• The Respiratory System
  – Cells produce energy:
    • For maintenance, growth, defense, and division
    • Through mechanisms that use oxygen and produce carbon dioxide
• Oxygen
  – Is obtained from the air by diffusion across delicate exchange surfaces of the lungs
  – Is carried to cells by the cardiovascular system, which also returns carbon dioxide to the lungs
The respiratory system, composed of conducting and respiratory portions, has several basic functions.
Functions of the Respiratory System

• Provides extensive gas exchange surface area between air and circulating blood
• Moves air to and from exchange surfaces of lungs
• Protects respiratory surfaces from outside environment
• Produces sounds
• Participates in olfactory sense
Components of the Respiratory System

• The Respiratory Tract
  – Consists of a conducting portion
    • From nasal cavity to terminal bronchioles
  – Consists of a respiratory portion
    • The respiratory bronchioles and alveoli
Components of the Respiratory System

- Alveoli
  - Are air-filled pockets within the lungs:
    - Where all gas exchange takes place
Components of the Respiratory System

Figure 15-1
Components of the Respiratory System

• Structure of Respiratory Epithelium
  – Changes along respiratory tract
Components of the Respiratory System

- Components of the **Respiratory Defense System**
  - Mucous cells and mucous glands:
    - Produce mucus that bathes exposed surfaces
  - Cilia:
    - Sweep debris trapped in mucus toward the pharynx *(mucus escalator)*
  - Filtration in nasal cavity removes large particles
  - Alveolar macrophages engulf small particles that reach lungs
Components of the Respiratory System

• Alveolar Epithelium
  – Is a very delicate, simple squamous epithelium
  – Contains scattered and specialized cells
  – Lines exchange surfaces of alveoli
The Respiratory Mucosa

Figure 15-2

(a) Movement of mucus to pharynx
(b) Ciliated columnar epithelial cell
Ciliated columnar epithelial cell
Mucous cell
Stem cell
Mucus layer
Lamina propria

SEM × 1647
15-2 The nose, pharynx, larynx, trachea, bronchi, and larger bronchioles conduct air into the lungs
The Nose

• Air enters the respiratory system
  – Through nostrils or external nares
  – Into nasal vestibule

• Nasal hairs
  – Are in nasal vestibule
  – Are the first particle filtration system
The Nose

• The Nasal Cavity
  – The **nasal septum**:  
    • Divides nasal cavity into left and right  
  – Mucous secretions from paranasal sinus and tears:  
    • Clean and moisten the nasal cavity  
  – Superior portion of nasal cavity is the olfactory region:  
    • Provides sense of smell
Structures of the Upper Respiratory System

Figure 15-3
The Pharynx

- A chamber shared by digestive and respiratory systems
- Extends from internal nares to entrances to larynx and esophagus
- Divided into the **nasopharynx**, the **oropharynx**, and the **laryngopharynx**
The Larynx

- Cartilages of the Larynx
  - Three large, unpaired cartilages form the larynx:
    - Thyroid cartilage
    - Cricoid cartilage
    - Epiglottis
The Thyroid Cartilage
- Also called the Adam’s apple
- Is hyaline cartilage
- Forms anterior and lateral walls of larynx
- Ligaments attach to hyoid bone, epiglottis, and laryngeal cartilages
The Larynx

• The Cricoid Cartilage
  – Is hyaline cartilage
  – Forms posterior portion of larynx
  – Ligaments attach to first tracheal cartilage
  – Articulates with arytenoid cartilages
The Larynx

• The Epiglottis
  – Composed of elastic cartilage
  – Ligaments attach to thyroid cartilage and hyoid bone
Figure 15-4 a,b
The Larynx

• Sound is varied by
  – Tension on vocal folds:
    - Vocal folds involved with sound are known as vocal cords
  – Voluntary muscles (position arytenoid cartilage relative to thyroid cartilage)

• Speech is produced by
  – Phonation:
    • Sound production at the larynx
  – Articulation:
    • Modification of sound by other structures
Figure 15-4 c,d,e
The Trachea

