17. Breathing and Exchange of Gases

POINTS TO REMEMBER :

- Breathing: (External respiration) the process of exchange of O_2 from the atmosphere with CO_2 produced by the cells.

RESPIRATORY ORGANS :

- Direct respiration by diffusion from the environment – sponges, coelenterates, flat worms etc.
- Cutaneous or by skin – earthworm.
- Tracheal system – insects.
- Gills – aquatic arthropods mollusks
- Lungs – terrestrial forms.

HUMAN RESPIRATORY SYSTEM:

- External nostril opens into the nasal chamber through nasal passage.
- The nasal chamber opens into the **nasopharynx**.
- Nasopharynx opens through **glottis** of the **larynx** into the **trachea**.
- Larynx is a cartilaginous box which produce sound hence called **sound box**.
- Cartilaginous **epiglottis** covers the glottis during swallowing to prevent entry of food into trachea.
- Trachea is a straight tube extending up to themed-thoracic cavity, which divides into right and left primary **bronchi** at the level of 5th thoracic vertebra.
- Each bronchus undergoes repeated divisions to form the secondary and tertiary bronchi and bronchioles ending up in very thin **terminal bronchioles**.
- Trachea, primary, secondary and tertiary bronchi and initial bronchioles are supported by cartilaginous rings.
- Each terminal bronchiole gives rise to a number of very thin, irregular-walled and vascularised bags like structures called **alveoli**.
- The branching network of bronchi, bronchioles and alveoli comprises the lungs.
- There are two lungs which are covered by a double layered pleura, with pleural fluid in them.
- Lungs are situated in the thoracic chamber which is anatomically a air tight chamber.
- The thoracic chamber is formed –
    - Dorsally by vertebral column.
    - Ventrally by sternum.
    - Laterally by ribs.
    - On the lower side by dome shaped diaphragm.

- Respiration involves in following steps –
    - Breathing or pulmonary ventilation by which atmospheric air is drawn in and CO_2 rich alveolar air is released out.
    - Diffusion of gases (O_2 and CO_2) across alveolar membrane.
    - Transport of respiratory gases by blood.
    - Diffusion of O_2 and CO_2 between blood and tissues.
    - Utilization of O_2 by the cells for catabolic reactions and resultant release of CO_2.

MECHANISM OF BREATHING :

Inspiration :

- Intake of atmospheric air into the lungs.
- It occurs if the pressure within the lungs (intra-pulmonary pressure) is lower than the atmospheric pressure.
- Contraction of diaphragm which increases the volume of thoracic chamber in the anterior posterior axis.
- The contraction of external intercostals muscles lifts up the ribs and the sternum causing an increase in the volume of thoracic chamber in the dorso ventral axis.
- It causes an increase in pulmonary volume decrease the intra-pulmonary pressure to less than the atmospheric pressure.
- It forces the air out side to move in to the lungs, i.e, **inspiration**.

Expiration :

- Relaxation of diaphragm and inter-costal muscles returns the diaphragm and sternum to their normal positions and reduce the thoracic and pulmonary volume.
- It increases in intrapulmonary pressure slightly above the atmospheric pressure.
- It causes the expulsion of air from the lungs, i.e, **expiration**.
- A healthy man breathes 12-16 times/minutes.
- The volume of air involved in breathing is estimated by **spirometer**.

Respiratory Volumes and Capacities :

- **Tidal volume**: volume of air inspired or expired during a normal breathing. It is about 500 ml.
- **Inspiratory reserve volume**: Additional volume of air, a person inspire by a forceful inspiration. It is about 2500-3000 ml.
- **Expiratory reserve volume**: Additional volume of air, a person expires by a forceful expiration. It is about 1000-1100 ml.
- **Residual volume**: Volume of air remaining in the lungs even after a forceful expiration. It is about 1200 ml.
- **Inspiratory capacity**: it includes tidal volume and Inspiratory reserve volume.
- **Expiratory capacity**: it includes tidal volume and expiratory reserve volume.
- **Functional residual capacity:** This includes ERV+RV.
- **Vital capacity:** IRV + TV + ERV.
- **Total lung capacity:** RV + IRV + TV + ERV

EXCHANGE OF GASES :

- Alveoli are the primary site of exchange of respiratory gases.
- Exchange of gases also takes place between blood and tissues.
- Exchange of O_2 and CO_2 take place in the pressure gradient, by simple diffusion.
- Pressure contributed by an individual gas in a mixture of gases is called the partial pressure and is represented by pO_2 for oxygen and pCO_2 for carbon dioxide.
- **Diffusion of O_2**
  - pO_2 in alveolar air = 104 mm Hg.
  - pO_2 in venous blood = 40 mm Hg.
  - O_2 diffuses from alveoli to venous blood.

