The Respiratory System

Functions
- Exchange of O₂ and CO₂ btw atmosphere and blood
- Regulation of blood and tissue pH

Extracellular Respiration
- Process where O₂ and CO₂ is exchanged between cells and external environment
- Four Steps
  1. Ventilation
     - gas exch. btw. atmosphere and air in the lungs
  2. Diffusion of gases across pulmonary capillaries
  3. Transport of gases in the blood
  4. Diffusion of gases across systemic capillaries to tissues

Anatomy
- Nasal Passageways and Mouth
- Pharynx
  - Common passage for digestive and respiratory systems
- Trachea
  - supported by rings of cartilage
  - lined with ciliated cells and mucus secreting cells
  - Larynx - voice box at entrance to trachea
- Lungs
- Conduction Network
  - Bronchi
  - Bronchioles
  - Alveolar Ducts
- Alveoli
  - Very small, thin-walled, inflatable sacs
  - Approx. 300 million/lung in human adults
  - Site of gas exchange (by diffusion)
  - Surrounded by pulmonary capillaries
Movements of Gases

- O₂ and CO₂ move by diffusion down a pressure gradient (for gases)
  - high pressure = high concentration
- Pressure differences between two regions drive air flow:
  - Atmospheric Pressure (ATM Pr) = Pressure exerted by the weight of air in the atmosphere
  - Intrapulmonary Pressure (IP Pr) = Pressure inside alveoli

• If IP Pr < ATM Pr, air rushes into lungs
• If IP Pr > ATM Pr, air rushes out of lungs
- Boyle's Law
  - Pressure ∝ 1/Volume
- Air flow into and out of lungs driven by changing lung volume
  - ↑ Lung Volume, ↓ IP Pr, air flows in
  - ↓ Lung Volume, ↑ IP Pr, air flows out

Mechanics of Lung Ventilation

**Inspiration** - active
- Due to contraction of inspiratory muscles
  - Diaphragm and External Intercostals
- Enlarges thoracic cavity
  - Expands lungs (↑ in V)
  - Drop in IP Pr below ATM Pr
  - Air moves into the lungs

**Expiration** - mainly passive
- Due to relaxation of inspiratory muscles
- Compresses thoracic cavity
  - Compresses lungs (↓ in V)
  - ↑ in IP Pr above ATM Pr
  - Air moves out of the lungs
- Additional air expired through contraction of expiratory muscles
  - internal intercostals and abdominal muscles

Blood Gas Transport

- Gases move along a pressure gradient
  - Dalton's Law
    - pressure of a gas mixture (air) = Σ pressures each gas would exert independently
  - P_{O2} = partial pressure of O₂
  - P_{CO2} = partial pressure of CO₂
  - each gas moves along own pr. gradient

- O₂
  - alveoli → blood → tissues
- CO₂
  - tissues → blood → alveoli
Alveoli

- Thin-walled
  - single epithelial layer
- separated from capillaries by thin layer of interstitial fluid
- Short diffusion distance
  - \( \text{O}_2 \) from air to blood
  - \( \text{CO}_2 \) from blood to air

Oxygen Transport

- \( \text{O}_2 \) is poorly soluble in blood plasma
- Most (~99%) \( \text{O}_2 \) transported bound to hemoglobin
  - Tetramer protein w/ 4 heme units
  - Can bind up to 4 \( \text{O}_2 \) molecules

Factors Affecting \( \text{O}_2 \) Binding

- \( P_{\text{O}_2} \)
  - \( \uparrow P_{\text{O}_2}, \uparrow \text{O}_2 \) binding
  - \( \downarrow P_{\text{O}_2}, \uparrow \text{O}_2 \) release
  - in lungs, \( \text{O}_2 \) uptake; at tissues, \( \text{O}_2 \) release

Factors Affecting \( \text{O}_2 \) Binding

- pH
  - \( \uparrow \text{pH}, \uparrow \text{O}_2 \) binding
  - \( \downarrow \text{pH}, \downarrow \text{O}_2 \) release

Factors Affecting \( \text{O}_2 \) Binding

- \( P_{\text{CO}_2} \)
  - \( \uparrow P_{\text{CO}_2}, \uparrow \text{O}_2 \) release
  - in lungs, \( \text{O}_2 \) uptake; at tissues, \( \text{O}_2 \) release

Factors Affecting \( \text{O}_2 \) Binding

- Temperature
  - \( \uparrow \text{temperature}, \uparrow \text{O}_2 \) release
  - increases \( \text{O}_2 \) release to active muscle

Factors Affecting \( \text{O}_2 \) Binding

- 2,3-DPG
  - \( \uparrow 2,3\text{-DPG}, \uparrow \text{O}_2 \) release
  - binds to Hb
  - stabilizes deoxygenated form
  - promotes \( \text{O}_2 \) release to tissues
  - released from RBCs in response to low blood \( P_{\text{O}_2} \)
    (e.g. high elevations)
**Carbon Dioxide Transport**

- 7-10% dissolved gas in plasma
- 20-23% bound to Hb (carbaminohemoglobin)
  - does not bind to the heme unit
  - Hb can bind O₂ and CO₂ simultaneously
- 70% dissolved in plasma in the form of bicarbonate (HCO₃⁻)

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+
\]

- CO₂ transport
- Acid-base balance

**Carbon Dioxide Transport**

- CO₂ released from cells, enters RBCs
- Carbonic anhydrase
  - Converts CO₂ and H₂O into H₂CO₃
- H⁺ binds to Hb, triggers O₂ release
- HCO₃⁻ released into plasma, Cl⁻ enters cell

**pH Regulation**

- HCO₃⁻ produced in RBCs acts as a buffer in the blood
  - Absorbs high levels of H⁺ from other sources (lactate, etc.)
  \[
  \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+
  \]
  - Helps maintain pH of body fluids

**pH Regulation**

- Dissolved CO₂ also reacts with H₂O in plasma to form H₂CO₃
  - More dissolved CO₂ in plasma, more carbonic acid, more acidic conditions
- Regulation of CO₂ levels in blood influences blood pH
  - ↓ CO₂, ↓ carbonic acid levels, ↑ pH
  - ↑ CO₂, ↑ carbonic acid levels, ↓ pH

- Normal pH of body fluids = 7.40
- Alkalosis (pH > 7.45)
  - Respiratory alkalosis
    - caused by hyperventilation
  - Metabolic alkalosis
    - cause by low acid levels or too much bicarbonate
- Acidosis (pH < 7.35)
  - Respiratory acidosis
    - Caused by hypoventilation
  - Metabolic acidosis
    - Too much acid in blood or excessive bicarbonate loss
### Control of Breathing

#### Respiratory control centers
- Located in pons and medulla
- Control activity of MNs innervating muscles used in breathing
  - An automatic response (involuntary).
  - Establishes basic breathing rhythm (cyclical activity)

#### Voluntary Control
- from higher brain centers (motor cortex)
- modulate activity of medulla

#### Peripheral Chemoreceptors
- Carotid Bodies
- Aortic Bodies
- monitor \([CO_2], [O_2]\) and \([H^+]\) in blood
  - send info. to medulla neurons
- Breathing Rate ↑’s with:
  - ↑ CO₂
  - ↑ H⁺
  - ↓ O₂

#### Central Chemoreceptors
- induced by ↓ pH, but not directly due to ↓ blood pH
- CO₂ penetrates blood-brain barrier (not H⁺)
- High \([CO_2]\) → more CO₂ in cerebrospinal fluid (CSF)
- ↑ H₂CO₃, ↓ pH in CSF