

## CHAPTER 23

### LECTURE OUTLINE

#### I. INTRODUCTION

- A. The two systems that cooperate to supply O<sub>2</sub> and eliminate CO<sub>2</sub> are the cardiovascular and the respiratory system.
  - 1. The respiratory system provides for gas exchange.
  - 2. The cardiovascular system transports the respiratory gases.
  - 3. Failure of either system has the same effect on the body: disruption of homeostasis and rapid death of cells from oxygen starvation and buildup of waste products.
- B. Respiration is the exchange of gases between the atmosphere, blood, and cells. It takes place in three basic processes: ventilation (breathing), external (pulmonary) respiration, and internal (tissue) respiration.

#### II. RESPIRATORY SYSTEM ANATOMY

- A. The respiratory system consists of the nose, pharynx, larynx, trachea, bronchi, and lungs (Figure 23.1, Table 23.1).
  - 1. The upper respiratory system refers to the nose, pharynx, and associated structures. The lower respiratory system refers to the larynx, trachea, bronchi, and lungs.
  - 2. The conducting system consists of a series of cavities and tubes - nose, pharynx, larynx, trachea, bronchi, bronchiole, and terminal bronchioles - that conduct air into the lungs. The respiratory portion consists of the area where gas exchange occurs - respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli.
  - 3. The branch of medicine that deals with the diagnosis and treatment of diseases of the ear, nose, and throat is called otorhinolaryngology.

##### B. Nose

- 1. The external portion of the nose is made of cartilage and skin and is lined with mucous membrane. Openings to the exterior are the external nares.
- 2. The external portion of the nose is made of cartilage and skin and is lined with mucous membrane (Figure 23.2a).
- 3. The bony framework of the nose is formed by the frontal bone, nasal bones, and maxillae (Figure 23.2).

4. The interior structures of the nose are specialized for warming, moistening, and filtering incoming air; receiving olfactory stimuli; and serving as large, hollow resonating chambers to modify speech sounds.
5. The internal portion communicates with the paranasal sinuses and nasopharynx through the internal nares.
6. The inside of both the external and internal nose is called the nasal cavity. It is divided into right and left sides by the nasal septum. The anterior portion of the cavity is called the vestibule.
7. The surface anatomy of the nose is shown in Figure 23.3.
8. Rhinoplasty (“nose job”) is a surgical procedure in which the structure of the external nose is altered for cosmetic or functional reasons. (Clinical Connection)

### **C. Pharynx**

1. The pharynx (throat) is a muscular tube lined by a mucous membrane (Figure 23.2b).
2. The anatomic regions are the nasopharynx, oropharynx, and laryngopharynx.
3. The nasopharynx functions in respiration. Both the oropharynx and laryngopharynx function in digestion and in respiration (serving as a passageway for both air and food).
4. A Tonsillectomy is the surgical removal of the tonsils (Clinical Connection)

### **D. Larynx**

1. The larynx (voice box) is a passageway that connects the pharynx with the trachea.
2. It contains the thyroid cartilage (Adam’s apple); the epiglottis, which prevents food from entering the larynx; the cricoid cartilage, which connects the larynx and trachea; and the paired arytenoid, corniculate, and cuneiform cartilages (Figure 23.4).

### **E. The Structures of Voice Production**

1. The larynx contains vocal folds (true vocal cords), which produce sound. Taut vocal folds produce high pitches, and relaxed vocal folds produce low pitches (Figure 23.5).
2. Sound originates from the vibration of the vocal folds, but other structures are necessary for converting the sound into recognizable speech.
3. Laryngitis is an inflammation of the larynx that is usually caused by respiratory infection or irritants. Cancer of the larynx is almost exclusively found in smokers (Clinical Connection).

