**Thibodeau: Anatomy and Physiology, 5/e**

**Chapter 24 - Physiology of the Respiratory System**

Respiratory physiology is a complex series of interacting and coordinated processes that play a critical role in maintaining the stability, or constancy, of our internal environment. The proper functioning of the respiratory system ensures the tissues of an adequate oxygen supply and prompt removal of carbon dioxide. This process is complicated by the fact that control mechanisms must maintain homeostasis throughout a wide range of constantly changing environmental conditions.

Functionally, the respiratory system is composed of an integrated set of regulated processes that include pulmonary ventilation (breathing), gas exchange in the lungs and tissues, transport of gases by the blood, and overall regulation of respiration.

Discussion begins with analysis of inspiration, expiration, and pulmonary volumes and moves into an analysis of transport of gases in the blood, including Dalton's law. The major factors that determine the volume of oxygen entering lung capillary blood are examined along with analysis of the Bohr versus Haldane effect. Finally, the factors that influence the respiratory control center are identified as factors that control respirations.

**Objectives**

After students have completed this chapter, they should be able to:

1. List and briefly discuss the regulated and integrated processes that ensure tissues of an adequate oxygen supply and prompt removal of carbon dioxide.
2. Define *pulmonary ventilation* and outline the mechanism of normal, quiet inspiration and expiration.
3. List by names and explain the volume of air exchanged in pulmonary ventilation.
4. Define the following terms: *tidal volume*, *expiratory reserve volume*, *inspiratory reserve volume*, *residual volume*, *minimal volume*, *inspiratory capacity*, *functional residual capacity*, *total lung capacity*.
5. Demonstrate the principles of partial pressures (Dalton's law) in explaining movement of respiratory gases between alveolar air and blood moving through pulmonary capillaries.
6. Discuss the major factors that determine the volume of oxygen entering lung capillary blood.
7. Explain how blood transports oxygen and carbon dioxide.
8. Interpret changes in the oxygen-hemoglobin dissociation curve at various blood pH levels.
9. Discuss gas exchange in tissue capillaries between arterial blood and cells.
10. Explain the reciprocal interaction of oxygen and carbon dioxide on blood gas transport (Bohr versus Haldane effect).
11. Discuss the primary factors that influence the respiratory control center and thereby control respirations.

**Lecture Outline**

I. Respiratory Physiology (p. 708)
   A. Supply O₂ and remove CO₂
   B. Control mechanisms that allow homeostasis over wide range of conditions
   C. Integrations of various physiological control systems

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Chapter 24 - Physiology of the Respiratory System

1. Acid-base balance
2. Water balance
3. Electrolyte balance
4. Circulation
5. Metabolism

D. Integrated set of regulated processes
   1. Pulmonary ventilation (breathing)
   2. Gas exchange in lungs and tissues
   3. Transport of gases by the blood
   4. Overall regulation of respiration

II. Pulmonary Ventilation (p. 708)

A. Mechanism of pulmonary ventilation (Fig. 24-1)
   1. Gas pressure gradient
   2. Establishment of pressure gradients
      a. Change in volume of thoracic cavity
      b. Boyle's law states that gas volume varies inversely with pressure at constant temperature (Box 24-1)

B. Inspiration (Fig. 24-2)
   1. Diaphragm and external intercostals contract
   2. Sternocleidomastoid, pectoralis minor, and serratus anterior muscles contract
   3. Volume of thorax increases
   4. Intrapleural (intrathoracic) and intraalveolar pressure decrease
   5. Intrathoracic pressure is less than atmospheric pressure
   6. Air moves into lungs
   7. Elastic recoil tends to return lungs to preinspiration volume

C. Expiration (Fig. 24-3)
   1. Inspiratory muscles relax
   2. Thorax decreases in size
   3. Intrathoracic pressure increases
   4. Intrathoracic pressure is greater than atmospheric pressure
   5. Air moves out of lungs
   6. Compliance is the ability of the lungs and thorax to stretch

