Respiratory Physiology
Lungs at Rest

Air passageway

Atmospheric pressure of 760 mm Hg on the inside

Atmospheric pressure of 760 mm Hg on the outside

Diaphragm
Atmospheric pressure

Lung
Thoracic wall
Parietal pleural
Pleural cavity
Visceral pleura
Diaphragm

Intrapleural pressure 756 mm Hg (−4 mm Hg)
Collapsing force of lungs 4 mm Hg
Intrapulmonary pressure 760 mm Hg (0 mm Hg)
Atelectasis
Lung Properties

• Compliance = Distensibility
  – Allows for lung expansion

• Elasticity
  – Allows for lung recoil back to original size
Boyle’s Law

• Ideal gas law
  – At constant temp, gas pressure varies inversely with volume.

• $P_1 V_1 = P_2 V_2$
Inspiration

Intra-alveolar pressure (760 mm Hg)

Atmospheric pressure (760 mm Hg)

Diaphragm

Intra-alveolar pressure (758 mm Hg)
Inspiration and the Thorax

- Normal inspiration
  - Sternum moves up and out
  - External intercostal muscles pull ribs up and out
  - Diaphragm contracts

- Maximal inspiration
  - Sternochleidomastoid elevates sternum
  - Pectoralis minor elevates ribs
  - Diaphragm contracts more
<table>
<thead>
<tr>
<th>Expiration</th>
<th>Sequence of events</th>
<th>Changes in anterior-posterior and superior-inferior dimensions</th>
<th>Changes in lateral dimensions</th>
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<tr>
<td></td>
<td>① Inspiratory muscles relax (diaphragm rises; rib cage descends due to gravity)</td>
<td>Ribs and sternum depressed as external intercostals relax</td>
<td>ExTERNAL intercostals relax</td>
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<td>② Thoracic cavity volume decreases</td>
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<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</td>
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<td>pressure is 0</td>
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</tbody>
</table>
Expiration

Normal expiration:
- Diaphragm
- Abdominal organs recoil and press diaphragm upward

Maximal expiration:
- Posterior internal intercostal muscles pull ribs down and inward
- Diaphragm
- Abdominal organs force diaphragm higher
- Abdominal wall muscles contract and compress abdominal organs
Respiratory Distress

• Surfactant
  – Keeps alveoli from collapsing
  – Reduces surface tension inside alveoli

• Respiratory distress syndrome (RDS)

• Acute respiratory distress syndrome (ARDS)
Respiratory Volumes and Capacities

- Inspiratory reserve volume
- Tidal volume
- Residual volume
- Expiratory reserve volume
- Vital capacity
- Inspiratory capacity
- Functional residual capacity
- Total lung capacity

Lung volume in milliliters (mL)

0 1,000 2,000 3,000 4,000 5,000 6,000
Respiratory Volumes and Capacities

- Inspiratory reserve volume
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- Vital capacity
- Inspiratory capacity
- Functional residual capacity
- Total lung capacity

Lung volume in milliliters (mL)

0, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000

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Respiratory Problems & Tests

• Anatomic dead space
• Alveolar/Physiologic dead space
• Obstructive Pulmonary Disease (affect gas flow)
  – Chronic bronchitis (asthma)
  – Emphysema
• Restrictive Disorders (affect total volume)
  – Cystic fibrosis
• Minute ventilation = gas moved/min
• FVC
• FEV
• Alveolar vent rate (AVR) accounts for dead space)
Gas Laws

• Dalton’s Law of Partial Pressures
  – Total pressure exerted by a mixture of gasses
    = sum of the pressures exerted independently by each gas in the mixture.

