Respiratory System

- Major functions of respiratory system: supply body with O\textsubscript{2} for cellular respiration and dispose of CO\textsubscript{2}, a waste product of cellular respiration
- Respiratory and circulatory system are closely coupled
- Also functions in olfaction and speech

- Apply fundamental knowledge of the respiratory system to succeed in the preparatory coursework for the health professions, biomedical research and advanced scientific study.
- Distinguish between the different types of pulmonary air volumes and capacities.
- Apply gas laws to respiratory physiology
Respiratory System

- **Respiration** involves four processes
  1. **Pulmonary ventilation** (breathing): movement of air into and out of lungs
  2. **External respiration**: exchange of O\textsubscript{2} and CO\textsubscript{2} between lungs and blood
  3. **Transport** of O\textsubscript{2} and CO\textsubscript{2} in blood
  4. **Internal respiration**: exchange of O\textsubscript{2} and CO\textsubscript{2} between systemic blood vessels and tissues

The Major Respiratory Organs

Anatomical Relationships Of Organs In The Thoracic Cavity
Hilum of the Lung

- Apex of lung
- Pulmonary artery
- Left superior lobe
- Oblique fissure
- Left inferior lobe
- Hilum of lung
- Aortic impression

(b) Photograph of medial view of the left lung.

Anatomical relationships of organs in the thoracic cavity

- Right lung
- Parietal pleura
- Visceral pleura
- Pleural cavity
- Pericardial membranes
- Anterior mediastinum
- Heart (in mediastinum)
- Pulmonary trunk
- Thoracic wall
- Left lung
- Left pulmonary vein
- Left pulmonary artery
- Left main bronchus
- Root of lung at hilum
- Esophagus (in mediastinum)
- Sternum

(c) Transverse section through the thorax, viewed from above. Lungs, pleural membranes, and major organs in the mediastinum are shown.

Nasal Cavity

- Posterior nasal aperture
- Sphenoidal sinus
- Cribriform plate of ethmoid bone
- Nasal cavity
- Nasal conchae (superior, middle, and inferior)
- Nasal meatuses (superior, middle, and inferior)
- Nasal vestibule
- Nares

Conchae:
- Increase surface area of mucosa
- Increase air turbulence

- Nasal cavity
- Nasal conchae (superior, middle, and inferior)
- Nasal meatuses (superior, middle, and inferior)
- Nasal vestibule
- Nares

- Nasal conchae
- Nasal meatuses
- Nasal vestibule
- Nares

- Nasal cavity
- Nasal conchae
- Nasal meatuses
- Nasal vestibule
- Nares
Pharynx, Larynx, and Upper Trachea

- Nasopharynx
  - Posterior nasal aperture
  - Pharyngeal tonsil
  - Opening of pharyngotympanic tube
  - Palatine tonsil
  - Isthmus of the faucets
- Oropharynx
- Laryngopharynx
- Esophagus
- Larynx
- Hard palate
- Soft palate
- Tongue
- Lingual tonsil
- Epiglottis
- Vestibular fold
- Thyroid cartilage
- Vocal fold
- Cricoid cartilage
- Thyroid gland

Air or air and food passageway

"Eustachian" tube

Unencapsulated lymphoid nodules

Epiglottis (elastic cartilage) protects airway (glottis) from food/drink during swallowing.

The Larynx

- Location of vocal folds typically known as the true vocal cords
- Airway – in and out – return to pseudostratified ciliated epithelium
- Valsalva’s maneuver
- Voice production

Movements of the vocal folds.
Tissue Composition Of The Tracheal Wall

- **Mucosa** - pseudostratified ciliated epithelium
- **Submucosa** - glandular
  - Seromucous gland in submucosa
- **Hyaline cartilage**
- **Adventitia**

*Windpipe*
- Supported by C-shaped rings of hyaline cartilage - prevents closing even when thoracic pressure changes and food in esophagus pushes
- Carina

Goblet cell

**Mucosa**
- Pseudostratified ciliated columnar epithelium
- Lamina propria (connective tissue)

**Submucosa**
- Seromucous gland in submucosa

**Hyaline cartilage**

Tissue composition of the tracheal wall

(b) Photomicrograph of the tracheal wall (320x)

