Human Digestive System

- Biomacromolecules (carbohydrates, proteins etc.) in food cannot be utilized by our body in their original form.
- They have to be broken down and converted into simple substances (glucose, amino acids etc.) in the digestive system.
- During the digestion process, Biomacromolecules like

1. **carbohydrates get broken into simple sugars such as glucose,**
2. **fats into fatty acids and glycerol,**
3. **proteins into amino acids.**

- This process of conversion of complex food substances to simple absorbable forms is called **digestion**.

Alimentary Canal

- The food passes through a continuous canal called **alimentary canal**. The canal can be divided into various compartments: (1) the buccal cavity, (2) foodpipe or oesophagus, (3) stomach, (4) small intestine, (5) large intestine ending in the rectum and (6) the anus.
- The activities of the gastro-intestinal tract [**alimentary canal**] are under neural and hormonal control for proper coordination of different parts.
- The sight, smell and/or the presence of food in the oral cavity can stimulate the secretion of saliva.
- Gastric and intestinal secretions are also, similarly, stimulated by neural signals.
- The muscular activities of different parts of the alimentary canal can also be moderated by neural mechanisms.

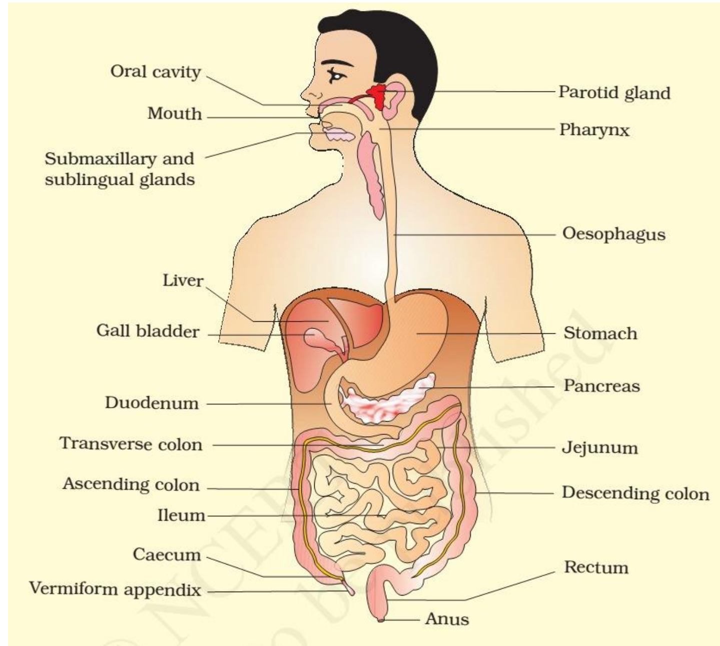
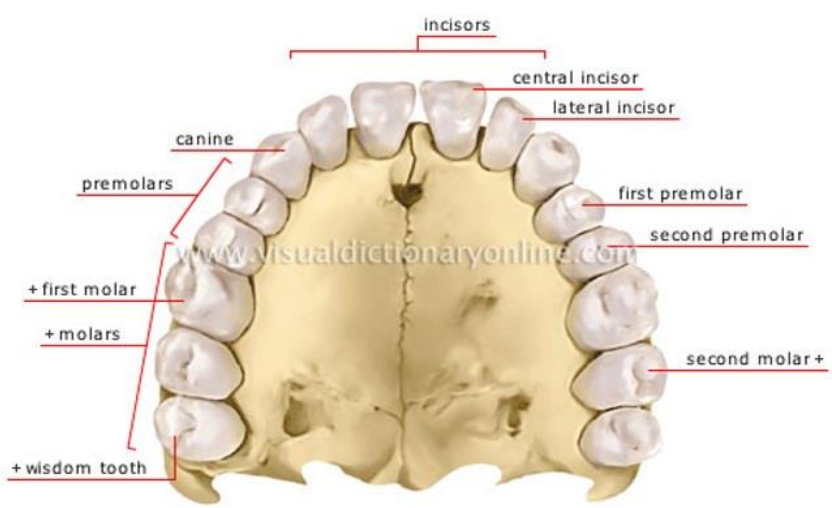
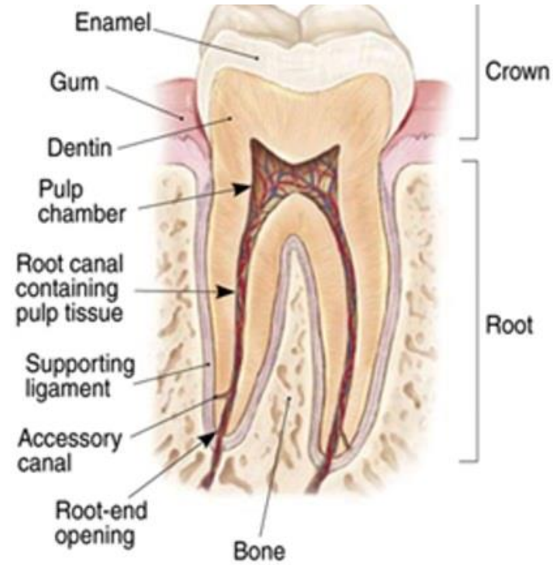


