Respiratory System Cheat Sheet

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Pulmonary Ventilation

Breathing; inhalation and exhalation of air involving exchange of air between the lungs and the atmosphere.

It occurs due to pressure difference between the lungs and the atmosphere created by the contraction and expansion of respiratory muscles.

Before respiration, air pressure inside the lungs is equal to air pressure in the atmosphere, ie, 760 mmHg.

Inhalation

For **inhalation** to occur, *air pressure in the lungs < air pressure of the atmosphere.*

According to **Boyle's law**, volume of container is inversely proportional to air pressure.

Hence, expansion of lungs must take place for decrease in air pressure within them.

Lung expansion occurs by contraction of diaphragm, external intercostal muscles and accessory inspiration muscles.

Diaphragm: a dome shaped skeletal muscle that forms the floor of the thoracic cavity. It in innervated by the phrenic nerves (emerging from the 3rd, 4th and 5th cervical levels of the spinal cord). The contraction of the diaphragm causes it to flatten and increases the vertical diameter of the thoracic cavity. This decreases the air pressure by 2-3 mmHg and causes and inhalation of 500 ml of air.

External Intercostals: contraction of these muscles causes an elevation of the ribs. They increase the anteroposterior and lateral diameters of the chest cavity.

Accessory muscles of inhalation: Serve little purpose during quiet inhalation, however they are capable of contracting vigorously during forced ventilation. They include: sternocleidomastoid muscles (elevates the sternum), scalene muscles (elevate the first two ribs) and the pectoralis minor muscle (elevate third through fifth rib)

As the lung volume increases in this way, the air pressure inside the lungs, called ***alveolar (intrapulmonic) pressure****, drops from 760 to 758 mmHg.*

The process of inhalation is said to be active.

Exhalation

For **exhalation to occur**, *air pressure in the lungs> atmospheric pressure.*

Exhalation results from elastic recoil of the chest wall and lungs, both of which has a tendency to spring back when stretched.

Two inwardly directed forces result in elastic recoil:

1. the recoil of elastic fibres that were stretched during inhalation.

2. the inward pull of the surface tension due to film of alveolar fluid.

As the diaphragm relaxes, the dome moves upwards due to its elasticity.

As the external intercostals relax, the ribs move downwards.

This results in an increase in air pressure to about 760 mmHg.

Exhalation (cont)

The process of exhalation is said to be passive.

During forceful exhalation, the internal intercostal and the abdominal muscles come into play.

They contract, causing an increase in air pressure within the lungs.

Contraction of the abdominal muscles moves the inferior ribs downward and compresses the abdominal viscera, thereby forcing the diaphragm superiorly.

Contraction of the internal intercostals, which extend inferiorly and posteriorly between adjacent ribs, pulls the ribs inferiorly.

Factors Affecting Pulmonary Ventilation

Surface Tension:

Compliance: Compliance refers to how much effort is required by the lungs to stretch the lungs and the chest walls. High compliance means that the lungs and chest wall expand easily. In lungs, compliance is related to two princple factors: surface tension and elasticity.

Airflow Resistance:

Exchange of Oxygen and Carbon Dioxide

Exchange of oxygen and carbon dioxide between alveolar air and pulmonary blood occurs by simple diffusion and is governed by the **Dalton's Law** and the **Henry's Law**

Dalton's Law

Each gas in a mixture of gases exerts its own pressure as if no other gases as present.

The pressure of a specific gas in a mixture is call partial pressure.

The partial pressures of O_2 and CO_2 determines their movement between atmosphere and lungs, lung and blood and blood and body cells.

Each gas diffuses across a semi permeable membrane from a region of higher pressure to a region of lower pressure.

Henry's Law

The amount of gas that will dissolve in a liquid is proportional to its partial pressure and solubility.

The ability of gas to stay in liquid is higher when their partial pressure is higher and when it has high solubility in water.