Conducting Zone Passages

- Three lobes on right; two lobes on left
- Segments
- Lobules
- C-rings replaced by hyaline plates
- Elastic tissue present - stroma
- Pseudostratified ciliated eventually replaced by columnar
- Smooth muscle in walls increases
A Cast Of The Bronchial Tree

Right lung

Left lung

Right
superior
lobe (3
segments)

Right
middle
lobe (2
segments)

Right
inferior
lobe
(5 segments)

Left superior
lobe (4 segments)

Left inferior
lobe
(5 segments)

Respiratory Zone Structures

- Terminal bronchioles <0.5 mm in diameter
- No cartilage involvement
- Smooth muscle dominates
- Epithelium now non-ciliated cuboidal in the smallest tubes
- Mucus production limited then ends

Respiratory Zone Structures

Alveolar surface area =
90 m² or 969 ft² in healthy lungs of adult male
**Alveoli And The Respiratory Membrane**

The respiratory membrane is a combination of alveolar squamous cells and capillary endothelial cells. It is approximately 0.5 µm thick and acts as a barrier between the blood and the air.

**Detailed anatomy of the respiratory membrane**

- **Type I alveolar cells** are simple squamous supported by a thin basement membrane and dominate.
- **Type II alveolar cells** are scattered surfactant-producing cuboidal cells that also produce antimicrobials.
- Alveolar pores allow for air exchange between adjacent alveoli.
- Alveolar macrophages move along the surface and eventually get swept out.

**Pleural cavity containing pleural fluid**

- **Atmospheric pressure** ($P_{atm}$) is 0 mm Hg at sea level.
- **Intrapleural pressure** ($P_{ip}$) is $-4$ mm Hg, maintaining negative pressure inside the pleural cavity.
- **Intrapulmonary pressure** ($P_{pul}$) is 0 mm Hg, which is equal to atmospheric pressure.
- **Transpulmonary pressure** is 4 mm Hg, the difference between $P_{atm}$ and $P_{pul}$.

Strong adhesive forces between visceral and parietal pleura keep $P_{ip}$ negative, preventing the lung from collapsing.
Pulmonary Ventilation

- **Boyle’s law**: relationship between pressure and volume of a gas
  - Gases always fill the container they are in
    - If amount of gas is the same and container size is reduced, pressure will increase
  - So pressure ($P$) varies inversely with volume ($V$)
  - Mathematically:
    - $P_1V_1 = P_2V_2$

When atmospheric pressure and intrapulmonary pressure are the same, no air moves
- muscles acting on the lungs change the intrapulmonary pressure

**Effect of Rib and Sternum**

<table>
<thead>
<tr>
<th>Sequence of Events</th>
<th>Changes in Inferior Posterior and Superior Inferior Dimensions</th>
<th>Changes in Lateral Dimensions</th>
<th>Changes to Inspirational Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rib repositioned posteriorly</td>
<td>Extra costal and subcostal contractions lead to 500 ml change in volume</td>
<td>Diaphragm is dominant inspirational muscle</td>
</tr>
<tr>
<td>2</td>
<td>Stomach repositioned anteriorly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Diaphragm moves inferiorly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Ribs and sternum are depressed as external intercostals relax</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Diaphragm moves superiorly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Thoracic cavity volume decreases</td>
<td>Extra costal and subcostal relax</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Elastic lungs recoil passively</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Intrapulmonary volume decreases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Intrapulmonary pressure rises</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Air (gases) flows out of lungs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Normal inspirations recruit the scalenes, sternocleidomastoids, pectoralis minors, and erector spinae

Normal expiration is passive
Gas Exchange:
Basic Properties of Gases

- **Dalton's law of partial pressures**
  - Total pressure exerted by mixture of gases is equal to sum of pressures exerted by each gas
  - **Partial pressure**
    - Pressure exerted by each gas in mixture
    - Directly proportional to its percentage in mixture

