Textbook of BIOLOGY
Grade 12

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Textbook of Biology Grade - 12

Note:
The material given in the box (Science titbits, Did you know, Critical thinking, STSC, Activity, Teacher’s Point) and parenthesis are not part of the text or SLO’s.

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PREFACE

Biology Grade - 12 is developed according to the National Curriculum 2006 and National Style Guide. It is being published since 2014 and now it is presented under the new management and supervision of textbook development, principles and guidelines with new design and layout.

The standard includes higher thinking, deep knowledge, problem solving substantive conversation and connections to the world beyond the class room and achieve the target set by the curriculum. The special features of the textbook are:

- Each chapter begins with a brief recalling statement i.e., introduction to the chapter. The textbook has coloured illustrations to capture the students' attention. Where necessary, concept mapping has also been incorporated.
- Necessary 'Tit Bits' and 'Critical Thinking' have been added in each chapter for motivating the students to apply their intelligence and acquire more knowledge.
- The exercises include multiple choice questions, short answer questions and extensive questions.
- At the end of the book a glossary and has been annexed.

In each chapter Science, Technology and Society connections are explained in accordance with the curriculum. These interventions will serve as a guide for evaluating the students' skills development through the chapter knowledge and their abilities to apply knowledge to the scientific and social problems. The duration or the number of periods is also allocated to complete each chapter, so that the teachers can develop their teaching strategy and plans in an effective manner accordingly.

A few SLO's though present in the Curriculum have been deleted on the recommendation of course committee, F.B.I.S, Education, Islamabad maintaining the standards of NCC 2016 and framework 2017.

Quality of Standards, Pedagogical Outcomes, Taxonomy Access and Actualization of Style is our motto.

With these elaborations, this series of new development is presented for use.

Prof. Dr. Inam ul Haq Javeid
(Pride of Performance)
Managing Director
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<table>
<thead>
<tr>
<th>Chapter No.</th>
<th>Title</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SECTION-3 LIFE PROCESSES</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Respiration</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>Homeostasis</td>
<td>22</td>
</tr>
<tr>
<td>16</td>
<td>Support and Movement</td>
<td>44</td>
</tr>
<tr>
<td>17</td>
<td>Nervous Coordination</td>
<td>68</td>
</tr>
<tr>
<td>18</td>
<td>Chemical Coordination</td>
<td>94</td>
</tr>
<tr>
<td>19</td>
<td>Behaviour</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>SECTION-4 CONTINUITY IN LIFE</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Reproduction</td>
<td>126</td>
</tr>
<tr>
<td>21</td>
<td>Development and Aging</td>
<td>144</td>
</tr>
<tr>
<td>22</td>
<td>Inheritance</td>
<td>170</td>
</tr>
<tr>
<td>23</td>
<td>Chromosome and DNA</td>
<td>208</td>
</tr>
<tr>
<td>24</td>
<td>Evolution</td>
<td>244</td>
</tr>
<tr>
<td></td>
<td>SECTION-5 ECOLOGY</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Man and His Environment</td>
<td>266</td>
</tr>
<tr>
<td></td>
<td>SECTION-6 APPLICATIONS OF BIOLOGY</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Biotechnology</td>
<td>292</td>
</tr>
<tr>
<td>27</td>
<td>Biology and Human Welfare</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>Glossary</td>
<td>330</td>
</tr>
</tbody>
</table>
After completing this lesson, you will be able to

- Define the respiratory surface and list its properties
- Describe the main structural features and functions of the components of human respiratory system.
- Describe the ventilation mechanism in humans.
- State lung volumes.
- Explain how breathing is controlled.
- Describe the transport of oxygen and carbon dioxide through blood.
- Describe the role of respiratory pigments.
- State the causes, symptoms and treatment of upper Respiratory Tract Infections (sinusitis) and lower Respiratory Tract Infections (pulmonary tuberculosis).
- Describe the disorders of lungs (lung cancer).
- 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.

14.1 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.
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: (a) It must be moist and permeable so that gases can pass through. (b) It must be thin, because diffusion is only efficient over distance of 1 mm or less. (c) It should possess a large surface area so that sufficient amounts of gases can be exchanged according to the organism’s need.

(d) It should possess a good blood supply. (e) There should be a good ventilation mechanism to maintain a steep diffusion gradient across the respiratory surface.

The human respiratory system can be divided into two regions, upper respiratory tract and lower respiratory tract.

14.1.1 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 a network of hairs. Both the nostrils and nasal cavities are lined by mucous membranes along with cilia.

Nose hairs, mucus and cilia serve as a defence mechanism against the harmful pathogens and solid particulate (relating to particles) 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 oesophagus and larynx. The pharynx is part of the digestive system and also the respiratory system. It is also important in vocalization. The human pharynx is conventionally divided into three sections: the nasopharynx, the oropharynx, and the laryngopharynx

**14.1.2 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 mucous membrane. Inside the larynx, two pairs of horizontal folds, in the mucous membrane extend inward from the lateral walls, called vocal cords. They contain elastic fibres and are responsible for vocal sounds, which are created when air is forced between the vocal cords, causing them to vibrate.

**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.

**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 continues 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 respiratory bronchioles. The respiratory bronchioles give rise to alveolar ducts. These alveolar ducts contain 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.

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. Each alveolar sac is made up of simple squamous epithelium.

14.1.3 The Mechanism of Breathing (Ventilation)

The lungs themselves neither draw in air nor push it out. The diaphragm, abdominal muscles and the intercostal muscles accomplish the expansion and contraction of the lungs. The diaphragm (meaning, partition) 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 (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.

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.
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.

14.1.4 Respiratory Volumes

Breathing (inspiration and expiration) occurs in a cyclical manner due to the movements of the chest wall and the lungs. The resulting changes in pressure, causes changes in lung volumes, i.e., the amount of air the lungs are capable of occupying. These volumes tend to vary, depending on the depth of respiration, gender, age and in certain respiratory diseases. Respiratory volume or pulmonary volume is the amount of air inhaled, exhaled and stored within the lungs at any given time. The amount of air which enters the lungs during normal inhalation at rest. The average tidal volume is 500ml. The same amount leaves the lungs during exhalation. The amount of extra air inhaled (above tidal volume) during a deep breath. This can be as high as 3000ml.
14.1.5 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 (lower) portion of the breathing centre acts to increase the rate and depth of inspiration and is called inspiratory centre. The dorsal (top) and lateral (side) 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 voluntary. 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.

