ZOOLOGY

UNIT II

RESPIRATION IN HUMANS

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DR. WKB'S ZOOLOGY STUDY MATERIAL

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RESPIRATION

Respiration is an essential physiological activity of all living organisms. The process of production of energy is called respiration. It is also defined as gaseous exchange between the organism and the environment. *Henri Dutrochet*, a French physiologist was first to coin the term respiration.

Depending on the availability of oxygen, Sachs (1890) classified cellular respiration into two major types namely aerobic and anaerobic.

Aerobic Respiration

It uses oxygen and completely oxidizes the organic food to carbon dioxide and water. It occurs in most plants and animals. The organisms which carry on this type of respiration are called *aerobes*. During aerobic respiration, 686 kcal or 2870 kJ of energy is liberated per mole of glucose.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + 686\ \text{kcal/2870 kJ}$$

Anaerobic Respiration

It does not use molecular oxygen and incompletely oxidizes the organic food with or without production of carbon dioxide. It, releases a small amount of energy. It occurs in yeasts, certain bacteria and some parasitic worms like *Ascaris*, *Taenia* etc. The organisms which carry on anaerobic respiration are termed anaerobes.

Respiration is further classified in to two types' namely external respiration and internal respiration.

External Respiration

This type of respiration is carried out by lungs and its accessory structures. External respiration is also called *Breathing*, which includes two phases namely inspiration (intake of O_2) and expiration (expelling out CO_2). Breathing is physical process and does not involve the release of energy like respiration. It is extracellular process and involves no enzyme. It is the common available process in most of the higher animal groups. In some lower organisms, such as jelly fishes, earthworms etc., skin play an important role in respiration. In amphibians, this purpose is served by the skin.

Internal Respiration

The gaseous exchange between the blood or other circulating fluid and the active cells of the organism constitutes internal respiration. Since it takes place at cellular level it is called cellular respiration.

Internal respiration is gas exchange that occurs at the level of body tissues. Internal respiration occurs as simple diffusion due to a partial pressure gradient. The partial pressure of oxygen in tissues is low, about 40 mm Hg, because oxygen is continuously used for cellular respiration. In contrast, the partial pressure of oxygen in the blood is about 100 mm Hg. This creates a pressure gradient that causes oxygen to dissociate from hemoglobin, diffuse out of the blood, cross the interstitial space, and enter the tissue.

Cellular respiration continuously produces carbon dioxide, the partial pressure of carbon dioxide is lower in the blood than it is in the tissue, causing carbon dioxide to diffuse out of the tissue, cross the interstitial fluid, and enter the blood. It is then carried back to the lungs either bound to hemoglobin, dissolved in plasma, or in a converted form.

PULMONARY VENTILATION

It is commonly known as Breathing. The process of taking fresh air from the atmosphere into lungs and expelling out the foul air from lungs to exterior is breathing. Breathing is mechanical process. It is completed in two steps namely:

Inspiration

It is also called as inhalation. It is active phase. It involves breathing in fresh air into lungs. It involves contraction of the diaphragm & external intercostal muscles and upward & outward movement of rib cage. These movements increase the volume of thoracic cavity and expand the lungs. Now alveolar pressure is lower than atmospheric pressure and air enters from atmosphere through respiratory passage to the alveoli.

Expiration

It is also called as exhalation. It is passive phase. It involves relaxation of the diaphragm & intercostal muscles and downward & inward movement of rib cage. These movements decrease the volume of thoracic cavity and set the lungs free to recoil. Now alveolar pressure is higher than atmospheric pressure and as a result air with CO_2 flows outside the body.

Each breathing consists of one inspiration and one expiration.

The rate of breathing averages 12-14 per minute in the normal resting person.

RESPIRATORY VOLUMES AND CAPACITIES

Spirometry is the process of recording the changes in the volume movement of air into and out of lungs and the instrument used for this purpose is called spirometer or respirometer.

The quantity of air the lungs can receive, hold or expel under different conditions are called pulmonary volumes.

The Combinations of two or more pulmonary volumes are called pulmonary capacities. The different types of pulmonary volumes and capacities are:

Tidal Volume (TV)

It is the volume of air inspired and expired during normal breathing or in each respiratory cycle without any effort. It is approximately 500mL.

It is contributed by alveolar volume (350 mL) and dead space volume (150mL).