• Partial pressure
  = amount of pressure each gas contributes

• Atmospheric changes
Gas Laws

• Henry’s Law
  – When a mixture of gasses is in contact with a liquid:
  – Each gas will dissolve in the liquid proportional to its partial pressure.
Gas Exchange

Net diffusion of CO₂

Net diffusion of O₂

PCO₂ = 45 mm Hg
PO₂ = 40 mm Hg

PCO₂ = 40 mm Hg
PO₂ = 104 mm Hg

Blood flow (from body tissues)

Alveolar wall

Blood flow (to body tissues)
Reduced alveolar ventilation; excessive perfusion

$\downarrow PO_2$, $\uparrow PCO_2$ in alveoli

Pulmonary arterioles serving these alveoli constrict

Reduced alveolar ventilation; reduced perfusion

Enhanced alveolar ventilation; inadequate perfusion

$\uparrow PO_2$, $\downarrow PCO_2$ in alveoli

Pulmonary arterioles serving these alveoli dilate

Enhanced alveolar ventilation; enhanced perfusion

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Oxygen Transport

Blood $P_{O_2} = 104$ mm Hg

Capillary

Hemoglobin molecules

Net diffusion of oxygen

Tissue cells

Blood flow (to lungs)

Tissue $P_{O_2} = 40$ mm Hg

Blood flow (from body tissues)

Net diffusion of oxygen

Hemoglobin molecules

Oxycyhemoglobin molecule

Alveolar wall

Alveolus

Oxygen molecules

Blood flow (from body tissues)
Oxygen Release and PO$_2$

% saturation of hemoglobin

PO$_2$ (mm Hg)

Oxyhemoglobin dissociation at 38°C
Other Factors Affecting Hb Sat.

- $P_{CO_2}$
- Temp
- Blood pH (amnt of $H^+$ ions)
- Amnt. of 2,3-bisphosphoglycerate (BPG)
  - Goes up as oxyhemoglobin level drops
Oxygen Release and $P_{CO_2}$

Oxyhemoglobin dissociation at 38°C
Oxygen Release and Blood Temperature

% saturation of hemoglobin vs. PO2 (mm Hg) for various temperatures: 0°C, 10°C, 20°C, 30°C, 38°C, 43°C

Oxyhemoglobin dissociation at various temperatures
Hypoxia

- Anemic hypoxia
- Ischemic hypoxia
- Histotoxic hypoxia
- Hypoxemic hypoxia
  - Carbon Monoxide poisoning
- Clinical terms
  - Apnea = temp. cessation of breathing
  - Dyspnea = difficulty breathing
  - Tachypnea = rapid, shallow breathing
CO₂ Transport

- Dissolved in plasma
  - ~7-10%
- Carbaminohemoglobin
  - Bound to globin AA’s
  - ~20%
- As bicarbonate (HCO₃⁻) ions
  - ~70%
Carbon Dioxide Transport

CO₂ dissolved in plasma

Blood flow from systemic arteriole

CO₂ combined with hemoglobin to form carbaminohemoglobin

Blood flow to systemic venule

Plasma

Red blood cell

Capillary wall

Cellular CO₂

Tissue cell

Tissue $P_{CO₂} = 45$ mm Hg

$CO₂ + H₂O \rightarrow HCO₃⁻ + H⁺$

$HCO₃⁻ + H⁺ \rightarrow H₂CO₃$

$H₂CO₃ \rightarrow CO₂ + H₂O$
Chloride Shift

Capillary wall

Red blood cell

Plasma

\( \text{Cl}^- \)

\( \text{HCO}_3^- \)

\( \text{Cl}^- \)

\( \text{HCO}_3^- \)

\( \text{HCO}_3^- \)
Carbon Dioxide Diffusion — Lungs

$P_{CO_2} = 40 \text{ mm Hg}$
Respiratory Center

- Fourth ventricle
- Midbrain
- Pneumotaxic area
- Pons
- Medulla oblongata
- Ventral respiratory group
- Dorsal respiratory group
- Medullary rhythmicity area
Inflation Reflex

- Respiratory center
- Spinal cord
- Sensory pathway
- Motor pathways
- Vagus nerve
- Phrenic nerve
- Stretch receptors
- Lung
- External intercostal muscles
- Intercostal nerve
- Rib
- Diaphragm
Homeostatic Imbalances of the Respiratory System

• Chronic Obstructive Pulmonary Diseases
  – Emphysema
  – Chronic Bronchitis
• Asthma
• Tuberculosis
• Lung cancer