**Science, Technology and Society Connections**

Describe the development of artificial breathing apparatus (for use under water and at high altitude and by fireman)

The word SCUBA is an acronym for Self-Contained Underwater Breathing Apparatus. It is also called aqualung.

A typical aqualung contains compressed air or a mixture called Nitrox which consists of about 35 percent oxygen and 65 percent nitrogen. This apparatus consist of a tank containing highly compressed air which the pressure down to an ambient pressure so divers could breathe comfortably at any depth.

**14.2 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 dioxides from tissues to the lungs.

**14.2.1 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 high partial pressure of oxygen, oxygen binds with haemoglobin. This binding is a reversible reaction that occurs in the alveoli of the lungs in the presence of enzyme carbonic anhydrase. Each molecule of

Teacher’s Point

Teacher would guide the students to make model to show mechanism of breathing.
haemoglobin can bind with four molecules of oxygen to form oxyhaemoglobin.

\[ \text{Hb} + 4\text{O}_2 \xrightarrow{\text{Carbonic anhydrase}} \text{Hb}4\text{O}_2 \] (Also written as HbO₈)

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

### 14.2.2 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 and 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:

\[ \text{CO}_2 + \text{H}_2\text{O} \xrightarrow{\text{Carbonic anhydrase}} \text{H}_2\text{CO}_3 \]

Carbonic acid, H₂CO₃ is an unstable compound and dissociates to form hydrogen ions and bicarbonate ions.

\[ \text{H}_2\text{CO}_3 \xrightarrow{\text{Carbonic anhydrase}} \text{H}^+ + \text{HCO}_3^- \]

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 (Hb₄O₂) to form haemoglobin bicarbonate acid (HHb) and oxygen is released to the tissue.

\[ \text{Hb}_4\text{O}_2 + \text{H}^+ \rightarrow \text{HHb} + 4\text{O}_2 \]

From inside of the erythrocytes negatively charged HCO₃⁻ 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 shifts** or **Hamburger's phenomenon**.

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 bicarbonate.
bicarbonates. The blood pH is thus maintained at approximately 7.4 by the buffer mechanism that exists in blood.

Transport of CO₂ depends on the partial pressure of CO₂. In case the partial pressure of CO₂ is higher in tissues than blood, the reaction proceeds as drawn in figure 14.7. However, in case the partial pressure of CO₂ is higher in the blood than outside of the blood (as in case of the lungs), the equation reverse and bicarbonate ions with hydrogen ion to release carbon dioxide and water.

(ii) As carboxyhaemoglobin

About 23% of carbon dioxide is carried as carboxyhaemoglobin. CO₂ combines with the globin part of haemoglobin. The reaction depends upon the partial pressure of CO₂. When the PCO₂ is higher in the tissues than blood, formation of carboxyhaemoglobin occurs. When, the PCO₂ is higher in the blood than tissues as in case of lungs, carboxyhaemoglobin releases its CO₂.

(iii) As dissolved CO₂ in plasma

Only 7% of carbon dioxide is carried this way. This is rather in efficient way to carry carbon dioxide, but it does occur.
14.2.3 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 (heme) in haemoglobin. The two well-known respiratory pigments are haemoglobin and myoglobin.

Haemoglobin

It contains four globin protein chains, each associated with haem, (also hem and heme) 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.

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 acts as a store of oxygen in resting muscle, only releasing it when supplies of oxyhaemoglobin have been exhausted.

Table 14.1 Differences between haemoglobin and myoglobin

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<thead>
<tr>
<th>Haemoglobin</th>
<th>Myoglobin</th>
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<tbody>
<tr>
<td>(1) It consists of four polypeptide chain.</td>
<td>(1) It consists of one polypeptide chain.</td>
</tr>
<tr>
<td>(2) Each molecule possesses four iron containing haem groups.</td>
<td>(2) Each molecule possesses one iron containing haem group.</td>
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</tbody>
</table>
Four oxygen molecules can bind to each haemoglobin molecule. It is found in RBCs. It transports oxygen. It has less affinity with oxygen. It loses oxygen at PO$_2$ 60 mmHg.

Only one oxygen molecule can bind to each myoglobin molecule. It is found in muscles. It stores oxygen. It has more affinity with oxygen. It loses oxygen at PO$_2$ 20 mmHg.

Science, Technology and Society Connections
Relate the transportation of gases to hiccups, sneezing and snoring.

Hiccups: It is the spasmodic contraction of the diaphragm while the glottis is closed, producing a sharp respiratory sound. It is reflexive and serves no known functions.

Sneezing: Deep inspiration is followed by a closure of the glottis. The forceful expiration that results abruptly opens the glottis, sending a blast air through the nasal cavity. The eyelids close reflexively during sneeze. Sneezing is a reflexive response to irritating stimulus of the nasal mucosa. Sneezing clears the upper respiratory passages.

Snoring: It is a rough, raspy noise that can occur when a sleeping person inhales through the mouth and nose. The noise usually is made by vibration of the soft palate which may occur as a result of vocal cord vibration.

14.3 RESPIRATORY DISORDERS
Several defence mechanisms protect the delicate lungs from the harmful substances we breathe. The hair around the nostrils, the mucous lining in the nose and pharynx and the cilia which are mucous elevator, serve to remove foreign particles in the inspired air. Continued inhalation of harmful substances results in the respiratory disorders.

14.3.1 Upper Respiratory Tract Infection
The infection of the upper respiratory tract includes sinusitis, 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 (purulent) 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.

Teacher’s Point
The teacher would guide the students to make model of haemoglobin and myoglobin.
Beside it the physician may also prescribe nebulization (steam inhalation) which can be useful in reducing inflammation in the sinuses and nose and to accelerate recovery.