Alveolar Volume

The alveolar volume is the air that reaches the respiratory surfaces of alveoli and engages in gas exchange. It is approximately 350 mL.

Dead Space Volume

Dead space volume or air is that air which does not reach the respiratory surface, it just fills the respiratory passage. It is approximately 150 mL.

Inspiratory Reserve Volume (IRV)

It is an extra amount of air that can be inspired forcibly after a normal inspiration. It is approximately 2,500 mL – 3,000 mL.

Expiratory Reserve Volume (ERV)

It is an extra amount of air that can be expelled after a normal expiration. It is approximately 1,000 mL – 1,200 mL.

Residual Volume (RV)

It is the volume of air that always remains in the lungs after forcible expiration. It is approximately 1,200 mL.

Vital Capacity (VC)

It is the total volume of air expired to maximum level after maximum inspiration. It is the sum total of tidal volume, inspiratory reserve volume and expiratory reserve volume. Thus VC = TV + IRV + ERV. It is approximately 3,500 mL – 4,700 mL.

Inspiratory Capacity (IC)

It is the maximum volume of air that can be inhaled after a normal expiration. It includes tidal volume and inspiratory reserve volume. Thus, IC = TV + IRV. It is approximately 2,500 mL – 3,500 mL.

Functional Residual Capacity (FRC)

It is the sum total of residual volume and the expiratory reserve volume (FRC = RV + ERV). It is approximately 2,400 mL.

Total Lung Capacity (TLC)

It is the total amount of air present in the lungs and the respiratory passage after a maximum inspiration. It is the sum total of vital capacity and the residual volume.

TLC = VC + RV OR TLC = TV + IRV + ERV + RV

It is approximately 4,900 mL – 5,900 mL.

MECHANISM OF GASEOUS EXCHANGE

All living things obtain the energy they need by metabolizing energy rich compounds, such as carbohydrates and fats. In the majority of organisms, this metabolism takes place by respiration, a process that requires oxygen. In the process, carbon dioxide gas is produced and must be removed from the body. Gas exchange is thus an essential process in energy metabolism, and gas exchange is an essential prerequisite to life, because where energy is lacking, life cannot continue.

The basic mechanism of gas exchange is diffusion across a moist membrane. ***Diffusion*** is the movement of molecules from a region of greater concentration to a region of lesser concentration, in the direction following the concentration gradient. In living systems, the molecules move across cell membranes, which are continuously moistened by fluid. Single celled organisms, such as bacteria and protozoa, are in constant contact with their external environment. Gas exchange occurs by diffusion across their membranes. Even in simple multicellular organisms, such as green algae, their cells may be close to the environment, and gas exchange can occur easily. In larger organisms, adaptations bring the environment closer to the cells. Liverworts, for instance, have numerous air chambers in the internal environment. *Sponges* and *Hydras* have water filled central cavities, and Planaria have branches of their gastrovascular cavity that connect with all parts of the body.

In animals, gas exchange follows the same general pattern as in plants. Oxygen and carbon dioxide move by diffusion across moist membranes. In simple animals, the exchange occurs directly with the environment. But with complex animals, such as mammals, the exchange occurs between the environment and the blood. The blood then carries oxygen to deeply embedded cells and transports carbon dioxide out to where it can be removed from the body.

Earthworms exchange oxygen and carbon dioxide directly through their skin. The oxygen diffuses into tiny blood vessels in the skin surface, where it combines with the red pigment hemoglobin. Hemoglobin binds loosely to oxygen and carries it through the animal's bloodstream. Carbon dioxide is transported back to the skin by the hemoglobin. Terrestrial arthropods have a series of openings called spiracles at the body surface. Spiracles open into tiny air tubes called tracheae, which expand into fine branches that extend into all parts of the arthropod body.

Fishes use outward extensions of their body surface called gills for gas exchange. Gills are flaps of tissue richly supplied with blood vessels. As a fish swims, it draws water into its mouth and across the gills. Oxygen diffuses out of the water into the blood vessels of the gill, while carbon dioxide leaves the blood vessels and enters the water passing by the gills.

Terrestrial vertebrates such as amphibians, reptiles, birds, and mammals have well-developed respiratory systems with lungs. Frogs swallow air into their lungs, where oxygen diffuses into the blood to join with hemoglobin in the red blood cells. Amphibians can also exchange gases through their skin. Reptiles have folded lungs to provide increased surface area for gas exchange. Rib muscles assist lung expansion and protect the lungs from injury.

