Respiratory System

Part 2
Respiration

- Exchange of gases between air and body cells
- Three steps
  1. Ventilation
  2. External Respiration
  3. Internal Respiration
Ventilation

- Pulmonary ventilation consists of two phases
  1. Inspiration: gases flow into the lungs
  2. Expiration: gases exit the lungs
- Relies on pressure gradients
  - Atmosphere and alveoli
- Negative pressure breathing
  - Thoracic pressures
  - Atmospheric pressure
Boyle’s Law

- The relationship between the pressure and volume of a fixed quantity of gas in a closed container
- Pressure \((P)\) varies inversely with volume \((V)\):

\[ P_1 V_1 = P_2 V_2 \]

While one increases the other decreases
Ventilation

- Intrapleural pressure is subatmospheric
  - Inward elastic recoil of lung tissue
  - Outward elastic recoil of chest wall

[Resting lung volume]
Ventilation

- Atmospheric pressure (P\textsubscript{atm})
  - Pressure exerted by the air surrounding the body
  - 760 mm Hg at sea level
- Thoracic pressures are described relative to P\textsubscript{atm}
  - Negative respiratory pressure is less than P\textsubscript{atm}
  - Positive respiratory pressure is greater than P\textsubscript{atm}
Atmospheric pressure

Intrapleural pressure: 756 mm Hg

Transpulmonary pressure: 760 mm Hg - 756 mm Hg = 4 mm Hg

Thoracic wall

Parietal pleura

Visceral pleura

Pleural cavity

Transpulmonary pressure 760 mm Hg

Intrapleural pressure 756 mm Hg (-4 mm Hg)

Intrapulmonary pressure 760 mm Hg (0 mm Hg)
Ventilation

- Intrapulmonary (intra-alveolar) pressure ($P_{pul}$)
  - Pressure in the alveoli
  - Fluctuates with breathing
  - Always eventually equalizes with $P_{atm}$
Ventilation

- Intrapleural pressure ($P_{ip}$):
  - Pressure in the pleural cavity
  - Fluctuates with breathing
  - Always a negative pressure ($<P_{atm}$ and $<P_{pul}$)
Ventilation

- Negative $P_{ip}$ is caused by opposing forces
  - Two inward forces promote lung collapse
    - Elastic recoil of lungs decreases lung size
    - Surface tension of alveolar fluid reduces alveolar size
  - One outward force tends to enlarge the lungs
    - Elasticity of the chest wall pulls the thorax outward
Atmospheric pressure

Thoracic wall

Diaphragm

Lung

Parietal pleura

Visceral pleura

Pleural cavity

Transpulmonary pressure

760 mm Hg

-756 mm Hg

= 4 mm Hg

Intrapleural pressure

756 mm Hg

(-4 mm Hg)

Intrapulmonary pressure

760 mm Hg

(0 mm Hg)
Pulmonary Ventilation

- Inspiration and expiration
- Mechanical processes that depend on volume changes in the thoracic cavity
  - Volume changes $\rightarrow$ pressure changes
  - Pressure changes $\rightarrow$ pressure gradient $\rightarrow$ gases flow to equalize pressure
Inspiration

- An **active** process
  - Inspiratory muscles contract
    - Thoracic volume increases
    - Lungs are stretched and intrapulmonary volume increases
      - Intrapulmonary pressure drops
      - Air flows into the lungs, down its pressure gradient
        - $P_{pul} = P_{atm}$
<table>
<thead>
<tr>
<th>Inspiration</th>
<th>Sequence of events</th>
<th>Changes in anterior-posterior and superior-inferior dimensions</th>
<th>Changes in lateral dimensions (superior view)</th>
</tr>
</thead>
<tbody>
<tr>
<td>① Inspiratory muscles contract (diaphragm descends; rib cage rises).</td>
<td></td>
<td>Ribs are elevated and sternum flares as external intercostals contract.</td>
<td></td>
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<td>② Thoracic cavity volume increases.</td>
<td></td>
<td></td>
<td>External intercostals contract.</td>
</tr>
<tr>
<td>③ Lungs are stretched; intrapulmonary volume increases.</td>
<td></td>
<td>Diaphragm moves inferiorly during contraction.</td>
<td></td>
</tr>
<tr>
<td>④ Intrapulmonary pressure drops (to –1 mm Hg).</td>
<td></td>
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<tr>
<td>⑤ Air (gases) flows into lungs down its pressure gradient until intrapulmonary pressure is 0 (equal to atmospheric pressure).</td>
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Expiration