14.3.2 Lower Respiratory Tract Infection

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

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, malaise (depression), weakness and dry cough with sputum, dull ache in the chest due to pleurisy (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.

14.3.3 Disorders of the Lungs

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

Lung Cancer

Cancer is a malignant (metastatic or that can be proliferated) tumour which may develop due to uncontrolled cell division.

Cause: Smoking is the main cause of lung cancer because tobacco smoke contains many carcinogens (cancer causing substance). In addition to this, asbestos, arsenic, radiation such as gamma and x-rays, the sun, and compounds in car exhaust fumes are all examples of carcinogens.

Symptoms: The first event appears to be thickening and callusing (over growth) of the cells lining the bronchi. Then there is a loss of cilia so that it is impossible to prevent dust and dirt from setting in the lungs. The tumour may grow until the bronchus is blocked, cutting off the supply of air to that lung.

Teacher’s Point

The teacher would guide the students to write a research paper on “how to protect the lungs”?
**Treatment:** The only treatment that offers a possibility of cure is to remove a lobe or the lung completely before secondary growths have time to form. This operation is called pneumonectomy. Treatments also include chemotherapy and radiotherapy.

**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 bury 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.

### 14.3.4 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 oesophagus.
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.

**Activity**

1. Identification of different parts of the respiratory and reproductive system of a dissected frog (dissection would be done by the teacher)
2. Examination of sheep lungs
3. Comparison and interpretation of the X-ray films of lungs of a smoker with that of a healthy man
1. **Select the correct answer**
   (i) 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
   (ii) 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
   (iii) 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
   (iv) Which of the following is the respiratory surface in human respiratory system:
   (A) larynx (B) trachea
   (C) bronchi (D) alveoli
   (v) How is most of the oxygen transported in the blood?
   (A) dissolved in plasma (B) bound to haemoglobin
   (C) as bicarbonate (D) dissolved in water
   (vi) The lateral walls of the chest cavity of man are composed of the:
   (A) ribs (B) intercostals muscles
   (C) ribs and intercostals muscles (D) ribs, intercostals muscles and diaphragm
   (vii) 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
   (viii) 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
(ix) Breathing is an example of
   (A) counter current exchange   (B) cellular respiration
   (C) ventilation                (D) diffusion

(x) Which event is not associated with the activity of expiration?
   (A) contraction of diaphragm
   (B) more dome like shape of diaphragm
   (C) backward and downward movement of rib cage
   (D) relaxation of external intercostals muscles

(xi) Respiratory pigments
   (A) combine reversibly with only oxygen   (B) all have four haem groups
   (C) attach to the alveolar wall               (D) None of them

(xii) 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

Short Questions

2. What is respiratory surface? Write the properties of respiratory surface
3. What organs constitute the respiratory system?
4. How nose and nasal cavity function in filtering the incoming air?
5. What is the role of ‘pharynx’ in human respiration?
6. Describe the structure and function of human larynx.
7. Describe the structure and function of alveoli.
8. Describe the structure and function of pleura.
9. How the contraction and relaxation of human lungs take place?
10. What is respiratory volume?
11. What is chloride shift?
12. What are the differences between haemoglobin and myoglobin?
13. What is the role of respiratory pigments?
14. What are the causes of lung cancer?
15. What are the advantages of having millions of alveoli rather than a pair of simple balloon like lungs?
16. Define/Describe/Explain briefly:

- internal respiration
- external respiration
- pharynx, vocal cords, bronchi, bronchioles
- alveoli, pleura, diaphragm, oxygen carrying capacity, chloride shift/Hamburger's
- haemoglobin, myoglobin, malignant cancer, callus, pneumonectomy, chemotherapy, radiotherapy

17. Write the differences between:

(a) Internal and external respiration
(b) Upper and lower respiratory tract
(c) Bromchi and bronchioles
(d) Oxyhaemoglon and carboxyhaemoglobin
(e) Haemoglobin and myoglobin

18. Describe the human upper respiratory tract.

19. Describe the human lower respiratory tract.

20. Describe the structure of human trachea in detail.

21. Describe the external structure of human lungs.

22. Describe the mechanism of breathing in man.

23. How the control of breathing takes place?

24. Explain the transport of oxygen in blood.

25. Explain the transport of carbon dioxide in blood.

26. What is the role of respiratory pigments in man?

27. Describe the cause, symptoms and treatments of:

   (a) Sinusitis
   (b) Pulmonary tuberculosis
   (c) Lung cancer

28. What are the effects of smoking on lungs?
HOMEOSTASIS

After completing this lesson, you will be able to

- Differentiate between osmoconformers and osmoregulators.
- Define osmoregulation.
- Explain the problems faced by osmoregulators.
- Explain the different methods of osmoregulation found in freshwater, marine water and terrestrial habitats.
- List various nitrogenous compounds excreted during the process of excretion.
- Explain the nature of excretory products in relation to habitat.
- Explain different organs of urinary system. Describe the structure of kidney and relate it with its function.
- Explain the detailed structure of nephron.
- Explain the processes of glomerular filtration, selective re-absorption and tubular secretion as the events in kidney functioning.
- Explain that concentration of urine is regulated by counter-current and hormonal mechanisms.
- Justify the functioning of kidneys as both excretion and osmoregulation.
- Compare the function of two major capillary beds in kidneys i.e. glomerular capillaries and peritubular capillaries.
- List urinary tract infections and the bacteria responsible.
- Explain the causes and treatments of kidney stones.
- Outline the causes of kidney failure.
- Explain in detail the mechanism dialysis.
- Define thermoregulation and explain its needs.
- Classify animals on the basis of the source of body's heat i.e. ectotherms and endotherms.
- Classify the animals on the bases of the ability to thermoregulate i.e. poikilotherms and homeotherms.
- Describe the regulatory strategies in man for thermoregulation.

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 or freshwater. The internal environment is formed by the interstitial fluid or tissue fluid surrounds and bathes all the tissue and circulating body fluids like lymph or plasma, the liquid part of the blood. Homeostasis is the
tendency of an organism or cell to regulate its internal conditions, such as the chemical composition of its body fluids, so as to maintain health and functioning, regardless of outside conditions.