D. Pulmonary volumes (Fig. 24-5)
   1. Spirometer used for measurement (Fig. 24-4)
   2. Volumes (Table 24-1)
      a. Tidal volume (TV): 500 ml

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Chapter 24 - Physiology of the Respiratory System

b. Expiratory reserve volume (ERV): 1,000–1,200 ml
c. Inspiratory reserve volume (IRV): 3,000–3,300 ml
d. Residual volume (RV): 1,200 ml

3. Capacities (Table 24-1)
a. Vital capacity (VC): 4,500–5,000 ml
b. Inspiratory capacity (IC): 3,500–3,800 ml
c. Functional residual capacity (FRC): 2,200–2,400 ml
d. Total lung capacity (TLC): 5,700–6,200 ml

4. Alveolar ventilation
a. Anatomical dead space (Fig. 24-6)

III. Pulmonary Gas Exchange (p. 716)
A. Partial pressure (Fig. 24-7)
1. Law of partial pressure (Dalton's law)
a. The partial pressure of a gas in a mixture is directly proportional to the concentration of that gas and the total pressure of the mixture
b. Oxygen and carbon dioxide pressure gradients (Table 24-2)

2. Exchange of gases in the lungs (Fig. 24-8)
a. Occurs between alveolar air and blood in capillaries
b. CO₂ moves into alveolar air (down its partial pressure gradient)
c. O₂ moves into blood (down its partial pressure gradient)
d. Factors influencing oxygen exchange
1) Gradient between alveolar PO₂ and blood PO₂
2) Functional surface area of respiratory membrane
3) Respiratory minute volume
4) Alveolar ventilation
e. Structural attributes that facilitate alveolar-blood exchange
1) Respiratory membrane is very thin
2) Alveolar and capillary surfaces are very large
3) Lung capillaries can hold a large amount of blood
4) Blood layer in capillaries is very thin

IV. How Blood Transports Gases (p. 720)
A. Hemoglobin (Fig. 24-9, Fig. 24-10)
1. Four polypeptide chains
2. Four heme groups
3. Oxygen binds to heme groups
4. Carbon dioxide binds to amino acids of polypeptide chains

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Chapter 24 - Physiology of the Respiratory System

B. Transport of oxygen (Fig. 24-8, Fig. 10)
   1. Oxyhemoglobin
      a. About 20.1 ml of dissolved O₂/100 ml blood
   2. Oxygen-hemoglobin dissociation curve (Fig. 24-11)
      a. Increased blood PO₂ accelerates O₂ attaching to hemoglobin (Hb)
      b. Decreased blood PO₂ accelerates O₂ dissociation from HbO₂
   3. Dissolved in plasma
      a. Only about 0.3 ml of dissolved O₂/100 ml blood

C. Transport of carbon dioxide (Fig. 24-15)
   1. Dissolved carbon dioxide (p. 722)
      a. Carried in the plasma; 10% of total carbon dioxide transported
   2. Carbamino compounds (carbaminohemoglobin) (Fig. 24-12)
      a. CO₂ carried on an amine group of Hb
      b. Accounts for 20% of CO₂ transported
      c. Rate law of chemistry
         1) The rate of the reaction varies with the concentration of CO₂
         2) This gives a carbon dioxide dissociation curve (Fig. 24-13)
   3. Bicarbonate (HCO₃⁻)
      a. Formation (Fig. 24-14)
         1) CO₂ and H₂O combine to form carbonic acid (H₂CO₃)
         2) This reaction occurs in the plasma slowly
         3) In the RBC the enzyme carbonic anhydrase greatly speeds the reaction; therefore, most of the bicarbonate is carried in the RBC
         4) About 70% of the CO₂ is carried as bicarbonate
      b. Chloride shift
         1) As the carbonic acid is formed, the H⁺ fraction combines with Hb, leaving the free bicarbonate ion. This means that HCO₃⁻ concentrations are high in the cell, so they diffuse out of the cell. As the bicarbonate diffuses out of the cell, Cl⁻ diffuses into the RBC. This is called the chloride shift.
   4. Carbon dioxide and pH
      a. Since carbon dioxide and water form carbonic acid, an increase in carbon dioxide results in increased acidity of the plasma

