CHAPTER 15

The Respiratory System
Chapter 15 Learning Outcomes

• 15-1
  • Describe the primary functions of the respiratory system, and explain how the respiratory exchange surfaces are protected from debris, pathogens, and other hazards.

• 15-2
  • Identify the structures that conduct air to the lungs, and describe their functions.

• 15-3
  • Describe the functional anatomy of alveoli, and the superficial anatomy of the lungs.

• 15-4
  • Define and compare the processes of external respiration and internal respiration.
Chapter 15 Learning Outcomes

• 15-5
  • Describe the physical principles governing the movement of air into the lungs and the actions of the respiratory muscles.

• 15-6
  • Describe the physical principles governing the diffusion of gases into and out of the blood.

• 15-7
  • Describe how oxygen and carbon dioxide are transported in the blood.

• 15-8
  • List the factors that influence the rate of respiration, and describe the reflexes that regulate respiration.
Chapter 15 Learning Outcomes

- 15-9
  - Describe the changes in the respiratory system that occur with aging.
- 15-10
  - Give examples of interactions between the respiratory system and other body systems.
Five Functions of the Respiratory System (15-1)

1. Provides large area for gas exchange between air and circulating blood

2. Moves air into and out of gas-exchange surfaces, the alveoli

3. Protects respiratory surfaces from dehydration, temperature changes, and pathogens
Five Functions of the Respiratory System (15-1)

4. Produces sounds allowing for speech and other forms of communication

5. Aids in sense of smell
Structures of the Respiratory Tract (15-1)

- Nasal cavity and paranasal sinuses
- Pharynx
- Larynx
- Trachea
- Bronchi
- Bronchioles
- Alveoli
Figure 15-1 The Components of the Respiratory System.

- Frontal sinus
- Nasal conchae
- Nose
- Hyoid bone
- Larynx
- Trachea
- Bronchus
- Bronchioles
- Vein
- Artery
- Capillary network
- Alveolus
- Diaphragm
- Right Lung
- Left Lung
- Nasal cavity
- Sphenoidal sinus
- Internal nares
- Pharynx
- Esophagus
Functional Zones of the Respiratory Tract (15-1)

- Conducting portion
  - From nasal cavity to larger bronchioles
  - Filters, warms, and humidifies air
  - Lined with respiratory mucosa with cilia
- Respiratory portion
  - Small bronchioles and alveoli
  - Where gas exchange occurs
Figure 15-2 The Respiratory Mucosa.

A diagrammatic view of the respiratory epithelium of the trachea, indicating the direction of mucus transport inferior to the pharynx.

- Movement of mucus to pharynx
- Ciliated columnar epithelial cell
- Mucous cell
- Stem cell
- Mucus layer
- Lamina propria

Superficial view

A surface view of the epithelium. The cilia of the epithelial cells form a dense layer that resembles a shag carpet. The movement of these cilia propels mucus across the epithelial surface.

a A diagrammatic view of the respiratory epithelium of the trachea, indicating the direction of mucus transport inferior to the pharynx.
1. Identify the five functions of the respiratory system.

2. What membrane lines the conducting portion of the respiratory tract?
The Nose (15-2)

- Air enters through external nares or nostrils into:
  - Nasal vestibule of nasal cavity
  - Hard palate forms floor of nasal cavity
  - Soft palate extends behind hard palate defining border of nasopharynx
  - Internal nares are opening between nasal cavity and nasopharynx
The Pharynx (15-2)

- Also called the throat
- Shared by respiratory and digestive systems
- Lined with stratified squamous epithelium
- Three subdivisions
  1. **Nasopharynx** – from internal nares to soft palate
  2. **Oropharynx** – from soft palate to base of tongue
  3. **Laryngopharynx** – from base of tongue to entrance of esophagus
Figure 15-3 The Nose, Nasal Cavity, and Pharynx.
The Larynx (15-2)

