

VI

unit



Energy: Supply and Use

The five chapters in this unit show how oxygen and nutrients are processed, taken up by the body fluids, and used by the cells to yield energy. This unit also describes how the stability of body functions (homeostasis) is maintained and how waste products are eliminated.



SELECTED KEY TERMS

The following terms and other boldface terms in the chapter are defined in the Glossary

alveolus (pl., alveoli)

asthma

bronchiole

bronchus (pl., bronchi)

chemoreceptor

compliance

diaphragm

emphysema

epiglottis

epistaxis

hemoglobin

hilum

hypercapnia

hypoxia

larynx

lung

mediastinum

pharynx

phrenic nerve

pleura

pneumothorax

respiration

surfactant

trachea

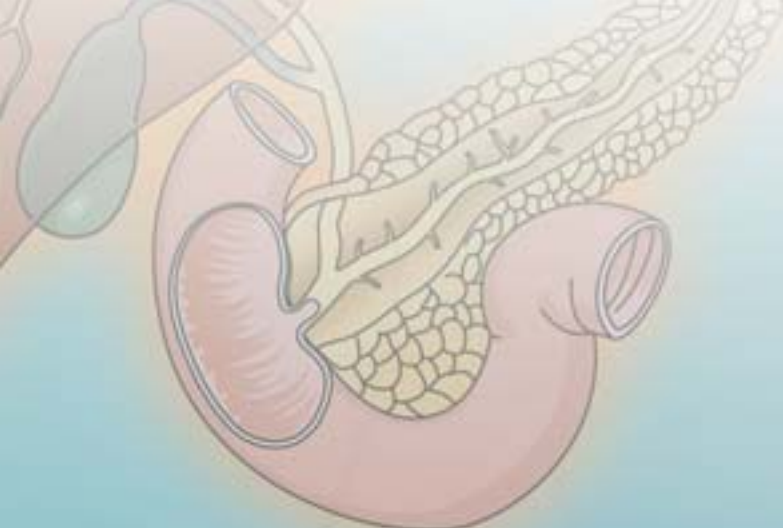
ventilation



LEARNING OUTCOMES

After careful study of this chapter, you should be able to:

1. Define *respiration* and describe the three phases of respiration
2. Name and describe all the structures of the respiratory system
3. Explain the mechanism for pulmonary ventilation
4. List the ways in which oxygen and carbon dioxide are transported in the blood
5. Describe nervous and chemical controls of respiration
6. Give several examples of altered breathing patterns
7. List and define four conditions that result from inadequate breathing
8. Describe several types of respiratory infection
9. Describe some allergic responses that affect the respiratory system
10. Name the diseases involved in chronic obstructive pulmonary disease (COPD)
11. Describe some disorders that involve the pleura
12. Describe equipment used to treat respiratory disorders
13. Show how word parts are used to build words related to respiration (see Word Anatomy at the end of the chapter)



chapter

18

Respiration

Phases of Respiration

Most people think of respiration simply as the process by which air moves into and out of the lungs, that is, *breathing*. By scientific definition, respiration is the process by which oxygen is obtained from the environment and delivered to the cells. Carbon dioxide is transported to the outside in a reverse pathway (Fig. 18-1).

Respiration includes three phases:

- ▶ **Pulmonary ventilation**, which is the exchange of air between the atmosphere and the air sacs (alveoli) of the lungs. This is normally accomplished by the inhalation and exhalation of breathing.
- ▶ **External exchange of gases**, which occurs in the lungs as oxygen (O_2) diffuses from the air sacs into the blood and carbon dioxide (CO_2) diffuses out of the blood to be eliminated.
- ▶ **Internal exchange of gases**, which occurs in the tissues as oxygen diffuses from the blood to the cells,

whereas carbon dioxide passes from the cells into the blood.

Gas exchange requires close association of the respiratory system with the circulatory system, as the circulating blood is needed to transport oxygen to the cells and transport carbon dioxide back to the lungs.

The term *respiration* is also used to describe a related process that occurs at the cellular level. In **cellular respiration**, oxygen is taken into a cell and used in the breakdown of nutrients with the release of energy. Carbon dioxide is the waste product of cellular respiration (see Chapter 20's discussion of metabolism).

Checkpoint 18-1 What are the three phases of respiration?

The Respiratory System

The respiratory system is an intricate arrangement of spaces and passageways that conduct air into the lungs

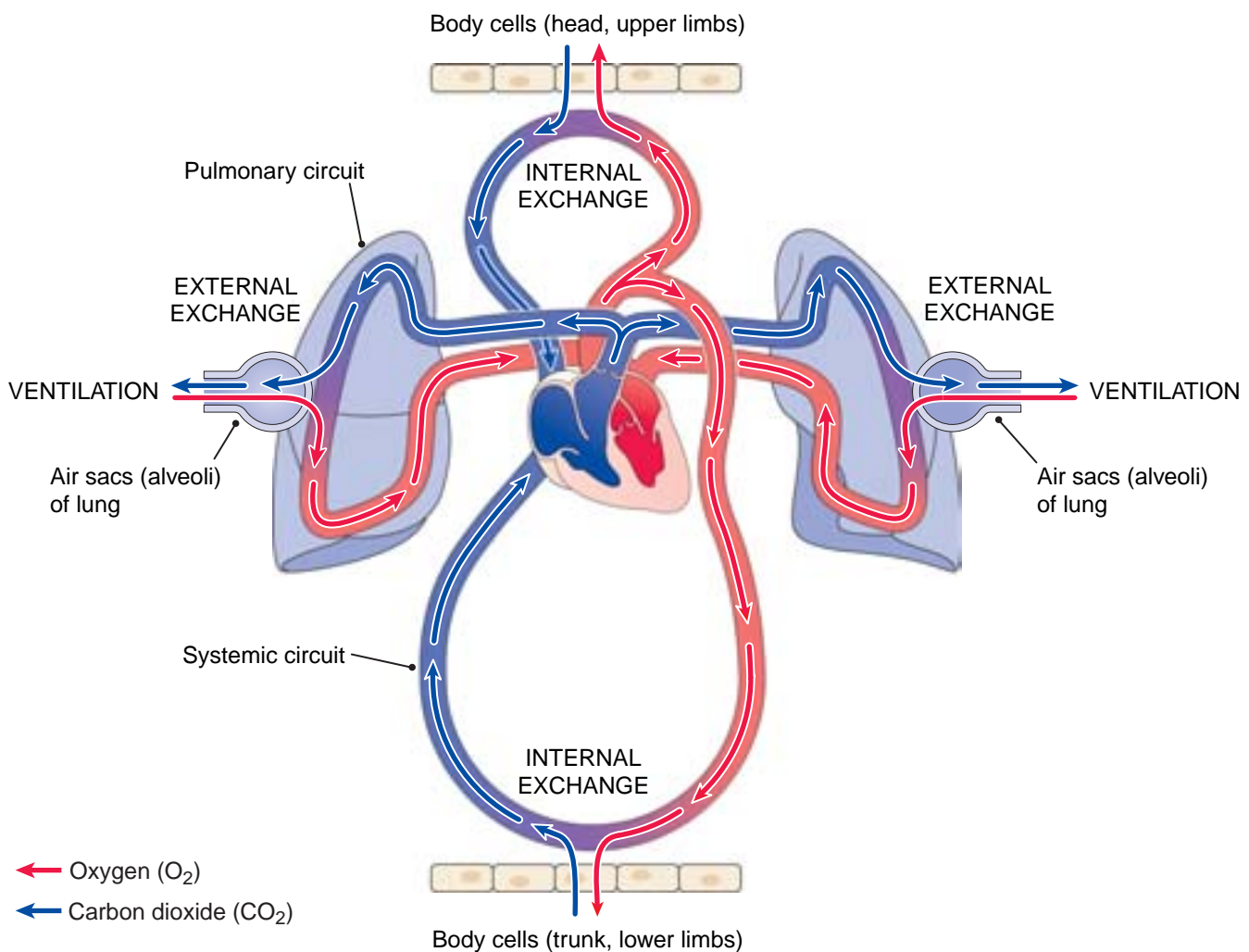


Figure 18-1 Overview of respiration. In ventilation, gases are moved into and out of the lungs. In external exchange, gases move between the air sacs (alveoli) of the lungs and the blood. In internal exchange, gases move between the blood and body cells. The circulation transports gases in the blood.