### **F. Trachea**

1. The trachea (windpipe) is anterior to the esophagus (Figure 23.6)

2. It extends from the larynx to the primary bronchi (Figure 23.7).
3. It is composed of smooth muscle and C-shaped rings of cartilage and is lined with pseudostratified ciliated columnar epithelium.
  - a. The cartilage rings keep the airway open.
  - b. The cilia of the epithelium sweep debris away from the lungs and back to the throat to be swallowed.
4. Two methods of bypassing obstructions from the respiratory passageways are tracheostomy and intubation. (Clinical Connection)

### **G. Bronchi**

1. The trachea divides into the right and left pulmonary bronchi (Figure 23.7).
2. The bronchial tree consists of the trachea, primary bronchi, secondary bronchi, tertiary bronchi, bronchioles, and terminal bronchioles.
3. Changes in histology reflect changes in function in the structures of the bronchial tree.
  - a. The mucous membrane changes from ciliated pseudostratified epithelium with many goblet cells (in the largest bronchi) to non-ciliated cuboidal epithelium in the smallest bronchioles.
  - b. The c-rings of the trachea are replaced by plates of cartilage (in the bronchi) and eventually cartilage disappears completely in the bronchioles.
  - c. As the amount of cartilage decreases the amount of smooth muscle increases.

### **H. Lungs**

1. Lungs are paired organs in the thoracic cavity; they are enclosed and protected by the pleural membrane (Figure 23.8).
  - a. The parietal pleura is the outer layer which is attached to the wall of the thoracic cavity.
  - b. The visceral pleura is the inner layer, covering the lungs themselves.
  - c. Between the pleurae is a small potential space, the pleural cavity, which contains a serous lubricating fluid secreted by the membranes.
  - d. The lungs extend from the diaphragm to just slightly superior to the clavicles and lie against the ribs anteriorly and posteriorly.
  - e. Injuries to the chest wall that allow air to enter the intrapleural space either from the outside or from the alveoli cause pneumothorax, filling the pleural cavity with air. (Clinical Connection).

2. The right lung has three lobes separated by two fissures; the left lung has two lobes separated by one fissure and a depression, the cardiac notch (Figure 23.9).
  - a. The secondary bronchi give rise to branches called tertiary (segmental) bronchi, which supply segments of lung tissue called bronchopulmonary segments.
  - b. Each bronchopulmonary segment consists of many small compartments called lobules, which contain lymphatics, arterioles, venules, terminal bronchioles, respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli (Figure 23.10).

### 3. Alveoli

- a. Alveolar walls consist of type I alveolar (squamous pulmonary epithelial) cells, type II alveolar (septal) cells, and alveolar macrophages (dust cells) (Figure 23.11).
- b. Type II alveolar cells secrete alveolar fluid, which keeps the alveolar cells moist and which contains a component called surfactant. Surfactant lowers the surface tension of alveolar fluid, preventing the collapse of alveoli with each expiration.
- c. Gas exchange occurs across the alveolar-capillary membrane (Figure 23.11).

### 4. Blood Supply to the Lungs

- a. Blood enters the lungs via the pulmonary arteries (pulmonary circulation) and the bronchial arteries (systemic circulation). Most of the blood leaves by the pulmonary veins, but some drains into the bronchial veins.
- b. In the lungs vasoconstriction in response to hypoxia diverts pulmonary blood from poorly ventilated areas to well ventilated areas. This phenomenon is known as ventilation – perfusion coupling.

### 5. Patency of the Respiratory System

- a. Patency helps to maintain the system so the air passageways are kept free of obstruction

### 6. Clinical Connection: Coryza, Seasonal Influenza and H1N1 influenza

## III. PULMONARY VENTILATION

- A. Respiration occurs in three basic steps: pulmonary ventilation, external respiration, and internal respiration.
- B. Inhalation (inspiration) is the process of bringing air into the lungs.

1. The movement of air into and out of the lungs depends on pressure changes governed in part by Boyle's law, which states that the volume of a gas varies inversely with pressure, assuming that temperature is constant (Figure 23.12).
2. The first step in expanding the lungs involves contraction of the main inspiratory muscle, the diaphragm (Figure 23.13).
3. Inhalation occurs when alveolar (intrapulmonic) pressure falls below atmospheric pressure. Contraction of the diaphragm and external intercostal muscles increases the size of the thorax, thus decreasing the intrapleural (intrathoracic) pressure so that the lungs expand. Expansion of the lungs decreases alveolar pressure so that air moves along the pressure gradient from the atmosphere into the lungs (Figure 23.14).
4. During forced inhalation, accessory muscles of inspiration (sternocleidomastoids, scalenes, and pectoralis minor) are also used.