- Made of nine cartilages, ligaments, and skeletal muscle
- Air enters the larynx through opening, the glottis

**Epiglottis**
- Projects over glottis
- Covers glottis during swallowing
- Prevents entry of liquids and food into respiratory tract
The Larynx (15-2)

• **Thyroid cartilage**
  - Forms anterior and lateral surfaces of larynx
  - Ridge on anterior surface is "Adam's apple"

• **Cricoid cartilage**
  - A ring of cartilage just inferior to thyroid cartilage
Vocal Cord Structure (15-2)

- Paired *arytenoid, cuneiform, and corniculate cartilages*
- Connected to thyroid cartilage by ligaments
- **False vocal cords** formed by upper pair of ligaments
  - Inelastic and reduce size of glottis
- **True vocal cords** formed by lower pair
  - Connect thyroid and arytenoid cartilages
  - Involved in sound production
Figure 15-4a–b The Anatomy of the Larynx and Vocal Cords.

Epiglottis
Hyoid bone
Extrinsic (thyrohyoid) ligament
Thyroid cartilage
Cricoid cartilage
Ligament
Tracheal cartilages
Trachea
Larynx

Corniculate cartilage
Cuneiform cartilage
False vocal cords
Vocal cords
Arytenoid cartilages

a Anterior view.
b Posterior view.
Figure 15-4c–e  The Anatomy of the Larynx and Vocal Cords.

- Corniculate cartilage
- Cuneiform cartilage
- False vocal cord
- True vocal cord
- Epiglottis
- Root of tongue

**c** Glottis in the open position.

**d** Glottis in the closed position.

**e** This photograph is a representative laryngoscopic view. For this view the camera is positioned within the oropharynx, just superior to the larynx.
Sound Production (15-2)

- Vibration of air over cords produces sound waves.
- Pitch determined by:
  - Diameter, length, and tension of vocal cords.
- Small, short vocal cords produce higher pitch.
- Pitch is altered when position of arytenoid cartilages is changed.
- Resonance occurs in nasal cavity and sinuses.
The Trachea (15-2)

- Runs from cricoid cartilage to branches of primary bronchi
- Walls supported by C-shaped tracheal cartilages
- Open part of cartilages:
  - Face posteriorly
  - Are connected by smooth muscle, the trachealis muscle
  - Under ANS control, sympathetic stimulation dilates trachea
Figure 15-5  The Anatomy of the Trachea.

A diagrammatic anterior view showing the plane of section for part (b)

A cross-sectional view of the trachea and esophagus
The Bronchi (15-2)

- Trachea branches into:
  - **Right primary bronchus**
    - Supplies right lung
    - Larger and at steeper angle
      - Creates more likely pathway for foreign objects
  - **Left primary bronchus**
    - Supplies left lung
The Bronchial Tree (15-2)

- **Secondary bronchi**
  - First branch off primary bronchi
  - Enters lung lobes
    - Two on left lung, three on right lung

- **Tertiary bronchi**
  - 9–10 branches in each lung
  - Supply bronchopulmonary segment
Figure 15-6a The Bronchial Tree and Lobules of the Lung.

The branching pattern of bronchi in the left lung, simplified.
Figure 15-6b The Bronchial Tree and Lobules of the Lung.

- Respiratory epithelium
- Bronchiole
- Bronchial artery (red), vein (blue), and nerve (yellow)
- Terminal bronchiole
- Respiratory bronchiole
- Elastic fibers
- Capillary beds
- Branch of pulmonary artery
- Smooth muscle around terminal bronchiole
- Arteriole
- Alveolar duct
- Alveoli
- Alveolar sac
- Interlobular septum
- Visceral pleura
- Pleural cavity
- Parietal pleura

The structure of a single pulmonary lobule, part of a bronchopulmonary segment.
Checkpoint (15-2)