External Respiration

External respiration, or pulmonary gas exchange is the diffusion of)2 from the air in the alveoli to the blood in the pulmonary capillaries and diffusion of CO_2 in the opposite direction.

External Respiration (cont)

It is the conversion of deoxygenated blood coming from the right side of the heart to oxygenated blood going to the left side of the heart.

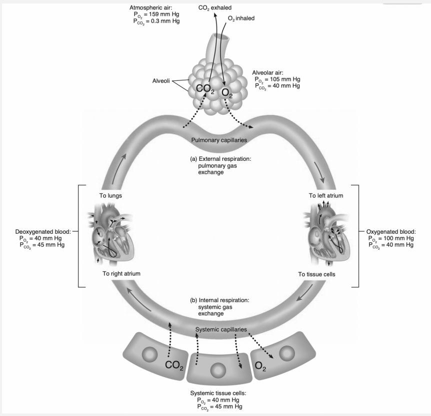
O2 diffuses from alveolar air, where its PO2 is 105 mmHg to blood capillaries, where its PO2 is 40 mmHg.

Diffusion occurs till the PO2 of the blood in the pulmonary capillaries matches the PO2 of the alveolar air, ie, 105 mmHg.

The PCO2 in the deoxygenated blood of the pulmonary capillaries is 45 mmHg and in the alveolar air is 40 mmHg.

Hence, CO2 diffuses from deoxygenated blood into the alveoli till the PCO2 of the blood decreases to 40 mmHg.

Figure:



Changes in partial pressures of oxygen and carbon dioxide (in mmHg) during external and internal respiration.

Internal Respiration

The exchange of gases between systemic capillaries and tissue cells is know as Internal Respiration or Systemic Gas Exchange.

PO2 of the systemic capillaries (100 mmHg) is more than PO2 of the tissue cells (40mmHg). Hence, oxygen from the capillaries diffuses into the tissue cells, where they are used for energy production.

By the time, blood exits the capillaries, PO2 is 40 mmHg.

PCO2 of the systemic capillaries (40 mmHg) is less than PCO2 of the tissue cells (45 mmHg). Hence, CO2, which is constantly produced by the cells, diffuses from the cells into the blood in the systemic capillaries.

The deoxygenated blood is then pumped to the heart and enters another cycle of external respiration.

Factors affecting rate of Gas Exchange

1. Partial pressure difference of the gases.

2. Surface area available for gas exchange.

3. Diffusion distance.

Factors affecting rate of Gas Exchange (cont)

4. Molecular weight and solubility of gases.

Transport of Oxygen

1.5% of inhaled O2 dissolves in the blood plasma, while 98.5% of inhaled O2 bind to haemoglobin in the red blood cells.

Heme portion of haemoglobin contains 4 iron atoms, each of which binds to an oxygen molecule.

Oxygen and haemoglobin combine in a reversible reaction to form oxyhemoglobin.

Relationship between Oxyhemoglobin and Partial Pressure of Oxygen:

The higher the PO2, the more oxygen will bind to haemoglobin. When reduced haemoglobin is completely converted into oxyhemoglobin, it is said to be fully saturated. When haemoglobin is a mix of Hb and Hb-O2, it is said to be partially saturated.

Percent Saturation of Haemoglobin: average saturation of haemoglobin with oxygen.

The relation between the Percent Saturation and Partial Pressure of Oxygen is illustrated by Oxygen- Haemoglobin Dissociation Curve.

When PO2=20 (deoxygenated blood in contracting skeletal muscles), percent saturation = 35%

When PO2=40 (deoxygenated blood in systemic veins), percent situation = 75%

When PO2=100 (oxygenated blood in systemic arteries), percent saturation is near 100.

Factors Influencing Affinity of Haemoglobin towards Oxygen:

1. Acidity: An increase in acidity, causes affinity of haemoglobin to O2 to decrease. Hence, curve shifts right. Decreases affinity means oxygen more readily dissociates from the haemoglobin and is more easily available to tissue cells.