15.1 MECHANISM OF HOMEOSTASIS

The internal factors which are influenced by external environment are called variables e.g., body temperature, water concentration, solute composition etc. Set point is the "ideal" or "normal" value of the variable that is previously "set" or "stored" in memory.

Homeostatic mechanism operates just like physical control system in having three components; receptors, control centre and effectors.

Receptor (sensor)

It detects changes in variable and feeds that information back to the control centre (integrator) (thermometer in following example).

Control centre (integrator)

It integrates (puts together) data from sensor and stored "set point" data (thermostat in following example).

Fig.15.1 Basic component of a control system
Effector

It is the mechanism that has an "effect" on the variable (heating coil in this example).

Example: In a common laboratory incubator, if temperature is decreased from set point, the thermometer (receptor) detects the change in temperature and signals the thermostat (control centre), which in turn activates the heating coil (effector). Similarly, if temperature is increased from the set point again thermometer detects the change and signals the thermostat to switch OFF heating.

Likewise, in human body, thermoreceptors are involved in the detection of temperature change. Hypothalamus in forebrain is the thermostat of the body. Stimulated once, it acts on effectors for cooling (e.g., sweat glands) or heating (e.g. muscles) the body to reverse the change to the set point. After receiving the signal from receptor, the control centre causes a change to correct the deviation by depressing it with negative feedback or enhancing it with positive feedback.

15.1.1 Concept of Feedback Mechanism in Homeostasis

Feedback system consists of a cycle of events in which information about a change (e.g., a change in temperature) is fed back into the system so that the regulator (the temperature regulating centre in the brain) can control the process (temperature regulation). There are two types of feedback: negative feedback and positive feedback.

Negative feedback

Negative feedback is mainly, how homeostasis is maintained. This feedback results in a reversal of the direction of change. Negative feedback tends to stabilize a system, correcting deviations from the set point.

For example, negative feedback mechanism is applied to control water content in the body. When body is deficient in water, hypothalamus stimulates posterior pituitary lobe to release antidiuretic hormone (ADH). ADH makes, collecting tubules and distal convoluted tubules permeable to water, thus more water is absorbed and maximum amount of water is retained in the body. The blood water content rises, which is sensed by hypothalamus. So ADH secretion slows down.

Positive feedback

Positive feedback response is, mainly responsible for amplification of the change in variable. This has a destabilizing effect, so does not result in homeostasis. Positive feedback is less common in naturally occurring systems than negative feedback, but it has its applications. For example, a baby suckling at the nipple sends...
nerve signals to sensory neurons in the hypothalamus. Oxytocin is made by neurosecretory cells and stored in the posterior pituitary. When oxytocin circulates to target cells in the breast, it triggers smooth muscle contraction and release of milk. The milk encourages more suckling at the nipple.

**Skills: Analyzing and Planning**

Investigate why positive feedback mechanisms in human are sometimes associated with severe health problem.

Most positive feedback mechanisms are harmful and in some cases resulting in death. For example, if a person breathes air that has very high carbon dioxide content, this produces a high concentration of carbon dioxide in blood. This is sensed by carbon dioxide receptors, which cause the breathing rate to increase. So the person breathes faster, taking in more carbon dioxide, which stimulates the receptors even more, so they breathe faster and faster which ultimately results in death.

**Skills: Analyzing and Planning**

List some behavioural responses of the animals to maintain homeostasis.

- The removal of heat by the evaporation of water from respiratory tract (panting). e.g., crocodiles, birds, dogs.
- Migration of some animals to suitable climate e.g., migratory birds.
- Some bask (take pleasure) in the sun e.g., marine iguana.
- Some animals huddle (crowd) together when it is cold.
- Some burrow when it is hot e.g., horned lizard.
- Elephants often seek relief from tropical heat by breathing and flapping their ears to cool their blood. Packed with blood vessels, their ears can radiate a lot of heat.

**Skills: Interpreting and Communication**

A flow chart to show negative feedback of homeostatic mechanisms by taking an example of hormone

Flow chart showing negative feedback in the regulation of the hypothalamus, anterior pituitary and thyroid:

1) Low body temperature or stress stimulates neurosecretory cells of hypothalamus.
2) The releasing hormones of hypothalamus trigger the release of thyroid stimulating hormone (TSH) in the anterior pituitary.
3) The TSH then stimulates the thyroid gland to release thyroxin.
4) Thyroxin causes an increase in the metabolic activity of most body cells, generating ATP energy and heat.
5) Both the raised body temperature and higher thyroxin levels in the body inhibit the releasing hormone cells of hypothalamus and the TSH producing cells.
15.2 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.

15.2.1 Osmoregulators and Osmoconformers

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.

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).

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.

15.2.2 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 tendency 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.

15.2.3 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 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, \( \text{Na}^+ \), \( \text{Cl}^- \) and some amount of \( \text{K}^+ \) are removed across the gill epithelium while divalent ions like \( \text{Mg}^{++} \), \( \text{Ca}^{++} \) 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. 90% of the water that they use is metabolic water derived from cellular oxidation.
15.3 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. The nitrogenous excretory products of animals are ammonia, urea and uric acid.

15.3.1 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 interfere 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, coelenterates. 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 urea. 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.

Uric acid

Uric acid is a purine even less toxic than urea, and it precipitates from solution, allowing the 4 nitrogen atoms per uric acid molecule to be excreted with just enough water so that the crystals do not scratch on the way out. 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 loss problems, terrestrial invertebrates and egg-laying vertebrates. These animals are called uricotelics.

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.