3. The surfaces of the nasal cavity are flushed by what materials or fluids?

4. The pharynx is a passageway for which two body systems?

5. When tension in the vocal cords increases, what happens to the pitch of the voice?

6. Why are C-shaped cartilages in the tracheal wall functionally better than completely circular cartilages?
Bronchioles (15-3)

- Entire bronchial tree branches about 32 times
- Each branch
  - Smaller in diameter
  - Gradually loses cartilage and gains smooth muscle
- The initial **bronchioles** are about 1 mm in diameter with no cartilage
- They continue to branch to *terminal bronchioles*
Bronchioles (15-3)

- Terminal bronchioles are 0.3–0.5 mm in diameter
- Each supplies one lung **lobule**
  - A segment of lung tissue bound by connective tissue partitions
  - Supplied by a bronchiole, pulmonary arteriole, and venule
- Branch into respiratory bronchioles
  - May have some gas exchange ability
  - Lead into **alveolar ducts**
Alveolar Ducts and Alveoli (15-3)

- Ducts end at **alveolar sacs**
  - Chambers that connect to multiple individual alveoli
- Each lung contains about 150 million alveoli
  - Give lung spongy, airy appearance
  - Vastly increase surface area to about 140 m$^2$
  - Allows for extensive, rapid gas diffusion to meet metabolic needs
Structure of Alveoli (15-3)

• Primary cells are pneumocytes type I
  • Unusually thin simple squamous epithelium

• Roaming alveolar macrophages

• Septal cells or pneumocytes type II
  • Produce surfactant
    • Helps keep alveoli open by reducing surface tension
    • Lack of surfactant triggers respiratory distress syndrome
The Respiratory Membrane (15-3)

- Where diffusion of gases takes place
- Can be as thin as 0.1–0.5 \( \mu m \)
- Three layers
  1. Squamous epithelial cells lining the alveoli
  2. Endothelial cells of adjacent capillary
  3. Fused basement membranes between alveolar and endothelial cells
- Endothelial cells of capillaries secrete angiotensin-converting enzyme (ACE)
  - Part of the homeostatic mechanism for maintaining BP

- **Pulmonary embolisms**
  - Pulmonary blood circuit is low pressure
  - Masses or clots can easily block pulmonary artery branch, stopping blood flow to lobules
Several alveoli open off of a single alveolar duct.

SEM of lung tissue showing the appearance and organization of the alveoli.
A diagrammatic view of alveolar structure. A single capillary may be involved in gas exchange with several alveoli simultaneously.

The respiratory membrane consists of an alveolar epithelial cell, a capillary endothelial cell, and their fused basement membranes.
The Lungs (15-3)

- **Lobes** are separated by deep fissures
  - Left lung has two lobes: *superior* and *inferior*
  - Right lung has three: *superior*, *middle*, and *inferior*
- Apex extends up to base of neck, above first rib
- Base of lung sits on diaphragm
- *Costal surface* against ribs
- *Mediastinal surface* of left lung has *cardiac notch*
Figure 15-8  The Gross Anatomy of the Lungs.

- Superior lobe
- Middle lobe
- Inferior lobe
- Apex
- Base
- Cardiac notch (in mediastinal surface)
- Inferior lobe
- Superior lobe (costal surface)
The Pleural Cavities (15-3)

- Surrounds each lung within thoracic cavity
- **Pleura** is serous membrane of pleural cavity
  - *Visceral pleura* covers outer surface of lungs
  - *Parietal pleura* lines inside of chest wall, diaphragm
  - Pleural layers secrete serous fluid, reducing friction
- **Pneumothorax** occurs when parietal pleura is punctured and lung collapses
Figure 15-9 Anatomical Relationships in the Thoracic Cavity.

- Parietal pleura
- Right pleural cavity
- Visceral pleura
- Right Lung
- Mediastinum
- Left Lung
- Pericardial cavity
- Heart
- Superior view
7. Trace the path of airflow from the glottis to the respiratory membrane.

