertebrate brain; develops into sensory integrating and relay centers that send sensory information to the cerebrum.

Migration Patterns: The regular movement of

species between habitats, often in response to seasonal changes. Climate change can alter these patterns, affecting species' survival and ecosystems.

Monarch Butterflies *(Danaus plexippus)*: A species of butterfly known for its long migrations. Climate change alters their migratory patterns and reduces the availability of milkweed, their primary food source.

Monoclonal antibodies: A single type of antibody that are produced by identical immune cells (clones).

Monocytes: A type of largest WBCs which mature to become macrophages or dendritic cells

Mucous membrane: The moist, inner lining of some organs and body cavities including digestive and respiratory tract

Mucus: A slippery sticky substance produced especially by mucous membranes which it moistens and protects

Myelin sheath: In a neuron, an insulating coat of cell membrane from Schwann cells that is interrupted by nodes of Ranvier, where saltatory conduction occurs.

Myofibril: A myofibril (also known as a muscle fibril) is a basic rod-like unit of a muscle.[1] Muscles are composed of tubular cells called myocytes, also known as muscle fibers, and these cells in turn contain many chains of myofibrils. They are created during embryo development in a process known as myogenesis. Myofibrils are composed of long proteins such as actin, myosin, and titin, and other proteins that hold them together. These proteins are organized into thin filaments and thick filaments, which repeat along the length of the myofibril in sections called sarcomeres. Muscles contract by sliding the thin (actin) and thick (myosin) filaments along each other.

Myofilaments: These are the filaments of myofibrils constructed from proteins.There are three different types of myofilaments, thick, thin, and elastic filaments.

Myoglobin: An oxygen-storing, pigmented protein in muscle cells.

Myosin: A type of protein filament that interacts with actin filaments to cause cell contraction.

Negative feedback: A primary mechanism of homeostasis, whereby a change in a physiological variable that is being monitored triggers a response that counteracts the initial fluctuation.

Nephron: The tubular excretory unit of the vertebrate kidney.

Nerve: A ropelike bundle of neuron fibers (axons and dendrites) tightly wrapped in connective tissue.

Neuron: A nerve cell; the fundamental unit of the nervous system, having structure and properties that allow it to conduct signals by taking advantage of the electrical charge across its cell membrane.

Neurosecretory cells: These are specialized nerve cells that produce and secrete hormones. Well-known examples of neurosecretory cells are oxytocin- and vasopressin-secreting neurons in the hypothalamus and cells in the adrenal medulla. These cells are found in vertebrates and invertebrates.

Neurotransmitter: A chemical messenger released from the synaptic terminal of a neuron at a chemical synapse that diffuses across the synaptic cleft and binds to and stimulates the postsynaptic cell.

Neutrophils: A type of white blood cell that act as immune system's first line of defence

Nissl body: Also known as Nissl or tigroid substance is a large granular body found in neurons. These granules are rough endoplasmic reticulum (RER) with rosettes of free ribosomes, and are the site of protein synthesis. It was named after Franz Nissl, a German psychiatrist who invented the Nissl staining method.

NK cells: A type of WBCs that kills virus infected cells, and detects and controls early signs of cancer

Nociceptor: A class of naked dendrites in the epidermis of the skin.

Norepinephrine: Also called noradrenaline or 4,5-ß-trihydroxy phenethylamine is a catecholamine with multiple roles including those as a hormone and a neurotransmitter.

Ocean acidification: A process where the ocean absorbs excess atmospheric CO_2, leading to the formation of carbonic acid and a reduction in the pH of seawater, negatively impacting marine life, especially organisms that form shells.

Ocean warming: The increase in ocean

temperatures due to global warming, which affects marine ecosystems and contributes to phenomena like coral bleaching and rising sea levels.

Osteoblast: A bone-forming cell that deposits collagen.

Osteon: The repeating organizational unit forming the microscopic structure of hard mammalian bone.