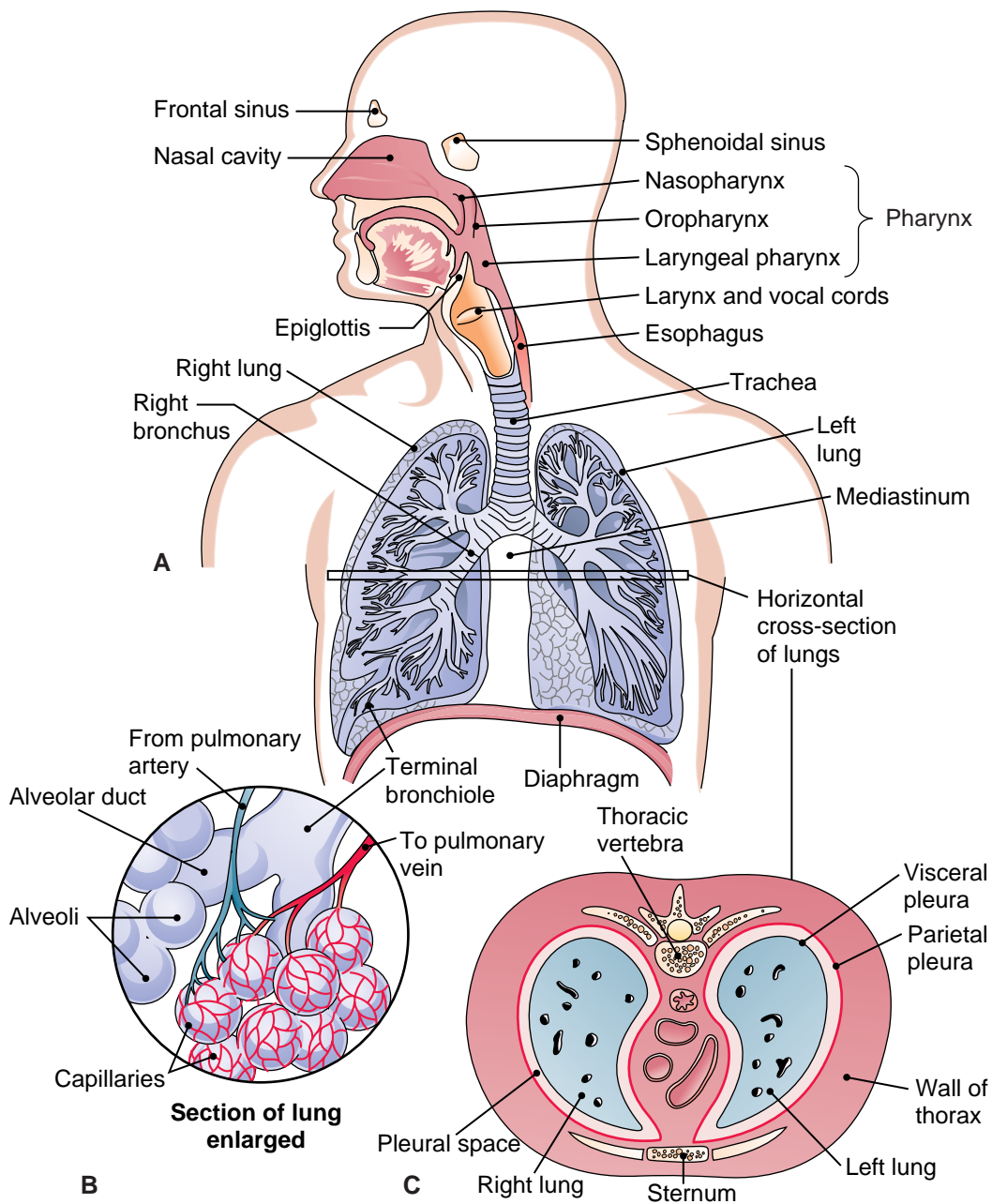


Figure 18-2 The respiratory system. (A) Overview. (B) Enlarged section of lung tissue showing the relationship between the alveoli (air sacs) of the lungs and the blood capillaries. (C) A transverse section through the lungs. **ZOOMING IN ♦** *What organ is located in the medial depression of the left lung?*

(Fig. 18-2). These spaces include the nasal cavities; the **pharynx** (FAR-inks), which is common to the digestive and respiratory systems; the voice box, or **larynx** (LAR-inks); the windpipe, or **trachea** (TRA-ke-ah); and the **lungs** themselves, with their conducting tubes and air sacs. The entire system might be thought of as a pathway for air between the atmosphere and the blood.

The Nasal Cavities

Air enters the body through the openings in the nose called the **nostrils**, or **nares** (NA-reze) (sing. naris). Im-

mediately inside the nostrils, located between the roof of the mouth and the cranium, are the two spaces known as the **nasal cavities**. These two spaces are separated from each other by a partition, the **nasal septum**. The superior portion of the septum is formed by a thin plate of the ethmoid bone that extends downward, and the inferior portion is formed by the vomer (see Fig. 7-5 A in Chapter 7). An anterior extension of the septum is made of hyaline cartilage. The septum and the walls of the nasal cavity are covered with mucous membrane. On the lateral walls of each nasal cavity are three projections called the **conchae** (KONG-ke) (see Figs. 7-5 A and 7-8 in Chapter 7). The

shell-like conchae greatly increase the surface area of the mucous membrane over which air travels on its way through the nasal cavities.

The mucous membrane lining the nasal cavities contains many blood vessels that deliver heat and moisture. The cells of this membrane secrete a large amount of fluid—up to 1 quart each day. The following changes are produced in the air as it comes in contact with the lining of the nose:

- ▶ Foreign bodies, such as dust particles and pathogens, are filtered out by the hairs of the nostrils or caught in the surface mucus.
- ▶ Air is warmed by blood in the well-vascularized mucous membrane.
- ▶ Air is moistened by the liquid secretion.

To allow for these protective changes to occur, it is preferable to breathe through the nose rather than through the mouth.

The **sinuses** are small cavities lined with mucous membrane in the skull bones. They are resonating chambers for the voice and lessen the weight of the skull. The sinuses communicate with the nasal cavities, and they are highly susceptible to infection.

Checkpoint 18-2 What happens to air as it passes over the nasal mucosa?

The Pharynx

The muscular **pharynx**, or throat, carries air into the respiratory tract and carries foods and liquids into the digestive system (see Fig. 18-2). The superior portion, located immediately behind the nasal cavity, is called the **nasopharynx** (na-zo-FAR-inks); the middle section, located posterior to the mouth, is called the **oropharynx** (o-ro-FAR-inks); and the most inferior portion is called the **laryngeal** (lah-RIN-je-al) **pharynx**. This last section opens into the larynx toward the anterior and into the esophagus toward the posterior.

The Larynx

The **larynx**, commonly called the *voice box* (Fig. 18-3), is located between the pharynx and the trachea. It has a framework of cartilage, part of which is the thyroid cartilage that protrudes in the front of the neck. The projection formed by the thyroid cartilage is commonly called the *Adam's apple* because it is considerably larger in the male than in the female.

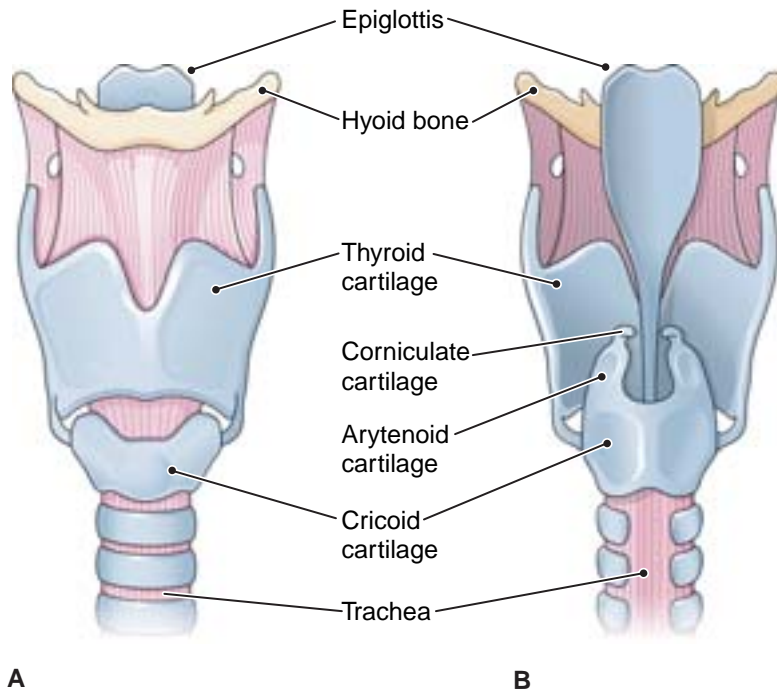


Figure 18-3 The larynx. (A) Anterior view. (B) Posterior view.

Folds of mucous membrane used in producing speech are located on both sides at the superior portion of the larynx. These are the vocal folds, or **vocal cords** (Fig. 18-4), which vibrate as air flows over them from the lungs. Variations in the length and tension of the vocal cords and the distance between them regulate the pitch of sound. The amount of air forced over them regulates volume. A difference in the size of the larynx and the vocal cords is what accounts for the difference between adult male and female voices. In general, a man's larynx is larger than a woman's. His vocal cords are thicker and longer, so they vibrate more slowly, resulting in a lower range of pitch. Muscles of the pharynx, tongue, lips, and face also are used to form clear pronunciations. The mouth, nasal cavities, paranasal sinuses, and the pharynx all serve as resonating chambers for speech, just as does the cabinet for an audio speaker.

The space between the vocal cords is called the **glottis** (GLOT-is). This is somewhat open during normal breathing but widely open during forced breathing (see Fig. 18-4). The little leaf-shaped cartilage that covers the larynx during swallowing is called the **epiglottis** (ep-ih-GLOT-is). The glottis and epiglottis help keep food and liquids out of the remainder of the respiratory tract. As the larynx moves upward and forward during swallowing, the epiglottis moves downward, covering the opening into the larynx. You can feel the larynx move upward toward the epiglottis during this process by placing the flat ends of your fingers on your larynx as you swallow. Muscles in the larynx assist in keeping foreign materials out of the respiratory tract by closing the glottis during swallowing. Muscles also close the glottis when one holds

his or her breath and strains, as to defecate or lift a heavy weight.

The Trachea

The **trachea**, commonly called the *windpipe*, is a tube that extends from the inferior edge of the larynx to the upper part of the chest superior to the heart. The trachea's purpose is to conduct air between the larynx and the lungs.

A framework of separate cartilages reinforces the trachea and keeps it open. These cartilages, each shaped somewhat like a tiny horseshoe or the letter C, are found along the trachea's entire length. The open sections in the cartilages are lined up at their posterior so that the esophagus can expand into this region during swallowing.

Checkpoint 18-3 What are the scientific names for the throat, voice box, and windpipe?

Checkpoint 18-4 What are the three regions of the pharynx?

The Bronchi

At its inferior end, the trachea divides into two primary, or main-stem, **bronchi** (BRONG-ki), which enter the lungs (see Fig. 18-2). The right bronchus is considerably larger in diameter than the left and extends downward in a more vertical direction. Therefore, if a foreign body is inhaled, it is likely to enter the right lung. Each bronchus enters the lung

at a notch or depression called the **hilum** (HI-lum). Blood vessels and nerves also connect with the lung in this region.

The Lining of the Air Passageways The trachea, bronchi, and other conducting passageways of the respiratory tract are lined with a special type of epithelium (Fig. 18-5). Basically, it is simple columnar epithelium, but the cells are arranged in such a way that they appear stratified. The tissue is thus described as *pseudostratified*, meaning “falsely stratified.” These epithelial cells have cilia to filter out impurities and to create fluid movement within the conducting tubes. The cilia beat to drive impurities toward the throat, where they can be swallowed or eliminated by coughing, sneezing, or blowing the nose.

Checkpoint 18-5 The cells that line the respiratory passageways help to keep impurities out of the lungs. What feature of these cells enables them to filter impurities and move fluids?

The Lungs

The **lungs** are the organs in which gas diffusion takes place through the extremely thin and delicate lung tissues (see Fig. 18-2). The two lungs are set side by side in the thoracic (chest) cavity. Between them are the heart, the great blood vessels, and other organs of the **mediastinum** (me-de-as-TI-num), the space between the lungs, including the esophagus, trachea, and lymph nodes.

On its medial side, the left lung has an indentation that accommodates the heart. The right lung is subdivided by fissures into three lobes; the left lung is divided into two lobes. Each lobe is then further subdivided into segments and then lobules. These subdivisions correspond to subdivisions of the bronchi as they branch throughout the lungs.

