Respiration: Gas Exchange / Acid Base Balance

Animal Physiology
Spring, 2008

**Purpose of Gas Exchange**

To transfer oxygen from the atmosphere to tissues of the body, and to move metabolically produced carbon dioxide from tissues of the body to the atmosphere.
Need to know facts about oxygen and carbon dioxide in living systems

- Oxygen is added to the atmosphere primarily through photosynthesis

- Oxygen is removed from the atmosphere primarily by animal respiration

- Oxygen is added to water as photosynthesis is carried out by aquatic plants and algae

- Both oxygen and carbon dioxide are transferred passively across the body surface by diffusion

- To maximize gas transfer, the respiratory surface area is large and the diffusion distance is small
Types of Respiration

Internal or cellular respiration

External respiration
**Internal Respiration**

Refers to the intracellular metabolic process carried out within the mitochondria to use oxygen and produce carbon dioxide during the Kreb’s cycle.

**External respiration**

Breathing or ventilation

Diffusion of air and carbon dioxide across the respiratory surface

Transportation of oxygen and carbon dioxide in blood

Exchange of oxygen and carbon dioxide between tissues and blood
Partial pressure

The individual pressure exerted independently by a particular gas within a mixture of gases.

Composition and partial pressures in atmospheric air

- 79% $N_2$
  - Partial pressure of $N_2 = 600$ mm Hg

- 21% $O_2$
  - Partial pressure of $O_2 = 160$ mm Hg

Total atmospheric pressure = 760 mm Hg

Partial pressure of $N_2$
  - In atmospheric air: $P_{N_2} = 760$ mm Hg $\times$ 0.79
  - $P_{N_2} = 600$ mm Hg

Partial pressure of $O_2$
  - In atmospheric air: $P_{O_2} = 760$ mm Hg $\times$ 0.21
  - $P_{O_2} = 160$ mm Hg
Oxygen Delivery!!!

It can be physically dissolved
It can be chemically bound to hemoglobin
**Hemoglobin**

Iron-bearing protein molecule contained within red blood cells

Has the ability to form loose, easily reversible combinations with oxygen

When not bound with oxygen, Hgb is referred to as **reduced hemoglobin**

When combined with oxygen, Hgb is referred to as **oxyhemoglobin**
What determines the percent of Hb saturation in the pulmonary blood?

\[ \text{PO}_2 \]

**Law of Mass Action**

If the concentration of one of the substances involved in a reversible reaction is increased, the reaction is driven toward the opposite side.

\[ \text{Hb} + \text{O}_2 \leftrightarrow \text{HbO}_2 \]
Plateau portion of the saturation curve:
Provides a good margin of safety in oxygen carrying capacity of the blood.
(Occurs in pulmonary capillaries)

Steep portion of the saturation curve:
Hb can release oxygen quickly as needed.
(Occurs in systemic capillaries)
What is the role of Hb in the blood?

Hb plays a crucial role in permitting the transfer of large quantities of oxygen before blood P0₂ equilibrates with the surrounding tissue.

Hb acts as a storage depot for oxygen, removing oxygen from solution as soon as it enters the blood from the alveoli.

Stored Hb does not contribute to P0₂.

Other factors besides the partial pressure of oxygen affect Hemoglobin saturation

C0₂
Acidity
Temperature
2,3-bisphosphoglycerate
Carbon Dioxide is transported in the blood in three ways:

- Physically dissolved
- Bound to Hb
- As bicarbonate

\[
\text{Carboxic anhydrase} \\
\text{C}_2\text{O}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{C}_0\text{3} \rightleftharpoons \text{H}^+ + \text{HC}_3\text{O}^- 
\]
In systemic tissue

Carbonic anhydrase converts carbon dioxide to bicarbonate in RBCs once released from tissues.

In lungs

In lungs, carbonic anhydrase is found in RBCs as well as lung epithelium.

pH Changes associated with gas exchange
Regulation of body pH
Need to know facts!

• Body pH is slightly alkaline (7.4) but can range from 7 – 7.8.
• Changes of body pH alters the dissociation of weak acids and thus affects how easily

\[
\text{Carbonic anhydrase} \\
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-
\]

• Body pH also affects ionization of proteins

Where does H\(^+\) come from?

• Through metabolism of ingested food
• Largest pool is due to

\[
\text{Carbonic anhydrase} \\
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-
\]
How is excess H\(^+\) removed?

• In terrestrial vertebrates, excess H\(^+\) is removed through the renal system.

• In aquatic animals, the excess H\(^+\) is excreted across regions of the body surface.

How do animals breath in oxygen and breath out carbon dioxide?
In Terrestrial Animals:

Air flow can occur by altering the volume of the lungs
During inspiration, the intra-alveolar pressure must be less than atmospheric pressure.

During expiration, the intra-alveolar pressure must be greater than atmospheric pressure.

Intra-alveolar pressure can be changed by altering the volume of the lungs according to

**Boyle’s Law**

At a constant temperature, the pressure exerted by a gas varies inversely with the volume of the gas!!!!
Inspiration is due to a fall in intra-alveolar pressure brought about by lung expansion!!! (from 760 mm Hg to 759 mm Hg)

Lung expansion is not caused by movement of air into the lungs. It is due to the contraction of respiratory muscles!!!