Oxyhaemoglobin: Haemoglobin that has combined with oxygen.

Oxytocin: It is a mammalian neurohypophysial hormone. Produced by the hypothalamus and stored and secreted by the posterior pituitary gland, oxytocin acts primarily as a neuromodulator in the brain. It is released in large amounts after distension of the cervix and uterus during lab or, facilitating birth, maternal bonding, and, after stimulation of the nipples, lactation. Childbirth and milk ejection result from positive feedback mechanisms.

Pacemaker (of the heart): The sinoatrial (SA) node of the heart; specialized cardiac muscle where each heartbeat begins.

Pain receptor: A kind of interoreceptor that detects pain; also called a nociceptor.

Parathyroid gland: Any of four small endocrine glands, embedded in the surface of the thyroid gland, that secrete parathyroid hormone.

Parathyroid hormone (PTH): A hormone secreted by the parathyroid glands that raises blood calcium level by promoting calcium release from bone and calcium retention by the kidneys.

Penicillin: It is a class of antibiotic medications. Penicillins treat bacterial infections like strep throat, ear infections and urinary tract infections. They work by attaching to and damaging the cell walls of bacteria.

Pepsin: An enzyme produced in the stomach that initiates digestion of proteion.

Peripheral nervous system (PNS): The sensory and motor neuron that connect to the central nervous system.

Peristalsis: Rhythmic waves of muscular contraction and relaxation in the walls of hollow tubular organs, such as the ureter or parts of the digestive tract, that serve to move the contents through the tube.

Peritubular capillaries: The network of tiny blood vessels that surrounds the proximal and distal tubules in the kidney.

Phagocytosis: Literally," cell eating"; a type of endocytosis by which certain cells engulf food particles, microorganisms, foreign matter, or other cells.

Pharmacokinetic properties: Pharmacokinetic properties of a drug are mainly governed by the physicochemical properties of the drug such as its solubility in aqueous solutions, lipophilicity, size and structure, ability to form hydrogen bonds, polar surface area, chemical stability, and susceptibility to enzymatic reactions.

Pineal gland: A small gland on the dorsal surface of the vertebrate forebrain that secretes the hormone melatonin.

Pinta Island Tortoise *(Chelonoidis abingdonii)*: A species of giant tortoise from the Galápagos Islands, with the last known individual, "Lonesome George," dying in 2012. Climate change contributed to habitat alteration that affected the species' survival.

Pituitary gland: An endocrine gland at the base of the hypothalamus; consists of a posterior lobe (neurohypophysis), which stores and releases two hormones produced by the hypothalamus, and an anterior lobe (adenohypophysis), which produces and secretes many hormones that regulate diverse body functions.

Plasma B cell: Stimulated B cells become plasma cells and secrete a great deal of antibodies

Plasma cell: Cell that secretes antibodies; differentiated B lymphocyte.

Platelets: Cell fragments in the blood that function in clotting; also called thrombocytes.

Polar Bears *(Ursus maritimus)*: A species of bear that relies on Arctic sea ice for hunting seals. The melting ice due to global warming threatens their survival.

Positive feedback: A physiological control mechanism in which a change in some variable triggers mechanisms that amplify the change.

Posterior pituitary: Also called the neurohypophysis; an extension of the hypothalamus composed of nervous tissue that secretes oxytocin and antidiuretic hormone made in the hypothalamus; a temporary storage site for these hormones.

Postsynaptic cell: The target cell at a synapse.

Presynaptic cell: The transmitting cell at a synapse.

Primary immune response: Response after first contact of the immune system with an infectious agent

Prolactin (PRL): A hormone produced and secreted by the anterior pituitary with a great diversity of effects in different vertebrate species. In mammals, it stimulates growth of and milk production by the mammary glands.

Prostaglandin (PG): One of a group of modified fatty acids secreted by virtually all tissues and performing a wide variety of functions as local regulators.