8. What would happen to the alveoli if surfactant were not produced?

9. What are the functions of the pleural surfaces?
External Respiration (15-4)

- Includes three processes involved in exchange of $O_2$ and $CO_2$ between body and external environment
  
1. Pulmonary ventilation or breathing
2. Gas diffusion across respiratory membrane and between blood and body tissues
3. Transport of $O_2$ and $CO_2$ in blood
External Respiration (15-4)

- **Hypoxia**
  - Low tissue oxygen
  - Metabolic activities become limited

- **Anoxia**
  - Supply of oxygen cut off completely
  - Cells die off quickly
  - Damage from strokes or heart attacks are a result of anoxia
Internal Respiration (15-4)

- Absorption and use of oxygen by tissue cells
- Release of carbon dioxide from tissue cells
Checkpoint (15-4)

10. Define external respiration and internal respiration.

11. Name the integrated steps involved in external respiration.
Pulmonary Ventilation (15-5)

- The physical movement of air into and out of the respiratory tract

- Respiratory cycle
  - A single breath of inhalation and exhalation

- Respiratory rate
  - Number of breaths per minute

- Alveolar ventilation
  - Movement of air into and out of alveoli
Pressure and Airflow into Lungs (15-5)

- Air moves down pressure gradient
- In closed, flexible container (lung), air pressure is changed by changing the volume of container
  - Increase in volume decreases air pressure
  - Decrease in volume increases air pressure
- Volume of lung depends on volume of thoracic cavity
Changes in Thoracic Volumes (15-5)

- Relaxed diaphragm is domed-shaped
  - Pushes up into thorax, compressing lungs
  - Contraction pulls it downward expanding lungs
- Rib cage
  - Elevation expands thorax, relaxation depresses it
Volume Change Causes Pressure Gradient (15-5)

- **Inhaling**
  - Increase in volume, pressure inside ($P_i$) decreases
  - $P_i$ lower than pressure out ($P_o$), air moves in

- **Exhaling**
  - Decrease in volume, $P_i$ increases
  - $P_i$ higher than $P_o$, air moves out

- At end-inhalation and end-exhalation, $P_i = P_o$
Just as raising the handle of a bucket increases the amount of space between it and the bucket, the volume of the thoracic cavity increases when the ribs are elevated and when the diaphragm is depressed during contraction.

When the rib cage and diaphragm are at rest, the pressures inside and outside are equal, and no air movement occurs.

Inhalation. Elevation of the rib cage and contraction of the diaphragm increase the size of the thoracic cavity. Pressure within the thoracic cavity decreases, and air flows into the lungs.

Exhalation. When the rib cage returns to its original position and the diaphragm relaxes, the volume of the thoracic cavity decreases. Pressure rises, and air moves out of the lungs.
Compliance (15-5)

- Compliance is expandability of the lungs
  - Low compliance leads to difficulty in breathing
  - Dramatically increased energy needed for breathing
  - Decrease in surfactant decreases compliance
- In  *emphysema*, loss of supporting tissues due to alveolar damage increases compliance
Modes of Breathing (15-5)

- **Quiet breathing**
  - Uses muscles of inspiration: diaphragm and external intercostals
  - Exhalation is passive

- **Forced breathing**
  - Uses primary and accessory muscles for inhalation
  - Uses internal intercostals and abdominals for exhalation
Lung Volumes and Capacities (15-5)

- **Tidal volume** ($V_T$)
  - Amount of air moved in and out of lungs during quiet breathing

- **Expiratory reserve volume** (ERV)
  - Amount of air voluntarily pushed out forcefully at end of $V_T$

- **Inspiratory reserve volume** (IRV)
  - Amount of air that can be taken in above $V_T$
Lung Volumes and Capacities (15-5)

- **Vital capacity** = $V_T + IRV + ERV$
  - Maximum amount of air moved in and out of lung in one cycle

- **Residual volume**
  - Amount of air remaining in lungs after maximal exhalation

- **Minimal volume**
  - Amount of air remaining in lungs after pneumothorax
Figure 15-11 Pulmonary Volumes and Capacities.

