Internal Gas Transport ("Blood")

Chapter 22

Functions of "Blood"

- Gas Transport
- Nutrient Transport
- Excretory Product Transport
- Cell Signal Transport
- Hydraulic Force
- Heat Conductance
- Immunity

Gas Transport - Plasma

- Solubility of the gas
- Pressure of the gas in the gas phase
  - Henry’s Law: \( V_g = \alpha (P_g/760) \times V_{H_2O} \)
  - Amount of gas dissolved is proportional to the pressure of the gas
- Temperature
  - \( \uparrow \) temperature, \( \downarrow \) solubility
- Presence of other solutes
  - \( \uparrow \) [solid solutes], \( \downarrow \) solubility of gases

O\(_2\) Transport - Plasma

- Amount of oxygen in mammalian blood plasma = 2 to 4 ml / L
- Very low
- Need way of increasing amount of oxygen carried by the blood

Respiratory Pigments

- Substances that reversibly bind oxygen
- Increase oxygen carrying capability of blood
  - Mammalian blood holds \(~200\) ml O\(_2\) / L blood
  - 50-100 x that of plasma alone

Types of Respiratory Pigments: Hemoglobins

- chordates, many invertebrates
- protein with heme (porphyrin derivative) attached
  - Contains Fe\(^{2+}\) that forms weak electrostatic bond with O\(_2\)
- myoglobin - monomeric form found in muscle, etc
- tetrameric hemoglobin
  - common blood pigment
  - cooperative binding properties
- dimeric and polymeric forms
- Within cells or free floating
- Multiple forms within individual organisms
Types of Respiratory Pigments: Other Pigments

- **Chlorocruorin**
  - Some polychaetes
  - Modified heme unit
  - Massive polymeric complexes
  - Green coloration

- **Hemerythrin**
  - Sipunculids, priapulids, brachiopods, some annelids
  - No heme (pair of Fe²⁺ bound directly to protein)
  - Monomeric, trimeric, and octomeric forms

- **Hemocyanin**
  - Mollusks, some arthropods
  - No heme units (paired Cu⁺ atoms bound to protein)
  - Blue coloration
  - Variable modular forms

Functions of Respiratory Pigments

- Gas transport (O₂ and CO₂)
- Gas (O₂) storage
- pH buffers
- Enhancing gradients for gas diffusion
- Non-respiratory transport (e.g., NO)
- Possible enzymatic function (e.g., NO)

Adult Human Tetrameric Hemoglobin

- Four individual polypeptide chains
  - 2 α chains
  - 2 β chains
- Porphyrin ring (heme)
  - Central Fe²⁺ ion
  - Attached to carboxyl end of each chain

Hemoglobin

- Hemoglobin reversibly binds O₂

\[
\text{Hb (deoxyhemoglobin)} + \text{O}_2 \rightleftharpoons \text{HbO}_2 \ (\text{oxyhemoglobin})
\]

- Loading vs. unloading determined by:
  - O₂ tension in the plasma
  - Affinity of Hb for O₂

Hemoglobin Dissociation Curve

- Relative amount of oxyHb at different O₂ tensions
- Sigmoidal relationship
  - Cooperative interactions
- \(P_{50}\)
  - \(P_{50}\) at which 50% of the Hb is saturated with O₂
  - Index of Hb affinity: ↑ \(P_{50}\), ↓ affinity

Factors Affecting Affinity

- Specific variant of Hb
- Cooperativity of binding in multimeric forms
- Temperature
- pH
- Carbon Dioxide
- Organic Phosphates
- Inorganic Ions
Hemoglobin Variants

- Different forms of respiratory pigments have different affinities for oxygen

Binding Cooperativity (Multimeric Forms)

- Sigmoidal dissociation curve in tetrametric Hb rather than hyperbolic
- Binding of O₂ to one or two sites enhances affinity to bind to the remaining two sites

Factors Affecting Affinity: Temperature

- ↑ temperature, ↓ affinity (shift curve to right)
- ↑ unloading in metabolically active tissue