Each primary bronchus enters the lung at the hilum and immediately subdivides. The right bronchus divides into three secondary bronchi, each of which enters one of the three lobes of the right lung. The left bronchus gives rise to two secondary bronchi, which enter the two lobes of the left lung. Because the bronchial subdivisions resemble the branches of a tree, they have been given the common name *bronchial tree*. The bronchi subdivide again and again, becoming progressively smaller as they branch through lung tissue.

The smallest of these conducting tubes are called **bronchioles** (BRONG-ke-oles). The bronchi contain small

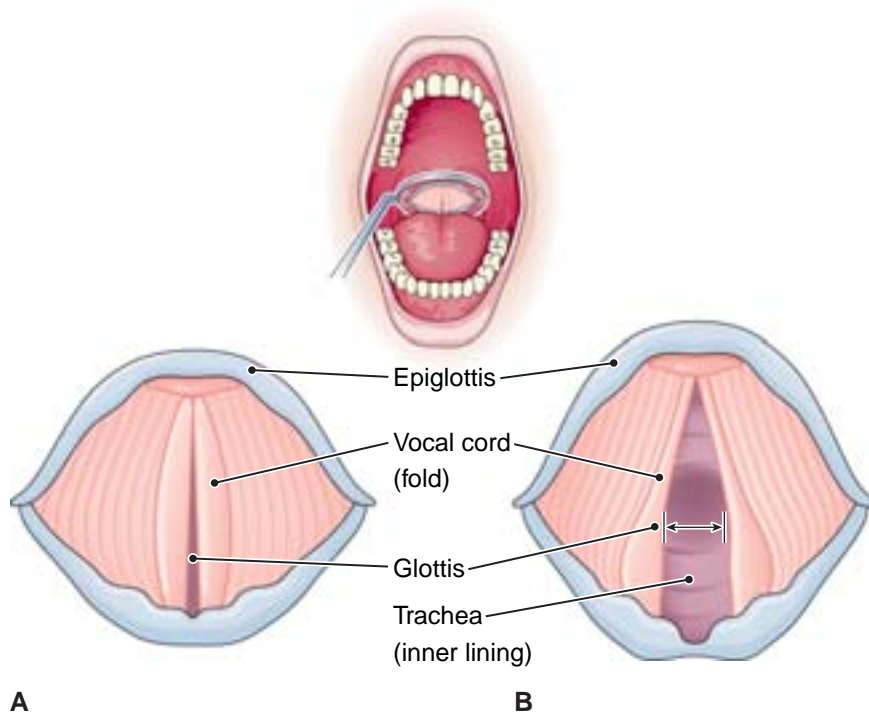


Figure 18-4 The vocal cords, superior view. (A) The glottis in closed position. (B) The glottis in open position. **ZOOMING IN** ♦ What cartilage is named for its position above the glottis?

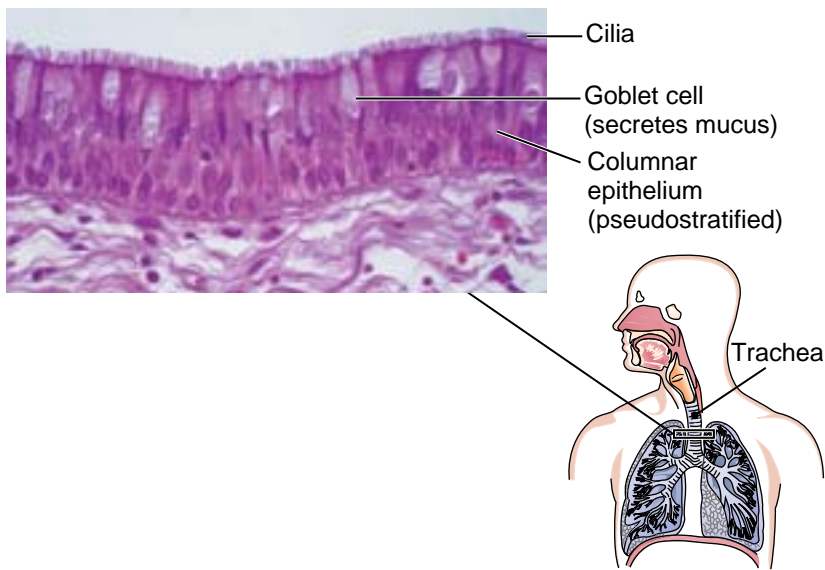


Figure 18-5 Microscopic view of ciliated epithelium. Ciliated epithelium lines the respiratory passageways, as shown here in the trachea. (Micrograph reprinted with permission from Cormack DH. *Essential Histology*. 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2001.)

bits of cartilage, which give firmness to their walls and hold the passageways open so that air can pass in and out easily. As the bronchi become smaller, however, the cartilage decreases in amount. In the bronchioles, there is no cartilage at all; what remains is mostly smooth muscle, which is under the control of the autonomic (involuntary) nervous system.

The Alveoli At the end of the terminal bronchioles, the smallest subdivisions of the bronchial tree, there are clusters of tiny air sacs in which most gas exchange takes place. These sacs are known as alveoli (al-VE-o-li) (sing. alveolus) (see Fig. 18-2). The wall of each alveolus is made of a single-cell layer of squamous (flat) epithelium. This thin wall provides easy passage for the gases entering and leaving the blood as the blood circulates through the millions of tiny capillaries covering the alveoli.

Certain cells in the alveolar wall produce **surfactant** (sur-FAK-tant), a substance that reduces the surface tension (“pull”) of the fluids that line the alveoli. This surface action prevents collapse of the alveoli and eases expansion of the lungs.

There are about 300 million alveoli in the human lungs. The resulting surface area in contact with gases approximates 60 square meters (some books say even more). This area is equivalent, as an example, to the floor surface of a classroom that measures about 24 by 24 feet. As with many other systems in the body, there is great functional reserve; we have about three times as much lung tissue as is minimally necessary to sustain life. Because of the many air spaces, the lung is light in weight; normally, a piece of lung tissue dropped into a glass of water will float. **Figure 18-6** shows a microscopic view of lung tissue.

The pulmonary circuit brings blood to and from the lungs. In the lungs, blood passes through the capillaries around the alveoli, where gas exchange takes place.

The Lung Cavities and Pleura

The lungs occupy a considerable portion of the thoracic cavity, which is separated from the abdominal cavity by the muscular partition known as the **diaphragm**. A continuous doubled sac, the **pleura**, covers each lung. The two layers of the pleura are named according to location. The portion of the pleura that is attached to the chest wall is the **parietal pleura**, and the portion that is attached to the surface of the lung is called the **visceral pleura**. Each closed sac completely surrounds the lung, except in the place where the bronchus and blood vessels enter the lung, a region known as the **root of the lung**.

Between the two layers of the pleura is the **pleural space** containing a thin film of fluid that lubricates the membranes. The effect of this fluid is the same as between two flat pieces of glass joined by a film of water; that is, the surfaces slide easily on each other but strongly resist separation. Thus, the lungs are able to move and enlarge effortlessly in response to changes in the thoracic volume that occur during breathing.

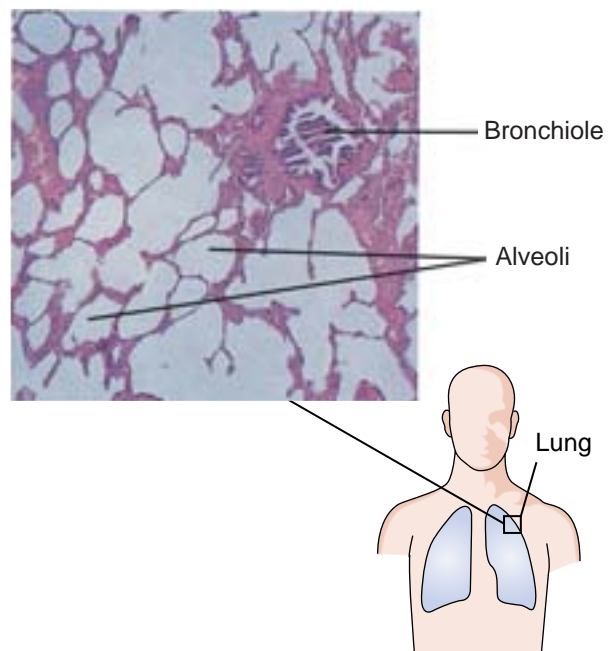


Figure 18-6 Lung tissue viewed through a microscope. (Micrograph courtesy of Dana Morse Bittus and BJ Cohen.)

Checkpoint 18-6 In what structures does gas exchange occur in the lung?

Checkpoint 18-7 What is the name of the membrane that encloses the lung?

► The Process of Respiration

Respiration involves ventilation of the lungs, exchange of gases, and their transport in the blood. Respiratory needs are met by central and peripheral controls of breathing.

Pulmonary Ventilation

Ventilation is the movement of air into and out of the lungs, normally accomplished by breathing. There are two phases of ventilation (Fig. 18-7):

- **Inhalation**, or inspiration, is the drawing of air into the lungs.
- **Exhalation**, or expiration, is the expulsion of air from the lungs.

In **inhalation**, the active phase of breathing, respiratory muscles contract to enlarge the thoracic cavity. During quiet breathing, the movement of the diaphragm accounts for most of the increase in thoracic volume. The diaphragm is a strong, dome-shaped muscle attached to the body wall around the base of the rib cage. The contraction and flattening of the diaphragm cause a piston-like downward motion that increases the vertical dimension of the chest. Other muscles that participate in breathing are the external and internal intercostal muscles. These muscles run at different angles in two layers between the ribs. As the external intercostals contract for inhalation, they lift the rib cage upward and outward. Put the palms of your hands on either side of the rib cage to feel this action as you inhale. During forceful inhalation, the rib cage is moved further up and out by contraction of muscles in the neck and chest wall.

As the thoracic cavity increases in size, gas pressure within the cavity decreases. This phenomenon follows a law in physics stating that when the volume of a given amount of gas increases, the pressure of the gas decreases. Conversely, when the volume

decreases, the pressure increases. If you blow air into a tight balloon that does not expand very much, the gas particles are in close contact and will hit the wall of the balloon frequently, creating greater pressure (Fig. 18-8). If you tap this balloon, it will spring back to its original shape. When you blow into a soft balloon that expands easily under pressure, the gas particles spread out into a larger area and will not hit the balloon's wall as often. If you tap the balloon, your finger will make an indentation. Thus, pressure in the chest cavity drops as the thorax expands. When the pressure drops to slightly below the air pressure outside the lungs, air is drawn into the lungs, as by suction.