Teacher's Point
Teacher would ask the students to think that from where the carbon dioxide used in the formation of urea comes from and where does the remainder of excess carbon dioxide go to be excreted.
### 15.4 EXCRETORY SYSTEM OF MAN

The excretory system (urinary system) consists of kidneys, ureter, 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, 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. 15.5 Excretory system of man](image)

**Fig. 15.6 Human kidney: (a) external structure (b) internal structure (longitudinal section)**

#### 15.4.1 Structure and Functions of Kidney

The science concerned with the structure, functions and diseases of the kidneys is called **nephrology**. A kidney is a reddish brown, bean shaped organ with a small surface. A fibrous connective tissue layer, called the **fibrous capsule**, encloses each kidney. The lateral surface of each kidney is convex, but its medial side is deeply concave. The resulting medial depression

**Teacher’s Point**

The teacher would ask the students to reply that why the left kidney is about 1.5 to 2.0 cm higher than the right one.
leads into a hollow chamber called the **renal sinus**. The entrance to this sinus is termed **hilum** (hilus), where the renal artery and nerves enter and the renal vein and the ureter exit. The kidney is divided into an outer **renal cortex** and inner **renal medulla** that surrounds the renal sinus. The renal medulla consists of a number of cone-shaped **renal pyramids**. The base of each pyramid is located at the boundary between renal cortex and the renal medulla. The tips of the pyramids, the **renal papillae** are pointed toward the centre of the kidney. Urine is collected in the renal pelvis and exit the kidney through **ureter**.

**Structure of 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 minor calyces through an opening in a renal papilla.

**Blood circulation to nephron**

The renal artery within kidney gives rise branches called **interlobular arteries** which project into the cortex and give rise the **afferent arterioles**. The afferent arterioles supply blood to the glomerular capillaries of the renal capsule. **Efferent arterioles** (rather than a venule) arise 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 **interlobular veins**, which drain into renal vein. The renal vein exits the kidney and connects to the inferior vena cava.

**Functions of kidney**

Kidneys function as excretory as well as osmoregulatory organs. Their excretory functions include the filtration of nitrogenous wastes from the blood and its removal outside the body in the form of urine. 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.

**Urine formation**

The formation of urine involves glomerular filtration, tubular reabsorption and tubular secretion.
Glomerular filtration (pressure filtration or ultrafiltration) 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 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.

**Selective reabsorption** (tubular 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, 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.

**The mechanism of urine concentration**

Water is reabsorbed along the whole length of the nephron, but the formation of hypertonic (more concentrated) urine is dependent on the reabsorption of water from the loop of Henle and collecting duct.

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 enzyme **renin**.
This is achieved by **counter current multiplier mechanism**. Due to the counter current, filtrate moving in limbs of loop of Henle and the blood moving in the capillaries of **vesa 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** (adrenal cortical hormone). 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.

### 15.5 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.

#### 15.5.1 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>
<thead>
<tr>
<th>Bacteria</th>
<th>Diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <em>Escherichia coli</em></td>
<td>1. UTI</td>
</tr>
<tr>
<td>2. <em>Proteus vugaris</em></td>
<td>2. UTI</td>
</tr>
<tr>
<td>3. <em>Klebsiella pneumoniae</em></td>
<td>3. UTI</td>
</tr>
<tr>
<td>4. <em>Neisseeria gonorrhoea</em></td>
<td>4. Urethritis, Gonorrhoea</td>
</tr>
<tr>
<td>5. <em>Treponema palladium</em></td>
<td>5. Syphilis</td>
</tr>
</tbody>
</table>

**Teacher’s Point**

The teacher would ask the students to reply that why kidneys are also called osmoregulatory organs?
15.5.2 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.

Skills: Initiating and Planning

Hypothesize kidney stone by studying the urine test of relevant patient.
When urine is acidic (low pH) the stone is of calcium of 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.

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 (C\textsubscript{2}O\textsubscript{4}\textsuperscript{2-}) 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.

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 break up 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.

### 15.5.3 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.

### 15.5.4 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 transfuse (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.

**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 (dialysis fluid) enters and leaves the cavity. During circulation, when blood passes through the blood vessels (capillary networks) within the peritoneum, the dialysate attracts certain molecules to cross the membrane into the dialysate.

### 15.5.5 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 (cadaver) 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.

When a donor kidney becomes available, it is relatively simple operation to transplant it into another body. The old kidneys are left in place and they do not harm. The existing kidneys are removed only if they cause persistent infection or high blood pressure. The new kidney is placed in the lower abdomen. Surgeon chooses the site because the new kidney can be attached easily to a large artery (femoral artery) and is usually right next to the bladder. As soon as the transplanted kidney is connected to the blood vessels, it will begin purifying the blood of waste products.

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.

15.6 THERMOREGULATION

Thermoregulation is defined as the maintenance of internal temperature within a range that allows cells to function efficiently. The body works to balance the amount of heat loss to maintain a stable internal temperature. Temperature colder or warmer than the enzymes optimum range, changes the shape of the active site and causing chemical reaction to stop.
15.6.1 Classification of Animals on The Basis of Temperature

Animals can be classified based upon ability to maintain constant body temperature as poikilotherms and homeotherms. **Poikilotherms** are all non-vertebrates, fishes, amphibian and reptiles. These are unable to maintain their body temperature within narrow limits using physiological mechanisms. **Homeotherms** are birds and mammals which are able to maintain a fairly constant body temperature by using physiological mechanisms.

Animals are also classified on the basis of source of body’s heat as ectotherms and endotherms. **Ectotherms** animals produce metabolic heat at low level and 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 by-product during metabolism in muscles, or by the action of hormones that increase metabolic rate. The examples of endotherms are birds and mammals.

15.6.2 Thermoregulatory Strategies in Man

Thermoregulatory centre in human body is located in the hypothalamus which acts as 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 centres of the brain. This means that we ‘feel’ changing our clothing or turning the heating up or down. Often, this behavioural response corrects the situation without the need for any physiological response.

**Hyperthermia** is the body temperature above 37°C. There are two main physiological responses to heat, vasodilation and sweating. **Vasodilation** is the expansion of blood capillaries which lie just beneath the epidermis of the skin. So there is more flow of the blood in blood capillaries of the skin. Sweat glands spread sweat over the skin. Evaporation of sweat from the skin carries heat from the blood thus produces cooling effect.

