6. CO2 transport and V/Q mismatch

CARBON DIOXIDE TRANSPORT

Carbon dioxide is a product of oxidative metabolism. Unlike O_2, CO_2 is very **soluble in water** and does not need a carrier for transport in the blood. Most (60%) of the carbon dioxide in blood is transported as **bicarbonate (HCO_3^-)**. The conversion of CO_2 to bicarbonate is catalyzed by the enzyme carbonic anhydrase located inside red blood cells.

$$\mathbf{CO_2 + H_2O = H_2CO_3 = HCO_3^- + H^+}$$

Once formed, the HCO_3^- is transported out of the RBC into the plasma in exchange for Cl^-.

About 10% of the total CO_2 in blood is transported as dissolved CO_2. The amount dissolved is proportional to the PCO_2, and to the solubility coefficient for CO_2. At $PaCO_2$ = 40 mm Hg, there would be approximately 26.8 ml CO_2/L of plasma.

The remaining 30% of the CO_2 combines with Hb to form carbamino-hemoglobin compounds.

Because **CO_2 diffuses 20X more rapidly than O_2,** a rise in blood CO_2 can be compensated by an increase in ventilatory rate. **Hyperventilation increases the amount of CO_2 removed from the body and increases the unloading of CO_2 from the blood in the lung.**

Ventilation & Perfusion

Ventilation is the process of bringing air in and out of the lungs. Perfusion is the process of bringing blood in and out of the lung capillary bed to allow for gas exchange. The right ventricle delivers blood to the lungs at relatively low pressures (mean pressure of 15 mmHg). However, lung perfusion pressure can increase for multiple reasons including obstruction of vessels (i.e., embolism) or increased resistance to flow (i.e., fibrosis). The lung will compensate for lowered blood flow (1) by recruiting other capillary beds within the lung and (2) by distention of small vessels. If these responses are inadequate, then pressure within the pulmonary artery will rise causing a rise in right ventricular pressure. This is called **pulmonary hypertension**.

Under normal conditions, regulatory mechanisms within the lung **match ventilation (V) to perfusion (Q) to optimize the oxygenation of the blood.** V/Q mismatch can occur when ventilated alveoli are not perfused giving a V/Q ratio of infinity and conversely, when unventilated alveoli are perfused, giving a V/Q ratio of zero. This latter condition is equivalent to shunting venous blood from the right to the left side of the heart bypassing the lungs. Usually lung disease is progressive. It leads to a gradual worsening of either ventilation or perfusion and therefore the **V/Q mismatch** is intermediate between zero and infinity. Many believe that V/Q mismatching is the most common cause of low PaO_2.

In a normal individual at the level of the lung, alveolar ventilation is about 4.0 L/min and pulmonary blood flow is about 5.0 L/min. This gives a V/Q = 0.8 overall. Note that **V/Q mismatch** can occur within the normal lung because blood flow is never perfectly uniform in this organ. In a normal person while standing, gravitational pull causes the apex of the lung to be more expanded than within the base thereby compressing the capillaries and reducing perfusion; V/Q ratios are greater than 1 in the apex. In contrast, perfusion is greater than ventilation at the base of the lung in an upright individual; V/Q ratios are less than 1.
One mechanism that compensates for V/Q mismatch is the **vasoconstriction of the lung vasculature in response to hypoxia (low O_2).** [Note that this is in contrast to the smooth muscle of the systemic vasculature which dilates in response to low O_2 conditions.] **Vasoconstriction of the lung vasculature to hypoxia** enables the blood to be shunted away from poorly ventilated areas. This occurs without an increase in pulmonary artery perfusion pressure because of the large capacity of the pulmonary capillaries.

A second compensation that compensates for V/Q mismatch occurs when $PACO_2$ falls (e.g. when V/Q ratio increases). In this instance, the concentration of hydrogen ions (H+) in and around the smooth muscle of the airways (bronchioles) decreases. This reduction in H+ results in airway constriction and a shift of ventilation away from the areas which are over ventilated (i.e., not perfused).