• The Trachea
  – Also called the windpipe
  – Extends from the cricoid cartilage into mediastinum:
    • Where it branches into right and left pulmonary bronchi

• The Submucosa
  – Beneath mucosa of trachea
  – Contains mucous glands
The Trachea

• The Tracheal Cartilages
  – 15–20 tracheal cartilages:
    • Strengthen and protect airway
    • Discontinuous where trachea contacts esophagus
  – Ends of each tracheal cartilage are connected by:
    • An elastic ligament and trachealis muscle
The Bronchi

• The Primary Bronchi
  – Right and left primary bronchi:
    • Separated by an internal ridge (the carina)

• The Right Primary Bronchus
  – Is larger in diameter than the left
  – Descends at a steeper angle
The Bronchi

• Structure of Primary Bronchi
  – Each primary bronchus:
    • Travels to a groove (*hilum*) along the medial surface of the lung
The Bronchi

• A Primary Bronchus
  – Branches to form secondary bronchi (lobar bronchi)
  – One secondary bronchus goes to each lobe

• Secondary Bronchi
  – Branch to form tertiary bronchi, also called the segmental bronchi
  – Each segmental bronchus:
    • Supplies air to a single bronchopulmonary segment
15-3 The smallest bronchioles and the alveoli within the lungs make up the respiratory portion of the respiratory tract.
The Bronchioles

• Each tertiary bronchus branches into multiple bronchioles
  – Bronchioles branch into terminal bronchioles:
    • One tertiary bronchus forms about 6500 terminal bronchioles

• Bronchiole Structure
  – Bronchioles:
    • Have no cartilage
    • Are dominated by smooth muscle
The Bronchial Tree and Lobules of the Lung

Figure 15-6a
The Bronchial Tree and Lobules of the Lung

Figure 15-6b
The Alveolar Ducts and Alveoli

• An Alveolus
  – Respiratory bronchioles are connected to alveoli along **alveolar ducts**
  – Alveolar ducts end at **alveolar sacs**:  
    • Common chambers connected to many individual alveoli
  – Has an extensive network of capillaries
  – Is surrounded by elastic fibers
Figure 15-7a  \textbf{(a) Alveolar organization}
Alveolar Organization

Figure 15-7b  **(b) Alveolar ducts and alveoli**

SEM × 270
Figure 15-7c

(c) Alveolar structure

Alveolar epithelial cell
Alveolar macrophage
Endothelial cell of capillary
Alveolar Epithelium

- Consists of simple squamous epithelium
- Consists of thin, delicate pneumocytes type I
- Patrolled by alveolar macrophages, also called dust cells
- Contains pneumocytes type II (septal cells) that produce surfactant
The Alveolar Ducts and Alveoli

- **Surfactant**
  - Is an oily secretion
  - Contains phospholipids and proteins
  - Coats alveolar surfaces and reduces surface tension
The Respiratory Membrane

- Three Layers of the Respiratory Membrane
  - Squamous epithelial lining of alveolus
  - Endothelial cells lining an adjacent capillary
  - Fused basal laminae between alveolar and endothelial cells
The Respiratory Membrane

Figure 15-7d

(d) The respiratory membrane
The Lungs

• The Lungs
  – Left and right lungs:
    • Are in left and right pleural cavities
  – The base:
    • Inferior portion of each lung rests on superior surface of diaphragm
  – Lobes of the lungs:
    • Lungs have lobes separated by deep fissures
The Lungs

• The right lung has three lobes
  – Superior, middle, and inferior
  – Separated by horizontal and oblique fissures

• The left lung has two lobes
  – Superior and inferior
  – Separated by an oblique fissure
The Lungs

Figure 15-8

- Superior lobe
- Middle lobe
- Inferior lobe
- Apex
- Base
- Anterior view
- Superior lobe (costal surface)
- Cardiac notch (in mediastinal surface)
- Inferior lobe