• Quiet expiration is normally a **passive** process
  • Inspiratory muscles relax
    • Thoracic cavity volume decreases
    • Elastic lungs recoil and intrapulmonary volume decreases
      • $P_{pul}$ rises
    • Air flows out of the lungs down its pressure gradient until $P_{pul} = 0$
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<tr>
<td>① Inspiratory muscles relax (diaphragm rises; rib cage descends due to recoil of costal cartilages).</td>
<td>Ribs and sternum are depressed as external intercostals relax.</td>
<td>External intercostals relax.</td>
</tr>
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<td>② Thoracic cavity volume decreases.</td>
<td></td>
<td></td>
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<tr>
<td>③ Elastic lungs recoil passively; intrapulmonary volume decreases.</td>
<td>Diaphragm moves superiorly as it relaxes.</td>
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<td>④ Intrapulmonary pressure rises (to +1 mm Hg).</td>
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<td>⑤ Air (gases) flows out of lungs down its pressure gradient until intrapulmonary pressure is 0.</td>
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Expiration
**Intrapulmonary pressure.** Pressure inside lung decreases as lung volume increases during inspiration; pressure increases during expiration.

**Intrapleural pressure.** Pleural cavity pressure becomes more negative as chest wall expands during inspiration. Returns to initial value as chest wall recoils.

**Volume of breath.** During each breath, the pressure gradients move 0.5 liter of air into and out of the lungs.
Air Flow

- Physical factors influencing efficiency of air flow
  - Inspiratory muscles overcome three factors that hinder air passage and pulmonary ventilation
    1. Airway resistance
    2. Alveolar surface tension
    3. Lung compliance

6b. Friction is **inversely** proportional to airway diameter
Air Flow

- Bronchoconstriction
  - Smooth muscle contracts
  - Reduced air flow
Lung Compliance

- Diminished by
  - Nonelastic scar tissue (fibrosis)
  - Reduced production of surfactant
  - Decreased flexibility of the thoracic cage
Gas Law’s

- Dalton’s Law of Partial Pressure
  - Describes how a gas behaves when it is part of a mixture
    - Partial pressure = pressure exerted by a single gas in the mixture = proportional to the percentage of gas in a mixture
    - Total pressure exerted by a mixture of gases is the sum of the pressures exerted by each gas
Gas Law’s

• Dalton’s Law of Partial Pressure
  • Example:
    • Air contains 20.9% O\textsubscript{2}
    • Atmospheric Pressure = 760 mmHg
      \[0.209 \text{P}_{\text{O}_2} \times 760 \text{ mmHg} = 160 \text{ mmHg}\]
      \[= \text{partial pressure of oxygen in the atmosphere}\]
Gas Law’s

- Fick’s Law of Diffusion
  - Gives the rate of diffusion for a given gas across a membrane
  - CO₂ has a high diffusion coefficient and diffuses 20 times more rapidly across a membrane than O₂

\[ V_g = (A) (P_1 - P_2) (D) (T) \]
Gas Law’s

- Diseases related to gas diffusion
  - Pulmonary edema
  - COPD
Gas Exchange

- External respiration
  - Pulmonary gas exchange
- Internal respiration
  - Gas exchange between blood capillaries and tissues
Inspired air:
\[ P_{O_2} = 160 \text{ mm Hg} \]
\[ P_{CO_2} = 0.3 \text{ mm Hg} \]

Alveoli of lungs:
\[ P_{O_2} = 104 \text{ mm Hg} \]
\[ P_{CO_2} = 40 \text{ mm Hg} \]