**C. Exhalation (expiration) is the movement of air out of the lungs.**

1. Exhalation occurs when alveolar pressure is higher than atmospheric pressure. Relaxation of the diaphragm and external intercostal muscles results in elastic recoil of the chest wall and lungs, which increases intrapleural pressure, decreases lung volume, and increases alveolar pressure so that air moves from the lungs to the atmosphere. There is also an inward pull of surface tension due to the film of alveolar fluid.
2. Exhalation becomes active during labored breathing and when air movement out of the lungs is impeded. Forced expiration employs contraction of the internal intercostals and abdominal muscles (Figure 23.14).

**D. Other factors that affecting pulmonary ventilation**

1. In the lungs, surface tension causes the alveoli to assume the smallest diameter possible.
  - a. During breathing, surface tension must be overcome to expand the lungs during each inspiration. It is also the major component of lung elastic recoil, which acts to decrease the size of the alveoli during expiration.
  - b. The presence of surfactant, a phospholipid produced by the type II alveolar (septal) cells in the alveolar walls, allows alteration of the surface tension of the alveoli and prevents their collapse following expiration.
2. As a result of inadequate surfactant, the alveoli of premature babies cannot remain open. This disorder, called Respiratory Distress Syndrome, results in blue skin color and labored breathing. (Clinical Connection)

- E. Compliance is the ease with which the lungs and thoracic wall can be expanded. Any condition that destroys lung tissue causes it to become filled with fluid, produces a deficiency in surfactant, or in any way impedes lung expansion or contraction, decreases compliance.
- F. The walls of the respiratory passageways, especially the bronchi and bronchioles, offer some resistance to the normal flow of air into the lungs. Any condition that obstructs the air passageway increases resistance, and more pressure to force air through is required.
- G. Breathing Patterns and Modified Respiratory Movements
  - 1. Breathing Patterns
    - a. Eupnea is normal variation in breathing rate and depth.
    - b. Apnea refers to breath holding.
    - c. Dyspnea relates to painful or difficult breathing.
    - d. Tachypnea involves rapid breathing rate.
    - e. Costal breathing requires combinations of various patterns of intercostal and extracostal muscles, usually during need for increased ventilation, as with exercise.
    - f. Diaphragmatic breathing is the usual mode of operation to move air by contracting and relaxing the diaphragm to change the lung volume.
  - 2. Modified respiratory movements are used to express emotions and to clear air passageways. Table 23.2 lists some of the modified respiratory movements.

#### **IV. LUNG VOLUMES AND CAPACITIES**

- A. Air volumes exchanged during breathing and rate of ventilation are measured with a spiromometer, or respirometer, and the record is called a spirogram (Figure 23.15)
- B. Among the pulmonary air volumes exchanged in ventilation are tidal (500 ml), inspiratory reserve (3100 ml), expiratory reserve (1200 ml), residual (1200 ml) and minimal volumes. Only about 350 ml of the tidal volume actually reaches the alveoli, the other 150 ml remains in the airways as anatomic dead space.
- C. Pulmonary lung capacities, the sum of two or more volumes, include inspiratory (3600 ml), functional residual (2400 ml), vital (4800 ml), and total lung (6000 ml) capacities (Figure 23.17).
- D. The minute volume of respiration is the total volume of air taken in during one minute (tidal volume x 12 respirations per minute = 6000 ml/min).

#### **V. EXCHANGE OF OXYGEN AND CARBON DIOXIDE**

A. To understand the exchange of oxygen and carbon dioxide between the blood and alveoli, it is useful to know some gas laws.

1. According to Dalton's law, each gas in a mixture of gases exerts its own pressure as if all the other gases were not present.
  - a. The partial pressure of a gas is the pressure exerted by that gas in a mixture of gases. The total pressure of a mixture is calculated by simply adding all the partial pressures. It is symbolized by P.
  - b. The partial pressures of the respiratory gases in the atmosphere, alveoli, blood, and tissues cells are shown in the text.
  - c. The amounts of O<sub>2</sub> and CO<sub>2</sub> vary in inspired (atmospheric), alveolar, and expired air.
2. Henry's law states that the quantity of a gas that will dissolve in a liquid is proportional to the partial pressure of the gas and its solubility coefficient (its physical or chemical attraction for water), when the temperature remains constant.
  - a. Nitrogen narcosis and decompression sickness (caisson disease, or bends) are conditions explained by Henry's law.
  - b. A major clinical application of Henry's law is hyperbaric oxygenation. This technique uses pressure to cause more oxygen to dissolve in the blood and is used to treat anaerobic bacterial infections (such as tetanus and gangrene) and a number of other disorders and injuries (Clinical connection)

