CHAPTER-17

Breathing and Exchange of Gases

Respiration

The process of exchange of 02 from the atmosphere with C02 produced by the cells is called breathing, commonly known as respiration.

Respiratory Organs

- Mechanisms of breathing vary among different groups of animals depending mainly on their habitats and levels of organisation.

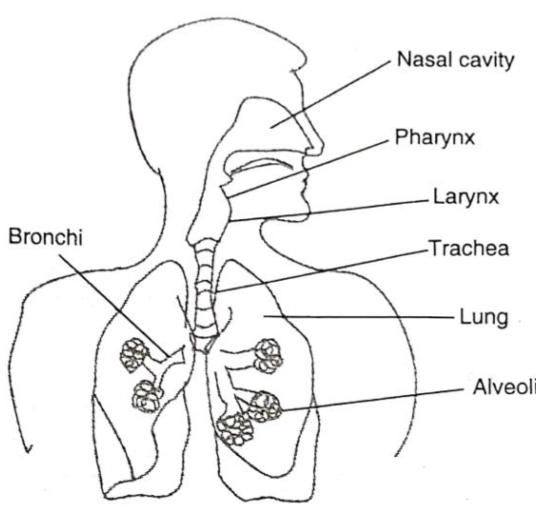
- Lower invertebrates like sponges, coelenterates, flatworms, etc., exchange 02 with CO2 by simple diffusion over their entire body surface.

- Earthworms use their moist cuticle and insects have a network of tubes (tracheal tubes) to transport atmospheric air within the body.

- Special vascularised structures called gills are used by most of the aquatic arthropods and mollusks.

- 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 also. Mammals have a well developed respiratory system.

Human Respiratory System



Respiratory System

Pharynx. 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 nasopharynx, which is a poution of pharynx, the common passage for food and air.

Larynx. Nasopharynx opens through glottis of 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. Trachea is a straight tube extending up to the mid-thoracic cavity, which divides at the level of 5th thoracic vertebra into a right and left primary bronchi.

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, and initial bronchioles 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.

Lungs. The branching network of bronchi, bronchioles and alveoli comprise the lungs. We have two lungs which are covered by a double layered pleura. Pleura is filled with pleural fluid. 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.

Conducting Part of Respiratory System. The part of respiratory system, starting with the external nostrils up to the terminal bronchioles, constitutes the conducting part. 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 of Respiratory System. The alveoli and their ducts form the respiratory or exchange part of the respiratory system. Exchange part is the site of actual diffusion of O2 and C02 between blood and atmospheric air.

Thoracic Chamber. 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, 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.

Steps of Respiration:

(i) Breathing or pulmonary ventilation by which atmospheric air is drawn in and CO_2 rich alveolar air is released out.

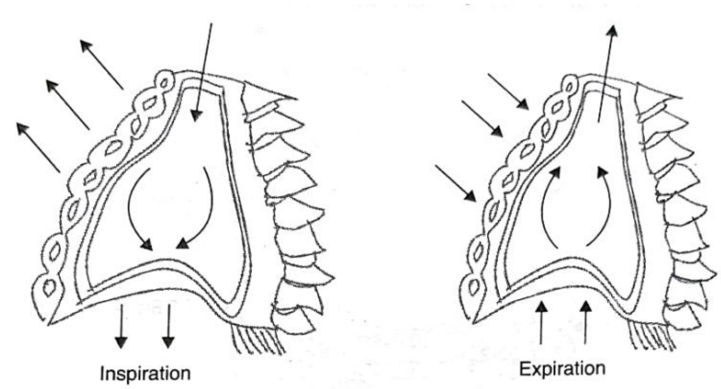
(ii) Diffusion of gases (O_2 and CO_2) across alveolar membrane.
(iii) Transport of gases by the blood.
(iv) Diffusion of O_2 and CO_2 between blood and tissues.
(v) Utilisation of O_2 by the cells for catabolic reactions and resultant release of CO_2

MECHANISM OF BREATHING

-Breathing involves two stages, viz., 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 intrapulmonary pressure is higher than the atmospheric pressure.

The diaphragm and a specialised 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 at thoracic chamber in the antero-posterior axis. The contraction of external intercostal muscles lifts up the ribs and the sternum causing an increase in the volume of the thoracic chamber in the dorsoventral axis. The overall increase in the thoracic volume causes a similar increase in pulmdnary volume. An increase in pulmonary volume decreases the intrapulmonary 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 intercostal 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.

Respiratory Volumes and Capacities

Tidal Volume (TV). Volume of air inspired or expired during a normal respiration. It is approx. 500 ml., i.e, a healthy man can inspire or expire approximately 6000 to 8000 ml of air per minute (12 x 500 = 6000).

lnspiratory Reserve Volume (IRV). Additional volume of air, a person can inspire by a forcible inspiration. This averages 2500 ml to 3000 ml.

Expiratory Reserve Volume (ERV). Additional volume of air, a person can expire by a forcible expiration. This averages 1000 ml to 1100 ml.