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The Lungs

Figure 15-9

Parietal pleura
Right pleural cavity
Visceral pleura
Right Lung
Left Lung
Mediastinum
Heart
Pericardial cavity
Two pleural cavities
  – Are separated by the mediastinum
Each pleural cavity
  – Holds a lung
  – Is lined with a serous membrane (the pleura)
The Pleural Cavities

• The Pleura
  – Consists of two layers:
    • Parietal pleura
    • Visceral pleura
  – Pleural fluid:
    • Lubricates space between two layers
15-4 External respiration and internal respiration allow gas exchange within the body
Introduction to Gas Exchange

• Respiration refers to two integrated processes
  – External respiration:
    • Includes all processes involved in exchanging $O_2$ and $CO_2$ with the environment
  – Internal respiration:
    • Also called cellular respiration
    • Involves the uptake of $O_2$ and production of $CO_2$ within individual cells
Three Processes of External Respiration

1. Pulmonary ventilation (breathing)
2. Gas diffusion:
   - Across membranes and capillaries
3. Transport of $O_2$ and $CO_2$:
   - Between alveolar capillaries
   - Between capillary beds in other tissues
15-5 Pulmonary ventilation — the exchange of air between the atmosphere and the lungs — involves pressure changes and muscle movement
Pulmonary Ventilation

- Pulmonary Ventilation
  - Is the physical movement of air in and out of the respiratory tract
  - Provides alveolar ventilation

- Atmospheric Pressure
  - The weight of air:
    - Has several important physiological effects
Pressure and Airflow to the Lungs

- Air flows from area of higher pressure to area of lower pressure
- A Respiratory Cycle
  - Consists of:
    - An inspiration (inhalation)
    - An expiration (exhalation)
Pulmonary Ventilation

- Pulmonary Ventilation
  - Causes volume changes that create changes in pressure
  - Volume of thoracic cavity changes:
    - With expansion or contraction of diaphragm or rib cage
Figure 15-10

**Pulmonary Ventilation**

**AT REST**
- Ribs and sternum elevate
- Diaphragm contracts

**INHALATION**
- Sternocleidomastoid
- Scalene muscles
- Pectoralis minor
- Serratus anterior
- External intercostal
- Diaphragm

**EXHALATION**
- Transversus thoracis
- Internal intercostals
- Rectus abdominis (other abdominal muscles not shown)

Pleural space

Pressure outside and inside are equal, so no movement occurs.
\[ P_o = P_i \]  

Volume increases; Pressure inside falls, and air flows in.
\[ P_o > P_i \]  

Volume decreases; Pressure inside rises, so air flows out.
\[ P_o < P_i \]  

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Compliance

• An indicator of expandability
• Low compliance requires greater force
• High compliance requires less force
• Factors That Affect Compliance
  – Connective tissue structure of the lungs
  – Level of surfactant production
  – Mobility of the thoracic cage
Modes of Breathing

• Respiratory movements are classified
  – By pattern of muscle activity
  – Into quiet breathing and forced breathing
Modes of Breathing

• Quiet Breathing (Eupnea)
  – Involves active inhalation and passive exhalation
  – Diaphragmatic breathing or deep breathing:
    • Is dominated by diaphragm
  – Costal breathing or shallow breathing:
    • Is dominated by rib cage movements
Respiratory Rates and Volumes

- Respiratory system adapts to changing oxygen demands by varying:
  - The number of breaths per minute (respiratory rate)
  - The volume of air moved per breath (tidal volume)
Lung Volumes and Capacities

Figure 15-11
Lung Volumes and Capacities

Figure 15-11

<table>
<thead>
<tr>
<th>Pulmonary volumes</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRV</td>
<td>3300 mL</td>
<td>1900 mL</td>
</tr>
<tr>
<td>$V_T$</td>
<td>500 mL</td>
<td>500 mL</td>
</tr>
<tr>
<td>ERV</td>
<td>1000 mL</td>
<td>700 mL</td>
</tr>
<tr>
<td>Residual volume</td>
<td>1200 mL</td>
<td>1100 mL</td>
</tr>
<tr>
<td>Total capacity</td>
<td>6000 mL</td>
<td>4200 mL</td>
</tr>
</tbody>
</table>