Protein Data Bank (PDB): A freely accessible online database that stores and provides 3D structural information of biomolecules.

Pulse: Alternate expansion and recoil of an artery.

Pyrogens: Cause the temperature set point of the hypothalamic thermostat of the body to rise and produce fever.

Quarantine: Isolating individuals or populations exposed to infectious diseases to prevent their spread.

Refractory periods: The short time immediately after an action potential in which the neuron cannot respond to another stimulus, owing to an increase in potential permeability.

Renal artery: The blood vessel bringing blood to the kidney.

Renal cortex: The outer portion of the vertebrate kidney.

Renal medulla: The inner portion of the vertebrate kidney, beneath the renal cortex.

Renal pelvis: Funnel-shaped chamber that receives processed filtrate from the vertebrate kidney's collecting ducts and is drained by the ureter.

Renal vein: The blood vessel draining the kidney.

Renin: A protein enzyme secreted by the kidneys into the blood stream, where it helps to maintain blood pressure.

Rennin: An enzyme found in gastric juice which cause coagulation.

Replication fork: A Y-shaped region on a replicating DNA molecule where new strands are growing.

Residual volume: The amount of air that remains in the lungs after forcefully exhaling.

Respiratory pigment: A protein that transports most of the oxygen in blood.

Respiratory surface: The part of an animal where gases are exchanged with the environment.

Resting potential: The membrane potential characteristic of a nonconducting, excitable cell, with the inside of the cell more negative than the outside.

Ricin: A highly toxic protein derived from castor beans, considered a bioregulator and potential biological weapon.

Rigor mortis: The stiffness of joints and muscular rigidity of a dead body, caused by depletion of ATP in the tissues. It begins two to four hours after death and lasts up to about four days, after which the muscles and joints relax

Rugae: Folds, such as those in the lining of the stomach.

Saltatory conduction: Rapid transmission of a nerve impulse along an axon, resulting from the action potential jumping from one node of Ranvier to another, skipping the myelin-sheathed regions of membrane.

Sarcomere: The fundamental repeating unit of striated muscle, delimited by the Z lines.

Sarcoplasmic reticulum: A specialized endoplasmic reticulum that regulates the calcium concentration in the cytosol.

Sea ice: Frozen ocean water that forms, expands, and melts in the ocean. It plays a crucial role in reflecting sunlight and regulating the Earth's temperature.

Sea-level rise: An increase in the level of the world's oceans due to the melting of ice caps and glaciers and the expansion of seawater as it warms.

Second line of defence: When pathogens successfully enter the skin or mucous membranes, it is activated to combat these foreign invaders. It is nonspecific and includes some WBCs, inflammation, fever and protective proteins

Second messenger: Molecule inside cells that acts to transmit signals from a receptor to a target. The term second messenger was coined upon the discovery of these substances in order to distinguish them from hormones and other molecules that function outside the cell as "first

messengers" in the transmission of biological information. Many second messenger molecules are small and therefore diffuse rapidly through the cytoplasm, enabling information to move quickly throughout the cell. Examples of second messenger molecules include cyclic AMP, cyclic GMP, inositol trisphosphate, diacylglycerol, and calcium.

Secondary immune response: Faster and stronger immune response after second and further contact of the immune system with an infectious agent

Semilunar valves: Valves between the ventricles of the heart and the arteries that carry blood away from the heart.

Sensory neuron: A nerve cell that receives information from the internal and external environments and transmits the signals to the central nervous system.

Septum (pl. septa)**:** A cross-wall or partition; for example, the walls that divide a hypha into cells. Permanently attached to sessile one location. Coral animals, for example, are sessile.

Sequence homology: The study of similarities and relationships between biological sequences, such as DNA, RNA, or protein sequences

Skeletal muscle (striated muscle): Muscle generally responsible for the voluntary movements of the body.