The ease with which one can expand the lungs and thorax is called **compliance**. Normal elasticity of the lung tissue, aided by surfactant, allows the lungs to expand under pressure and fill adequately with air during inhalation. Compliance is decreased when the lungs resist expansion. Conditions that can decrease compliance include diseases that damage or scar lung tissue, fluid accumulation in the lungs, deficiency of surfactant, and interference with the action of breathing muscles.

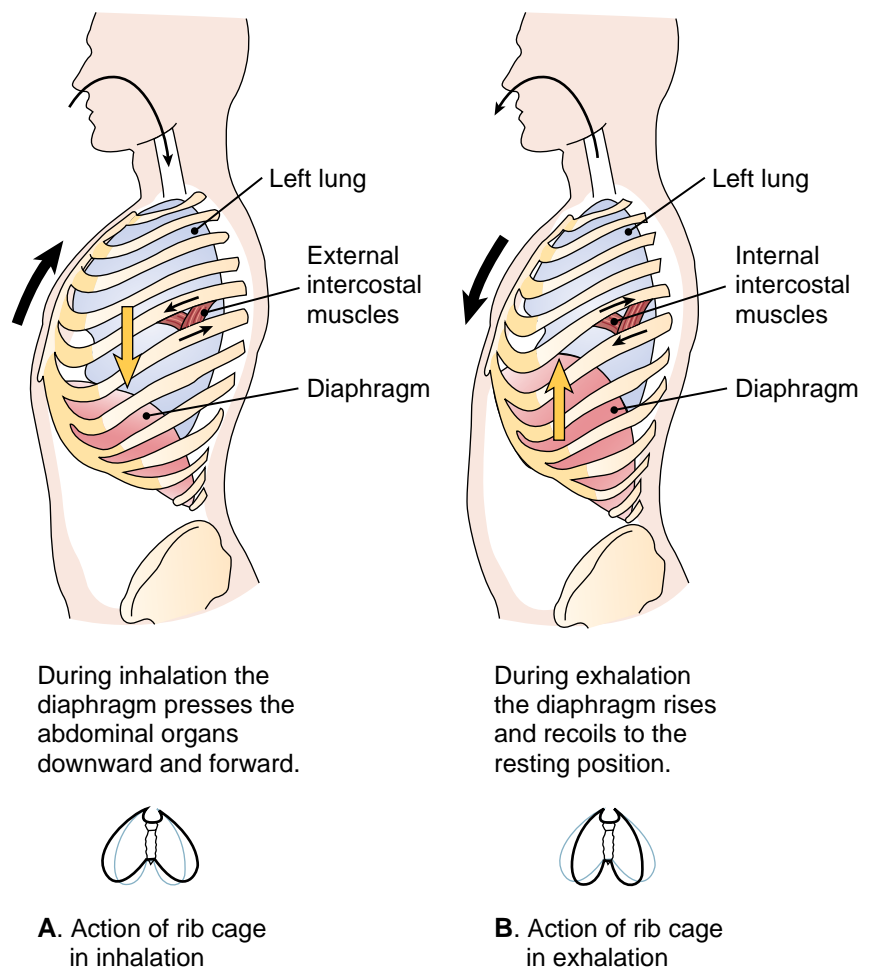


Figure 18-7 Pulmonary ventilation. (A) Inhalation. (B) Exhalation. **ZOOMING IN** ♦ What muscles are located between the ribs?

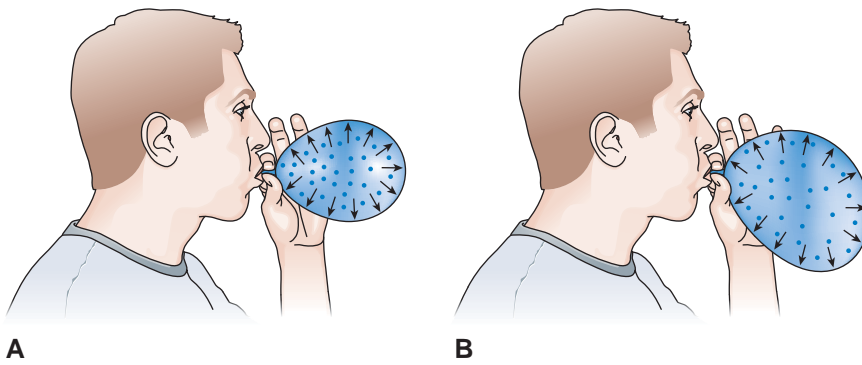


Figure 18-8 The relationship of gas pressure to volume. (A) Inflation of a stiff balloon creates strong air pressure against the wall of the balloon. (B) The same amount of air in a soft balloon spreads out into the available space, resulting in lower gas pressure. **ZOOMING IN** ♦ What happens to gas pressure as the volume of its container increases?

Air enters the respiratory passages and flows through the ever-dividing tubes of the bronchial tree. As the air traverses this route, it moves more and more slowly through the great number of bronchial tubes until there is virtually no forward flow as it reaches the alveoli. The incoming air mixes with the residual air remaining in the respiratory passageways, so that the gases soon are evenly distributed. Each breath causes relatively little change in the gas composition of the alveoli, but normal continuous breathing ensures the presence of adequate oxygen and the removal of carbon dioxide.

In **exhalation**, the passive phase of breathing, the respiratory muscles relax, allowing the ribs and diaphragm to return to their original positions. The lung tissues are elastic and recoil to their original size during exhalation.

Surface tension within the alveoli aids in this return to resting size. During forced exhalation, the internal intercostal muscles contract, pulling the bottom of the rib cage in and down. The muscles of the abdominal wall contract, pushing the abdominal viscera upward against the relaxed diaphragm.

Table 18-1 gives the definitions and average values for some of the breathing volumes and capacities that are important in evaluating respiratory function. A lung *capacity* is a sum of volumes. These same values are shown on a graph as they might appear on a tracing made by a **spirometer** (spi-ROM-eh-ter), an instrument for recording lung volumes (Fig. 18-9). The tracing is a **spirogram** (SPI-ro-gram).

Checkpoint 18-8 What are the two phases of breathing? Which is active and which is passive?

Gas Exchange

External exchange is the movement of gases between the alveoli and the capillary blood in the lungs (see Fig. 18-1). The barrier that separates alveolar air from the blood is composed of the alveolar wall and the capillary wall, both of which are extremely thin. This respiratory membrane is not only very thin, it is also moist. The moisture is important because the oxygen and carbon dioxide must

go into solution before they can diffuse across the membrane. Recall that **diffusion** refers to the movement of molecules from an area in which they are in higher concentration to an area in which they are in lower concentration. Therefore, the relative concentrations of a gas on the two sides of a membrane determine the direction of diffusion. Normally, inspired air contains about 21% oxygen and 0.04% carbon dioxide; expired air has only 16% oxygen and 3.5% carbon dioxide. These values illustrate that a two-way diffusion takes place through the walls of the alveoli and capillaries (Fig. 18-10).

Internal exchange takes place between the blood and the tissues. In metabolism, the cells constantly consume oxygen and produce carbon dioxide. Based on relative concentrations of these gases, oxygen diffuses out of the blood and carbon dioxide enters.

Table 18-1 Lung Volumes and Capacities

VOLUME	DEFINITION	AVERAGE VALUE (mL)
Tidal volume	The amount of air moved into or out of the lungs in quiet, relaxed breathing	500
Residual volume	The volume of air that remains in the lungs after maximum exhalation	1200
Inspiratory reserve volume	The additional amount that can be breathed in by force after a normal inhalation	2600
Expiratory reserve volume	The additional amount that can be breathed out by force after a normal exhalation	900
Vital capacity	The volume of air that can be expelled from the lungs by maximum exhalation after maximum inhalation	4000
Functional residual capacity	The amount of air remaining in the lungs after normal exhalation	2100
Total lung capacity	The total volume of air that can be contained in the lungs after maximum inhalation	5200

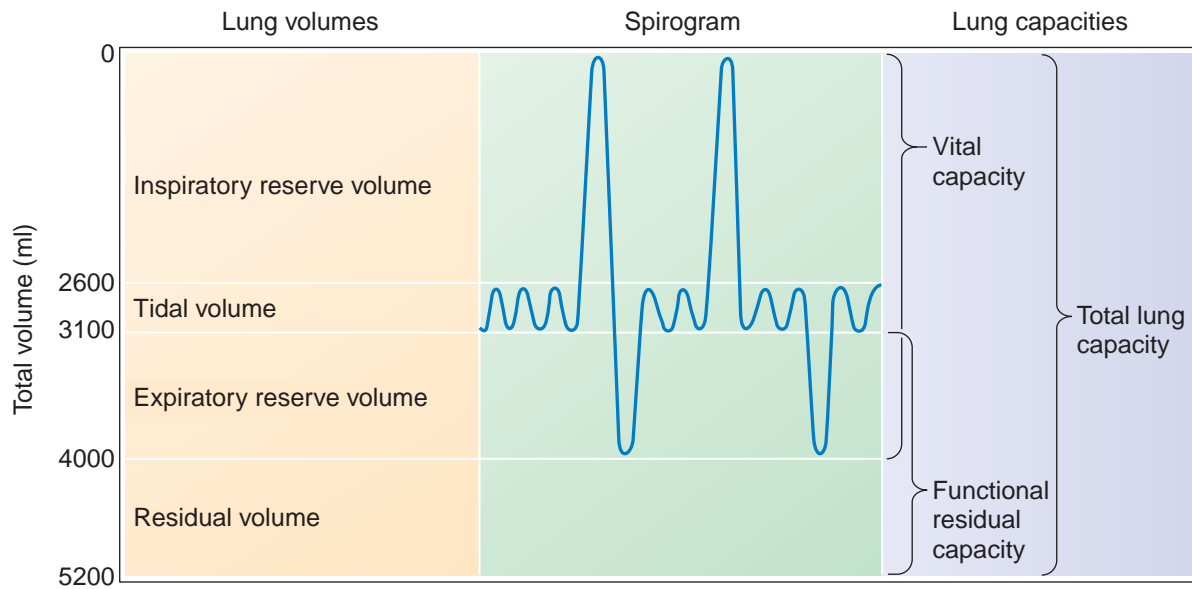


Figure 18-9 A spirogram. The tracing of lung volumes is made with a spirometer. **ZOOMING IN ♦** What lung volume cannot be measured with a spirometer?