V. Systemic Gas Exchange (Fig. 24-16)
Chapter 24 - Physiology of the Respiratory System

A. Gases move down their concentration gradient.

B. \( \text{O}_2 \) unloading
   1. Oxygen diffuses from arteries to interstitial spaces to cells (where \( \text{O}_2 \) levels are the lowest) (Fig. 24-16)
   2. The arterial blood unloads a varying amount of \( \text{O}_2 \) to the tissues (Fig. 24-17)
      a. At rest
      b. During exercise

C. \( \text{CO}_2 \) loading
   1. Carbon dioxide diffuses from the cells where it is produced to the interstitial spaces and then to the veins (Fig. 24-16)

D. Interaction between \( \text{PO}_2 \) and \( \text{PCO}_2 \) on gas transport (Fig. 24-18)
   1. Increased \( \text{PCO}_2 \) decreases the affinity between Hb and \( \text{O}_2 \); therefore more \( \text{O}_2 \) will be released; this is called the Bohr effect
   2. Plasma pH becoming more acidic (normally occurs as plasma \( \text{PCO}_2 \) levels rise) also has the same effect of decreasing the affinity between Hb and \( \text{O}_2 \); this is called the Haldane effect

VI. Regulation of Breathing (p. 727)

A. Changes in ventilation result in relative constancy of respiratory gases

B. Found in the brainstem are the respiratory control centers (Fig. 24-19)
   1. Medullary rhythmicity area has two control centers
      a. Inspiratory center
         1) Stimulates inspiratory muscles
         2) Primary respiratory pacemaker
      b. Expiratory center
         1) Stimulates expiratory muscles
         2) Active only when forced expiration is needed
   2. Apneustic center in pons stimulates inspiratory center to cause longer and deeper breathing
   3. Pneumotaxic center in pons inhibits inspiratory center and apneustic center, thus preventing overinflation of the lungs

C. Factors that influence breathing (Figs. 24-20)
   1. Medullary rhythmicity area receives feedback from many sources
      a. \( \text{PCO}_2 \) increase stimulates respiration rate increase
         1) Central chemoreceptors (medulla)
         2) Peripheral chemoreceptors (carotid bodies and aorta)
      b. pH decrease stimulates respiration rate increase
         1) Peripheral chemoreceptors (carotid bodies and aorta)
      c. \( \text{PO}_2 \) decrease stimulates respiration rate (emergency only)

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d. Arterial blood pressure (respiratory pressoreflex) increase slows respiration

e. Hering-Breuer reflexes: stretch receptors inhibit inspiration
   1) Prevents overfilling of the lungs

2. Cerebral cortex
   a. Motor area
      1) May consciously decide to breathe faster or slower
   b. Painful stimuli
      1) Causes a reflex apnea
   c. Sudden cold stimuli
      1) Causes a reflex apnea
   d. Stimulation by irritation of pharynx or larynx
      1) Causes temporary apnea

VII. The Big Picture: Respiratory Physiology and the Whole Body (p. 732)
   A. Provides O\textsubscript{2} for, and removes CO\textsubscript{2} from, body cells
   B. Circulatory system—gas exchange
   C. Nervous system—respiratory regulation
   D. Muscular system—flow of air
   E. Skeletal system—expansion and contraction of thorax
   F. Immune system—protection of respiratory system
   G. Speech production
   H. pH and CO\textsubscript{2} regulation

VIII. Mechanisms of Disease: Disorders Associated with Respiratory Function (p. 732)
   A. Restrictive pulmonary disorders
      1. Alveolar fibrosis
      2. Rheumatoid lung
      3. Obesity
      4. Metabolic disorders
   B. Obstructive pulmonary disorders
      1. Chronic obstructive pulmonary disease (COPD)
         a. Bronchitis (Fig. 24-21)
         b. Emphysema (Fig. 24-22)
         c. Asthma (Fig. 24-23)