- **Diffusion of CO_2**
  - pCO_2 is venous blood = 45 mm Hg.

  - pCO_2 is alveolar air = 40 mm Hg
  - CO_2 diffuses from venous blood to alveoli.

- Solubility of CO_2 is 20-25 times higher than that of O_2; the amount of CO_2 that can diffuse through the diffusion membrane per unit difference in partial pressure is much higher compared to that of O_2.
- Respiratory membrane is formed by;
  - Thin Squamous epithelium of the alveoli.
  - Endothelium of alveolar capillaries
  - Basement membrane between them.

TRANSPORT OF GASES :

- Blood is the medium of transport of O_2 and CO_2.
- About 97 per cent of O_2 is transported by RBCs in the blood.
- 3 per cent of O_2 is transported in the plasma in dissolved state.
- 20-25 per cent of CO_2 transported in the RBC in the form of carbamino-haemoglobin.
- 70 percent CO_2 carried as bicarbonate ion in plasma.
- 7 percent CO_2 transported in dissolved state in plasm.

Transport of Oxygen :

- Haemoglobin is red coloured pigment present in the RBC.
- O_2binds with hemoglobin reversibly to form **oxy-hemoglobin.**
- Each haemoglobin can binds maximum with **four O_2** molecules.
- Binding of Oxygen with haemoglobin is primarily related with partial pressure of O_2.
- Partial pressure of CO_2, hydrogen ion concentration (pH) and temperature are the factors that influence this binding.
- A sigmoid curve is obtained when percentage of saturation of hemoglobin with O_2 is plotted against the partial pressure of O_2 (pO_2). This curve is called **oxygen dissociation curve.**
- Condition favourable for binding of Hemoglobin with O_2 at alveolar level;
  - High pO_2
  - Low H^+ ion concentration.
  - Low temperature.

- Condition favourable for dissociation of HbO_2 into Hb and O_2 at tissue level;
  - Low pO_2
  - High H^+ ion concentration.
  - High temperature.

- Every 100 ml of oxygenated blood can deliver around 5 ml of O_2 to the tissues under normal physiological conditions.

Transport of Carbon dioxide:

- 20-25 percent of CO_2 is carried out in the RBC by binding with the free amino group of haemoblobin by formation of carbamino-haemoglobin.

- $CO_2 + HbNH_2 \xrightarrow{\text{Carbonic anhydrase}} HbNHCOOH$ (Carbamino haemoglobin)

- When pCO_2 is high and pO_2 is low as in the tissues, more binding of CO_2 occurs whereas, when the pCO_2 is low and pO_2 is high as in the alveoli, dissociation of CO_2 from carbamino-haemoglobin takes place.
- 70 per cent of CO_2 transported in the form of HCO_3- in the plasma.
- CO_2 from the tissue diffused into the plasma and along with the water it forms carbonic acid which dissociated into HCO_3- and H^+. This reaction is catalysed by an enzyme called **carbonic anhydrase** present in the plasma membrane of RBC and plasma.

- $CO_2 + HO_2 \xrightarrow{\text{Carbonic anhydrase}} H_2CO_3$ (Carbonic acid)

REGULATION OF RESPIRATION :

- Specialized centre present in the medulla region of the brain called respiratory rhythm centre is primarily responsible for regulation of breathing.
- Pneumotaxis centre of pons region of brain has moderate regulation.
- Neural signal from this centre can reduce the duration of inspiration and alter the rate of respiration.
- Chemosensitive area adjacent to rhythm centre is sensitive to CO_2 and H^+ ion.
- Receptors associated with aortic arch and carotid artery also can recognize changes in the CO_2 and H^+ concentration and send necessary signals to the rhythm centre for remedial actions.

DISORDERS OF REPIRATORY SYSTEM :

- **Asthma :** is a difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles.
- **Emphysema :** a chronic disorder in which alveolar walls are damaged due to which respiratory surface is decreased. It caused due to smoking.