At this point, blood returning from the tissues and entering the lung capillaries through the pulmonary circuit is relatively low in oxygen and high in carbon dioxide. Again, the blood will pick up oxygen and give up carbon dioxide. After a return to the left side of the heart,

it starts once more on its route through the systemic circuit.

Checkpoint 18-9 Gases move between the alveoli and the blood by the process of diffusion. What is the definition of diffusion?

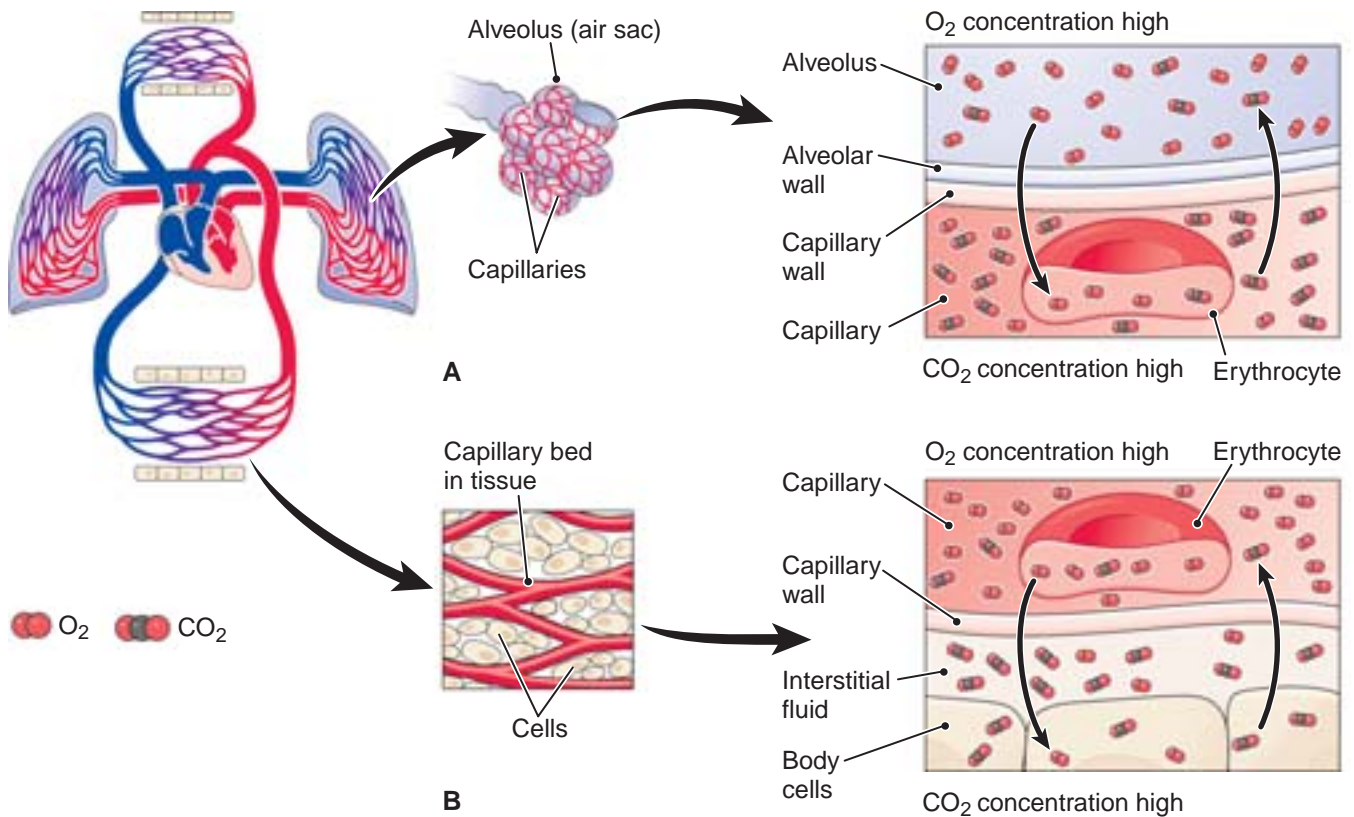


Figure 18-10 Gas exchange. **(A)** External exchange between the alveoli and the blood. Oxygen diffuses into the blood and carbon dioxide diffuses out, based on concentrations of the two gases in the alveoli and in the blood. **(B)** Internal exchange between the blood and the cells. Oxygen diffuses out of the blood and into tissues, while carbon dioxide diffuses from the cells into the blood.

Transport of Oxygen

A very small percentage (1.5%) of the oxygen in the blood is carried in solution in the plasma. (Oxygen does dissolve in water, as shown by the fact that aquatic animals get their oxygen from water.) However, almost all (98.5%) of the oxygen that diffuses into the capillary blood in the lungs binds to **hemoglobin** in the red blood cells. If not for hemoglobin and its ability to hold oxygen in the blood, the heart would have to work much harder to supply enough oxygen to the tissues. The hemoglobin molecule is a large protein with four small iron-containing “heme” regions. Each heme portion can bind one molecule of oxygen.

Oxygenated blood (in systemic arteries and pulmonary veins) is 97% saturated with oxygen. That is, the total hemoglobin in the red cells is holding 97% of the maximum amount that it can hold. Deoxygenated blood (in systemic veins and pulmonary arteries) is usually about 70% saturated with oxygen. This 27% difference represents the oxygen that has been taken up by the cells. Note, however, that even blood that is described as deoxygenated still has a reserve of oxygen. Even under conditions of high oxygen consumption, as in vigorous exercise, for example, the blood is never totally depleted of oxygen.

In clinical practice, gas concentrations are expressed as pressure in millimeters of mercury (mmHg), as is blood pressure. Because air is a mixture of gases, each gas exerts only a portion of the total pressure, or a **partial pressure** (P). The partial pressures of oxygen and carbon dioxide are symbolized as P_{O_2} and P_{CO_2} respectively.

To enter the cells, oxygen must separate from hemoglobin. Normally, the bond between oxygen and hemoglobin is easily broken, and oxygen is released as blood travels into areas where the oxygen concentration is relatively low. Cells are constantly using oxygen in metabolism and obtaining fresh supplies by diffusion from the blood.

The poisonous gas, carbon monoxide (CO) at low partial pressure binds with hemoglobin at the same sites as does oxygen. However, it binds more tightly and displaces oxygen. Even a small amount of carbon monoxide causes a serious reduction in the blood's ability to carry oxygen.

For an interesting variation on normal gas transport, see Box 18-1 on liquid ventilation.

Checkpoint 18-10 What substance in red blood cells carries almost all of the oxygen in the blood?

Transport of Carbon Dioxide

Carbon dioxide is produced continuously in the tissues as a byproduct of metabolism. It diffuses from the cells into the blood and is transported to the lungs in three ways:

- About 10% is dissolved in the plasma and in the fluid within red blood cells. (Carbonated beverages are examples of water in which CO_2 is dissolved.)
- About 15% is combined with the protein portion of hemoglobin and plasma proteins.
- About 75% is transported as an ion, known as a **bicarbonate ion**, which is formed when carbon dioxide undergoes a chemical change after it dissolves in blood fluids.

The bicarbonate ion is formed slowly in the plasma but much more rapidly inside the red blood cells, where an enzyme called **carbonic anhydrase** (an-HI-drase) increases the speed of the reaction. The bicarbonate formed in the red blood cells moves to the plasma and then is carried to the lungs. In the lungs, the process is reversed as bicarbonate reenters the red blood cells and releases carbon dioxide for diffusion into the alveoli and exhalation. For those with a background in chemistry, the equation for these reactions follows. The arrows going in both directions signify that the reactions are reversible. The

Box 18-1 Clinical Perspectives

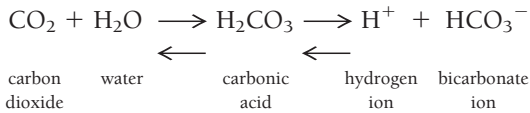
Liquid Ventilation: Breath in a Bottle

Researchers have been attempting for years to develop a fluid that could transport high concentrations of oxygen in the body. Such a fluid could substitute for blood in transfusions or be used to carry oxygen into the lungs. Early work on liquid ventilation climaxed in the mid-1960s when a pioneer in this field submerged a laboratory mouse in a beaker of fluid and the animal survived total immersion for more than 10 minutes. The fluid was a synthetic substance that could hold as much oxygen as does air.

A newer version of this fluid, a fluorine-containing chemi-

cal known as PFC, has been tested to ventilate the collapsed lungs of premature babies. In addition to delivering oxygen to the lung alveoli, it also removes carbon dioxide. The fluid is less damaging to delicate lung tissue than is air, which has to be pumped in under higher pressure. Others who might benefit from liquid ventilation include people whose lungs have been damaged by infection, inhaled toxins, asthma, emphysema, and lung cancer, but more clinical research is required. Scientists are also investigating whether liquid ventilation could be used to deliver drugs directly to lung tissue.

upper arrows describe what happens as CO_2 enters the blood; the lower arrows indicate what happens as CO_2 is released from the blood to be exhaled from the lungs.



Carbon dioxide is important in regulating the blood's pH (acid–base balance). As a bicarbonate ion is formed from carbon dioxide in the plasma, a hydrogen ion (H^+) is also produced. Therefore, the blood becomes more acidic as the amount of carbon dioxide in the blood increases to yield more hydrogen and bicarbonate ions. The exhalation of carbon dioxide shifts the blood's pH more toward the alkaline (basic) range. The bicarbonate ion is also an important buffer in the blood, acting chemically to help keep the pH of body fluids within a steady range of 7.35 to 7.45.

Checkpoint 18-11 What is the main form in which carbon dioxide is carried in the blood?

Regulation of Respiration

Centers in the central nervous system control the fundamental respiratory pattern. This pattern is modified by special receptors that detect changes in the blood's chemical composition.

Nervous Control Regulation of respiration is a complex process that must keep pace with moment-to-moment changes in cellular oxygen requirements and carbon dioxide production. Regulation depends primarily on a respiratory control center located partly in the medulla and partly in the pons of the brain stem. The control center's main part, located in the medulla, sets the basic pattern of respiration. This pattern can be modified by centers in the pons. These areas continuously regulate breathing, so that levels of oxygen, carbon dioxide, and acid are kept within normal limits.