Figure 16.1 The human digestive system

Buccal Cavity or Oral Cavity – Teeth, Tongue, Saliva

- The process of taking food into the body is called **ingestion**. Ingestion happens through mouth. The mouth leads to the buccal cavity or oral cavity.
- The oral cavity has a number of teeth and a muscular tongue. Each tooth is embedded in a socket of jaw bone.
- Majority of mammals including human being forms two sets of teeth during their life, a set of **temporary milk or deciduous teeth [milk teeth]** replaced by a set of **permanent or adult teeth [permanent teeth]**.
- An adult human has 32 permanent teeth which are of four different types, namely, **incisors (I), canine (C), premolars (PM) & molars (M)**.
- Arrangement of teeth in each half of the upper and lower jaw in the order I, C, PM, M is represented by a dental formula which in human is 2123/2123 [2-I,1-C,2-PM,3-M]
- The hard chewing surface of the teeth, made up of **enamel** (Enamel is the hardest substance in the human body and contains the **highest percentage of minerals**), helps in the mastication (chewing) of food.





- Our mouth has the **salivary glands** which secrete saliva. The saliva breaks down the **<u>starch into sugars</u>**.
- The saliva secreted into the oral cavity contains **electrolytes (Na+, K+, Cl", HCOs)** and enzymes, **SALIVARY AMYLASE** and **LYSOZYME**.
- The chemical process of digestion is initiated in the oral cavity by the hydrolytic action of the carbohydrate splitting enzyme, the **salivary amylase**.
- About 30 per cent of starch is **hydrolysed** here by this enzyme (optimum pH 6.8) into a disaccharide - **maltose**.

$$\text{Polysaccharides (starch)} \xrightarrow{\text{Amylase}} \text{Disaccharides}$$

$$\text{Starch} \xrightarrow[\text{pH 6.8}]{\text{Salivary Amylase}} \text{Maltose}$$

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{Glucose + Glucose}$$

$$\text{Lactose} \xrightarrow{\text{Lactase}} \text{Glucose + Galactose}$$

$$\text{Sucrose} \xrightarrow{\text{Sucrase}} \text{Glucose + Fructose}$$

- **Lysozyme** present in saliva acts as an **antibacterial** agent that prevents infections.
- The tongue is a fleshy muscular organ attached at the back to the floor of the buccal cavity. It mixes saliva with the food during chewing and helps in swallowing food.
- The tongue is attached to the floor of the oral cavity by the **frenulum** (a fold of skin beneath the tongue).
- The upper surface of the tongue has small projections called **papillae**, some of which bear taste buds.

Foodpipe/Oesophagus

- The oral cavity leads into a short **pharynx** which serves as a common passage for food and air. The esophagus and the trachea (wind pipe) open into the pharynx.
- A cartilaginous flap called **epiglottis** prevents the entry of food into the glottis during swallowing. [Glottis == opening of the wind pipe].
- The swallowed food passes into the foodpipe or oesophagus. The oesophagus is a thin, long tube which extends posteriorly [further back in position] passing through the neck, **thorax** [the part of the body of a mammal between the neck and the abdomen] and diaphragm [separates the thorax from the abdomen in mammals] and leads to a 'J' shaped bag like structure called stomach.
- Mucus in saliva helps in lubricating and adhering the masticated food particles into a bolus. The bolus is then conveyed into the pharynx and then into the oesophagus by swallowing or **deglutition**.
- The bolus further passes down through the oesophagus by successive waves of muscular contractions called **peristalsis**. The **gastro-oesophageal sphincter** controls the passage of food into the stomach.