#Bohr's Effect: the effect of pH on the affinity of haemoglobin towards oxygen. An increase in H^+ in blood causes O2 to unload from haemoglobin and the binding of haemoglobin to oxygen causes unloading of H^+ from haemoglobin. The explanation for the Bohr effect is that hemoglobin can act as a buffer for hydrogen ions (H☐). But when H☐ ions bind to amino acids in haemoglobin, they alter its structure slightly, decreasing its oxygen-carrying capacity.

2. Partial Pressure of CO2: As CO2 enters the blood, much of it is converted into carbonic acid (H2CO3), a reaction catalysed by and enzyme in RBC called carbonic anhydrase. The carbonic acid does formed dissociates into bicarbonate ions and H^+ ions. As H^+ ion concentration in blood increases, acidity increases, causing more dissociation of oxygen from haemoglobin. Dissociation curve moves right.

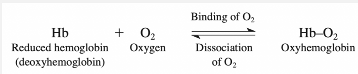
3. Temperature: Within limits, an increase in temperature promotes unloading of O2 from haemoglobin. Metabolically active cells release acids and heat which in turn promote release of O2 from haemoglobin to be used by them.

Transport of Oxygen (cont)

4. 2,3-bisphosphoglycerate: decreases affinity of haemoglobin towards oxygen. Certain hormones such as hGH, thyroxine epinephrine, norepi- nephrine and testosterone increase BPG production. ,

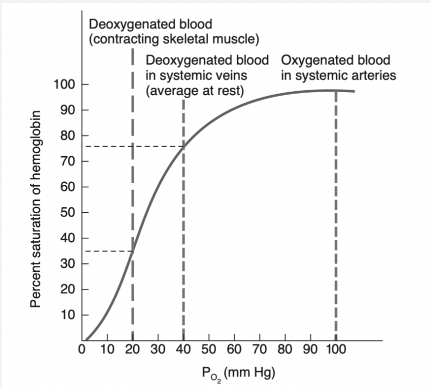
Foetal Haemoglobin has a much greater affinity to oxygen that adult haemoglobin. This is very important because the O_2 saturation in maternal blood in the placenta is quite low, and the foetus might suffer hypoxia were it not for the greater affinity of foetal haemoglobin for O_2.

Figure:



Binding of Oxygen to Haemoglobin to form Oxyhemoglobin.

Figure:



Oxygen Dissociation Curve. Factors increasing affinity of haemoglobin towards oxygen move the graph towards the left, and factors decreasing the affinity of haemoglobin towards oxygen move the graph towards the right.

Transport of Carbon Dioxide

1. Dissolved CO_2: The smallest percentage—about 7%—is dissolved in blood plasma.

2. Carbamino compounds: about 23%, combines with the amino groups of amino acids and proteins in blood to form carbamino compounds. most of the CO_2 transported in this manner is bound to hemoglobin. The main CO_2 binding sites are the termi- nal amino acids in the two alpha and two beta globin chains. Heamoglobin that has bound CO_2 is termed carbaminohemoglo- bin ($Hb–CO_2$)

3. Bicarbonate ions: icarbonate ions. The greatest percentage of CO_2—about 70%—is transported in blood plasma as bicarbonate ions (HCO_3☐). As CO_2 diffuses into systemic capillaries and enters red blood cells, it reacts with water in the presence of the enzyme carbonic anhydrase (CA) to form carbonic acid, which dissociates into H^+ and HCO_3^-.