Residual Volume (RV). Volume of air remaining in the lungs even after a forcible expiration. _ This averages 1100 ml to 1200 ml. By adding up a few respiratory volumes described above, one can derive various pulmonary capacities, which can be used in clinical diagnosis.

lnspiratory Capacity (IC). Total volume of air a person can inspire after a normal expiration. This includes tidal volume and inspiratory reserve volume (TV + IRV).

Expiratory Capacity (EC). Total volume of air a person can expire after a normal inspiration. This includes tidal volume and expiratory reserve volume (TV+ERV).

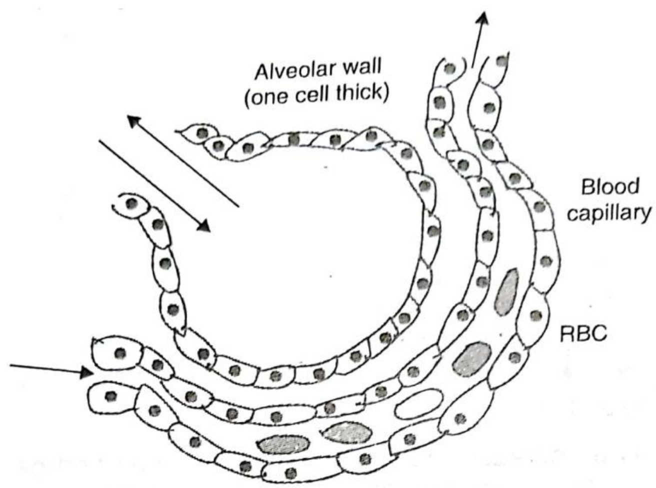
Functional Residual Capacity (FRC). Volume of air that will remain in the lungs after a normal expiration. This includes ERV + RV.

Vital Capacity (VC). The maximum volume of air a person can breathe in after a forced expiration. This includes ERV, TV and RV or the maximum volume of air a person can breathe out after a forced inspiration.

Total Lung Capacity. Total volume of air accommodated in the lungs at the end of a forced inspiration. This includes RV, ERV, TV and IRV or vital capacity + residual volume.

EXCHANGE OF GASES

Alveoli are the primary sites of exchange of gases. Exchange of gases also occur between blood and tissues. 02 and C02 are exchanged in these sites by simple diffusion mainly based on pressure/concentration gradient. Solubility of the gases as well as the thickness of the membranes involved in diffusion are also some of the important factors that can affect the rate of diffusion. Pressure contributed by an individual gas in a mixture of gases is called partial pressure and is represented as p02 for oxygen and pC02 for carbon dioxide

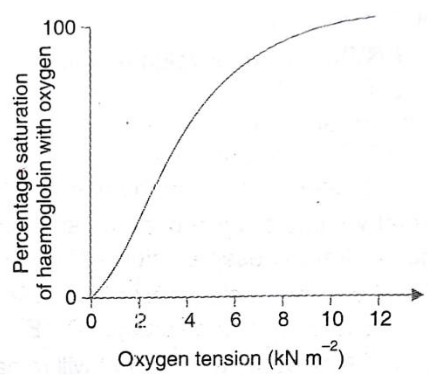


Exchange of Gases in Alveoli

TRANSPORT OF GASES

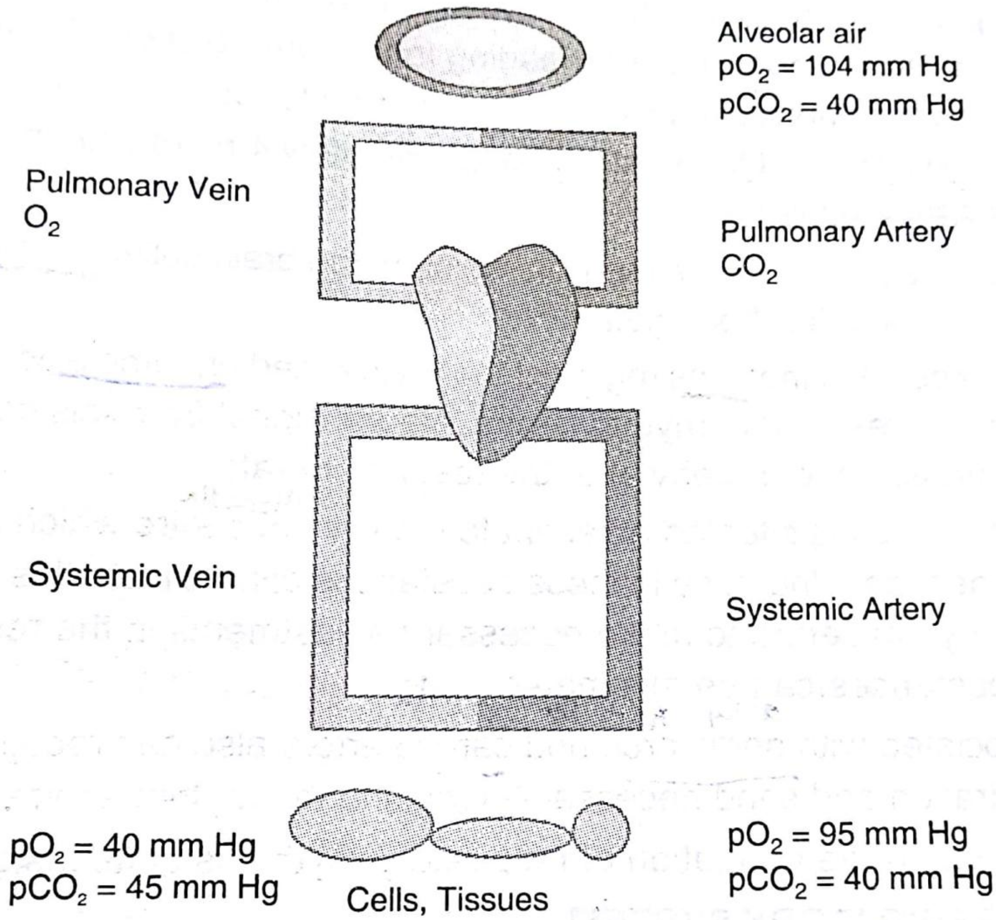
Blood is the medium of transport for O_2 and CO_2. About 97 per cent of O_2 is transported by RBCs in the blood. The remaining 3 per cent of O_2 is carried in a dissolved state through the plasma. Nearly 20-25 per cent of CO_2 is transported by RBCs whereas 70 per cent of it is carried as bicarbonate. About 7 per cent of CO_2 is carried in a dissolved state through plasma.