## **B. External and Internal Respiration**

1. In internal and external respiration, O<sub>2</sub> and CO<sub>2</sub> diffuse from areas of their higher partial pressures to areas of their lower partial pressures (Figure 23.16)
2. External respiration results in the conversion of deoxygenated blood (depleted of O<sub>2</sub> but higher in CO<sub>2</sub>) going to the lungs, to oxygenated blood (saturated with O<sub>2</sub> and lower in CO<sub>2</sub>) returning from the lungs to the heart.
3. External respiration depends on partial pressure differences, a large surface area for gas exchange, a small diffusion distance across the alveolar-capillary (respiratory) membrane, and the solubility and molecular weight of the gases.
4. Internal (tissue) respiration is the exchange of gases between tissue blood capillaries and tissue cells (Figure 23.16) and results in the conversion of oxygenated blood into deoxygenated blood.
5. At rest only about 25% of the available oxygen in oxygenated blood actually enters tissue cells. During exercise, more oxygen is released.

## VI. TRANSPORT OF OXYGEN AND CARBON DIOXIDE IN THE BLOOD

### A. Oxygen Transport

1. In each 100 ml of oxygenated blood, 1.5% of the O<sub>2</sub> is dissolved in the plasma and 98.5% is carried with hemoglobin (Hb) inside red blood cells as oxyhemoglobin (HbO<sub>2</sub>) (Figure 23.17).
  - a. Hemoglobin consists of a protein portion called globin and a pigment called heme.
  - b. The heme portion contains 4 atoms of iron, each capable of combining with a molecule of oxygen.
  - c. Hemoglobin and Oxygen Partial Pressure
  - d. The most important factor that determines how much oxygen combines with hemoglobin is PO<sub>2</sub>.
  - e. The relationship between the percent saturation of hemoglobin and PO<sub>2</sub> is illustrated in Figure 23.18, the oxygen-hemoglobin dissociation curve.
  - f. The greater the PO<sub>2</sub>, the more oxygen will combine with hemoglobin, until the available hemoglobin molecules are saturated.
  - g. Other Factors Affecting Hemoglobin Affinity for Oxygen
    - 1) In an acid (low pH) environment, O<sub>2</sub> splits more readily from hemoglobin (Figure 23.19). This is referred to as the Bohr effect.
    - 2) Low blood pH (acidic conditions) results from high PCO<sub>2</sub>.
    - 3) Within limits, as temperature increases, so does the amount of oxygen released from hemoglobin (Figure 23.20). Active cells require more oxygen, and active cells (such as contracting muscle cells) liberate more acid and heat. The acid and heat, in turn, stimulate the oxyhemoglobin to release its oxygen.
    - 4) BPG (2, 3-biphosphoglycerate) is a substance formed in red blood cells during glycolysis. The greater the level of BPG, the more oxygen is released from hemoglobin.
    - 5) Fetal hemoglobin has a higher affinity for oxygen because it binds BPG less strongly and can carry more oxygen to offset the low oxygen saturation in maternal blood in the placenta (Figure 23.21).
    - 6) Because of the strong attraction of carbon monoxide (CO) to hemoglobin, even small concentrations of CO will reduce the oxygen

carrying capacity leading to hypoxia and carbon monoxide poisoning. (Clinical Connection)

### **B. Carbon Dioxide Transport**

1. CO<sub>2</sub> is carried in blood in the form of dissolved CO<sub>2</sub> (7%), carbaminohemoglobin (23%), and bicarbonate ions (70%) (Figure 23.17)
2. The conversion of CO<sub>2</sub> to bicarbonate ions and the related chloride shift maintains the ionic balance between plasma and red blood cells (Figure 23.22).