Blood leaving lungs and entering tissue capillaries:
\[ P_{O_2} = 100 \text{ mm Hg} \]
\[ P_{CO_2} = 40 \text{ mm Hg} \]

Blood leaving tissues and entering lungs:
\[ P_{O_2} = 40 \text{ mm Hg} \]
\[ P_{CO_2} = 45 \text{ mm Hg} \]

Systemic veins
\[ P_{O_2} \text{ less than } 40 \text{ mm Hg} \]
\[ P_{CO_2} \text{ greater than } 45 \text{ mm Hg} \]
External Respiration

- Exchange of $O_2$ and $CO_2$ across the respiratory membrane
  - From lung to blood
- Influenced by
  - Partial pressure gradients
  - Gas solubilities
  - Structural characteristics of the respiratory membrane
External Respiration

- Respiratory membrane
  - Membrane of lung epithelium
  - Pulmonary capillary membrane
  - Surfactant
(c) Detailed anatomy of the respiratory membrane
External Respiration

- Partial pressure gradient for O\textsubscript{2} in the lungs is steep
  - Venous blood Po\textsubscript{2} = 40 mm Hg
  - Alveolar Po\textsubscript{2} = 104 mm Hg

Oxygen readily diffuses from alveoli to lung capillaries
External Respiration

- Partial pressure gradient for $\text{CO}_2$ in the lungs
  - Venous blood $\text{Pco}_2 = 45 \text{ mm Hg}$
  - Alveolar $\text{Pco}_2 = 40 \text{ mm Hg}$
- But...
  - $\text{CO}_2$ is 20 times more soluble in plasma than oxygen
  - $\text{CO}_2$ diffuses in equal amounts with oxygen!
Inspired air:
\[ P_{O_2} \] 160 mm Hg
\[ P_{CO_2} \] 0.3 mm Hg

Alveoli of lungs:
\[ P_{O_2} \] 104 mm Hg
\[ P_{CO_2} \] 40 mm Hg

Blood leaving lungs and entering tissue capillaries:
\[ P_{O_2} \] 100 mm Hg
\[ P_{CO_2} \] 40 mm Hg

Blood leaving tissues and entering lungs:
\[ P_{O_2} \] 40 mm Hg
\[ P_{CO_2} \] 45 mm Hg

Pulmonary arteries

Pulmonary veins (\( P_{O_2} \) 100 mm Hg)

Systemic veins

Systemic arteries

Tissues:
\[ P_{O_2} \] less than 40 mm Hg
\[ P_{CO_2} \] greater than 45 mm Hg
Factors Affecting External Respiration

Anatomical adaptations

- Moist surfaces
- Thickness and surface area
- Narrow capillaries = RBC’s single file

Physiological and physical factors

- Pulmonary disease
- Affect of drugs on minute volume
- Partial pressure changes with altitude
Internal Respiration

- Capillary gas exchange in body tissues
- Partial pressures and diffusion gradients are reversed compared to external respiration
  - $P_{O_2}$ in tissue is always lower than in systemic arterial blood
  - $P_{CO_2}$ in tissue is higher than in systemic arterial blood
Inspired air:
\( P_{O_2} \) 160 mm Hg
\( P_{CO_2} \) 0.3 mm Hg

Alveoli of lungs:
\( P_{O_2} \) 104 mm Hg
\( P_{CO_2} \) 40 mm Hg

Blood leaving lungs and entering tissue capillaries:
\( P_{O_2} \) 100 mm Hg
\( P_{CO_2} \) 40 mm Hg

Blood leaving tissues and entering lungs:
\( P_{O_2} \) 40 mm Hg
\( P_{CO_2} \) 45 mm Hg

Pulmonary arteries

Pulmonary veins (\( P_{O_2} \) 100 mm Hg)

Systemic veins

Systemic arteries

Tissues:
\( P_{O_2} \) less than 40 mm Hg
\( P_{CO_2} \) greater than 45 mm Hg