From the respiratory center in the medulla, motor nerve fibers extend into the spinal cord. From the cervical (neck) part of the cord, these nerve fibers continue through the **phrenic** (FREN-ik) nerve (a branch of the vagus nerve) to the diaphragm. The diaphragm and the other respiratory muscles are voluntary in the sense that they can be regulated consciously by messages from the higher brain centers, notably the cerebral cortex. It is possible for a person to deliberately breathe more rapidly or more slowly or to hold his or her breath and not breathe at all for a while. In a short time, however, the respiratory center in the brain stem will override the voluntary desire to not breathe, and breathing will resume. Most of the time, we breathe without thinking about it, and the respiratory center is in control.

Checkpoint 18-12 What part of the brain stem sets the basic pattern of respiration?

Checkpoint 18-13 What is the name of the motor nerve that controls the diaphragm?

Chemical Control Of vital importance in the control of respiration are **chemoreceptors** (ke-mo-re-SEP-tors) which, like the receptors for taste and smell, are sensitive to chemicals dissolved in body fluids. The chemoreceptors that regulate respiration are located centrally (near the brain stem) and peripherally (in arteries).

The central chemoreceptors are on either side of the brain stem near the medullary respiratory center. These receptors respond to the CO_2 level in circulating blood, but the gas acts indirectly. CO_2 is capable of diffusing through the capillary blood-brain barrier. It dissolves in CSF (the fluid in and around the brain) and separates into hydrogen ion and bicarbonate ion, as explained previously. It is the presence of hydrogen ion and its effect in lowering pH that actually stimulates the central chemoreceptors. The rise in blood CO_2 level, known as **hypercapnia** (hi-per-KAP-ne-ah), thus triggers ventilation.

The peripheral chemoreceptors that regulate respiration are found in structures called the *carotid* and *aortic bodies*. The carotid bodies are located near the bifurcation (forking) of the common carotid arteries in the neck, whereas the aortic bodies are located in the aortic arch. These bodies contain sensory neurons that respond mainly to a decrease in oxygen supply. They are not usually involved in regulating breathing, because they don't act until oxygen drops to a very low level. Because there is usually an ample reserve of oxygen in the blood, carbon dioxide has the most immediate effect in regulating respiration at the level of the central chemoreceptors. When the carbon dioxide level increases, breathing must be increased to blow off the excess gas. Oxygen only becomes a controlling factor when its level falls considerably below normal.

Checkpoint 18-14 What gas is the main chemical controller of respiration?

Abnormal Ventilation

In **hyperventilation** (hi-per-ven-tih-LA-shun), an increased amount of air enters the alveoli. This condition results from deep and rapid respiration that commonly occurs during anxiety attacks, or when a person is experiencing pain or other forms of stress. Hyperventilation causes an increase in the oxygen level and a decrease in the carbon dioxide level of the blood, a condition called **hypocapnia** (hi-po-KAP-ne-ah). The loss of carbon dioxide increases the blood's pH (alkalosis) by removing acidic products, as shown by the equation cited previously. The change in pH results in dizziness and tingling

sensations. Breathing may stop because the respiratory control center is not stimulated. Gradually, the carbon dioxide level returns to normal, and a regular breathing pattern is resumed. In extreme cases, a person may faint, and then breathing will involuntarily return to normal. In assisting a person who is hyperventilating, one should speak calmly, reassure him or her that the situation is not dangerous, and encourage even breathing from the diaphragm.

In **hypoventilation**, an insufficient amount of air enters the alveoli. The many possible causes of this condition include respiratory obstruction, lung disease, injury to the respiratory center, depression of the respiratory center, as by drugs, and chest deformity. Hypoventilation results in an increase in the carbon dioxide concentration in the blood, leading to a decrease in the blood's pH (acidosis), again according to the equation previously mentioned.

Breathing Patterns

Normal rates of breathing vary from 12 to 20 times per minute for adults. In children, rates may vary from 20 to 40 times per minute, depending on age and size. In infants, the respiratory rate may be more than 40 times per minute. Changes in respiratory rates are important in various disorders and should be recorded carefully. To determine the respiratory rate, the healthcare worker counts the client's breathing for at least 30 seconds, usually by watching the chest rise and fall with each inhalation and exhalation. The count is then multiplied to obtain the rate in breaths per minute. It is best if the person does not realize that he or she is being observed because awareness of the measurement may cause a change in the breathing rate.

Some Terms for Altered Breathing The following is a list of terms designating various abnormalities of res-

piration. These are symptoms, not diseases. Note that the word ending *-pnea* refers to breathing.

- ♦ **Hyperpnea** (hi-PERP-ne-ah) refers to an abnormal increase in the depth and rate of respiration.
- ♦ **Hypopnea** (hi-POP-ne-ah) is a decrease in the rate and depth of breathing.
- ♦ **Tachypnea** (tak-IP-ne-ah) is an excessive rate of breathing that may be normal, as in exercise.
- ♦ **Apnea** (AP-ne-ah) is a temporary cessation of breathing. Short periods of apnea occur normally during deep sleep. More severe sleep apnea can result from obstruction of the respiratory passageways or, less commonly, by failure in the central respiratory center.
- ♦ **Dyspnea** (disp-NE-ah) is a subjective feeling of difficult or labored breathing.
- ♦ **Orthopnea** (or-THOP-ne-ah) refers to a difficulty in breathing that is relieved by sitting in an upright position, either against two pillows in bed or in a chair.
- ♦ **Kussmaul** (KOOS-mowl) **respiration** is deep, rapid respiration characteristic of acidosis (overly acidic body fluids) as seen in uncontrolled diabetes.
- ♦ **Cheyne-Stokes** (CHANE-stokes) **respiration** is a rhythmic variation in the depth of respiratory movements alternating with periods of apnea. It is caused by depression of the breathing centers and is seen in certain critically ill patients.

Results of Inadequate Breathing Conditions that may result from decreased respiration include the following:

- ♦ **Cyanosis** (si-ah-NO-sis) is a bluish color of the skin and mucous membranes caused by an insufficient amount of oxygen in the blood.
- ♦ **Hypoxia** (hi-POK-se-ah) means a lower than normal oxygen level in the tissues. The term anoxia (ah-NOK-se-ah) is sometimes used instead, but is not as accurate because it means a total lack of oxygen.

Box 18-2 A Closer Look

Adaptations to High Altitude: Living With Hypoxia

Our bodies work best at low altitudes where oxygen is plentiful. However, people are able to live at high altitudes where oxygen is scarce and can even survive climbing Mount Everest, the tallest peak on our planet, showing that the human body can adapt to hypoxic conditions. This adaptation process compensates for decreased atmospheric oxygen by increasing the efficiency of the respiratory and cardiovascular systems.

The body's immediate response to high altitude is to increase the rate of ventilation (hyperventilation) and raise heart rate to increase cardiac output. Hyperventilation makes more oxygen available to the cells and increases blood pH (al-

kalosis), which boosts hemoglobin's capacity to bind oxygen. Over time, the body adapts in additional ways. Hypoxia stimulates the kidneys to secrete erythropoietin, prompting red bone marrow to manufacture more erythrocytes and hemoglobin. Also, capillaries proliferate, increasing blood flow to the tissues. Some people are unable to adapt to high altitudes, and for them, hypoxia and alkalosis lead to potentially fatal **altitude sickness**.

Successful adaptation to high altitude illustrates the principle of homeostasis and also helps to explain how the body adjusts to hypoxia associated with disorders such as chronic obstructive pulmonary disease.

- ▶ **Hypoxemia** (hi-pok-SE-me-ah) refers to a lower than normal oxygen concentration in arterial blood.
- ▶ **Suffocation** is the cessation of respiration, often the result of a mechanical blockage of the respiratory passages.

Box 18-2 offers information on adjusting to high altitudes and other hypoxic conditions.

Disorders of the Respiratory System

Infection is a major cause of respiratory disorders. These may involve any portion of the system. Allergies and environmental factors also affect respiration, and lung cancer is a major cause of cancer deaths in both men and women.

Disorders of the Nasal Cavities and Related Structures

The paranasal sinuses are located in the skull bones in the vicinity of the nasal cavities. Infection may easily travel into these sinuses from the mouth, nose, and throat along the mucous membranes that line them. The resulting inflammation is called **sinusitis**. Chronic (long-standing) sinus infection may cause changes in the epithelial cells, resulting in tumor formation. Some of these growths have a grapelike appearance and cause obstruction of the air pathway; these tumors are called **polyps** (POL-ips).

The partition separating the two nasal cavities is called the *nasal septum*. Because of minor structural defects, the nasal septum is rarely exactly in the midline. If it is markedly to one side, it is described as a **deviated septum**. In this condition, one nasal space may be considerably smaller than the other. If an affected person has an attack of hay fever or develops a cold with accompanying swelling of the mucosa, the smaller nasal cavity may be completely closed. Sometimes, the septum is curved in such a way that both nasal cavities are occluded, forcing the person to breathe through his or her mouth. Such an occlusion may also prevent proper drainage from the sinuses and aggravate a case of sinusitis.

The most common cause of nosebleed, also called **epistaxis** (ep-e-STAK-sis) (from a Greek word meaning “to drip”), is injury to the mucous membranes in the nasal cavity. Causes of injury include infection, drying of the membranes, picking the nose, or other forms of trauma. These simple nosebleeds usually stop on their own, but some measures that help are applying pressure to the upper lip under the nose, pinching the nose together, or applying ice to the forehead. Epistaxis may signal more serious problems, such as blood clotting abnormalities, excessively high blood pressure, or tumors. Serious injuries that lead to nosebleed, or a nose-

bleed that will not stop, require professional medical care. Treatment may include packing the nose with gauze or other material, administering vasoconstrictors, or cauterizing the wound.

Infection

The respiratory tract mucosa is one of the most important portals of entry for disease-producing organisms. The transfer of disease organisms from the respiratory system of one person to that of another occurs most rapidly in crowded places, such as schools, theaters, and institutions. Droplets from one sneeze may be loaded with many billions of disease-producing organisms.

To some degree, the mucous membranes can protect themselves by producing larger quantities of mucus. The runny nose, an unpleasant symptom of the common cold, is the body’s attempt to wash away the pathogens and protect deeper tissues from further infection. If the resistance of the mucous membrane is reduced, however, the membrane may act as a pathway for the spread of disease. The infection may travel along the membrane into the nasal sinuses, or middle ear, along the respiratory passageways, or into the lung. Each infection is named according to the part involved, such as pharyngitis (commonly called a *sore throat*), laryngitis, or bronchitis.

Among the infections transmitted through the respiratory passageways are the common cold, diphtheria, chickenpox, measles, influenza, pneumonia, and tuberculosis. Any infection that is confined to the nose and throat is called an **upper respiratory infection** (URI). Very often, an upper respiratory infection is the first evidence of infectious disease in children. Such an infection may precede the onset of a serious disease, such as rheumatic fever, which may follow a streptococcal throat infection.