Factors Affecting Affinity: pH

- **Bohr effect**
  - ↑ affinity with ↑ pH
  - ↓ affinity with ↓ pH
- Increases unloading to metabolically active tissues
  - ↑ CO₂ and other acids

Factors Affecting Affinity: CO₂

- **Bohr effect**
  - ↑ P_CO₂, ↓ affinity
  - right shift of the curve
  - even when pH buffered
- CO₂ binds to amino end of polypeptide chains
  - binding reduces affinity

Factors Affecting Affinity: pH and CO₂

- **Root effect (fish)**
  - ↓ pH or ↑ P_CO₂ lowers overall O₂ content at saturation
  - Acid-sensitive globins in Hb
- Used to release O₂ to swim bladder and eyes
Factors Affecting Affinity: Organic Phosphates

- Erythrocytes (RBCs)
  - carry hemoglobin
  - contain phosphates (ATP, DPG, IP₃, GTP, etc.)
- DPG - decreases O₂ affinity of Hb
  - induces unloading of O₂

Factors Affecting Affinity: Inorganic Ions

- ↑ [ion], ↓ affinity
- some ions have greater effects than others
  - Ca²⁺ and Mg²⁺ important,
  - Na⁺ and Cl⁻ not important

Effects of Hypoxia

- Adaptation: increased oxygen affinity of hemoglobin
  - e.g. South American camels
  - e.g. Fish from low oxygenated waters
  - increases Hb uptake in the blood

Effects of Hypoxia

- Acclimation: decreased Hb affinity for O₂
  - e.g. Humans at high elevations
  - increased DPG levels
    - more O₂ unloading
  - increased Hb content of blood
    - polycythemia (↑ RBC count)

Effects of Body Size

- Smaller animals tend to have Hb with lower O₂ affinity
  - have relatively higher metabolic rates
  - increased O₂ delivery to tissues
- Also, more capillaries and Hb that is more sensitive to pH

Effects of Multiple Pigments

- Facilitate O₂ transfer from one part of the body to another
  - e.g. hemoglobin (blood) and myoglobin (muscle)
  - difference in affinity enhances O₂ transfer from blood to muscles
Carbon Dioxide Transport

- CO₂ content dependent on P_CO₂

**Fig. 22.20**

Carbon Dioxide Transport

- Carbon dioxide can be transported by the blood in three ways:
  1. Dissolved gas in plasma
     - 5-10% in human arterial blood
  2. Bound to Hb (carbaminohemoglobin)
     - 5-25% in humans
  3. Dissolved as bicarbonate
     - 70-90% in humans

Carbaminohemoglobin

- CO₂ will bind to the N-terminus of a Hemoglobin molecule
  - not to the heme unit
- Affinity ↓’s with ↑ P_O₂
  - in lungs, high P_O₂ induces O₂ loading and CO₂ unloading
  - in tissues, high P_CO₂ induces CO₂ loading and O₂ unloading

**Fig. 22.22**

Bicarbonate

- Most of the CO₂ in the blood is carried in the form of bicarbonate
  \[ CO₂ + H₂O ⇌ H₂CO₃ ⇌ H⁺ + HCO₃⁻ \]
- Occurs spontaneously in the plasma
- Rate increased inside RBCs by the presence of carbonic anhydrase (catalyzes reaction)

Bicarbonate

- Tissues
  - ↑P_CO₂, increased H⁺ + HCO₃⁻ formation
  - H⁺ binds to Hb, induces unloading of O₂
  - HCO₃⁻ diffuses into plasma, acts as a buffer
- Lungs
  - ↓P_CO₂, bicarbonate converted back into CO₂
  - H⁺ releases Hb, induces O₂ loading

Carbonic Anhydrase

- ↑ speed of CO₂ diffusion from tissues to blood and from blood to exterior
- ↑ speed at which H⁺ dissociates from Hb in the lungs (↑ O₂ affinity)
- more carbonic anhydrase activity in smaller animals