Stomach

- The inner lining of the stomach secretes **mucous, hydrochloric acid** and **digestive juices**.

1. The mucous protects the lining of the stomach.
2. The acid kills many ***bacteria*** that enter along with the food and makes the medium in the stomach ***acidic***.
3. The digestive juices break down the ***proteins*** into simpler substances.

- A **muscular sphincter (gastro-oesophageal)** [a ring of muscle surrounding and serving to guard or close an opening] regulates the opening of oesophagus into the stomach.
- The stomach, located in the upper left portion of the abdominal cavity, has three major parts – a cardiac portion into which the oesophagus opens, a **fundic region** and a **pyloric portion** which opens into the first part of small intestine.

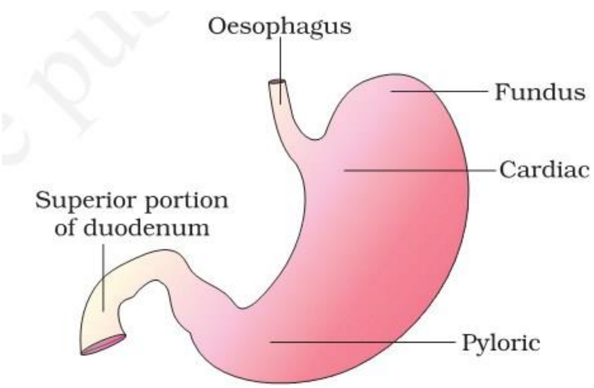


Figure 16.3 Anatomical regions of human stomach

Small intestine

- Small intestine is distinguishable into three regions, a **'C' shaped duodenum**, a **long coiled middle portion jejunum** and a **highly coiled ileum**.
- The opening of the stomach into the duodenum is guarded by the **pyloric sphincter**. Ileum opens into the large intestine.
- The small intestine is highly coiled and is about **5 meters long**. It receives secretions from the liver and the pancreas. Besides, its wall also secretes juices.

- The digested food passes into the blood vessels in the wall of the intestine. This process is called **absorption**.
- The inner walls of the small intestine have thousands of finger-like outgrowths. These are called **villi (singular villus)**. The villi **increase the surface area for absorption** of the digested food.
- Villi are supplied with a network of capillaries and a **large lymph** (a colourless fluid containing white blood cells) vessel called the **lacteal**.
- The absorbed substances are transported via the blood vessels to different organs of the body where they are used to build complex substances such as the proteins required by the body. This is called **assimilation**.
- In the cells, **glucose** breaks down with the help of **oxygen** into **carbon dioxide** and **water**, and **energy** is released.
- The food that remains undigested and unabsorbed then enters into the large intestine.

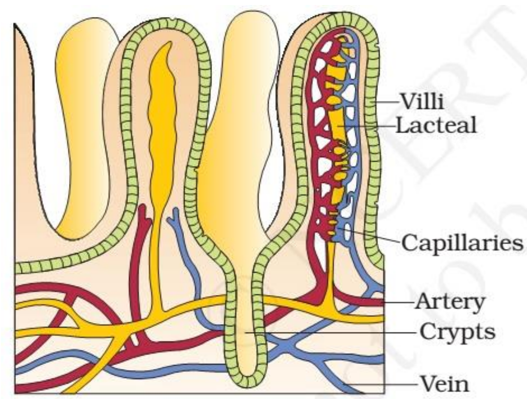


Figure 16.5 A section of small intestinal mucosa showing villi

Large intestine

- The large intestine is wider and shorter than small intestine. It is about 1.5 metre in length. Its function is to absorb water and some salts from the undigested food material.
- The remaining waste passes into the rectum and remains there as semi-solid faeces. The faecal matter is removed through the anus from time-to-time. This is called **egestion**.

