

OXYGEN TRANSPORT

- Oxygen transport in the human body is a critical physiological process that ensures that every cell receives the necessary oxygen for cellular respiration, metabolism, and energy production. Oxygen transport involves several systems and mechanisms, including the **respiratory system, the circulatory system, and the interaction between oxygen and hemoglobin** in red blood cells.
- Oxygen is transported by the blood either combined with hemoglobin in the red blood cells (greater than 98%) or dissolved in the blood plasma (less than 2%). Only about 3 ml of oxygen is dissolved in each liter of plasma. Assuming a total plasma volume of 3 to 5 L, only about 9 to 15 ml of oxygen can be carried in the dissolved state. This limited amount of oxygen cannot adequately meet the needs of even resting body tissues, which generally require more than 250 ml of oxygen per minute (depending on body size). However, hemoglobin, a protein contained within each of the body's 4 to 6 billion red blood cells, allows the blood to transport nearly 70 times more oxygen than can be dissolved in plasma.

The oxygen transport processes are as follows:

1. Oxygen Intake through the Respiratory System

Oxygen is first taken into the body through the lungs during the process of breathing (ventilation). Inhaled air enters the nose or mouth, travels down the trachea, and reaches the bronchi, which further divide into smaller bronchioles, and finally end in the alveoli—tiny air sacs where gas exchange occurs.

The alveolar walls are very thin, and they are surrounded by a dense network of capillaries. Oxygen diffuses across the alveolar-capillary membrane into the blood, down its concentration gradient. The concentration of oxygen in the alveoli is higher than in the capillary blood, facilitating the movement of oxygen into the blood.

2. Oxygen Transport via Hemoglobin in Red Blood Cells/Oxygen Saturation

Once oxygen enters the bloodstream, it primarily binds to hemoglobin (Hb), a protein found in red blood cells. Hemoglobin is made up of four subunits, each containing an iron atom that can bind to one molecule of oxygen. This allows each hemoglobin molecule to carry up to four oxygen molecules.

Hemoglobin has a high affinity for oxygen when the oxygen partial pressure is high (such as in the lungs) and a lower affinity when the partial pressure is low (such as in the tissues). This **cooperative binding** property means that the binding of one oxygen molecule increases the affinity for subsequent oxygen molecules to bind. The process by which hemoglobin binds and releases oxygen is described by the **oxygen-hemoglobin dissociation curve**, which shows the relationship between the partial pressure of oxygen (pO₂) and hemoglobin saturation with oxygen.

3. Role of the Oxygen-Hemoglobin Dissociation Curve

The **oxyhemoglobin dissociation curve** is a graphical representation that shows how hemoglobin in the blood binds to oxygen (O_2) and releases it depending on the partial pressure of oxygen (pO_2). It's essential for understanding how oxygen is picked up in the lungs and delivered to tissues in the body.

a. Shape of the Curve

The curve is typically **S-shaped** (sigmoidal) because of how hemoglobin interacts with oxygen. It shows the relationship between the **partial pressure of oxygen (pO_2)** and the **percentage of hemoglobin bound with oxygen (saturation)**.

- At **high pO_2** (like in the lungs, where oxygen is abundant), hemoglobin binds easily to oxygen, and the curve is steep, meaning it rapidly picks up oxygen.
- At **low pO_2** (like in tissues that need oxygen), hemoglobin releases oxygen more easily, and the curve flattens out, allowing oxygen to be unloaded where it's needed.