Inspiratory capacity

Functional residual capacity
Lung Volumes and Capacities

• Pulmonary Function Tests
  – Measure rates and volumes of air movements
15-6 Gas exchange depends on the partial pressures of gases and the diffusion of molecules
Gas Exchange

• Gas Exchange
  – Occurs between blood and alveolar air
  – Across the respiratory membrane

• Depends on
  – Partial pressures of the gases
  – Diffusion of molecules between gas and liquid
Mixed Gases and Partial Pressures

• Composition of Air
  – Nitrogen ($N_2$) is about 78.6%
  – Oxygen ($O_2$) is about 20.9%
  – Water vapor ($H_2O$) is about 0.5%
  – Carbon dioxide ($CO_2$) is about 0.04%
Partial Pressures

- Atmospheric pressure (760 mm Hg):
  - Produced by air molecules bumping into each other
- Each gas contributes to the total pressure:
  - In proportion to its number of molecules (Dalton’s law)
<table>
<thead>
<tr>
<th>SOURCE OF SAMPLE</th>
<th>NITROGEN (N₂)</th>
<th>OXYGEN (O₂)</th>
<th>WATER VAPOR (H₂O)</th>
<th>CARBON DIOXIDE (CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INHALED AIR (DRY)</td>
<td>597 (78.6%)</td>
<td>159 (20.9%)</td>
<td>3.7 (0.5%)</td>
<td>0.3 (0.04%)</td>
</tr>
<tr>
<td>ALVEOLAR AIR (SATURATED)</td>
<td>573 (75.4%)</td>
<td>100 (13.2%)</td>
<td>47 (6.2%)</td>
<td>40 (5.2%)</td>
</tr>
<tr>
<td>EXHALED AIR (SATURATED)</td>
<td>569 (74.8%)</td>
<td>116 (15.3%)</td>
<td>47 (6.2%)</td>
<td>28 (3.7%)</td>
</tr>
</tbody>
</table>
PP in the Blood

• $O_2$ and $CO_2$
  - Blood arriving in pulmonary arteries has:
    • Low $P_{O_2}$
    • High $P_{CO_2}$
  - The concentration gradient causes:
    • $O_2$ to enter blood
    • $CO_2$ to leave blood
  - Rapid exchange allows blood and alveolar air to reach equilibrium
Gas Exchange

• Interstitial Fluid
  – \( P_{O_2} \) 40 mm Hg
  – \( P_{CO_2} \) 45 mm Hg

• Concentration gradient in peripheral capillaries is opposite of lungs
  – \( CO_2 \) diffuses into blood
  – \( O_2 \) diffuses out of blood
Figure 15-12a
Gas Exchange

Figure 15-12b
Most \( \text{O}_2 \) is transported bound to hemoglobin (Hb), whereas \( \text{CO}_2 \) is transported as carbonic acid, bound to Hb, or dissolved in plasma.
• Red Blood Cells (RBCs)
  – Transport $O_2$ to, and $CO_2$ from, peripheral tissues
  – Remove $O_2$ and $CO_2$ from plasma, allowing gases to diffuse into blood
Oxygen Transport

• $\text{O}_2$ binds to iron ions in hemoglobin (Hb) molecules
  – In a reversible reaction
• Each RBC has about 280 million Hb molecules
  – Each binds four oxygen molecules
Oxygen Transport

• Environmental Factors Affecting Hemoglobin
  – $P_{O_2}$ of blood
  – Blood pH
  – Temperature
Carbon Dioxide Transport

• \((\text{CO}_2)\)
  – Is generated as a by-product of aerobic metabolism
    (cellular respiration)
  – \(\text{CO}_2\) in the bloodstream:
    • May be:
      – converted to carbonic acid
      – bound to protein portion of hemoglobin
      – dissolved in plasma
Carbon Dioxide Transport