### **C. Summary of Gas Exchange and Transport in Lungs and Tissues**

1. CO<sub>2</sub> in blood causes O<sub>2</sub> to split from hemoglobin.
2. Similarly, the binding of O<sub>2</sub> to hemoglobin causes a release of CO<sub>2</sub> from blood.
3. A summary of all reactions that occur during gas exchange is found in Figure 23.22)

## **VII. CONTROL OF RESPIRATION**

### **A. Respiratory Center**

1. The area of the brain from which nerve impulses are sent to respiratory muscles is located bilaterally in the reticular formation of the brain stem. This respiratory center consists of a medullary rhythmicity area (inspiratory and expiratory areas), pneumotaxic area, and apneustic area (Figure 23.23).
2. Medullary Rhythmicity Area
  - a. The function of the medullary rhythmicity area is to control the basic rhythm of respiration.
  - b. The inspiratory area has an intrinsic excitability of autorhythmic neurons that sets the basic rhythm of respiration.
  - c. The expiratory area neurons remain inactive during most quiet respiration but are probably activated during high levels of ventilation to cause contraction of muscles used in forced (labored) expiration (Figure 23.24).

### **3. Pneumotaxic Area**

- a. The pneumotaxic area in the upper pons helps coordinate the transition between inspiration and expiration (Figure 23.24).
- b. The apneustic area sends impulses to the inspiratory area that activate it and prolong inspiration, inhibiting expiration.

### **B. Regulation of the Respiratory Center**

#### **1. Cortical Influences**

- a. Cortical influences allow conscious control of respiration that may be needed to avoid inhaling noxious gasses or water.
- b. Breath holding is limited by the overriding stimuli of increased  $[H^+]$  and  $[CO_2]$ .

## 2. Chemoreceptor Regulation of Respiration

- a. Central chemoreceptors (located in the medulla oblongata) and peripheral chemoreceptors (located in the walls of systemic arteries) monitor levels of  $CO_2$  and  $O_2$  and provide input to the respiratory center (Figure 23.25).
  - 1) Central chemoreceptors respond to change in  $H^+$  concentration or  $PCO_2$ , or both in cerebrospinal fluid.
  - 2) Peripheral chemoreceptors respond to changes in  $H^+$ ,  $PCO_2$ , and  $PO_2$  in blood.
- b. A slight increase in  $PCO_2$  (and thus  $H^+$ ), a condition called hypercapnia, stimulates central chemoreceptors (Figure 23.26).
  - 1) As a response to increased  $PCO_2$ , increased  $H^+$  and decreased  $PO_2$ , the inspiratory area is activated and hyperventilation, rapid and deep breathing, occurs
  - 2) If arterial  $PCO_2$  is lower than 40 mm Hg, a condition called hypocapnia, the chemoreceptors are not stimulated and the inspiratory area sets its own pace until  $CO_2$  accumulates and  $PCO_2$  rises to 40 mm Hg.
- c. Severe deficiency of  $O_2$  depresses activity of the central chemoreceptors and respiratory center.
- d. Hypoxia refers to oxygen deficiency at the tissue level and is classified in several ways (Clinical Connection).
  - 1) Hypoxic hypoxia is caused by a low  $PO_2$  in arterial blood (high altitude, airway obstruction, fluid in lungs).
  - 2) In anemic hypoxia, there is too little functioning hemoglobin in the blood (hemorrhage, anemia, carbon monoxide poisoning).
  - 3) Stagnant hypoxia results from the inability of blood to carry oxygen to tissues fast enough to sustain their needs (heart failure, circulatory shock).

- 4) In histotoxic hypoxia, the blood delivers adequate oxygen to the tissues, but the tissues are unable to use it properly (cyanide poisoning).
- 5) Proprioceptors of joints and muscles activate the inspiratory center to increase ventilation prior to exercise induced oxygen need.
- 6) The inflation (Hering-Breuer) reflex detects lung expansion with stretch receptors and limits it depending on ventilatory need and prevention of damage.
- 7) Other influences include blood pressure, limbic system, temperature, pain, stretching the anal sphincter, and irritation to the respiratory mucosa.
- 8) Table 23.3 summarizes the changes that increase or decrease ventilation rate and depth.

