PULMONARY DIFFUSION

Gas exchange in the lungs between the alveoli and the capillary blood, called pulmonary diffusion, serves two major functions:

- It replenishes the blood's oxygen supply, which is depleted at the tissue level as it is used for oxidative energy production.
- It removes carbon dioxide from returning systemic venous blood.

Atmospheric air contains several gases, mainly **Nitrogen** (about 78%), **Oxygen** (about 21%), small amounts of **Carbon Dioxide**, and traces of other gases such as argon and water vapour. When we breathe in, this **whole mixture of gases enters the lungs**. However, the body **uses mainly oxygen** for metabolic processes and removes carbon dioxide as a waste product. Nitrogen and most other gases are **not significantly used by the body** and are inhaled and exhaled largely unchanged.

Mechanism of Pulmonary Diffusion

Pulmonary diffusion **occurs across the alveolar-capillary membrane**, which is a thin barrier that separates the air in the alveoli from the blood in the capillaries. The process is driven by the principles of diffusion and is governed by several factors:

1. **Partial Pressure Gradient**:

   The air we breathe is a mixture of gases. Each exerts a pressure in proportion to its concentration in the gas mixture. The individual pressures from each gas in a mixture are **referred to as partial pressures.** According to **Dalton's law**, the total pressure of a mixture of gases equals the sum of the partial pressures of the individual gases in that mixture.

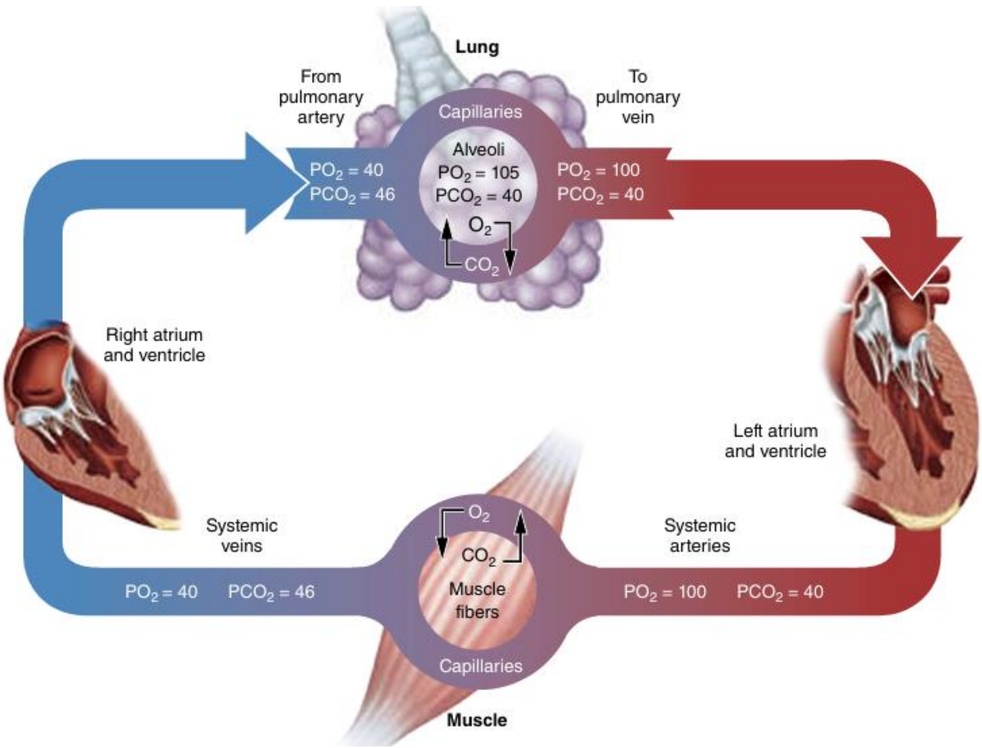
- The primary driver of diffusion is the **difference in partial pressures of gases between the alveolar air and the blood**.
- Oxygen from the alveolar air moves into the blood, and carbon dioxide from the blood moves into the alveolar air. This movement occurs from areas of higher partial pressure to areas of lower partial pressure, following **Fick's Law of Diffusion** (Fick's law **states that the rate of diffusion through a tissue such as the respiratory membrane is proportional to the surface area and the difference in the partial pressure of gas between the two sides of the tissue**).

