Mammals

- Respiratory system is located within the chest cavity, or **thorax**.

- **Upper Respiratory Tract:**
  - Mouth, nasal cavity, pharynx, larynx, & trachea

- **Lower Respiratory Tract:**
  - Bronchi & gas exchange surfaces
Mammals

• **Alveoli:**
  ◦ Thin walled, blind-end sacs
  ◦ *Site of gas exchange*

• Epithelium composed of two cell types:
  ◦ **Type I**: thin, responsible for gas exchange
  ◦ **Type II**: thick, maintain fluid balance across lungs & secrete surfactants

• Alveoli wrapped with an extensive capillary network covering 80-90% of the surface.
Mammalian Alveoli
Mammals

- Properties of Surfactant:
  1. Lowers surface tension in the alveoli
     * Increases compliance
     * Decreases work of inspiration
  2. Promotes stability of alveoli
  3. Helps to keep the lungs dry
Mammalian Lungs

- Lungs are surrounded by the **pleural sac**

- Pleural sac consists of 2 layers of cells with a small layer of fluid between them.

- **Pleural Cavity** = fluid-filled space
  - Lubricates and allows two layers to slide past one another during ventilation
Mammals

- Energy needed to ventilate the lungs is dependent upon:

  - **Compliance**  \( (C = \Delta V/\Delta P) \)
    - ease of stretch

  - **Elastance**
    - how readily it returns to original state
Mammals

- Lower compliance =
  - Harder to expand lungs
  - Higher energetic cost of inspiration

- Low elastance =
  - Lungs will not spring back to original shape when muscles relax.
  - Expiration becomes active, rather than passive
Mammals

- Surfactant increases lung compliance.
- Surface tension is lowered by adding surfactants which disrupt cohesive forces.
- Reduce surface tension in fluid layer lining lungs and reduce tendency of the walls of small airways and alveoli to stick together.
Lung Volumes & Capacities

- **Tidal Volume** = total amount of air moved in an average ventilatory cycle.

- **Dead Space**: air that enters with a ventilatory cycle but does not participate in gas exchange.

- Alveolar ventilation volume ($V_A$): total amount of fresh air involved in gas exchange during a respiratory cycle.
  - $V_A = V_T - V_D$
Normal lung volumes and capacities for a healthy 70-kg human male

<table>
<thead>
<tr>
<th>Lung Volumes</th>
<th>Lung Capacities</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_T =$ Tidal volume = 500 ml</td>
<td>IC = Inspiratory capacity = $V_T + IRV = 3500$ ml</td>
</tr>
<tr>
<td>$IRV =$ Inspiratory reserve volume = 3000 ml</td>
<td>VC = Vital capacity = $V_T + IRV + ERV = 4500$ ml</td>
</tr>
<tr>
<td>$ERV =$ Expiratory reserve volume = 1000 ml</td>
<td>FRC = Functional residual capacity = ERV + RV = 2200 ml</td>
</tr>
<tr>
<td>$RV =$ Residual volume* = 1200 ml</td>
<td>TLC = Total lung capacity = $V_T + ERV + IRV + RV = 5700$ ml</td>
</tr>
</tbody>
</table>

*Cannot be measured by spirometry
Mammals

- Airway resistance will affect work required to breath.

- **Small changes in airway diameter will have large effects on resistance to flow.**
  - Greater driving force needed = more energy
Ventilation & Perfusion

- For gas exchange to occur efficiently:

  ventilation of the respiratory surface must be matched to the perfusion of the respiratory surface with blood.
Control of Ventilation

- Respiratory centers in the brain
- Chemoreceptors
- Stretch Receptors
- Baroreceptors
Summary of Respiratory Systems
Respiratory Systems: Gas Transport to Tissues
Oxygen Transport

- Oxygen can be transported to the tissues in 2 different ways:
  - Dissolved in circulatory fluid
  - Via Oxygen Carrier
    - Hemoglobin (Hb)
      - Increases Oxygen Carrying Capacity 50x
Oxygen Transport

- Majority of oxygen diffusing into blood binds to Hb.

- Reduces blood $P_{O_2}$ by taking it out of solution

- Helps maintain the $P_{O_2}$ gradient across the respiratory surface.
  - Improves oxygen extraction
Oxygen Transport

- At tissues, the mitochondrial oxygen consumption decreases $P_{O_2}$ of the blood.