Ingestion → Digestion → Absorption → Assimilation → Egestion

- It consists of **caecum**, **colon** and **rectum**. Caecum is a small blind sac which hosts some **symbiotic micro-organisms**.
- A narrow finger -like tubular projection, the vermiform **appendix** which is a vestigial organ [small remnant of something that was once more noticeable], arises from the caecum.

Appendix was helpful in digesting **roughage** (fibrous indigestible material in vegetable foodstuffs which aids the passage of food and waste products through the gut). Thousands of years ago, when man used to eat roots, leaves, etc., it was essential. But now it has lost its significance.

- The caecum opens into the colon. The colon is divided into three parts - an ascending, a transverse and a descending part. The descending part opens into the rectum which opens out through the anus.
- No significant digestive activity occurs in the large intestine. The functions of large intestine are: absorption of some water, minerals and certain drugs; secretion of mucus which helps in adhering the waste (undigested) particles together and lubricating it for an easy passage.
- The undigested, unabsorbed substances called faeces enters into the caecum of the large intestine through **ileo-caecal** valve, which prevents the back flow of the faecal matter. It is temporarily stored in the rectum till defaecation.

Layers of Alimentary Canal

- The wall of alimentary canal from oesophagus to rectum possesses four layers namely **serosa, muscularis, sub-mucosa** and **mucosa**.

1. Serosa is the outermost layer and is made up of a thin **mesothelium (epithelium of visceral organs)** with some connective tissues.
2. Muscularis is formed by **smooth muscles**.
3. The submucosal layer is formed of **loose connective tissues** containing nerves, blood and lymph vessels. In duodenum, glands are also present in sub-mucosa.

- The innermost layer lining the lumen of the alimentary canal is the mucosa. This layer forms irregular folds (**rugae**) in the stomach and small finger-like foldings called **villi** in the small intestine. **Mucosal epithelium** has **goblet cells** which secrete mucus that help in **lubrication**. Mucosa also forms glands in the stomach (**gastric glands**).

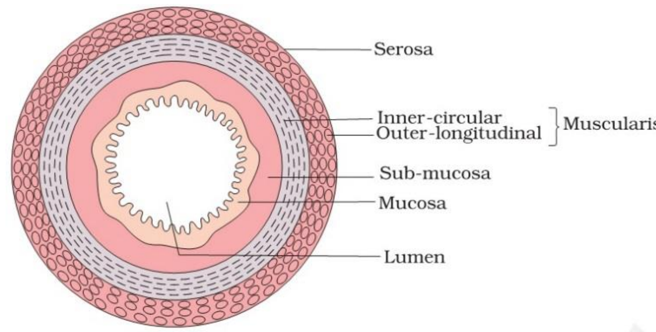


Figure 16.4 Diagrammatic representation of transverse section of gut

Digestive Glands

- The digestive glands associated with the alimentary canal include the **salivary glands**, the **liver** and the **pancreas**.

Salivary glands

- Saliva is mainly produced by three pairs of salivary glands, the parotids (cheek), the sub-maxillary (lower jaw) and the sub-linguals (below the tongue).
- These glands situated just outside the buccal cavity secrete salivary juice into the buccal cavity.
- The saliva breaks down the **starch into sugars**.

Liver

- The liver is a reddish brown gland situated in the upper part of the abdomen on the right side.
- It is the **largest gland** in the body.
- It secretes **bile juice** that is stored in a sac called the **gall bladder**.
- The bile plays an important role in the **digestion of fats**.
- It has two lobes. The hepatic lobules are the structural and functional units of liver containing **hepatic cells**.
- The bile secreted by the hepatic cells passes through the hepatic ducts and is stored and concentrated in a thin muscular sac called the **gall bladder.**

- The duct of **gall bladder (cystic duct)** along with the **hepatic duct from the liver**, forms the common **bile duct**.
- The bile duct and the pancreatic duct open together into the duodenum as the common **hepato-pancreatic duct** which is guarded by a sphincter called the **sphincter of Oddi**.