The Common Cold The common cold is the most widespread of all respiratory diseases—of all communicable diseases, for that matter. More time is lost from school and work because of the common cold than any other disorder. (See Box 5-2 in Chapter 5: The Cold Facts About the Common Cold.) The causative agents are viruses that probably number more than 200 different types. Medical science has yet to establish the effectiveness of any method for preventing the common cold. Because there are so many organisms involved, the production of an effective vaccine against colds seems unlikely.

The symptoms of the common cold are familiar: first the swollen and inflamed mucosa of the nose and the throat, then the copious discharge of watery fluid from the nose, and finally the thick and ropy discharge that occurs when the cold is subsiding. The scientific name for the common cold is **acute coryza** (ko-RI-zah); the word coryza can also mean simply “a nasal discharge.”

Respiratory Syncytial Virus (RSV) RSV is the most common cause of lower respiratory tract infections in in-

infants and young children worldwide. The name comes from the fact that the virus induces fusion of cultured cells (formation of a syncytium) when grown in the laboratory. Infection may result in bronchiolitis or pneumonia, but the virus may affect the upper respiratory tract as well. Most susceptible are premature infants, those with congenital heart disease, and those who are immunodeficient. Exposure to cigarette smoke is a definite risk factor.

The virus usually enters through the eyes and nose following contact with contaminated air, nasal secretions or objects. The incubation period is 3 to 5 days, and an infected person sheds virus particles during the incubation period and up to 2 weeks thereafter. Thorough hand-washing helps to reduce spread of the virus. Infection usually resolves in 5 to 7 days, although some cases require hospitalization and antiviral drug treatments.

Croup Croup usually affects children under 3 years of age and is associated with a number of different infections that result in upper respiratory inflammation. Constriction of the airways produces a loud, barking cough, wheezing, difficulty in breathing, and hoarseness. If croup is severe, the child may produce a harsh, squeaking noise (stridor) when breathing in through a narrowed trachea. Viral infections, such as those involving parainfluenza, adenovirus, RSV, influenza, or measles, are usually the cause. Although croup may be frightening to parents and children, recovery is complete in most cases within a week. Home treatments include humidifying room air or having the child breathe in steam. Also, cool air may shrink the respiratory tissues enough to bring relief.

Influenza Influenza (in-flu-EN-zah), or “flu,” is an acute contagious disease characterized by an inflammatory condition of the upper respiratory tract accompanied by generalized aches and pains. It is caused by a virus and may spread to the sinuses and downward to the lungs. Inflammation of the trachea and the bronchi causes the characteristic cough of influenza, and the general infection causes an extremely weakened condition. The great danger of influenza is its tendency to develop into a particularly severe form of pneumonia. At intervals in history, there have been tremendous epidemics of influenza in which millions of people have died. Vaccines have been effective, although the protection is of short duration.

Pneumonia Pneumonia (nu-MO-ne-ah) is an inflammation of the lungs in which the air spaces become filled with fluid. A variety of organisms, including staphylococci, pneumococci, streptococci, *Legionella pneumophila* (as in Legionnaires disease), chlamydias, and viruses may be responsible. Many of these pathogens may be carried by a healthy person in the mucosa of the upper respiratory tract. If the person remains in good health, they may be carried for a long time with no ill effect. If the patient’s resistance to infection is lowered, however, the pathogens may invade the tissues and cause disease.

Susceptibility to pneumonia is increased in patients with chronic, debilitating illness or chronic respiratory disease, in smokers, and in people with alcoholism. It is also increased in cases of exposure to toxic gases, suppression of the immune system, or viral respiratory infections.

There are two main kinds of pneumonia as determined by the extent of lung involvement and other factors:

- **Bronchopneumonia**, in which the disease process is scattered throughout the lung. The cause may be infection with a staphylococcus, gram-negative *Proteus* species, colon bacillus (not normally pathogenic), or a virus. Bronchopneumonia most often is secondary to an infection or to some agent that has lowered the patient’s resistance to disease. This is the most common form of pneumonia.
- **Lobar pneumonia**, in which an entire lobe of the lung is infected at one time. The causative organism is usually a pneumococcus, although other pathogens may also cause this disease. *Legionella* is the causative agent of a severe lobar pneumonia that occurs mostly in localized epidemics.

Most types of pneumonia are characterized by the formation of a fluid, or **exudate**, in the infected alveoli; this fluid consists chiefly of serum and pus, products of infection. Some red blood cells may be present, as indicated by red streaks in the sputum. Sometimes, so many air sacs become filled with fluid that the victim finds it hard to absorb enough oxygen to maintain life.

Pneumocystis Pneumonia (PCP) PCP occurs mainly in people with weakened immune systems, such as HIV-positive individuals or transplant recipients on immunosuppressant drugs. The infectious agent was originally called *P. carinii* and classified as a protozoon. It has now been reclassified as an atypical fungus and renamed *P. jiroveci*. The organism grows in the fluid that lines the alveoli of the lungs. Laboratories diagnose the disease by microscopic identification of the organism in a sputum sample, bronchoscopy specimen, or lung biopsy specimen. PCP is treated with antimicrobial drugs, although these medications may cause serious side effects in immunocompromised patients.

Tuberculosis Tuberculosis (tu-ber-ku-LO-sis) (TB) is an infectious disease caused by the bacillus *Mycobacterium tuberculosis*. Although the tubercle bacillus may invade any body tissue, it usually grows in the lung. Tuberculosis remains a leading cause of death from communicable disease, primarily because of the relatively large numbers of cases among recent immigrants, elderly people, and poor people in metropolitan areas. The spread of AIDS has been linked with a rising incidence of TB because this viral disease weakens host defenses.

The name *tuberculosis* comes from the small lesions, or tubercles, that form where the organisms grow. If unchecked, these lesions degenerate and may even liquefy to cause cavities within an organ. In early stages, the disease may lie dormant, only to flare up at a later time. The tuberculosis organism can readily spread into the lymph nodes or into the blood and be carried to other organs. The lymph nodes in the thorax, especially those surrounding the trachea and bronchi, are frequently involved. Infection of the pleura results in tuberculous pleurisy (inflammation of the pleura). In this case, a collection of fluid, known as an **effusion** (e-FU-zhun), accumulates in the pleural space.

Drugs can be used successfully in many cases of tuberculosis, although strains of the TB organism that are resistant to multiple antibiotics have appeared recently. The best results have been obtained by use of a combination of several drugs, with prompt, intensive, and uninterrupted treatment once a program is begun. Therapy is usually continued for a minimum of 6 to 18 months; therefore, close supervision by the healthcare practitioner is important. Adverse drug reactions are rather common, necessitating changes in the drug combinations. Drug treatment of patients whose infection has not progressed to active disease is particularly effective.

Hay Fever and Asthma

Hypersensitivity to plant pollens, dust, certain foods, and other allergens may lead to **hay fever** or **asthma** (AZ-mah) or both. Hay fever, known medically as *allergic rhinitis*, is characterized by a watery discharge from the eyes and nose. Hay fever often appears in a seasonal pattern due to pollen allergy. The response may be chronic if the allergen is present year round. The symptoms of asthma are caused by reversible changes, which include inflammation of airway tissues and spasm of the involuntary muscle in bronchial tubes. Spasm constricts the tubes, causing resistance to air flow. The person experiences a sense of suffocation and has labored breathing (dyspnea), often with wheezing. Treatment may include inhaled steroids to prevent inflammation and inhaled bronchodilators to open airways during acute episodes.

Patients vary considerably in their responses, and most cases of asthma involve multiple causes. Respiratory infection, noxious fumes, or drug allergy can initiate episodes, but one of the more common triggers for asthma attacks is exercise. The rapid air movement in sensitive airways causes smooth muscle spasm in the breathing passages.

A great difficulty in the treatment of hay fever or asthma is identification of the particular substance to which the patient is allergic. Allergists usually give a number of skin tests, but in most cases, the results are inconclusive. People with allergies may benefit from a series of injections to reduce their sensitivity to specific substances.

Chronic Obstructive Pulmonary Disease (COPD)

Chronic obstructive pulmonary disease (COPD) is the term used to describe several lung disorders, including **chronic bronchitis** and **emphysema** (em-fih-SE-mah). Most affected patients have symptoms and lung damage characteristic of both diseases. In chronic bronchitis, the airway linings are chronically inflamed and produce excessive secretions. Emphysema is characterized by dilation and finally destruction of the alveoli.

In COPD, respiratory function is impaired by obstruction to normal air flow, reducing exchange of oxygen and carbon dioxide. There is air trapping and over-inflation of parts of the lungs. In the early stages of these diseases, the small airways are involved, and several years may pass before symptoms become evident. Later, the affected person develops dyspnea as a result of difficulty in exhaling air through the obstructed air passages.

In certain smokers, COPD may result in serious disability and death within 10 years of the onset of symptoms. Giving up smoking may reverse progression of the disorder, especially when it is diagnosed early and other respiratory irritants also are eliminated. Sometimes, the word *emphysema* is used to mean COPD.

COPD is also called COLD (chronic obstructive lung disease).

Sudden Infant Death Syndrome (SIDS)

SIDS, also called “crib death,” is the unexplained death of a seemingly healthy infant under 1 year of age. Death usually occurs during sleep, leaving no signs of its cause. Neither autopsy nor careful investigation of family history and circumstances of death provides any clues. Certain maternal conditions during pregnancy are associated with an increased risk of SIDS, although none is a sure predictor. These include cigarette smoking, age under 20, low weight gain, anemia, illegal drug use, and infections of the reproductive or urinary tracts.

Some guidelines that have reduced the incidence SIDS are:

- ▶ Place the baby supine (on its back) for sleep, unless there is some medical reason not to do so. A reminder for parents and other caregivers is the slogan “Back to sleep.” A side position is not as effective, as the baby can roll over, and it should never be put to sleep prone (face down). In the prone position, the baby can re-breathe its own CO₂, building up CO₂ and diminishing blood O₂ levels. The position may also cause obstruction in the upper airways or lead to overheating by reducing loss of body heat.
- ▶ Keep the baby in a smoke-free environment. Maternal smoking during pregnancy, or smoking in the baby’s environment after birth, increases the risk of SIDS.

- ▶ Use a firm, flat baby mattress, no soft foam, fur, or fiber-filled bedding.
- ▶ Avoid overheating the baby with room air, clothing or bedding, especially when the baby has a cold or other infection.