- **Henry's law**
  - For gas mixtures in contact with liquids:
    - Each gas will dissolve in the liquid in proportion to its partial pressure
    - At equilibrium, partial pressures in the two phases will be equal
  - Amount of each gas that will dissolve depends on:
    - Solubility: CO₂ is 20x more soluble in water than O₂, and little N₂ will dissolve
    - Temperature: as temperature of liquid rises, solubility decreases

---

<table>
<thead>
<tr>
<th>Table 22.4</th>
<th>Comparison of Gas Partial Pressures and Approximate Percentages in the Atmosphere and in the Airway</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS</td>
<td>ATMOSPHERE (PER LITRE)</td>
</tr>
<tr>
<td>N₂</td>
<td>78.1</td>
</tr>
<tr>
<td>O₂</td>
<td>20.9</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.04</td>
</tr>
<tr>
<td>H₂O</td>
<td>1.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
</tr>
</tbody>
</table>

Partial Pressure Gradients Promoting Gas Movements In The Body
Oxygen Transport

- **Association of oxygen and hemoglobin**
  - Each Hb molecule is composed of four polypeptide chains, each with an iron-containing heme group
  - So each Hb can transport four oxygen molecules
- **Oxyhemoglobin (HbO₂)**: hemoglobin-O₂ combination
- **Reduced hemoglobin (deoxyhemoglobin) (HHb)**: hemoglobin that has released O₂

\[
\text{Lungs: } \text{HHb} + \text{O}_2 \rightleftharpoons \text{HbO}_2 + \text{H}^+ \\
\text{Tissues}
\]
Oxygen Transport

Influence of other factors on hemoglobin saturation

- BPG is produced by RBCs during glycolysis; BPG levels rise when oxygen levels are low
  - As cells metabolize glucose, they use O\(_2\), causing:
    - Increases in P\(_{CO_2}\) and H\(^+\) in capillary blood
    - Declining blood pH (acidosis) and increasing P\(_{CO_2}\) cause Hb-O\(_2\) bond to weaken
    - Referred to as Bohr effect
    - O\(_2\) unloading occurs where needed most
    - Heat production in active tissue directly and indirectly decreases Hb affinity for O\(_2\)
    - Allows increased O\(_2\) unloading to active tissues

Carbon Dioxide Transport

- Occurs primarily in RBCs, where enzyme carbonic anhydrase reversibly and rapidly catalyzes this reaction
- In systemic capillaries, after HCO\(_3^-\) is created, it quickly diffuses from RBCs into plasma
  - Outrush of HCO\(_3^-\) from RBCs is balanced as Cl\(^-\) moves into RBCs from plasma
- Referred to as chloride shift

Carbon Dioxide Transport

- Haldane effect
  - Amount of CO\(_2\) transported is affected by P\(_{O_2}\)
  - The lower the P\(_{O_2}\) and hemoglobin O\(_2\) saturation, the more CO\(_2\) can be carried in blood
  - Reduced hemoglobin buffers H\(^+\) and forms carboxyhemoglobin more easily
  - Process encourages CO\(_2\) exchange at tissues and at lungs
    - At tissues, as more CO\(_2\) enters blood, more oxygen dissociates from hemoglobin (Bohr effect)
      - As HbO\(_2\) releases O\(_2\), it more readily forms bonds with CO\(_2\) to form carboxyhemoglobin
Transport and Exchange of CO\(_2\) and O\(_2\) at Tissues

Oxygen release and carbon dioxide pickup at the tissues

- Partially saturated, fully saturated
- Hb Affinity for O\(_2\) varies with the extent of oxygen saturation
- Rate of Hb binding/releasing oxygen dependent on P\(_{\text{O}_2}\), temperature, blood pH, P\(_{\text{CO}_2}\), and BPG (2,3 bisphosphoglycerate)

Transport and exchange of CO\(_2\) and O\(_2\) at lungs

- Alveolus
- Oxygen pickup and carbon dioxide release in the lungs

Responding to Changing Conditions

- What causes change?
- Responses:
  - Reserve capacity built in
    - In volume – structure of conducting passages, muscular involvement, lung involvement
    - Dilation
    - Recruitment
  - In blood flow – adjustment in heart rate and lung involvement
  - In hemoglobin – changes in affinity for O\(_2\)
  - In respiratory rate – stimulation from the brain
Changing Delivery of Oxygen by Hemoglobin

• At rest, hemoglobin carries more oxygen than it actually delivers to tissues
  • Only 23% of what is carried is delivered
  • Tissue Po₂ determines % liberated
• Hemoglobin saturation (all hemes carrying oxygen) changes with changing conditions
  • temperature and pH-related conformational shift in hemoglobin reduces its capacity to carry
Respiratory centers in the brain stem

Pontine respiratory centers interact with the medullary respiratory centers to smooth the respiratory pattern.