Transport of Carbon Dioxide (cont)

#Haldane Effect: The lower the amount of oxyhemoglobin (Hb–O2), the higher the CO2 carrying capacity of the blood, a relationship known as the **Haldane effect.**

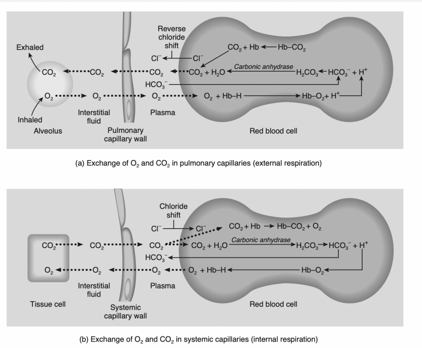
Some HCO3⁻ moves out into the blood plasma, down its concentration gradient. In exchange, chloride ions (Cl⁻) move from plasma into the RBCs. This exchange of negative ions, which maintains the electrical balance between blood plasma and RBC cytosol, is known as the chloride shift

Figure:

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \overset{CA}{\rightleftharpoons} \underset{\text{Carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

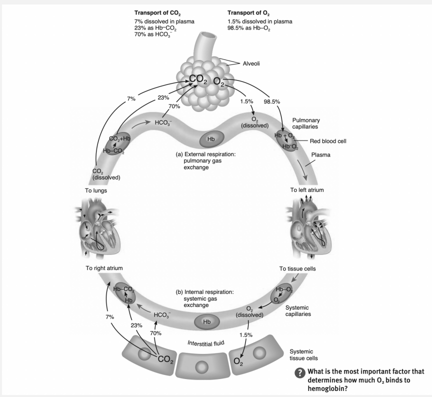
Formation of carbonic acid by carbonic anhydrase and its dissociation to form bicarbonate ions.

Figure:



Summary of chemical reactions that occur during gas exchange.

Figure:



Transport of oxygen (O2) and carbon dioxide (CO2) in the blood.

Summary of chemical reactions

(a) As carbon dioxide (CO2) is exhaled, haemoglobin (Hb) inside red blood cells in pulmonary capillaries unloads CO2 and picks up O2 from alveolar air. Binding of O2 to Hb-H releases hydrogen ions (H^+). Bicarbonate ions ($HCO3^-$) pass into the RBC and bind to released H^+, forming carbonic acid (H2CO3). The H2CO3 dissociates into water (H2O) and CO2, and the CO2 diffuses from blood into alveolar air. To maintain electrical balance, a chloride ion (Cl^-) exits the RBC for each $HCO3^-$ that enters (reverse chloride shift). (b) CO2 diffuses out of tissue cells that produce it and enters red blood cells, where some of it binds to haemoglobin, forming carbaminohemoglobin (Hb–CO2). This reaction causes O2 to dissociate from oxyhemoglobin (Hb–O2). Other molecules of CO2 combine with water to produce bicarbonate ions ($HCO3^-$) and hydrogen ions (H^+). As Hb buffers H^+, the Hb releases O2 (Bohr effect). To maintain electrical balance, a chloride ion (Cl^-) enters the RBC for each $HCO3^+$ that exits (chloride shift).

Control of Respiration

Respiratory Centres: Clusters of neurons in the medulla oblongata and pons in the brain stem that send nerve impulses to the respiratory muscles, stimulating them to contract.

Control of Respiration (cont)

The respiratory centre can be divided into three areas on the basis of their function:

1) Medullary Rhythmicity Area: controls the basic rhythm of respiration and is present in the medullary oblongata. Can be classified into inspiratory and expiratory areas:

Inspiratory Area: Nerve impulses generated from the inspiratory area set the basic rhythm of breathing. Nerve impulses are generated for 2 seconds. The nerve impulse travels to the external intercostals through the intercostal nerves and the diaphragm through the phrenic nerves. This causes the diaphragm and the muscles to contract. At the end of the 2 seconds, the muscles must relax for 3 seconds, allowing for passive elastic recoil of the muscles for exhalation.

Expiratory Area: Remains inactive during quiet breathing. During forceful expiration, the inspiratory centre activates the expiratory centre to send nerve impulses to the abdominal and internal intercostals muscles, causing them to contract and forcing air out of the lungs.

2) Pneumotaxic Area: Present in the upper pons. Transmit inhibitory impulses to the inspiratory area, preventing the lungs from becoming too full of air.

3) Apneustic Area: Present in the lower pons. This area sends stimulatory impulses to the inspiratory area that activate it and prolong inhalation.