- $O_2$ dissociates from Hb

- $O_2$ diffuses down its gradient, into the cells, and into the mitochondria.
Hemoglobin (Hb)

- Type of *respiratory pigment*

- Most common respiratory pigment in animals.

- All respiratory pigments consist of:
  - at least one molecule of a protein in the *globin* family non-covalently bound to a *heme* molecule.
(a) Hemoglobin molecule

(b) Heme group containing iron (Fe)
Hemoglobin (Hb)

- Blood hemoglobins of vertebrates are found inside red blood cells
- Generally consist of 4 globin molecules.
- Main functions are oxygen transport and storage.
Oxygen-Equilibrium Curves

- Show relationships between the partial pressure of oxygen ($P_{O_2}$) in the plasma, and the percentage of oxygenated Hb in a volume of blood.

- At $P_{O_2} = 0 \rightarrow$ no $O_2$ bound to Hb

- As $P_{O_2}$ increases $\rightarrow$ $O_2$ binds to Hb
  - Blood is saturated when all available molecules are fully bound to oxygen.
Oxygen-Equilibrium Curves

- Typically, oxygen equilibrium curves are expressed in terms of percent saturation.
Oxygen-Equilibrium Curves

- Can also be expressed in terms of total oxygen content of the blood.
Regulation

- Animals can regulate the amount of Hb in their blood.

- In many vertebrates exposure to environmental hypoxia triggers RBC production and/or release.
  - Contraction of spleen
  - More RBCs = higher HCT
Variation

- Variation between species

- Ex. Diving marine mammals have extremely high levels of blood Hb compared to terrestrial mammals.

- Ex. Antarctic ice fish do not have any Hb
Oxygen Affinity

- Oxygen affinity of Hb: How readily Hb binds oxygen

- Expressed in terms of $P_{50}$

- $P_{50} =$ the oxygen partial pressure at which Hb is 50% saturated.
Affinity

- Low $P_{50}$ = high affinity
- High $P_{50}$ = low affinity
- Hb has an extremely high affinity for CO
- Hb binds with CO more than 200x more readily than with O2
Oxygen-Equilibrium Curves

- Hemoglobin curves exhibit a sigmoidal oxygen equilibrium curve.
  - Have 2 alpha and 2 beta subunits
  - ↑ $O_2$ bound to Hb, ↑ its affinity for $O_2$
  - T State & R State

- **Cooperative binding** leads to sigmoidal shape
Oxygen-Equilibrium Curves
Oxygen-Equilibrium Curves
Oxygen-Equilibrium Curves
Oxygen-Equilibrium Curve

- In reality, Hb saturation is a series of curves influenced by:
  - pH: hydrogen ion \([H^+]\) in blood
  - \(\text{CO}_2\)
  - Temperature
  - 2-3 diphosphoglycerate \([2-3 \text{ DPG}]\) in blood
Bohr Effect

- Facilitates oxygen transport to active tissues

- At respiratory surface, where $P_{\text{CO}_2}$ is low and pH is high, $O_2$ affinity of Hb will be high.

- Metabolizing tissues produce $\text{CO}_2$: 
  $\uparrow [\text{CO}_2]$ and $[H^+]$, thus $\downarrow$ pH.

- This shifts curve to the right, facilitating oxygen release at the tissues.
Effects of Exercise

The diagrams illustrate the effects of exercise on the percent saturation of hemoglobin at different temperatures and pH levels. The graphs show how changes in temperature and pH affect the oxygen binding capacity of hemoglobin. The left graph displays the percent saturation of hemoglobin at 20°C, 37°C, and 43°C, while the right graph shows the effect of pH at 7.6, 7.4, and 7.2. The bottom graph compares the percent saturation of hemoglobin with no 2,3-DPG, normal 2,3-DPG, and high 2,3-DPG conditions.
Carbon Dioxide Transport

- Waste product of mitochondrial respiration

- Much more soluble in bodily fluids, but very little of $\text{CO}_2$ in blood is actually in the molecular form $\text{CO}_2$

- 10-15% dissolved in plasma
- 10-15% bound with proteins ($\text{HbCO}_2$)
- 75% exists as bicarbonate ($\text{HCO}_3^-$) in RBCs
Carbon Dioxide Transport
Respiratory Acid-Base Balance

- **Respiratory Acidosis** = Ventilation is insufficient to remove all of the CO$_2$ produced by metabolism.
  - ie. hypoventilation

- **Respiratory Alkalosis** = Ventilation is greater than needed to remove CO$_2$ produced by metabolism.
  - ie. hyperventilation