Skin: The body's largest organ which protects body from germs and regulates body temperature

Sliding-filament model: The theory explaining how muscle contracts, based on change within a sarcomere, the basic unit of muscle organization, stating that thin (actin) filaments slide across thick (myosin) filaments, shortening the sarcomere. The shortening of all sarcomeres in a myofibril shortens the entire myofibril.

Small intestine: Portion of the vertebrate digestive tract that extends from the stomach to the large intestine.

Snow Leopards *(Panthera uncia)*: A large cat species native to mountain ranges in Central and South Asia, threatened by climate change as warming temperatures shrink their habitat and prey base.

Somatic nervous system: The branch of the motor division of the vertebrate peripheral nervous system composed of motor neurons that carry signals to skeletal muscles in response to external stimuli.

Species extinction: The complete disappearance of a species from Earth, often accelerated by climate change, habitat loss, pollution, and over-exploitation.

Spleen: A lymphoid organ located near stomach which stores blood cells

Staghorn coral: A type of branching coral that is especially vulnerable to coral bleaching due to ocean warming and acidification, leading to the loss of coral reefs.

Stomach: Muscular region of the vertebrate digestive tract extending from the oesophagus to the small intestine.

Structural biology: Study of the 3D structure and organization of biological molecules

Structural homology: The study of similarities in three-dimensional (3D) structures between biological molecules, such as proteins, RNA, or DNA

Sulfonamides: These are synthetic bacteriostatic antibiotics that competitively inhibit conversion of p-aminobenzoic acid to dihydropteroate, which bacteria need for folate synthesis and ultimately purine and DNA synthesis.

Suppressor T cells: Shut down the immune response after infection is successfully removed

Symbiotic Algae: Algae that live inside the tissues of corals, providing them with nutrients through photosynthesis. The relationship is crucial for coral health, and stress from warming oceans can cause corals to expel these algae, leading to bleaching.

Synapse: The locus where one neuron communicates with another neuron in a neural pathway; a narrow gap between a synaptic terminal of an axon and a signal-receiving portion (dendrite or cell body) of another neuron or effector cell. Neurotransmitter molecules released by synaptic terminals diffuse across the synapse, relaying messages to the dendrite or effector.

Synaptic cleft: A narrow gap separating the synaptic knob of a transmitting neuron from a receiving neuron or an effctor cell.

Synaptic terminal: A bulb at the end of an axon in which neurotransmitter molecules are stored and released.

Synaptic vesicle: Membranous sac containing neurotransmitter molecules at the tip of the presynaptic axon.

Systole: the part of the cardiac cycle when the heart is contracting.

T cell (T lymphocyte): lymphocyte that is processed in the thymus. T cells have a wide variety of immune function but are primarily responsible for cell-mediated immunity.

T cells: A type of WBCs that kill virus infected cells, cancerous cells and help other B and T cells to perform their functions

T-cell receptor: a protein receptor located on the surface of a T cell which binds a specific antigen and triggers the immune response of the cell.

Testosterone: The most abundant androgen hormone in the male body.

Tetracyclines: These are a class of broad-spectrum antibiotics used in the management and treatment of a variety of infectious diseases.

Thalamus: One of two integrating centres of the vertebrate forebrain. Neurons with cell bodies in the thalamus relay neural input to specific areas in the cerebral cortex and regulate what information goes to the cerebral cortex.

Therapeutic: The branch of medicine concerned with the treatment of disease and the action of remedial agents.

Third line of defence: specific adaptive immunity and consists of immune cells that target specific antigens

Threshold: The potential an excitable cell membrane must reach for an action potential to be initiated.

Thrombus: A blood clot formed within a blood vessel or within the heart.

Thromcytopenia: When the number of blood platelets is lower than the normal i.e. 150,000 to 450,000.

Thymus gland: A tiny organ below the breast bone which is responsible for T-cell maturation.

Thyroid gland: An endocrine gland, located on the ventral surface of the trachea, that secretes two iodine-containing hormones, triiodothyronine (T3) and thyroxine (T4), and calcitonin.