Oxygen Diffusion:

- The PO_2 of air outside the body at standard atmospheric pressure is 159 mmHg. However, this pressure decreases to approximately 105 mmHg when air is inhaled and enters the alveoli, where it is moistened and mixes with the air already present in the alveoli. The blood, stripped of much of its oxygen by the metabolic needs of the tissues, typically enters the pulmonary capillaries with a PO_2 of about 40 mmHg. This is about 60 to 65 mmHg less than the PO_2 in the alveoli. In other words, the pressure gradient for oxygen across the respiratory membrane is typically about 65 mmHg. This pressure gradient drives the oxygen from the alveoli into the blood to equilibrate the pressure of the oxygen on each side of the membrane.

- The PO_2 in the alveoli stays relatively constant at about 105 mmHg. The blood leaving the lungs through the pulmonary veins and subsequently returning to the systemic (left) side of the heart has a rich supply of oxygen to deliver to the tissues. But the PO_2 in the pulmonary vein is now approximately 100 mmHg, not the 105 mmHg found in the alveolar air and pulmonary capillaries. This is because approximately 2% of the blood is shunted (physiological shunting) from the aorta through the Bronchial Arteries directly to the lungs to meet the oxygen needs of the lungs themselves. After delivering oxygen to these tissues, this blood becomes **partially deoxygenated. Some of the blood from this enters the pulmonary veins.**

- At the same time, fully oxygenated blood from the **Pulmonary Capillaries** is also entering the pulmonary veins after gas exchange in the alveoli. When the **partially deoxygenated blood from the bronchial circulation mixes with the fully oxygenated blood**, the overall oxygen level of the blood decreases slightly.



Partial pressure of oxygen (PO_2) and carbon dioxide (PCO_2) in blood as a result of gas exchange in the lungs and gas exchange between the capillary blood and tissues.

Carbon Dioxide Diffusion:

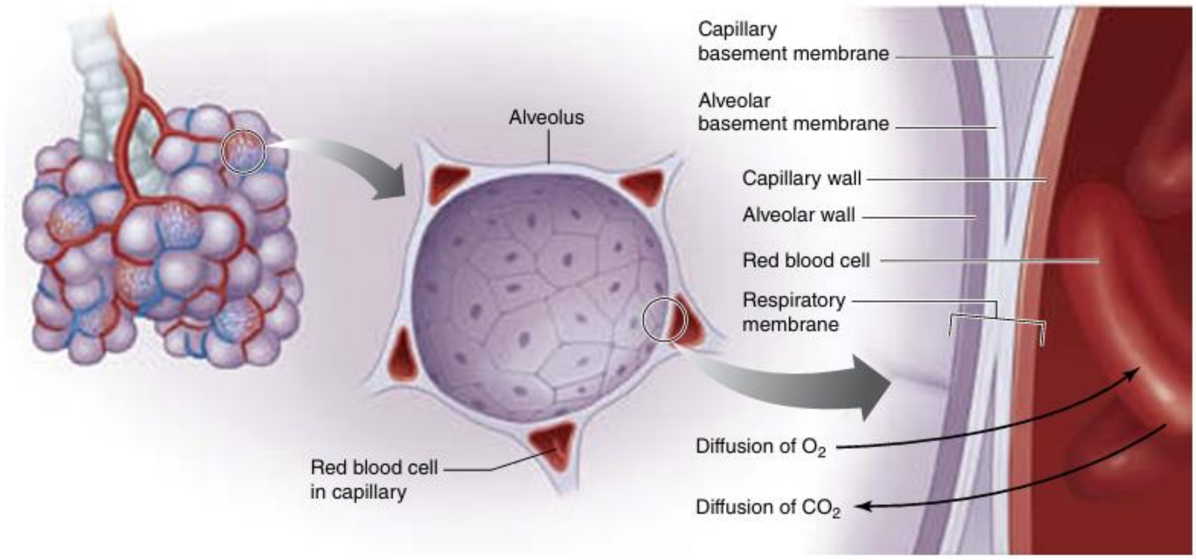
- Carbon dioxide, like oxygen, moves along a partial pressure gradient. The blood passing from the right side of the heart through the alveoli has a PCO_2 of about 46 mmHg. Air in the alveoli has a PCO_2 of about 40 mmHg. Although this results in a relatively small pressure gradient of only about 6 mmHg, it is more than adequate to allow for the exchange of CO_2 **because of a higher diffusion coefficient of carbon dioxide than oxygen.**