Pulmonary Volumes and Capacities (adult male)

<table>
<thead>
<tr>
<th>Volume (mL)</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume ($V_T$ 500 mL)</td>
<td>2700</td>
<td>1900</td>
</tr>
<tr>
<td>Inspiratory reserve volume (IRV)</td>
<td>2200</td>
<td>500</td>
</tr>
<tr>
<td>Inspiratory capacity</td>
<td>1200</td>
<td>700</td>
</tr>
<tr>
<td>Vital capacity</td>
<td>6000 mL</td>
<td>4200 mL</td>
</tr>
<tr>
<td>Expiratory reserve volume (ERV)</td>
<td>0</td>
<td>1100</td>
</tr>
<tr>
<td>Expiratory reserve volume (ERV)</td>
<td>0</td>
<td>1100</td>
</tr>
<tr>
<td>Total lung capacity</td>
<td>6000 mL</td>
<td>4200 mL</td>
</tr>
<tr>
<td>Functional residual capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual volume</td>
<td>1200</td>
<td>1900</td>
</tr>
<tr>
<td>Minimal volume (30–120 mL)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
12. Define compliance and identify some factors that affect it.

13. What is tidal volume?

14. Mark breaks a rib and it punctures the chest wall on his left side. What will happen to his left lung?

15. In pneumonia, fluid accumulates in the alveoli of the lungs. How would vital capacity be affected?
Gas Exchange (15-6)

• Relies on:
  • Diffusion of molecules between gas and liquid
  • Partial pressure gradient
    • Between alveolar air and plasma
    • Between plasma and interstitial fluid
Partial Pressure of a Gas in a Mixture (15-6)

• 100 percent of atmospheric air is made up of:
  • 78.6 percent nitrogen, 20.9 percent oxygen, 0.04 percent carbon dioxide
  • Remaining percentage is water vapor
  • At sea level atmospheric pressure is 760 mm Hg

• Each gas in a mixture contributes a proportional pressure, a \textbf{partial pressure} (P_{gas})

• \( P_{O_2} = 760 \text{ mm Hg} \times 20.9\% = 159 \text{ mm Hg} \)
Atmospheric vs. Alveolar Partial Pressures (15-6)

- Air entering respiratory structures changes in character
  - Increase in water vapor and temperature
  - Alveolar air is mixture of atmospheric air and residual volume
- Exhaled air is changed also
  - Mixes with air in conducting zone or dead space that never reached alveoli
Table 15-1 Partial Pressures (mm Hg) and Normal Gas Concentrations (%) in Air

<table>
<thead>
<tr>
<th>Source of Sample</th>
<th>Nitrogen ($N_2$)</th>
<th>Oxygen ($O_2$)</th>
<th>Carbon Dioxide ($CO_2$)</th>
<th>Water Vapor ($H_2O$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhaled Air (Dry)</td>
<td>597 (78.6%)</td>
<td>159 (20.9%)</td>
<td>0.3 (0.04%)</td>
<td>3.7 (0.5%)</td>
</tr>
<tr>
<td>Alveolar Air (Saturated)</td>
<td>573 (75.4%)</td>
<td>100 (13.2%)</td>
<td>40 (5.2%)</td>
<td>47 (6.2%)</td>
</tr>
<tr>
<td>Exhaled Air (Saturated)</td>
<td>569 (74.8%)</td>
<td>116 (15.3%)</td>
<td>28 (3.7%)</td>
<td>47 (6.2%)</td>
</tr>
</tbody>
</table>
Deoxygenated blood enters pulmonary arteries