• Bicarbonate Ions
  – Move into plasma by an exchange mechanism (the **chloride shift**) that takes in Cl\(^-\) ions without using ATP
Carbon Dioxide Transport

Figure 15-13

- CO₂ diffuses into 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
- Cl⁻ moves out of RBC in exchange for Cl⁻ (chloride shift)
Gas Transport

• CO₂ in the Bloodstream
  – 70% is transported as carbonic acid (H₂CO₃):
    • Which dissociates into H⁺ and bicarbonate (HCO₃⁻)
  – 23% is bound to amino groups of globular proteins in Hb molecule
    • Forming carbaminohemoglobin
  – 7% is transported as CO₂ dissolved in plasma
A Summary of the Gas Transport and Exchange

Figure 15-14a
A Summary of the Gas Transport and Exchange

Figure 15-14b
15-8 Neurons in the medulla and pons, along with respiratory reflexes, control respiration
Control of Respiration

- Peripheral and alveolar capillaries maintain balance during gas diffusion by
  - Changes in blood flow and oxygen delivery
  - Changes in depth and rate of respiration
Control by the Respiratory Centers of the Brain

• When oxygen demand rises
  – Cardiac output and respiratory rates increase under neural control:
    • Have both voluntary and involuntary components
Control by the Respiratory Centers of the Brain

- **Involuntary Centers**
  - Regulate respiratory muscles
  - In response to sensory information

- **Voluntary Centers**
  - In cerebral cortex affect:
    - Respiratory centers of pons and medulla oblongata
    - Motor neurons that control respiratory muscles
Control by the Respiratory Centers of the Brain

- The Respiratory Centers
  - Three pairs of nuclei in the reticular formation of medulla oblongata and pons

- Respiratory Rhythmicity Centers of the Medulla Oblongata
  - Set the pace of respiration
  - Can be divided into two groups:
    - Dorsal respiratory group (DRG)
    - Ventral respiratory group (VRG)
Control by the Respiratory Centers of the Brain

- **Dorsal Respiratory Group (DRG)**
  - Inspiratory center
  - Functions in quiet and forced breathing

- **Ventral Respiratory Group (VRG)**
  - Inspiratory and expiratory center
  - Functions only in forced breathing
Basic Regulatory Patterns of Respiration

Figure 15-15
Control of Respiration

• Respiratory Reflexes
  – Changes in patterns of respiration induced by sensory input
Control of Respiration

• Five Sensory Modifiers of Respiratory Center Activities
  – **Chemoreceptors** are sensitive to $P_{CO_2}$, $P_{O_2}$, or pH of blood or cerebrospinal fluid
  – **Baroreceptors** in aortic or carotid sinuses are sensitive to changes in blood pressure
  – **Stretch receptors** respond to changes in lung volume
  – **Irritating physical or chemical stimuli** in nasal cavity, larynx, or bronchial tree
  – **Other sensations** including pain, changes in body temperature, abnormal visceral sensations
Control of Respiration

• Baroreceptor Reflexes
  – Carotid and aortic baroreceptor stimulation:
    • Affects blood pressure and respiratory centers
  – When blood pressure falls:
    • Respiration increases
  – When blood pressure increases:
    • Respiration decreases
Control of Respiration

- The **Hering–Breuer Reflexes**
  - Two baroreceptor reflexes involved in forced breathing
    - **Inflation reflex:**
      - prevents overexpansion of lungs
    - **Deflation reflex:**
      - inhibits expiratory centers
      - stimulates inspiratory centers during lung deflation
Control of Respiration

• Chemoreceptor Reflexes
  – Respiratory centers are strongly influenced by chemoreceptor input from
    • Cranial nerve IX
    • Cranial nerve X
    • Receptors that monitor cerebrospinal fluid:
      – Respond to $P_{CO_2}$ and pH of CSF
Control of Respiration