Transport of Oxygen



Transport of Oxygen

Role of Haemoglobin. Haemoglobin is a red coloured iron containing pigment present in the RBCs. 0_2 can bind with haemoglobin in a reversible manner to form oxyhaemoglobin Each haemoglobin molecule can carry a maximum of four molecules of 0_2. Binding of oxygen with haemoglobin is primarily related to partial pressure of O_2. Partial pressure of $C0_2$, hydrogen ion concentration and temperature are the other factors which can interfere with this binding. A sigmoid curve is obtained when percentage saturation of haemoglobin with O2 is plotted against the $p0_2$. This curve is called the oxygen dissociation curve and is highly useful in studying the effect of factors like pCO_2, H+ concentration, etc., on binding of O with haemoglobin.



Pressure Differential in Exchange of Gases

Partial pressure of gasses compared to atmospheric pressurE					
Respiratory gases	Atmospheric Air	Alveoli	Blood (Deoxygenated)	Blood (oxygenated)	Tissue
O_2	159	104	40	95	40
CO_2	0.3	40	45	40	45

Transport of carbon dioxide

CO_2 is carried by haemoglobin as carbamino-haemoglobin (about 20-25 per cent)This binding is related to the partial pressure of $C0_2$.

$p0_2$ is a major factor which could affect this binding. When pCO_2 is high and $p0_2$ is low as in the tissues, more binding of carbon dioxide occurs whereas, when the pCO_2 is low and $p0_2$ is high as in the alveoli, dissociation of CO_2 from carbamino-haemoglobin takes place, i.e., CO_2 which is bound to haemoglobin from the tissues is delivered at the alveoli.

At the tissue site where partial pressure of CO_2 is high due to catabolism, CO_2 diffuses into blood (RBCs and plasma) and forms HCO3 - and H+. At the alveolar site where pCO_2 is low, the reaction proceeds in the opposite direction leading to the formation of CO_2 and H_20. Thus, CO_2 trapped as bicarbonate at the tissue level and transported to the alveoli is released out as $C0_2$. Every 100 ml of deoxygenated blood delivers approximately 4 ml of $C0_2$ to the alveoli.

REGULATION OF RESPIRATION

-A specialised centre present in the medulla region of the brain called respiratory rhythm centre is primarily responsible for this regulation.

-Another centre present in the pons region of the brain called pneumotaxic centre can moderate the functions of the respiratory rhythm centre. Neural signal from this centre can reduce the duration of inspiration and thereby alter the respiratory rate.

A chemosensitive area is situated adjacent to the rhythm centre which is highly sensitive to 002 and hydrogen ions. Increase in these substances can activate this centre, which in turn can signal the rhythm centre to make necessary adjustments in the respiratory process by which these substances can be eliminated

-Receptors associated with aortic arch and carotid artery also can recognize changes in CO_2 and H^+ concentration and sennecessary signals to the rhythm centre for remedial actions
-The role of oxygen in the regulation of respiratory rhythm is quite insignificant.

DISORDERS 0F RESPIRATORY SYSTEM

Asthma is a difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles.

Emphysema is a chronic disorder in which alveolar walls are damaged due to which respiratory surface is decreased. One of the major causes of this is cigarette smoking.

Pneumonia. This Is inflammation of lungs and can be because of bacterial, viral or other causes