Thyroid-stimulating hormone (TSH): A tropic hormone produced and secreted by the anterior pituitary that regulates the release of thyroid hormones.

Thyroxine (T4): One of the two iodine -containing hormones that are secreted by the thyroid gland and help regulate metabolism, development and maturation in vertebrates.

Tonsils: Lymphoid tissue near pharynx which trap and kill harmful pathogens that enter through mouth and nose

Trachea: The windpipe; that portion of the respiratory tube that has C-shaped cartilaginous rings and passes from the larynx to two bronchi.

Transplant rejection: Triggers the transplant recipient's immune mechanisms, which may act to destroy the donor tissue

Tridothyronine (T3): One of the two iodine -containing hormones that are secreted by the thyroid gland and help regulate metabolism, development and maturation in vertebrates.

Tris HCl: Tris, or tris(hydroxymethyl) amino methane, or known during medical use as tromethamine or THAM, is an organic compound with the formula $(HOCH_2)_3CNH_2$. It is extensively used in biochemistry and molecular biology as a component of buffer solutions such as in TAE and TBE buffers, especially for solutions of nucleic acids. It contains a primary amine and thus undergoes the reactions associated with typical amines, e.g. condensations with aldehydes. In medicine, tromethamine is occasionally used as a drug, given in intensive care for its properties as a buffer for the treatment of severe metabolic acidosis in specific circumstances. Some medications are formulated as the "tromethamine salt" including hemabate (carboprost as trometamol salt), and "ketorolac trometamol"

Urea: A soluble nitrogenous waste produced in the liver by a metabolic cycle that combines ammonia with carbon dioxide.

Ureter: A duct leading from the kidney to the urinary bladder.

Uric acid: An insoluble precipitate nitrogenous waste excreted by land snails, insects and many reptiles and birds.

Urinary bladder: The pouch where urine is stored prior to elimination.

Vaccines: Boosts immunity by introducing a small, harmless piece of a pathogen (antigen) to the body, which triggers a specific immune response

Vasa recta: In the blood supply of the kidney, the vasa recta renis (or straight arteries of kidney, or straight arterioles *of kidney*) are a series of straight capillaries in the medulla (Latin: vasa, "vessels"; recta, "straight"). They lie parallel to the loop of Henle.

Vasoconstriction: A decrease in the diameter of superficial blood vessels triggered by nerve signals that contract the muscles of the vessel walls.

Vasodilation: An increase in the diameter of superficial *blood vessels* triggered by nerve signals that relax the muscles of the vessel walls.

Ventilation: Any method of increasing contact between the respiratory medium and the respiratory surface.

Ventricle: (1) A heart chamber that pumps blood out of a heart. (2) A space in the vertebrate brain, filled with cerebrospinal fluid.

Viscera: The internal body organs, especially those located in the abdominal or thoracic cavities.

Vocal cord: One of two small bands of muscle within the larynx. These muscles vibrate to produce the voice. The vocal cords form a "V" inside the larynx, a 2-inch-long, tube-shaped organ in the neck. When we talk, the vocal cords tighten up and move closer together. Air from the lungs is forced between them and makes them vibrate, producing the sound of our voice. The tongue, lips, and teeth form this sound into words

X-ray crystallography technique: Provides precise 3D structure of the biomolecule, revealing its atomic arrangement, bond lengths, and angles

Z lines: The border of a sarcomere.