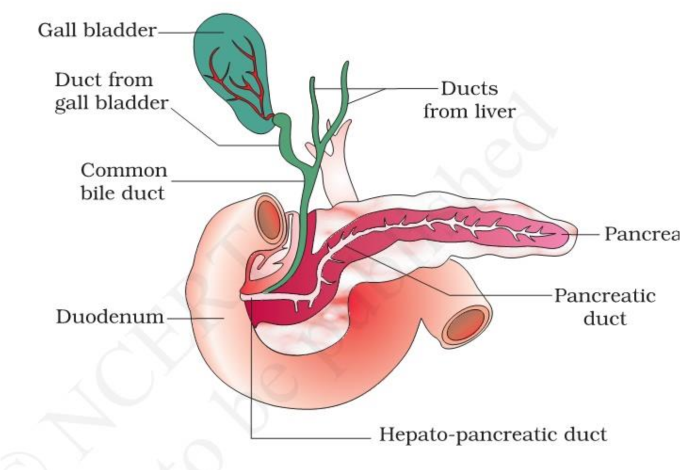


Figure 16.6 The duct systems of liver, gall bladder and pancreas

Pancreas

- The pancreas is a large cream coloured gland located just below the stomach.
- The pancreatic juice acts on **carbohydrates and proteins** and changes them into simpler forms.
- The partly digested food now reaches the lower part of the small intestine where the intestinal juice [succus entericus] completes the digestion of all components of the food.
- The pancreas is a compound (both **exocrine and endocrine**) elongated organ situated between the limbs of the 'U' shaped duodenum.
- The exocrine portion secretes an **alkaline pancreatic juice** containing enzymes and the endocrine portion secretes **hormones, insulin and glucagon**.

Digestion – Enzyme Action in Stomach

- The stomach stores the food for 4-5 hours. The food mixes thoroughly with the acidic gastric juice of the stomach by the churning movements of its muscular wall and is called the **chyme**.
- The proenzyme [inactive precursor of an enzyme] pepsinogen, on exposure to hydrochloric acid gets converted into the active enzyme **PEPSIN**, the proteolytic (breakdown of proteins or peptides into amino acids) enzyme of the stomach.
- Pepsin converts **proteins into proteoses and peptones** (peptides).
- The mucus and **bicarbonates** present in the gastric juice play an important role in **lubrication** and **protection** of the mucosal epithelium from excoriation by the highly concentrated hydrochloric acid. HCl provides the **acidic** pH (pH 1.8) **optimal for pepsins.**
- **Rennin** is a proteolytic enzyme found in gastric juice of infants which helps in the **digestion of milk proteins.**

Digestion – Enzyme Action in Small Intestine

- The pancreatic juice contains inactive enzymes - trypsinogen, chymotrypsinogen, procarboxypeptidases, amylases, lipases and nucleases.
- Trypsinogen is activated by an enzyme, **enterokinase**, secreted by the intestinal mucosa into active **TRYPSIN**, which in turn **activates the other enzymes** in the pancreatic juice.

$$\left.\begin{array}{l}\text{Proteins}\\ \text{Peptones}\\ \text{Proteoses}\end{array}\right\} \xrightarrow[\text{Carboxypeptidase}]{\text{Trypsin/Chymotrypsin}} \text{Dipeptides}$$

$$\text{Nucleic acids} \xrightarrow{\text{Nucleases}} \text{Nucleotides} \longrightarrow \text{Nucleosides}$$

$$\text{Nucleotides} \xrightarrow{\text{Nucleotidases}} \text{Nucleosides} \xrightarrow{\text{Nucleosidases}} \text{Sugars} + \text{Bases}$$

$$\text{Dipeptides} \xrightarrow{\text{Dipeptidases}} \text{Amino acids}$$

- The bile released into the duodenum contains bile pigments (bilirubin and biliverdin), bile salts, cholesterol and phospholipids but no enzymes.
- Bile helps in **emulsification of fats**, i.e., breaking down of the fats into very small micelles. Bile also activates **LIPASES**. Small amounts of **lipases** are secreted by gastric glands.

$$\text{Fats} \xrightarrow{\text{Lipases}} \text{Diglycerides} \longrightarrow \text{Monoglycerides}$$

$$\text{Di and Monoglycerides} \xrightarrow{\text{Lipases}} \text{Fatty acids} + \text{Glycerol}$$

- The intestinal mucosal epithelium has **goblet cells** which secrete mucus. The secretions of

- **Diarrhoea:** The abnormal frequency of bowel movement and increased liquidity of the faecal discharge is known as diarrhoea. It reduces the absorption of food.
- **Constipation:** In constipation, the faeces are retained within the rectum as the bowel movements occur irregularly.
- **Indigestion:** In this condition, the food is not properly digested leading to a feeling of fullness. The causes of indigestion are inadequate enzyme secretion, anxiety, food poisoning, over eating, and spicy food.