• Hypercapnia
  – An increase in arterial $P_{CO_2}$
  – Stimulates chemoreceptors in the medulla oblongata:
    • To restore homeostasis
Figure 15-16
Control by Higher Centers

• Voluntary Control of Respiration

  1. Strong emotions:
     • Can stimulate respiratory centers in hypothalamus

  2. Emotional stress:
     • Can activate sympathetic or parasympathetic division of ANS
     • Causing bronchodilation or bronchoconstriction

  3. Anticipation of strenuous exercise:
     • Can increase respiratory rate and cardiac output
     • By sympathetic stimulation
Respiratory Changes at Birth

1. Before birth
   - Pulmonary vessels are collapsed
   - Lungs contain no air

2. During delivery
   - Placental connection is lost
   - Blood $P_{O_2}$ falls
   - $P_{CO_2}$ rises
Respiratory Changes at Birth

3. At birth
   – Newborn overcomes force of surface tension to inflate bronchial tree and alveoli and take first breath

4. Large drop in pressure at first breath
   – Pulls blood into pulmonary circulation
   – Closing foramen ovale and ductus arteriosus
   – Redirecting fetal blood circulation patterns

5. Subsequent breaths
   – Fully inflate alveoli
15-9 Respiratory performance declines with age
Respiratory System and Aging

- Elastic tissues deteriorate and arthritis sets in:
  - Altering lung compliance
  - Lowering vital capacity
  - Restricting chest movements
  - Limiting respiratory minute volume

- Emphysema
  - Affects individuals over age 50
  - Depending on exposure to respiratory irritants (e.g., cigarette smoke)
15-10 The respiratory system provides oxygen to, and removes carbon dioxide from, other organ systems.
Integration with Other Systems

• Maintaining homeostatic \( \text{O}_2 \) and \( \text{CO}_2 \) levels in peripheral tissues requires coordination between several systems
  – Particularly the respiratory and cardiovascular systems
Integration with Other Systems

- Coordination of Respiratory and Cardiovascular Systems
  - Improves efficiency of gas exchange by controlling lung perfusion
  - Increases respiratory drive through chemoreceptor stimulation
  - Raises cardiac output and blood flow through baroreceptor stimulation
The Respiratory System in Perspective

Functional Relationships Between the Respiratory System and Other Systems
The Integumentary System protects portions of upper respiratory tract; hairs guard entry to external nares.
The Skeletal System’s rib movements by respiratory muscles assist breathing; axial skeleton surrounds and protects lungs.
The Nervous System monitors respiratory volume and blood gas levels; controls pace and depth of respiration.
The Endocrine System

hormones epinephrine and norepinephrine stimulate respiratory activity and dilate respiratory passageways
The Cardiovascular System

- The Cardiovascular System’s red blood cells transport oxygen and carbon dioxide between lungs and peripheral tissues.
- The Respiratory System’s transport of carbon dioxide as bicarbonate ions contributes to the buffering capability of blood.
The Lymphoid System’s tonsils protect against infection at entrance to respiratory tract; lymphatic vessels monitor lymph drainage from lungs and mobilize specific defenses when infection occurs.

The Respiratory System’s alveolar phagocytes present antigens to trigger specific defenses; mucous membrane lining the nasal cavity and upper pharynx traps pathogens, protects deeper tissues.
The Muscular System’s activity generates carbon dioxide; respiratory muscles fill and empty lungs; other muscles control entrances to respiratory tract; intrinsic laryngeal muscles control airflow through larynx and produce sounds.
The Digestive System provides substrates, vitamins, water, and ions that are necessary to all cells of the respiratory system.

The Respiratory System can assist in defecation by increased thoracic and abdominal pressure through contraction of respiratory muscles.
The Urinary System eliminates organic wastes generated by cells of the respiratory system; maintains normal fluid and ion balance in the blood.

The Respiratory System assists in the regulation of pH by eliminating carbon dioxide.
The Reproductive System

The Respiratory System changes respiratory rate and volume during sexual arousal.