Birds have large air spaces called *air sacs* in their lungs. When a bird inhales, its rib cage spreads apart and a partial vacuum is created in the lungs. Air rushes into the lungs and then into the air sacs, where most of the gas exchange occurs. This system is birds' adaptation to the rigors of flight and their extensive metabolic demands.

The lungs of mammals are divided into millions of microscopic air sacs called alveoli (the singular is *alveolus*). Each alveolus is surrounded by a rich network of blood vessels for transporting gases. In addition, mammals have a dome-shaped diaphragm that separates the thorax from the abdomen, providing a separate chest cavity for breathing and pumping blood. During inhalation, the diaphragm contracts and flattens to create a partial vacuum in the lungs. The lungs fill with air, and gas exchange follows.

The exchange of gases occurs at two levels namely along alveolar surface and in tissues.

Gas Exchange across the Alveoli

In the human body, oxygen is used by cells of the body's tissues to produce ATP, while carbon dioxide is produced as a waste product. The ratio of carbon dioxide production to oxygen consumption is referred to as the respiratory quotient (RQ), which typically varies between 0.7 and 1.0. If glucose alone were used to fuel the body, the RQ would equal one, as one mole of carbon dioxide would be produced for every mole of oxygen consumed. Glucose, however, is not the only fuel for the body; both proteins and fats are used as well. Since glucose, proteins, and fats are used as fuel sources, less carbon dioxide is produced than oxygen is consumed; the RQ is, on average, about 0.7 for fat and about 0.8 for protein.

The RQ is a key factor because it is used to calculate the partial pressure of oxygen in the alveolar spaces within the lung: the alveolar PO_2 ($P_{ALV}O_2$). The lungs never fully deflate with an exhalation; therefore, the inspired air mixes with this residual air, lowering the partial pressure of oxygen within the alveoli. This results in a lower concentration of oxygen in the lungs than is found in the air outside the body. When the RQ is known, the partial pressure of oxygen in the alveoli can be calculated: alveolar PO_2 = inspired PO_2 − ((alveolar PO_2)/RQ)

In the lungs, oxygen diffuses out of the alveoli and into the capillaries surrounding the alveoli. Oxygen (about 98 percent) binds reversibly to the respiratory pigment hemoglobin found in red blood cells. These red blood cells carry oxygen to the tissues where oxygen dissociates from the hemoglobin, diffusing into the cells of the tissues. More specifically, alveolar PO_2 is higher in the alveoli ($P_{ALV}O_2$=100mmHg) than blood PO_2 in the capillaries (40mmHg). Since this pressure gradient exists, oxygen can diffuse down its pressure gradient, moving out of the alveoli and entering the blood of the capillaries where O_2 binds to hemoglobin. At the same time, alveolar PCO_2 is lower (P_{ALV} CO_2 = 40mmHg) than blood PCO_2 (45mmHg). Due to this gradient, CO_2 diffuses down its pressure gradient, moving out of the capillaries and entering the alveoli.

Oxygen and carbon dioxide move independently of each other; they diffuse down their own pressure gradients. As blood leaves the lungs through the pulmonary veins, the venous PO_2 =100mmHg, whereas the venous PCO_2 = 40mmHg. As blood enters the systemic capillaries, the blood will lose oxygen and gain carbon dioxide because of the pressure difference between the tissues and blood. In systemic capillaries, PO_2=100mmHg, but in the tissue cells, PO_2=40mmHg. This pressure gradient drives the diffusion of oxygen out of the capillaries and into the tissue cells. At the same time, blood PCO_2=40mmHg and systemic tissue PCO_2=45mmHg. The pressure gradient drives CO_2 out of tissue cells and into the capillaries. The blood returning to the lungs through the pulmonary arteries has a venous PO_2=40mmHg and a PCO_2=45mmHg. The blood enters the lung capillaries where the process of exchanging gases between the capillaries and alveoli begins again.

In short, the change in partial pressure from the alveoli to the capillaries drives the oxygen into the tissues and the carbon dioxide into the blood from the tissues. The blood is then transported to the lungs where differences in pressure in the alveoli result in the movement of carbon dioxide out of the blood into the lungs and oxygen into the blood.