2. **Alveolar-Capillary Membrane Structure:**

   Gas exchange between the air in the alveoli and the blood in the pulmonary capillaries occurs across the respiratory membrane (also called the alveolar-capillary membrane). This membrane is composed of

   - the alveolar wall,
   - the capillary wall, and
   - their respective basement membranes.

- The **primary function of these membranous surfaces is for gas exchange**. The alveolar-capillary membrane is **very thin (about 0.2–0.5 micrometers)**, which facilitates efficient gas exchange. It is **made up of a single layer of epithelial cells in the alveoli and endothelial cells in the capillaries**. These cells are closely apposed to each other, minimizing the distance gases must travel.



Anatomy of the respiratory membrane, showing the exchange of oxygen and carbon dioxide between an alveolus and pulmonary capillary blood.

3. **Surface Area:**

- The surface area available for gas exchange is vast due to the large number of alveoli in the lungs (approximately 300 million). This large surface area maximizes the ability for oxygen to diffuse into the blood and for carbon dioxide to diffuse into the alveolar air.
- Disorders that reduce the surface area (such as **emphysema**) can impair gas exchange and lead to **hypoxemia** (low blood oxygen levels).

4. **Solubility of Gases:**

   The solubility of gases plays an important role in diffusion. A gas's solubility in blood is a constant, and blood temperature also remains relatively constant at rest. Thus, the most critical factor for gas exchange between the alveoli and the blood is the pressure gradient between the gases in the two areas. Oxygen is less soluble in plasma compared to CO_2, but it is still efficiently diffused into the blood. CO_2, being more soluble, diffuses more readily across the membrane.

5. **Diffusion Coefficient of Gases**

   The **diffusion coefficient** of gases is a measure of how easily a gas diffuses across a membrane. Oxygen is less soluble in plasma compared to carbon dioxide, which means that although CO_2 diffuses more rapidly across the alveolar-capillary membrane, oxygen is still able to diffuse efficiently into the blood due to the large surface area and strong partial pressure gradient. Carbon dioxide's diffusion coefficient **is 20 times greater** than that of oxygen, so CO2 can diffuse across the respiratory membrane much more rapidly.

6. **Ventilation-Perfusion Matching (V/Q Ratio):**
   For optimal diffusion, ventilation (air reaching the alveoli) must be matched with perfusion (blood flow through the capillaries). If the ventilation is high but perfusion is low (as in **pulmonary embolism**) or if perfusion is high but ventilation is low (as in certain forms of **pneumonia**), the efficiency of pulmonary diffusion can be compromised

Factors Affecting Pulmonary Diffusion

Several factors influence the efficiency of pulmonary diffusion:

1. **Altitude**:
   - At higher altitudes, the partial pressure of oxygen in the air decreases, leading to a reduced gradient for oxygen diffusion into the blood. This can result in hypoxemia if the body does not adjust sufficiently.
2. **Age**:
   - As people age, the efficiency of pulmonary diffusion can decrease due to changes in lung tissue elasticity and alveolar surface area.
3. **Exercise**:
   - During physical activity, cardiac output and respiratory rate increase, which enhances pulmonary diffusion by improving the matching of ventilation and perfusion and increasing the blood flow through the lungs.
4. **Pulmonary Diseases**:
   - Conditions like pulmonary fibrosis, emphysema, and chronic obstructive pulmonary disease (COPD) **can thickens the alveolar-capillary membrane or reduce alveolar surface area,** making diffusion less efficient.
5. **Blood Flow**:
   - Adequate blood flow is essential for efficient diffusion. Conditions that impair blood flow, such as **pulmonary hypertension or heart failure**, can reduce the capacity for pulmonary diffusion.

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