**Physiological responses to cold**

Spasmodic contraction of the muscles is called **shivering**. This contraction produces heat which helps to raise the body temperature. **Vasoconstriction** reduces blood flow to the skin. **Piloerection** literally means “erection of skin hair”. It traps air in the erected hair which is insulator for the heat. **Increased metabolic rate** is also a physiological response to cold.

**Teacher’s Point**

The teacher would arrange a study tour for the students to kidney transplant centres of public and private sector so that the students can make an assignment of their visit.
Construct a flowchart that illustrates how wastes are removed by the kidneys.
1. Select the correct answer

(i) 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.

(ii) 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.

(iii) 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.

(iv) 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

(v) 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

(vi) 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
(vii) 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 reabsorption
(C) glomerulus, by ultrafiltration
(D) proximal convoluted tubule, by selective reabsorption

(viii) 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

(ix) The main difference between endotherms and ectotherms is
(A) how they conserve water
(B) where from they get most of their body heat
(C) whether they are warm or cold blooded
(D) whether they live on land or in the water

(x) 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

Short Questions
2. What are the three components of homeostatic mechanism?
3. Investigate feedback mechanism.
4. What are osmoregulators and osmoconformers?
5. What are the problems faced by osmoregulators?
6. Name the organs of the urinary system and write their major functions.
7. What is anhydrobiosis?
8. Describe glomerular filtration.
9. What are the functions of kidneys?
10. Describe the counter current multiplier mechanism.
11. Name the parts of a nephron and trace the blood supply to the nephron.
12. What general processes are involved with urine formation?
13. How reabsorption is a selective process?
14. Describe urinary tract infection.
15. Name three urinary tract infections and bacteria responsible.
16. What are the causes of kidney failure?
17. Suggest why protein intake needs to be limited in kidney failure.
18. By what physical processes do solutes enter or leave the blood during dialysis?
19. Why do blood and dialysate flow in opposite direction?
20. Suggest two problems that might occur if the dialysate was pure water.
21. What is the main problem with a kidney transplant when it has been carried out?
22. Compare peritoneal dialysis with haemodialysis and suggest which one is advantageous?
23. How animals can be classified on the bases of the ability to thermoregulation?
24. How do blood vessels in the skin help regulate body temperature during hot and cold external condition?
25. Why women are more likely to acquire UTI as compared to men?
27. Define/Describe/Explain:
   homeostasis, receptor (sensor), control centre (integrator), effector, feedback system,
   negative feedback system, positive feedback system, osmoregulators,
   osmoconformers, ionocytes, rectal gland, anhydrobiosis, ammonia, urea, uric acid,
   peritubular capillaries, glomerular filtration, tubular secretion, selective reabsorption,
   urethritis, cystitis, pyelonephritis, nephrolithiasis, extracorporeal shock wave lithotripsy,
   percutaneous nephronlithotripsy, kidney failure, renal dialysis, peritoneal dialysis,
   poikilotherms, homeotherms, ectotherms, endotherms, hyperthermia, vasodilation,
   vasoconstriction, catheter, dialyzer, dialysate, nephrology, urology
28. Write the differences between:
   (a) negative and positive feedback mechanism
   (b) osmoregulation and osmoconformers
   (c) ammonotelic and ureotelic
   (d) ureotelic and uricotelics
   (e) major and minor calyces
   (f) proximal and distal convoluted tubule
   (g) afferent and efferent arterioles
   (h) hypercalcemia and hyperuricema
   (i) extracorporeal shock wave lithotripsy and percutaneous nephronlithotripsy
   (j) chronic renal failure and acute renal failure
   (k) peritoneal dialysis and haemodialysis
   (l) renal cortex and renal medulla
   (m) fibrous capsule and Bowman’s capsule
   (n) vasodilatation and vasoconstriction
   (o) dialyzer and dialysate
29. Explain the components of homeostatic mechanism.
30. Describe feedback mechanism in homeostasis.
31. Describe the osmoregulatory adaptations in
   (a) Freshwater animals
   (b) Marine animals
   (c) Terrestrial animals
32. Discuss relationship between excretory products and habitats.
33. Describe the structure and function of human kidney.
34. Describe the structure of human nephron.
35. Describe the blood circulation to human nephron.
36. Discuss the ‘urine formation ‘and mechanism of urine concentration in man.
37. What are kidney stones? Discuss the causes and treatment of kidney stones?
38. What is renal dialysis? Describe the two types of renal dialysis.
39. What is kidney transplantation? Describe principles of kidney transplant. What are the
    problems associated with kidney transplant?
40. What is thermoregulation? Classify animals on the basis of temperature. What are the
    thermoregulatory strategies in man?
After completing this lesson, you will be able to

- Describe the structure of bone and compare it with that of cartilage.
- Explain the functions of osteoblasts, osteoclasts and osteocytes.
- Identify the main divisions of human skeleton.
- List the bones of appendicular and axial skeleton of man.
- Describe three types of joints i.e. fibrous joints, cartilaginous joints and synovial joints and give example of each.
- Relate the bipedal posture of man with his skeleton and musculature.
- Identify the bones of the pelvic girdles, pectoral girdle, arms and legs by using the model of human skeleton.
- Describe the disorders of human skeleton (disc-slip, spondylosis, sciatica, arthritis) and their causes.
- State different types of fractures (simple, compound and complicated) and describe the repair process of simple fractures.
- Describe the injuries in joints (dislocation and sprain) and their first aid treatment.
- Describe the first-aid treatment for fracture.
- Compare smooth muscles, cardiac muscles and skeletal muscles.
- Explain the ultra-structure of the skeletal muscle.
- Explain the sliding filaments model of muscle contraction.
- Describe the action of antagonistic muscles in the movement of knee joint.
- Explain muscle fatigue, cramps and tetany.
- Differentiate between tetanus and muscle tetany.
- Compare the structure of skeletal, smooth and cardiac muscles with the help of prepared slides.
- Draw a diagram of sarcomere and label its parts.
- Justify how the main functions of the skeleton are to act as a system of rods and levers, which are moved by the muscles.
- Justify why do the muscles pull but do not push.
- Name the techniques for joint transplantation.
- Justify why the use of calcium in teenage and twenties can be a preventive action against osteoporosis.
- Reason out the rigor mortis.
- Relate improper posture to bone/joint problems.