ABOUT THE AUTHORS

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Prof. Jawaid Mohsin was born on 12th February in 1945 in the province of Bihar. Malik is the title given to his ancestor Syed Ibrahim by the king Tughlaq. Syed Ibrahim was a saint, the commander in chief of the army and conqueror of Bihar. Syed Ibrahim is the descendent of Hazrat Ghos-e-Azam, Syed Abdul Qadir Jilani (رحمۃ اللہ علیہ) at the seventh generation. The ancestors of Syed Ibrahim migrated from Iraq to Afghanistan and settled in the village "Bunt Nagar" near Ghazni. Prof.Jawaid is a former head for the department of Zoology, Federal Government Postgraduate College, H-8 Islamabad` where he served for more than twenty-five years. He is also a former Principal, Federal Government College, H-9, F-10/4 Islamabad and Director Colleges and Director and Director Administration, Federal Directorate of Education, Islamabad. He has contributed his services to FBISE in various capacities such as paper setter, head examiner etc. He developed the modern question paper of FBISE which consists of three parts i.e., MCQ's, short answer question and extensive answer questions is now used all over Pakistan. In 1968 he did his post-graduation in zoology with specialization in Entomology, from Dhaka University, East Pakistan (former). He taught in Muhammadpur College, Quaid-e-Azam College and the prestigious Notre Dame College of Dhaka. He taught various classes for more than forty-five years in various capacities. He has also worked as Education Officer, in Nigeria for four years. He has successfully completed the 61st advance course in administration and development held in 1996 at National Institute of Public Administration (NIPA), Karachi. In 1995. He was awarded a shield by the honourable Mr. Rafiq Tarar, the then President of Pakistan, for his services to humanity. He has published four research papers in Science Journals of Pakistan on Butterflies of Pakistan. He has contributed articles on science and sports in Urdu and English dailies of Islamabad. He is co-author and managing author of more than fifty textbooks on General Science and Biology as well as Biology Practical Notebooks. He has travelled to Singapore, Thailand, Indonesia, India, Bangladesh, UAE, Saudi Arabia, Egypt, Italy, Holland, UK, Qatar, USA and Nigeria. He has also served as a National Consultant, Science Education, JICA sponsored project for the promotion of Student centered and Inquiry based SCIB) learning, National Institute of Science and Technical Education, Ministry of Education, Islamabad, He retired from survive on 12th November 2005. He has published four literary books in Urdu on which a student has obtained M.Phil., Degree from a university in Islamabad. He has served as book reviewer at National curriculum Council (NCC) and member interview committee of FPSC for selection of faculty for a number of years.

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Ruqayya Shaikh did her M.Sc and M.Phil in Animal Sciences from Quaid-i-Azam University, Islamabad. She started her professional career as a Zoology lecturer at Islamabad College for girls, F-6/2, Islamabad. At present she is working as Associate Professor in the same institute. She has been teaching General Science to secondary school classes, Biology to SSC, HSSC and BS classes, Zoology to B.Sc classes for the last two decades. Recently she certified in instructional leadership, College of Education, University of Massachusetts, USA.
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Mr. Abid Ali Mughal is currently the Assistant Professor and Head of the Biology Department at Islamabad Model College for Boys H-9 Islamabad. He completed his M.Sc (Hons) in Plant Sciences from the University of Sindh Jamshoro in 2002, where he was awarded the Vice Chancellor's Medal for achieving first position. From 2002 to 2003, he served as a Research Fellow at PAEC's Nuclear Institute of Agriculture Tandojam. In 2003, he began his teaching career as a lecturer in Botany at F.G. Degree College Wah Cantt. His research interests include investigating factors affecting tDNA transfer from Agrobacterium to Soybean for his M.Phil in Biotechnology, and studying the effects of chronic exposure to antibiotics on rural populations for his Ph.D. in Environmental Sciences. Mr. Mughal has presented his research papers at international conferences in Lithuania, the Netherlands, and France. He is the Co-author of NBF Biology for grades 11 & 12 according to the curriculum 2006, and the Principal author of Biology for grade 12 of KPK textbook board based on Curriculum 2006. His interactive video lectures covering all biology topics are available on his website www.BiologyGuardian.com and YouTube channel www.youtube.com/c/BiologyGuardian. Currently, he is a member of the Course Committee of SSC and HSSC Biology in the Federal Board and a Co-opted member of the Board of Studies of Botany at Quaid-i-Azam University Islamabad.