Ventral respiratory group (VRG) contains rhythm generators whose output drives respiration.

Dorsal respiratory group (DRG) integrates peripheral sensory input and modifies the rhythms generated by the VRG.

Phrenic nerve (from C3, C4, C5) innervates the diaphragm.

Dorsal respiratory group (DRG)

Pontine respiratory centers

Medulla

Pons

Intercostal nerves

External intercostal muscles

Diaphragm

Phrenic nerve

Ventral respiratory group (VRG)

Rhythmic generator of ventilation

Dorsal respiratory group (DRG)

Pons

Medulla

Pons

Medulla

Respiratory muscles

Respiratory centers

Afferent impulses

Phrenic nerve

Ventilation

Changes in PCO₂ regulate ventilation by a negative feedback mechanism.

Central chemoreceptors sensitive to changes in arterial PCO₂ (mainly 60% of the CO₂ response)

Peripheral chemoreceptors sensitive to changes in pH (30% of the CO₂ response)

Afferent impulses

Respiratory centers

Medullary respiratory centers

Afferent impulses

Brain

Sensory nerve fiber in cranial nerve IX (pharyngeal branch of glossopharyngeal)

External carotid artery

Internal carotid artery

Common carotid artery

Carotid body

Cranial nerve X (vagus nerve)

Sensory nerve fiber in cranial nerve X

Aortic bodies in aortic arch

Aorta

Heart

Brain

Sensory nerve fiber in cranial nerve IX (pharyngeal branch of glossopharyngeal)

Changes in PCO₂ regulate ventilation by a negative feedback mechanism.
Neural and chemical influences on brain stem respiratory centers

Higher brain centers (cerebral cortex — voluntary control over breathing)

Respiratory centers (medulla and pons)

Stretch receptors in lungs

Peripheral chemoreceptors

Central chemoreceptors

Irritant receptors

Receptors in muscles and joints

Other receptors (e.g., pain) and emotional stimuli acting through the hypothalamus

Respiratory Volumes And Capacities

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Adult male average value</th>
<th>Adult female average value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume (TV)</td>
<td>500 ml</td>
<td>500 ml</td>
<td>Amount of air inhaled or exhaled with each breath under resting conditions</td>
</tr>
<tr>
<td>Inspiratory reserve volume (IRV)</td>
<td>3100 ml</td>
<td>1900 ml</td>
<td>Amount of air that can be forcefully inhaled after a normal tidal volume inspiration</td>
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<tr>
<td>Expiratory reserve volume (ERV)</td>
<td>1200 ml</td>
<td>700 ml</td>
<td>Amount of air that can be forcefully exhaled after a normal tidal volume expiration</td>
</tr>
<tr>
<td>Residual volume (RV)</td>
<td>1200 ml</td>
<td>1100 ml</td>
<td>Amount of air remaining in the lungs after a forced expiration</td>
</tr>
<tr>
<td>Total lung capacity (TLC)</td>
<td>6000 ml</td>
<td>4200 ml</td>
<td>Maximum amount of air contained in lungs after a maximum inspiration. When TV + IRV + ERV + RV = TLC</td>
</tr>
<tr>
<td>Inspiratory capacity (IC)</td>
<td>3600 ml</td>
<td>3100 ml</td>
<td>Maximum amount of air that can be inspired after a normal tidal volume inspiration</td>
</tr>
<tr>
<td>Functional residual capacity (FRC)</td>
<td>2400 ml</td>
<td>1800 ml</td>
<td>Maximum amount of air that can be expired after a normal tidal volume expiration</td>
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<tr>
<td>Residual volume (RV)</td>
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Respiratory Volumes And Capacities

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