Some 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.
16.1 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.

16.1.1 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 (lumen) filled by yellow bone marrow. The outer connective tissue around the bone is called periosteum and the inner region is called endosteum. 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.

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. Osteoclasts perform bone resorption (demineralization), 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.

### 16.1.2 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.

![Fig. 16.3 Structure of cartilage](image)

<table>
<thead>
<tr>
<th>Table 16.1 Comparison between bone and cartilage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feature</strong></td>
</tr>
<tr>
<td>Collagen</td>
</tr>
<tr>
<td>Cell types</td>
</tr>
<tr>
<td>Blood vessel</td>
</tr>
<tr>
<td>Minerals</td>
</tr>
<tr>
<td>External covering</td>
</tr>
</tbody>
</table>

### 16.1.3 Divisions of Human Skeleton

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

**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.
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. Ear ossicles are the six bones found in ears. These are incus (left and right), malleus (left and right) and stapes (sta-peez) (left and right). 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.
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**.

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.

**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.

**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 along 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, (see figure 16.4).

**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. Tibia 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.

**Teacher Point**

The teacher would ask the students to distinguish between male and female pelvis.
16.1.4 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).

**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.

**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),

**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. Synovial joints
Synovial joints

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 joint, Pivot joint, Ball-and-socket joint, Gliding joint.

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.

Teacher Point

The teacher will ask the students to use library or Internet resources to find out more about joint replacement.
16.2 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 spondylisis, sciatica and arthritis.

16.2.1 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.

![Fig. 16.11 Structure of (a) intervertebral disc (b) slipped disk](image-url)

Science, Technology and Society Connections

- 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.
Spondylosis
It is the immobility and fusion of vertebral joint. Cervical spondylosis results from chronic cervical degeneration, with herniation of disc and aging.

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.

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.

Science, Technology and Society Connections
Justify the use of calcium in teenage and twenties can be a preventive action against 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.

16.2.2 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.

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.

Teacher Point
The teacher will ask the students to use library or Internet resources to find out more about osteoporosis.
16.2.3 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 (hematoma), 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.

![Fig. 16.13 Bone fractures](image)

**Bone remodelling**

It takes place when a compact bone is formed in which the osteons from both sides break extend across the fracture line to connect the bone. 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.
16.2.4 Injuries to Joints

Torsion or sudden impact to the side of a joint can be devastating. We will discuss here dislocation and sprain.

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.

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.

16.2.5 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 depends 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.

16.3 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.
16.3.1 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).

![Types of muscles](image)

(a) Smooth muscles  (c) Skeletal muscles  (b) Cardiac muscles

**Table 16.2 Comparison of three types of muscle tissues**

<table>
<thead>
<tr>
<th>Property</th>
<th>Smooth Muscles</th>
<th>Cardiac Muscles</th>
<th>Skeletal Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle appearance</td>
<td>Unstriped</td>
<td>Irregular striped</td>
<td>Regular striped</td>
</tr>
<tr>
<td>Cell shape</td>
<td>Spindle</td>
<td>Branched</td>
<td>Spindle or cylindrical</td>
</tr>
<tr>
<td>Number of nuclei</td>
<td>One per cell</td>
<td>One per cell</td>
<td>Many per cell</td>
</tr>
<tr>
<td>Speed of contraction</td>
<td>Slow</td>
<td>Intermediate</td>
<td>Slow to rapid</td>
</tr>
<tr>
<td>Contraction caused by</td>
<td>Nervous system</td>
<td>Spontaneous</td>
<td>Nervous system</td>
</tr>
<tr>
<td>Function</td>
<td>Controls movement of</td>
<td>Pumps blood</td>
<td>Move skeleton</td>
</tr>
<tr>
<td></td>
<td>substances through</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>hollow organs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voluntary control</td>
<td>Usually no control</td>
<td>Usually no control</td>
<td>Have control</td>
</tr>
</tbody>
</table>
16.3.2 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. 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). Within the muscle fibres are numerous thin myofibrils (myo, muscle, fibra, thread) which possess characteristic cross striations.

Fig. 16.15 Structure of skeletal muscle
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 (or microfilaments) **actin** and **myosin**. The cytoplasm of the myofibril is called **sarcoplasm**. It contains **sarcoplasmic reticulum**.

Muscle fibres range from approximately 1mm to about 4cm in length and from 10 – 100 μm in diameter. All the muscle fibres in the given muscle have similar dimensions. 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.

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 filaments and thick filaments. Transversing the middle of each I band is a dark line called the **Z line** (Z for zwischenscheibe, a German word meaning ‘between discs’). The section of myofibril between two Z lines is called a **sarcomere**, which is a contractile unit. From the Z line actin filaments extend in both directions, whilst in the centre of the sarcomere are found myosin filaments.

**Ultra - structure of skeletal muscles**

In certain regions of the sarcomere, actin and myosin filaments overlap. Transverse sections in these regions indicate that six actin filaments surround each myosin filament. This arrangement of actin and myosin filaments results in a number of other bands being recognizable in the sarcomere. Myosin and actin filaments constitute the **A band** because they are **anisotropic** that can polarize visible light. Actin filaments alone constitute I **band**, which are **isotropic** or polarizing. The centre of the **A band** is lighter than the other regions in a relaxed sarcomere as there are no overlap between the actin and myosin in this region. It is called the

**Extra Reading Material**

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.
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.

Thick myofilaments are 16 nm in diameter and are composed of only myosin protein.

The thin filaments are 7–8 nm thick and are composed chiefly of the actin protein.

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. One of these polypeptides (TnI) is an inhibitory subunit that binds to actin; another (TnT) binds to tropomyosin and helps position it on actin. The third (TnC) binds calcium ions. Both troponin and tropomyosin help control the myosin-actin interactions involved in contraction.

16.3.3 Muscle Contraction – Sliding Filament Model

The sliding filament theory of contraction states that during contraction the thin filaments slide past the thick ones so that the actin and myosin filaments overlap to a greater degree. In a relaxed muscle fibre, the thick and thin filaments 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 filaments, 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 filaments 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.