### **VIII. EXERCISE AND THE RESPIRATORY SYSTEM**

- A. The respiratory system works with the cardiovascular system to make appropriate adjustments for different exercise intensities and durations.
- B. As blood flow increases with a lower O<sub>2</sub> and higher CO<sub>2</sub> content, the amount passing through the lung (pulmonary perfusion) increases and is matched by increased ventilation and oxygen diffusion capacity as more pulmonary capillaries open.
- C. Ventilatory modifications can increase 30 times above resting levels, in an initial rapid rate due to neural influences and then more gradually due to chemical stimulation from changes in cell metabolism. A similar, but reversed, effect occurs with cessation of exercise.
- D. Smokers have difficulty breathing for a number of reasons, including nicotine, mucous, irritants, and that fact that scar tissue replaces elastic fibers (Clinical Connection)

### **IX. DEVELOPMENT OF THE RESPIRATORY SYSTEM**

- A. The respiratory system begins as an outgrowth of endoderm called the laryngotracheal bud, part of which divides into two lung buds that grow into the bronchi and lungs (Figure 23.28).
- B. The smooth muscle, cartilage, and connective tissue of the bronchial tubes and pleural sacs develop from mesenchyma (mesodermal) cells.

### **X. AGING AND THE RESPIRATORY SYSTEM**

- A. Aging results in decreased vital capacity, decreased blood oxygen level, diminished alveolar macrophage activity, and decreased ciliary action of the epithelium lining the respiratory tract.
- B. Elderly people are more susceptible to pneumonia, bronchitis, emphysema, and other pulmonary disorders.

## **XI. FOCUS ON HOMEOSTASIS: THE RESPIRATORY SYSTEM**

- A. Examines the role of the respiratory system in maintaining homeostasis.

## **XII. DISORDERS: HOMEOSTATIC IMBALANCES**

- A. Asthma is characterized by the following: spasms of smooth muscle in bronchial tubes that result in partial or complete closure of air passageways; inflammation; inflated alveoli; and excess mucus production. A common triggering factor is allergy, but other factors include emotional upset, aspirin, exercise, and breathing cold air or cigarette smoke.
- B. Chronic obstructive pulmonary disease (COPD) is a type of respiratory disorder characterized by chronic and recurrent obstruction of air flow, which increases airway resistance.
  - 1. The principal types of COPD are emphysema and chronic bronchitis.
  - 2. Bronchitis is an inflammation of the bronchial tubes, the main symptom of which is a productive (raising mucus or sputum) cough.
- C. In bronchogenic carcinoma (lung cancer), bronchial epithelial cells are replaced by cancer cells after constant irritation has disrupted the normal growth, division, and function of the epithelial cells. Airways are often blocked and metastasis is very common. It is most commonly associated with smoking.
- D. Pneumonia is an acute infection of the alveoli. The most common cause is the pneumococcal bacteria but other microbes may be involved. Treatment involves antibiotics, bronchodilators, oxygen therapy, and chest physiotherapy.
- E. Tuberculosis (TB) is an inflammation of pleurae and lungs produced by the organism *Mycobacterium tuberculosis*. It is communicable and destroys lung tissue, leaving nonfunctional fibrous tissue behind.
- F. Coryza (common cold) is caused by viruses and usually is not accompanied by a fever, whereas influenza (flu) is usually accompanied by a fever greater than 101°F.
- G. Pulmonary edema refers to an abnormal accumulation of interstitial fluid in the interstitial spaces and alveoli of the lungs. It may be pulmonary or cardiac in origin.

- H. Cystic fibrosis is an inherited disease of secretory epithelia that affects the respiratory passageways, pancreas, salivary glands, and sweat glands.
- I. Asbestos-related diseases result from inhalation of asbestos particles.
- J. Sudden Infant Death Syndrome is the sudden death of an apparently healthy infant, usually occurring during sleep. The cause is unknown but may be associated with hypoxia, possibly resulting from sleeping position. As such, it is recommended that infants sleep on their backs for the first six months.
- K. Acute respiratory distress syndrome is a form of respiratory failure characterized by excessive leakiness of respiratory membranes and severe hypoxia.

**XIII. MEDICAL TERMINOLOGY** - Alert students to the medical terms associated with the respiratory system.