Exchange of Gases in Tissues

In the tissues, exchange of gases occurs between the blood and the tissue cells through tissue fluids that surround the tissue cells. Blood that reaches the tissues has more partial pressure of O_2 (PO_2 = 100 mmHg), than that in the tissues (PO_2 = 20 mmHg). Similarly partial pressure of CO_2 is more in tissues (= 52 mmHg) than in the blood (= 40 mmHg).

Due to these differences in partial pressure of gases, o2 from blood diffuses in the tissues and CO_2 from tissues diffuses into the blood. This exchange of gases occurs simultaneously.

The venous blood goes to the right side of the heart that sends it to lungs via pulmonary artery for reoxygenation. The venous blood is 75% saturated at 40 mmHg of O_2 and contains 14.4 mL of O_2/100 mL of blood.

TRANSPORT OF OXYGEN & CARBON DIOXIDE IN BLOOD

Blood plays very significant role in transportation of O_2 from lungs to the body tissues and CO_2 from body tissue to lungs.

O_2 Transport

The transport of oxygen from the lungs to the cells is called oxygen transport. The oxygen is carried by blood in two forms namely in solution (plasma) and as oxyhaemoglobin by RBCs.

About 1.5% - 3% of oxygen is carried as dissolved oxygen in blood plasma and 98.5% is carried with RBCs.

In alveoli, higher concentration of Oxygen causes Haemoglobin (Hb) to take up O_2 and becomes oxyhaemoglobin (HbO_2). This occurs when pCO_2 is low, pH is high and temperature is low.

$$\boxed{Hb + O_2 \longrightarrow HbO_2}$$

In tissues, lower concentration of O_2 causes haemoglobin to release O_2 (become dissociated) and becomes deoxyhaemoglobin (Hb). This occurs when pCO_2 is high, pH is low and temperature is high.

Bohr Effect

High concentration of CO_2 in the tissues decreases the affinity of haemoglobin for O_2. It helps to unload O2 from oxyhaemoglobin (HbO_2). It is called Bohr effect named after Bohr (1994).

CO_2 Transport

The transport of carbon dioxide from the tissues to the lungs through the blood is called CO_2 transport. CO_2 is transported in blood in three forms:

- About 5% of CO_2 is transported as dissolved CO_2 in blood plasma. When CO_2 enters blood, small fraction of it combines with water to form carbonic acid, which dissolves in plasma and is carried to the lungs where the reaction is reversed to release CO_2.

$$CO_2 + H_2O \underset{\text{Lungs}}{\overset{\text{Tissues}}{\longleftrightarrow}} H_2CO_3$$

- About 10% of CO_2 is transported as carbaminohaemoglobin. A part of CO_2 entering RBCs combines with globin of haemoglobin to form carbaminohaemoglobin. When pCO_2 is high and pO_2 is low then binding of CO_2 occurs (as in tissues). When pCO_2 is low, pO_2 is high then dissociation of CO_2 occurs (as in alveoli). CO_2 is bound with haemoglobin in tissue and dissociates in alveoli where it is released.
- About 85% of CO_2 is transported as bicarbonate ions in RBC as well as in plasma. Most of the carbon dioxide entering the blood from the tissues diffuses into the RBC. In the RBC, CO_2 combines with water to form carbonic acid (H_2CO_3). In the RBC, this reaction is accelerated by an enzyme called carbonic anhydrase. The carbonic acid is unstable and it immediately dissociates into H^+ ions and bicarbonate ions ($HCO3^-$). The bicarbonate ions diffuse through the RBC membrane into the plasma. But the H^+ ions are retained inside the RBC. To maintain neutrality, Cl^- (chloride) ions of plasma diffuse into the RBC. This is called *chloride shift or Hamburger phenomenon*. Chloride ions are provided by the dissociation of NaCl present in the plasma. The Na ions of plasma combine with bicarbonate ions to form sodium bicarbonate. The hydrogen ions, released from the carbonic acid combine with HbO_2. When H+ combine with HbO_2, O_2 is released and HBO_2 is converted into reduced haemoglobin (HHb). Thus when H+ combines with HbO_2, HbO_2 unloads O_2. The O_2 released from HbO_2 diffuses into the tissue cells where it is consumed. The blood leaving the tissues

contains large quantities of bicarbonate and reduced haemoglobin and small amount of carbonic acid. No further changes take place until the blood reaches the capillaries of the lungs.

Any Error in this document is silent testimony of the fact that it was a human effort"

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