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 muscle is required to contract, calcium ions bind with the troponin molecules and 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 to ADP and phosphate (Pi) and the crossed bridges are broken down. The formation and breakdown of cross bridges occur again and again during the sliding of the filament.
16.3.4 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 contract. 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.
16 Support and Locomotion

16.3.5 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 by breaking glucose.

**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**

The insufficient parathyroid hormone production causes a significant drop in the blood calcium level, *tetany* results. In tetany, the body shakes from continuous muscle contraction i.e., muscle, twitches and convulsion occurs. Tetany results in the excitability of neurons and results in loss of sensation. If untreated the system progress to spasm of larynx, paralysis and ultimately death occurs.

<table>
<thead>
<tr>
<th>Table 16.3 Difference between tetany and tetanus</th>
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<tbody>
<tr>
<td>Tetany</td>
</tr>
<tr>
<td>Caused by low calcium level in blood</td>
</tr>
<tr>
<td>Results in the excitability of neurons and results in loss of sensation</td>
</tr>
</tbody>
</table>

**Activity**

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
16 Support and Locomotion

Exercise

M.C.Qs

1. Select the correct answer

(i) The atlas and axis vertebrae are located in:
   (A) lumbar region  (B) cervical region
   (C) thoracic region (D) pelvic region

(ii) Skeletal muscles contain dark band, which are anisotropic, are called
   (A) A band  (B) I band  (C) Z band  (D) M line

(iii) The acetabulum provides the articular surface for the
   (A) humerus  (B) femur  (C) pelvis  (D) fibula

(iv) Scapula is connected with sternum by
   (A) ribs  (B) carpals  (C) clavicle  (D) atlas

(v) 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

(vi) Thin myofilaments consist of
   (A) actin, myosin, troponin  (B) actin, tropomyosin, troponin
   (C) actin, tropomyosin, fibrin  (D) actin, myoglobin, troponin

(vii) 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

(viii) A human internal organs are protected mainly by the
   (A) hydrostatic skeleton  (B) axial skeleton
   (C) exoskeleton  (D) appendicular skeleton

(ix) 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
16 Support and Locomotion

(C) It allows the muscles to produce opposing movements
(D) It double the strength of contraction

(x) 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

(xi) The deep infolding of the muscle fibre membrane is called
(A) sarcoplasmic reticula  (B) Z lines  (C) T-tubules  (D) sarcomeres

(xii) Bone dissolving cells are called
(A) chondrocytes  (B) osteoblasts  (C) osteoclasts  (D) osteocytes

(xiii) Which of the following cartilage is found at the end of long bones?
(A) calcified  (B) fibrous  (C) elastic  (D) hyaline

(xiv) At times ligaments are overstretched or torn. It is called
(A) sprain  (B) dislocation  (C) fracture  (D) tension

(xv) Which ion is essential for muscle contraction?
(A) Na  (B) K  (C) Ca  (D) Cl

Short Questions

2. How do compact bone and spongy bone differ in structure?
3. Name three types of cells associated with bone and write their functions.
4. Compare structure of bone with that of cartilage.
5. Name the bones of axial and appendicular skeleton.
6. Name the bones of cranium.
7. Describe the five groups of vertebrae.
8. What is the structure of the human rib cage.
9. Name the bones that form the (a) pectoral girdle (b) pelvic girdle.
10. Name the bones of upper and lower limbs.
11. What are the main types of joints found in bones?
12. What is fibrous joint?
13. What is cartilaginous joint? Describe the two types of cartilaginous joints.
14. What are the four steps required for bone fracture repair?
15. What skeletal structures are affected from the osteoarthritis?
16. List the major parts of skeletal muscle fibre and write the function of each part.
17. What is Z line and M line and what are their functions?
18. How the arrangement of actin filaments and myosin filaments produce I band, A band and H zone?
19. Describe the antagonistic arrangement of skeletal muscles.
20. Why are ligaments elastic and why does the tendon need to be inelastic?
21. Why do sprinters run on their toes?
22. Draw a diagram of sarcomere and label its parts.
23. Define/Describe/Explain briefly:
osteology, epiphysis, diaphysis, peristeum, endosteum, compact bone, spongy bone,
osteoblasts, osteocytes, osteoclasts, perichondrium, lacunae, chondrocytes, hyaline
cartilage, fibrocartilage, elastic cartilage, hyoid bone, arthrology, sutures,
syndesmose, gomophoses, synchondroses, symphysis, synovial joint, hinge joint,
pivot joint, ball and socket joint, saddle joint, condyloid joint, gliding joint,
osteoarthritis, rheumatoid arthritis, gouty arthritis, sprain, myofilaments, epimusium,
perimysium, endomysium, fescicle, sarcolemma, myofibrils, actin, myosin,
sarcoplasm, tendon, ligament, sarcomere, tropomyosin, troponin, flexor muscle,
extensor muscle, antagonistic arrangement, hamstring muscle, biceps femoris,
muscle fatigue, cramp, tetany.
24. 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) nucleus pulposus and annulus fibrosus
   (i) rheumatid arthritis and gouty arthritis
   (j) simple and compound bone fracture
   (k) tropomysin and troponin
   (l) tendons and ligaments
   (m) callus and bony callus
   (n) tetany and tetanus
25. Explain the structure of bone with diagram.
26. Explain the structure of cartilage with diagram.
27. Describe the bones of appendicular and axial skeleton of man.
28. Describe the bones of cranium.

29. What are the following common types of disorders of human skeleton:
   (a) Slipped disc
   (b) Spondylosis
   (c) Sciatica
   (d) Arthritis

30. Give a detail account of bone repair.

31. 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

32. Describe three types of muscle tissues in man.

33. Explain the ultra structure of skeletal muscle.

34. Explain the sliding filament model of muscle contraction.

35. Explain the action of antagonistic muscles in the movement of knee joint in man.

36. 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.

37. Describe the following muscle disorder:
   (a) Muscle fatigue
   (b) Cramp
   (c) Tetany