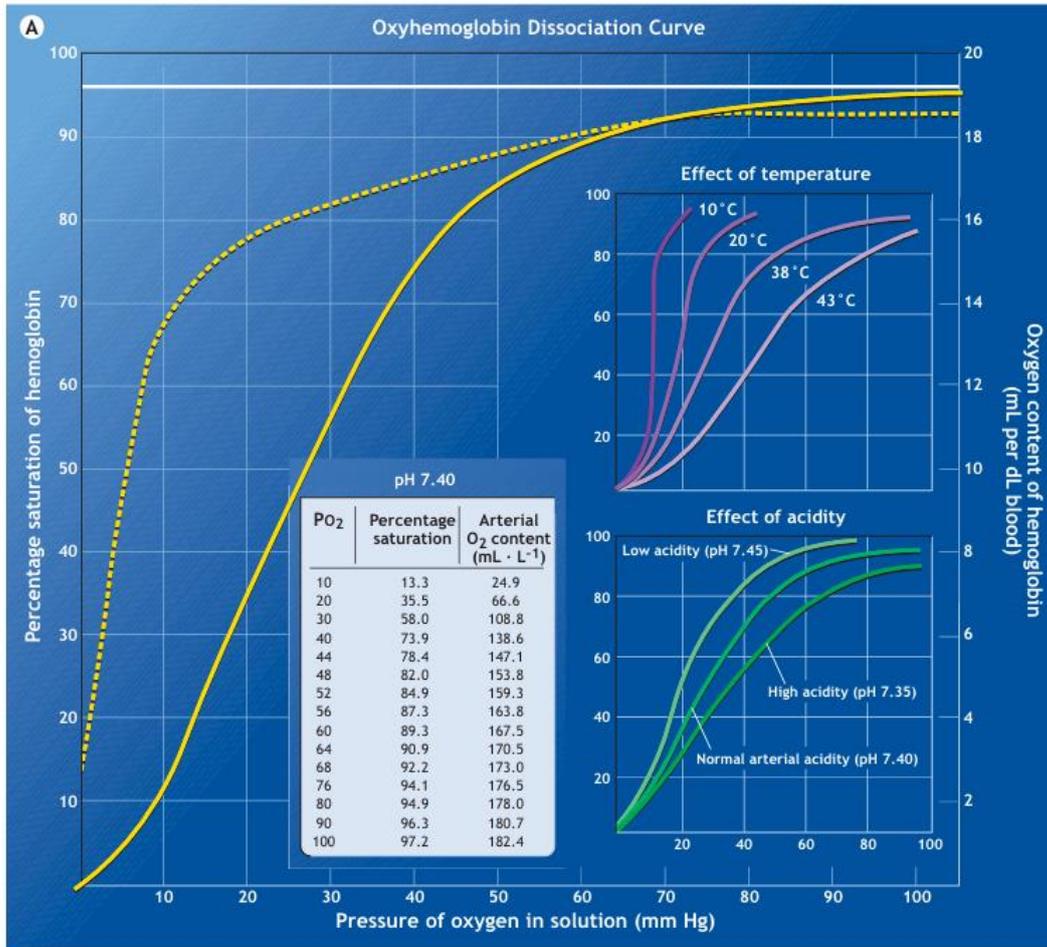
b. Cooperative Binding

The S-shape of the curve happens because of **cooperative binding**. Hemoglobin has four subunits, and when one subunit binds to oxygen, it makes it easier for the other subunits to bind oxygen as well. This helps hemoglobin quickly become fully saturated in the lungs and unload oxygen in tissues when needed.

c. Shifts in the Curve

The curve can shift to the left or right based on various factors:

- **Right Shift (easier oxygen release):** According **Bohr Effect** increased levels of carbon dioxide (CO_2), decreased pH (increased acidity), and increased temperature, all of which are typical in active tissues (like muscles), shift the curve to the right. This promotes the release of oxygen from hemoglobin to tissues.
- **Left Shift (easier oxygen binding):** This happens when CO_2 is low (since CO_2 is being expelled from the body), pH is higher (less acidic), and temperature is lower. This makes it easier for hemoglobin to hold on to oxygen, which is important in the lungs, where oxygen is plentiful.



4. Blood Oxygen-Carrying Capacity

- The oxygen-carrying capacity of blood is the maximal amount of oxygen the blood can transport. It depends primarily on the blood hemoglobin content. Each 100 ml of blood contains an average of 14 to 18 g of hemoglobin in men and 12 to 16 g in women. Each gram of hemoglobin can combine with about 1.34 ml of oxygen, so the oxygen-carrying capacity of blood is approximately 16 to 24 ml per 100 ml of blood when blood is fully saturated with oxygen. At rest, as the blood passes through the lungs, it is in contact with the alveolar air for approximately **0.75 s**. This is sufficient time for hemoglobin to become 98% to 99% saturated. At high intensities of exercise, the contact time is greatly reduced, which can reduce the binding of hemoglobin to oxygen and slightly decrease the saturation.
- People with low hemoglobin concentrations, such as those with anemia, have reduced oxygen-carrying capacities. Depending on the severity of the condition, these people might feel few effects of anemia while they are at rest because their cardiovascular system can compensate for reduced blood oxygen content by increasing cardiac output. However, during activities in which oxygen delivery can become a limitation, such as highly intense aerobic effort, reduced blood oxygen content limits performance.

5. Oxygen Delivery to Tissues

- As blood circulates through the body via arteries and capillaries, the oxygen-rich blood reaches various tissues and organs. The oxygen is delivered to cells primarily via diffusion, where it passes from the capillary blood into tissue cells, following the concentration gradient. This process is facilitated by the lower oxygen partial pressure in the tissues (due to cellular consumption of oxygen for energy production) and the higher oxygen content in the blood.
- Myoglobin, an oxygen-binding protein in muscle cells, facilitates oxygen diffusion and storage. It has a higher affinity for oxygen than hemoglobin and acts as an intracellular transporter, helping maintain oxygen supply to mitochondria, especially in conditions of low oxygen availability.
- The efficiency of this oxygen exchange is influenced by various factors, including capillary density, the rate of blood flow, and the metabolic activity of the tissues.

6. Oxygen Utilization in Cells

Once inside the muscle cell, oxygen is transported to the mitochondria, where it is used in oxidative phosphorylation to generate ATP. This process is essential for sustaining muscle contractions during prolonged or intense exercise. The efficiency of oxygen transport and utilization depends on factors such as capillary density, mitochondrial content, and myoglobin concentration in the muscle.

7. Oxygen Return to the Lungs

After the oxygen is delivered to tissues and cells, the blood, now lower in oxygen content, returns to the heart through the venous system. The blood then enters the lungs via the pulmonary circulation, where oxygen is replenished, and the cycle repeats.

Factors Affecting Oxygen Transport

Several factors can influence the efficiency of oxygen transport:

- **Altitude:** At high altitudes, atmospheric pressure decreases, which leads to a reduction in the partial pressure of oxygen. This can cause reduced oxygen saturation in hemoglobin, prompting the body to adapt by increasing red blood cell production.
- **Diseases:** Conditions such as anaemia, carbon monoxide poisoning, chronic obstructive pulmonary disease (COPD), and other respiratory or circulatory issues can impair oxygen transport and delivery.
- **Exercise:** During physical activity, muscles require more oxygen, which increases the oxygen demand and can lead to a temporary shift in the oxygen-hemoglobin dissociation curve to improve oxygen unloading in the tissues.

References

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