- $P_{O_2} = 40 \text{ mm Hg}; \ P_{CO_2} = 45 \text{ mm Hg}$

Gases move down partial pressure gradients

- Oxygen from alveolar air ($P_{O_2} = 100 \text{ mm Hg}$)
- Carbon dioxide into alveolar air ($P_{CO_2} = 40 \text{ mm Hg}$)
- Blood mixes with low $O_2$ blood from conducting zone

- Oxygenated blood to left atrium, $P_{CO_2} = 95 \text{ mm Hg}$
Partial Pressures in Systemic Circuit (15-6)

- Oxygenated blood enters systemic arteries
  - $P_{O_2} = 95$ mm Hg; $P_{CO_2} = 40$ mm Hg
- Gases move down partial pressure gradients
  - Oxygen from plasma to tissues ($P_{O_2} = 40$ mm Hg)
  - Carbon dioxide from tissue to plasma ($P_{CO_2} = 45$ mm Hg)
- Deoxygenated blood to right atrium
  - $P_{O_2} = 40$ mm Hg; $= P_{CO_2} = 45$ mm Hg

*ANIMATION* Respiration: Gas Exchange
Figure 15-12 An Overview of Respiration and Respiratory Processes.

(a) **External Respiration**
- Alveolus: $PO_2 = 40$, $PCO_2 = 45$
- Respiratory membrane:
  - $PO_2 = 100$
  - $PCO_2 = 40$
- Pulmonary capillary: $PO_2 = 100$, $PCO_2 = 40$

(b) **Internal Respiration**
- Interstitial fluid: $PO_2 = 95$, $PCO_2 = 40$
- Systemic capillary:
  - $PO_2 = 40$
  - $PCO_2 = 45$
  - $PO_2 = 40$
  - $PCO_2 = 45$
16. True or false: Each gas in a mixture exerts a partial pressure equal to its relative abundance.

17. What happens to air as it passes through the nasal cavity?

18. Compare the oxygen and carbon dioxide content of alveolar air and atmospheric air.
Gas Transport in Blood (15-7)

- O$_2$ and CO$_2$ have limited solubility in plasma
- Tissues need more O$_2$, and to get rid of more CO$_2$, than can be dissolved
  - RBCs can carry both gases on hemoglobin
  - CO$_2$ can chemically convert to soluble compound
  - As gases are removed from plasma, more diffuse in
- All reactions are reversible
Oxygen Transport (15-7)

- 1.5 percent of $O_2$ transported in solution in plasma
- Remainder binds to iron sites on hemoglobin (Hb)
- Reversible reaction
  \[ Hb + O_2 \rightleftharpoons HbO_2 \]
- Rate of release of $O_2$ determined by:
  - $P_{O_2}$ of tissues, pH, and temperature
  - Low $P_{O_2}$ and pH, and high temp increases $O_2$ release

**ANIMATION** Respiration: Percent $O_2$ Saturation of Hemoglobin
Carbon Dioxide Transport (15-7)

- A product of aerobic cell metabolism
- Transported in three ways
  1. 7 percent of CO$_2$ is dissolved in plasma
  2. 23 percent is in RBC bound to Hb
     - Bound to globin portion of Hb
     - Forms carbaminohemoglobin
3. 70 percent is transported as bicarbonate ions

\[ \text{carbonic anhydrase}\]
\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \]

- This reaction occurs in RBC
- Chloride shift
  - \( \text{HCO}_3^- \) diffuses out of RBC in exchange for \( \text{Cl}^- \)
- Reactions are rapid and reversed in pulmonary capillaries

ANIMATION Respiration: Oxygen and Carbon Dioxide Transport
Figure 15-13 Carbon Dioxide Transport in Blood.

CO₂ diffuses into the bloodstream

7% remains dissolved in plasma (as CO₂)

93% diffuses into RBCs

23% binds to Hb, forming carbaminohemoglobin, Hb•CO₂

70% converted to H₂CO₃ by carbonic anhydrase

H₂CO₃ dissociates into H⁺ and HCO₃⁻

H⁺ removed by buffers, especially Hb

HCO₃⁻ moves out of RBC in exchange for Cl⁻ (chloride shift)

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Figure 15-14  A Summary of Gas Transport and Exchange.