Respiration – Breathing and Exchange of Gases

- Oxygen (O_2) is utilized by the organisms to indirectly break down nutrient molecules like glucose and to derive energy for performing various activities. Carbon dioxide (CO_2) which is harmful is also released during the above **catabolic reactions**. It is, therefore, evident that O_2 has to be continuously provided to the cells and CO_2 produced by the cells have to be released out. This process of exchange of O_2 from the atmosphere with CO_2 produced by the cells is called breathing, commonly known as respiration.

Metabolic Pathways

Metabolic pathways that lead to a more complex structure from a simpler structure are called **biosynthetic pathways** or **anabolic pathways**. Example: **acetic acid becomes cholesterol.**

Metabolic pathways that lead to a simpler structure from a complex structure are called **catabolic pathways**. Example: **glucose becomes lactic acid in our skeletal muscle**.

Anabolic pathways **consume energy**. Assembly of a protein from amino acids requires energy input.

On the other hand, catabolic pathways lead to the release of energy. For example, when glucose is degraded to lactic acid in our skeletal muscle, energy is liberated. This metabolic pathway from glucose to lactic acid which occurs in 10 metabolic steps is called **glycolysis**.

Living organisms have learnt to trap this energy liberated during degradation and store it in the form of chemical bonds.

As and when needed, this **bond energy** is utilized for biosynthetic, osmotic and mechanical work that we perform.

The most important form of energy currency in living systems is the bond energy in a chemical called **adenosine triphosphate (ATP)**.

- Mechanisms of breathing vary among different groups of animals depending mainly on their habitats and levels of organization.
- Lower invertebrates like sponges, coelenterates, flatworms, etc., exchange O_2 with CO_2 by **simple diffusion** over their entire body surface.
- Earthworms use their moist **cuticle** and insects have a network of tubes (**tracheal tubes**) to transport atmospheric air within the body.
- Special vascularized structures called **gills** are used by most of the aquatic arthropods and molluscs whereas vascularised bags called lungs are used by the terrestrial forms for the exchange of gases.
- Among vertebrates, fishes use gills whereas reptiles, birds and mammals respire through lungs. Amphibians like frogs can respire through their moist **skin** Mammals usually have a well-developed respiratory system.

Human Respiratory System

- We have a pair of external nostrils opening out above the upper lips. It leads to a nasal chamber through the nasal passage. The nasal chamber opens into the **pharynx**, a portion of which is the **common passage** for food and air.
- The pharynx opens through the larynx region into the trachea. **Larynx** is a cartilaginous box which helps in sound production and hence called the **sound box**.
- During swallowing glottis can be covered by a thin elastic cartilaginous flap called **epiglottis** to prevent the entry of food into the larynx.
- Trachea is a straight tube which divides into a right and left primary **bronchi**. Each bronchi undergoes repeated divisions to form the

secondary and tertiary bronchi and **bronchioles** ending up in very thin terminal bronchioles. The tracheae, primary, secondary and tertiary bronchi are supported by **incomplete cartilaginous rings**.

- Each terminal bronchiole gives rise to a number of very thin, irregular-walled and vascularised bag-like structures called **alveoli**. The branching network of bronchi, bronchioles and alveoli comprise the lungs.
- We have two lungs which are covered by a double layered **pleura**, with pleural fluid between them. It **reduces friction** on the lung-surface. The outer pleural membrane is in close contact with the thoracic lining whereas the inner pleural membrane is in contact with the lung surface.
- The part starting with the external nostrils up to the terminal bronchioles constitute the conducting part whereas the alveoli and their ducts form the respiratory or exchange part of the respiratory system.
- The conducting part transports the atmospheric air to the alveoli, **clears it from foreign particles, humidifies** and also brings the **air to body temperature**. Exchange part is the site of **actual diffusion** of O2 and CO2 between blood and atmospheric air.
- The lungs are situated in the thoracic chamber which is anatomically an air-tight chamber. The thoracic chamber is formed dorsally by the **vertebral column**, ventrally by the **sternum** [breastbone], laterally by the ribs and on the lower side by the dome-shaped **diaphragm**.
- The anatomical setup of lungs in thorax is such that any change in the volume of the thoracic cavity will be reflected in the lung (pulmonary) cavity. Such an arrangement is essential for breathing, as we cannot directly alter the pulmonary volume.