$O_2$ pickup
Figure 15-14 A Summary of Gas Transport and Exchange.

O$_2$ pickup

- Plasma
- Alveolar air space
- Red blood cell
- Pulmonary capillary

O$_2$ delivery

- Systemic capillary
- Red blood cell
- Cells in peripheral tissues

Hb $\rightarrow$ O$_2$

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Figure 15-14  A Summary of Gas Transport and Exchange.

**O₂ pickup**

**O₂ delivery**

**Cells in peripheral tissues**

**Cells in peripheral tissues**

- **Alveolar air space**
- **Plasma**
- **Pulmonary capillary**
- **Red blood cell**
- **Hb → O₂**
- **O₂ delivery**
- **Chloride shift**
- **HCO₃⁻**
- **H⁺ + HCO₃⁻**
- **Cl⁻**
- **CO₂ pickup**
- **CO₂**
- **H₂CO₃**
- **H₂O**
- **Hb → CO₂**
- **Systemic capillary**
- **Systemic capillary**

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Figure 15-14  A Summary of Gas Transport and Exchange.

**O₂ pickup**

**O₂ delivery**

**CO₂ delivery**

**CO₂ pickup**

- **Plasma**
- **Alveolar air space**
- **Red blood cell**
- **Pulmonary capillary**
- **Systemic capillary**
- **Cells in peripheral tissues**

**O₂ pickup**

- **Hb → O₂**

**O₂ delivery**

- **Hb → O₂**

**CO₂ delivery**

- **Hb → CO₂ → H₂CO₃ → H₂O**

**CO₂ pickup**

- **H₂CO₃ → H⁺ + HCO₃⁻**

**Chloride shift**

- **H⁺ + HCO₃⁻ → CO₂**

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19. Identify the three ways that carbon dioxide is transported in the bloodstream.

20. As you exercise, hemoglobin releases more oxygen to active skeletal muscles than it does when the muscles are at rest. Why?

21. How would blockage of the trachea affect blood pH?
Local Control of Respiration (15-8)

- Increased peripheral tissue activity
  - Decrease in tissue $P_{O_2}$ and increase in $P_{CO_2}$ causes more rapid diffusion of $O_2$ into cells, $CO_2$ out of cells

- Pulmonary ventilation-perfusion matching
  - When alveolar capillary $P_{O_2}$ is low, precapillary sphincters constrict, shunting blood to high $P_{O_2}$ lung lobules
  - When air in bronchioles is high $P_{CO_2}$ they dilate; when low they constrict
Brain Respiratory Centers (15-8)

- Voluntary control resides in cerebral cortex
- Involuntary control resides in medulla oblongata
  - **Respiratory rhythmicity centers** set breathing rate
    - *Dorsal respiratory group (DRG)* has inspiratory center
    - *Ventral respiratory group (VRG)* has expiratory center
- Pons
  - Paired nuclei adjust respiration in response to emotions, speech patterns
Respiratory Rhythmicity Centers (15-8)

- DRG triggers every breath
  - Innervates diaphragm and external intercostals
  - Center stimulates muscles for two seconds
    - Causes inspiration
  - Becomes "silent" for three seconds and muscles relax
    - Causes passive exhalation
- VRG functions only during forced breathing
**Figure 15-15** Basic Regulatory Patterns of Respiration.

### a Quiet Breathing

**INHALATION** (2 seconds)

- Diaphragm and external intercostal muscles contract and inhalation occurs.
- Dorsal respiratory group active
- Dorsal respiratory group inhibited

**EXHALATION** (3 seconds)

- Diaphragm and external intercostal muscles relax and passive exhalation occurs.

### b Forced Breathing

**INHALATION**

- Muscles of inhalation contract, and opposing muscles relax. Inhalation occurs.
- DRG and inspiratory center of VRG are active.
- Expiratory center of VRG is inhibited.

**EXHALATION**

- Muscles of inhalation relax and muscles of exhalation contract. Exhalation occurs.
- DRG and inspiratory center of VRG are inhibited.
- Expiratory center of VRG is active.
Mechanoreceptor Respiratory Reflexes (15-8)

- Respond to changes in lung volume or BP
  - **Inflation reflex**
    - Prevents overinflation of lungs
    - Afferent fibers of vagus nerves inhibit DRG and stimulate VRG
  - **Deflation reflex**
    - Inhibits VRG, stimulates DRG
    - BP rises, carotid and aortic bodies stimulate DRG, respiration increases
Chemoreceptor Respiratory Reflexes (15-8)

- Receptors in carotid and aortic bodies respond to changes in pH, $P_{CO_2}$, and $P_{O_2}$
  - Receptors in medulla oblongata respond to pH and $P_{CO_2}$
  - $P_{CO_2}$ has strongest and most immediate effect
  - Chemoreceptors respond to pH, especially during exercise, with increase in $H_2CO_3$ and lactic acid
  - Increases in $P_{CO_2}$ and decreases in pH are prime stimulators of respiratory rate increases
Control by Higher Centers (15-8)

- Voluntary control of respiratory muscles
  - Respiration can be suppressed or exaggerated
  - Control required for singing and talking
- Limbic centers of brain
  - Trigger changes in respiratory depth and rate due to emotional influences
  - Effects are involuntary
Figure 15-16  The Control of Respiration.

- **Cerebrum**
  - Cerebral cortex
  - Limbic system
  - Hypothalamus

- **Higher Centers**
  - Respiratory centers of pons
  - Chemoreceptors and baroreceptors of carotid and aortic sinuses

- **Medulla oblongata**
  - Respiratory Rhythmicity Centers
  - Dorsal respiratory group (DRG)
  - Ventral respiratory group (VRG)

- **Respiratory Centers of Pons**
  - N IX and N X
  - Chemoreceptors and baroreceptors of carotid and aortic sinuses
  - Stretch receptors of lungs
  - Spinal cord

- **Motor Neurons**
  - Controlling diaphragm
  - Controlling other respiratory muscles

- **Phrenic Nerve**

**Key**
- = Stimulation
- = Inhibition

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Respiratory Changes at Birth (15-8)

- Before delivery of newborn:
  - Pulmonary vessels are collapsed
  - Lungs and conducting zone have no air

- At birth:
  - Powerful contractions of muscles of inspiration overcome surface tension to inflate lungs
  - Drop of pressure that pulls air into lungs also pulls blood into pulmonary vessels
22. Are peripheral chemoreceptors as sensitive to levels of carbon dioxide as they are to levels of oxygen?

23. Strenuous exercise stimulates which set of respiratory reflexes?

24. Little Johnny tells his mother he will hold his breath until he turns blue and dies. Should she worry?
Respiratory Performance and Age (15-9)

- Chest movement can decline with arthritic changes in ribs and muscular weakness
- Aging causes increased compliance
  - Can counteract loss of chest movement
- Some emphysema is normal in aging
  - Smoking vastly decreases respiratory performance
  - Emphysema likely to become more severe and debilitating
25. Describe two age-related changes that combine to reduce the efficiency of the respiratory system.
Respiratory System Works with Other Systems (15-10)

• The respiratory system has extensive structural and functional connections to:
  • The cardiovascular system
The RESPIRATORY System

The respiratory system provides oxygen and eliminates carbon dioxide for our cells. It is crucial to maintaining homeostasis for all body systems.
26. Describe the functional relationship between the respiratory system and all other organ systems.

27. What homeostatic functions of the nervous system support the functional role of the respiratory system?