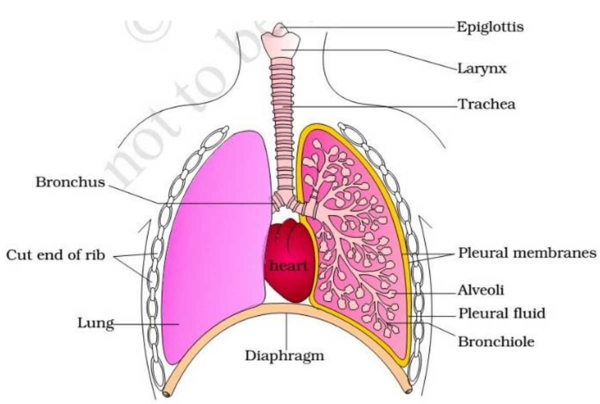


Figure 17.1 Diagrammatic view of human respiratory system (Sectional view of the left lung is also shown)

Respiration involves the following steps:

1. Breathing or pulmonary ventilation by which atmospheric air is drawn in and CO2 rich alveolar air is released out.
2. Diffusion of gases (O2 and CO2) across alveolar membrane.
3. Transport of gases by the blood.
4. Diffusion of O2 and CO2 between blood and tissues.
5. Utilisation of O2 by the cells for catabolic reactions and resultant release of CO2.

Mechanism of Breathing

- Breathing involves two stages: **inspiration** during which atmospheric air is drawn in and **expiration** by which the alveolar air is released out.

- The movement of air into and out of the lungs is carried out by creating a pressure gradient between the lungs and the atmosphere.
- Inspiration can occur if the pressure within the lungs (intra-pulmonary pressure) is less than the atmospheric pressure, i.e., there is a negative pressure in the lungs with respect to atmospheric pressure. Similarly, expiration takes place when the intra-pulmonary pressure is higher than the atmospheric pressure.
- The **diaphragm** and a specialized set of muscles – external and internal **intercostals** between the ribs, help in generation of such gradients.
- Inspiration is initiated by the **contraction** of diaphragm which increases the volume of thoracic chamber in the antero-posterior axis. The **contraction** of external inter-costal muscles lifts up the ribs and the sternum causing an increase in the volume of the thoracic chamber in the dorso-ventral axis. The overall **increase in the thoracic volume** causes a **similar increase in pulmonary volume**.
- An increase in pulmonary volume decreases the intra-pulmonary pressure to less than the atmospheric pressure which forces the air from outside to move into the lungs, i.e., inspiration.
- Relaxation of the diaphragm and the inter-costal muscles returns the diaphragm and sternum to their normal positions and reduce the thoracic volume and thereby the pulmonary volume. This leads to an increase

in intra-pulmonary pressure to slightly above the atmospheric pressure causing the expulsion of air from the lungs, i.e., expiration. We have the ability to increase the strength of inspiration and expiration with the help of additional muscles in the abdomen.

- On an average, a healthy human breathes **12-16 times/minute**. The volume of air involved in breathing movements can be estimated by using a **spirometer** which helps in clinical assessment of pulmonary functions.

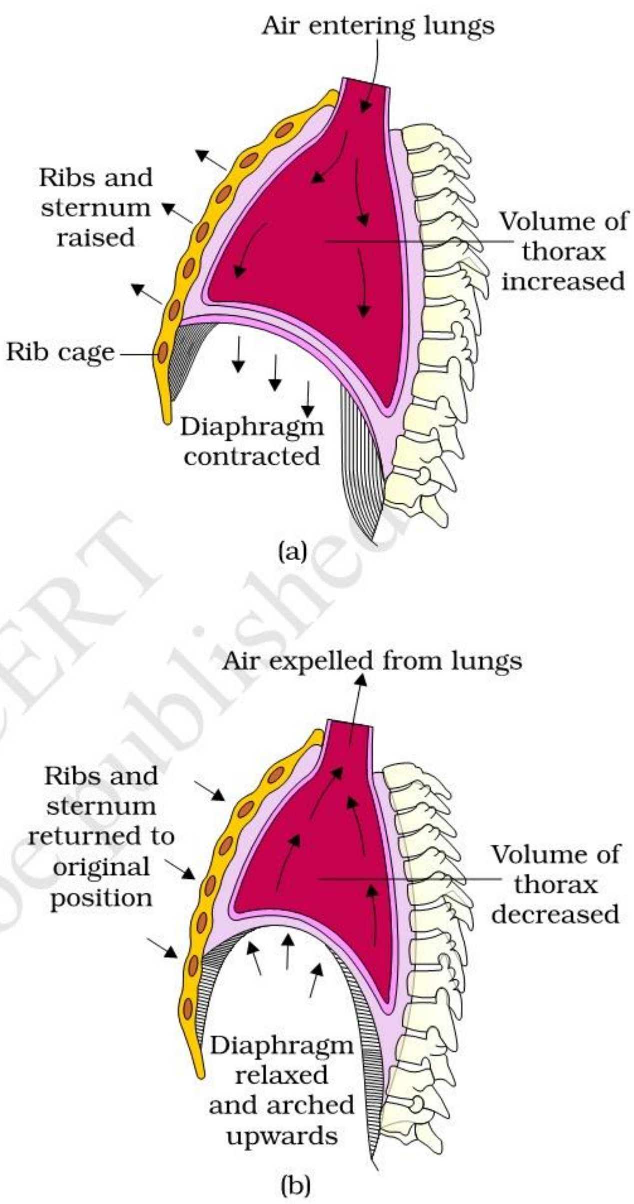


Figure 17.2 Mechanism of breathing showing : (a) inspiration (b) expiration

Exchange of Gases

- **Alveoli** are the primary sites of exchange of gases. Exchange of gases also occur between **blood and tissues**. O2 and CO2 are exchanged in these sites by simple **diffusion** mainly based on pressure/concentration gradient.
- **Partial pressure** of gasses, **Solubility** of the gases as well as the **thickness** of the membranes involved in diffusion are some important factors that can affect the rate of diffusion.

TABLE 17.1 Partial Pressures (in mm Hg) of Oxygen and Carbon dioxide at Different Parts Involved in Diffusion in Comparison to those in Atmosphere

Respiratory Gas	Atmospheric Air	Alveoli	Blood (Deoxygenated)	Blood (Oxygenated)	Tissues
O_2	159	104	40	95	40
CO_2	0.3	40	45	40	45

- Pressure contributed by an individual gas in a mixture of gases is called partial pressure.

Transport of Gases

- **Blood** is the medium of transport for O2 and CO2.
- About **97 per cent** of O2 is transported by **RBCs** in the blood. The remaining 3 per cent of O2 is carried in a **dissolved state** through the plasma.
- Nearly 20-25 per cent of CO2 is transported by **RBCs** whereas 70 per cent of it is carried as **bicarbonate**. About 7 per cent of CO2 is carried in a **dissolved state** through plasma.

Transport of Oxygen

- **Haemoglobin** is a red coloured **iron** containing pigment present in the RBCs. O2 can bind with haemoglobin in a reversible manner to form **oxyhaemoglobin**.
- Each haemoglobin molecule can carry a maximum of **four** molecules of O2. Binding of oxygen with haemoglobin is primarily related to **partial pressure** of O2.
- Partial pressure of CO2, hydrogen ion concentration and temperature are the other factors which can interfere with this binding.

Transport of Carbon dioxide

- CO2 is carried by haemoglobin as **carbamino-haemoglobin** (about 20-25 per cent). This binding is related to the partial pressure of CO2. Partial pressure of O2 is a major factor which could affect this binding. RBCs contain a very high concentration of the