Checkpoint 18-15 What does COPD mean and what two diseases are commonly involved in COPD?

Respiratory Distress Syndrome (RDS)

RDS covers a range of inflammatory disorders that result from other medical problems or from direct injury to the lungs. **Acute respiratory distress syndrome (ARDS)**, or shock lung, usually appears in adults, in contrast to a form of the syndrome that occurs in premature newborns, as described later. Some causes of ARDS are:

- ▶ Airway obstruction as from mucus, foreign bodies, emboli or tumors
- ▶ Sepsis (systemic infection)
- ▶ Aspiration (inhalation) of stomach contents
- ▶ Allergy
- ▶ Lung trauma

Inflammation and damage to the alveoli results in pulmonary edema, dyspnea (difficulty in breathing), decreased compliance, hypoxemia, and formation of fibrous scar tissue in the lungs. The incomplete expansion of a lung or portion of a lung, such as results from ARDS, is called **atelectasis** (at-e-LEK-tah-sis), or collapsed lung.

In premature newborns, atelectasis may result from insufficient production of surfactant by the immature lungs. **Respiratory distress syndrome of the newborn** is now treated by administration of surfactant that is produced in bacteria by genetic engineering. The syndrome was formerly called *hyaline membrane disease* because of the clear membrane formed from lung exudates in the alveoli.

Cancer

Tumors can arise in all portions of the respiratory tract. Two common sites are described as follows.

Lung Cancer Cancer of the lungs is the most common cause of cancer-related deaths in both men and women. The incidence rate in women continues to increase, whereas the rate in men has been decreasing recently. By far, the most important cause of lung cancer is cigarette smoking. Smokers suffer from lung cancer 10 times as often as do nonsmokers. The risk of getting lung cancer is increased in people who started smoking early in life, smoke large numbers of cigarettes daily, and inhale deeply. Smokers who are exposed to toxic chemicals or particles in the air have an even higher rate of lung cancer. Smoking has also been linked with an increase in COPD and cancers of respiratory passages.

A common form of lung cancer is **bronchogenic** (brong-ko-JEN-ik) **carcinoma**, so called because the malignancy originates in a bronchus. The tumor may grow until the bronchus is blocked, cutting off the supply of air to that lung. The lung then collapses, and the secretions trapped in the lung spaces become infected, with a resulting pneumonia or formation of a lung abscess. This type of lung cancer can spread, causing secondary growths in the lymph nodes of the chest and neck and in the brain and other parts of the body. A treatment that offers a possibility of cure before secondary growths have had time to form is complete removal of the lung. This operation is called a **pneumonectomy** (nu-mo-NEK-to-me).

Malignant tumors of the stomach, breast, and other organs may spread to the lungs as secondary growths (metastases).

Cancer of the Larynx Cancer of the larynx usually involves squamous cell carcinoma, and its incidence is definitely linked to cigarette smoking and alcohol consumption. Symptoms include sore throat, hoarseness, ear pain, and enlarged cervical lymph nodes. The cure rate is high for small tumors that have not spread when treated with radiation and (sometimes) surgery. Total or partial removal of the larynx is necessary in cases of advanced cancer that do not respond to radiation or chemotherapy. During and after laryngectomy a patient may need to have an opening, or stoma, created in the trachea with a tube (tracheostomy tube) for breathing. Patients have to care for the stoma and the “trach” (trake) tube. If the vocal cords are removed, a patient can learn to speak by using air forced out of the esophagus or by using a mechanical device to generate sound.

Disorders Involving the Pleura

Pleurisy (PLUR-ih-se), or inflammation of the pleura, usually accompanies a lung infection—particularly pneumonia or tuberculosis. This condition can be quite painful because the inflammation produces a sticky exudate that roughens the pleura of both the lung and the chest wall; when the two surfaces rub together during ventilation, the roughness causes acute irritation. The sticking together of two surfaces is called an **adhesion** (ad-HE-zhun). Infection of the pleura also causes an increase in the amount of pleural fluid. This fluid may accumulate in the pleural space in quantities large enough to compress the lung, resulting in an inability to obtain enough air.

Pneumothorax (nu-mo-THOR-aks) is an accumulation of air in the pleural space (Fig. 18-11). The lung on the affected side collapses, causing the patient to have great difficulty breathing. Pneumothorax may be caused by a wound in the chest wall or by rupture of lung air spaces. In pneumothorax caused by a penetrating wound in the chest wall, an airtight cover over the opening pre-

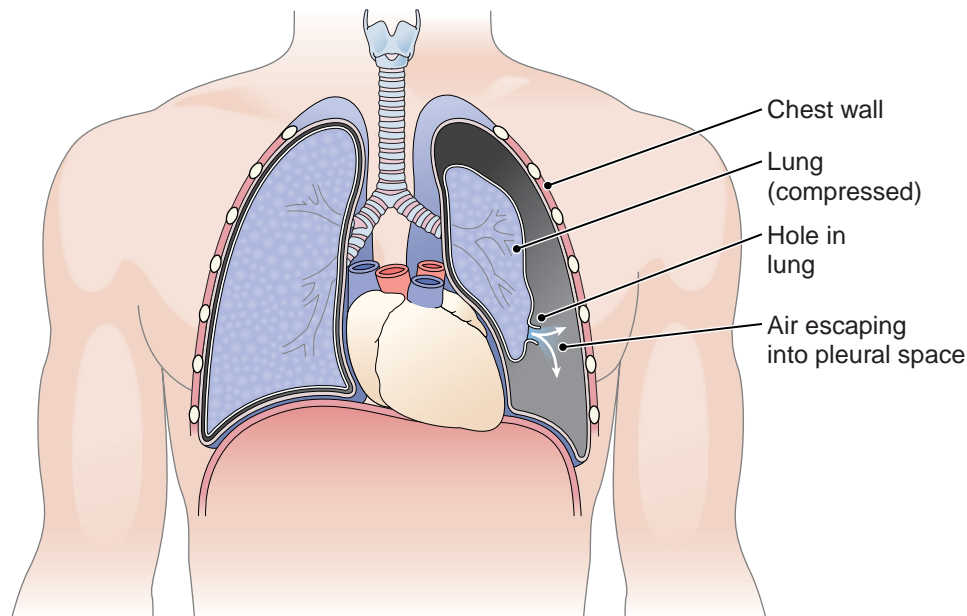


Figure 18-11 Pneumothorax. Injury to lung tissue allows air to leak into the pleural space and put pressure on the lung. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

vents further air from entering. The remaining lung can then function to provide adequate amounts of oxygen.

Blood in the pleural space, a condition called **hemothorax**, is also caused by penetrating chest wounds. In such cases, the first priority is to stop the bleeding.

The abnormal accumulation of fluid or air in the pleural space from any of the above conditions may call for procedures to promote lung expansion. In **thoracentesis** (thor-ah-sen-TE-sis) a large-bore needle is inserted between ribs into the pleural space to remove fluid (Fig. 18-12). The presence of both air and fluid in the pleural space may require insertion of a chest tube, a large tube with several openings along the internal end. The tube is securely connected to a chest drainage system. These procedures restore negative pressure in the pleural space and allow re-expansion of the lung.

Age and the Respiratory Tract

With age, the tissues of the respiratory tract lose elasticity and become more rigid. Similar rigidity in the chest wall, combined with arthritis and loss of strength in the breathing muscles, results in an overall decrease in compliance and in lung capacity. Reduction

in protective mechanisms, such as phagocytosis in the lungs, leads to increased susceptibility to infection. The incidence of emphysema increases with age, hastened by cigarette smoking and by exposure to other environmental irritants. Although there is much individual variation, especially related to one's customary level of activity, these changes gradually lead to reduced capacity for exercise.

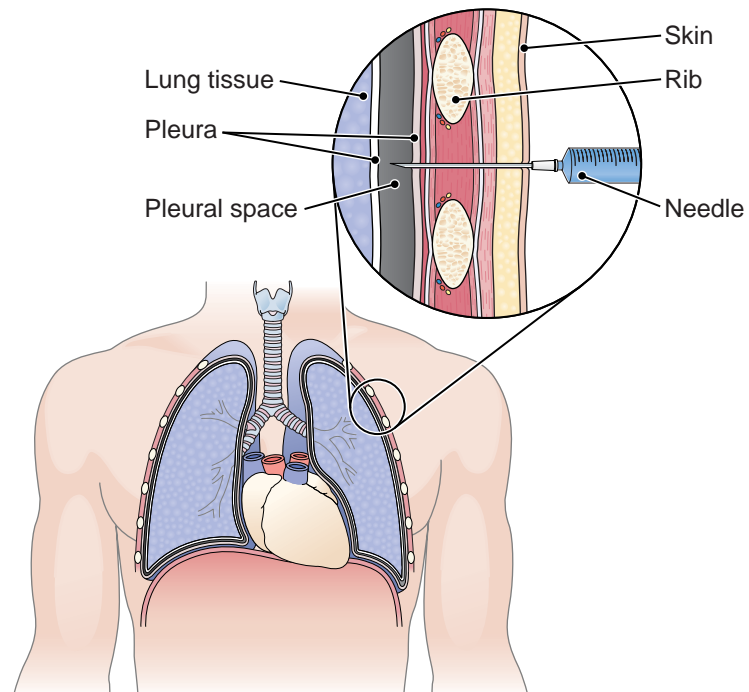


Figure 18-12 Thoracentesis. A needle is inserted into the pleural space to withdraw fluid. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

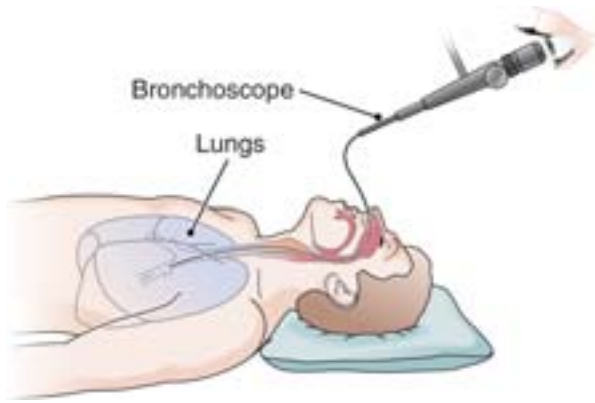


Figure 18-13 Use of a bronchoscope. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

► Special Equipment for Respiratory Treatment

The **bronchoscope** (BRONG-ko-sko-pe) is a rigid or flexible fiberoptic tubular instrument used for inspection of the primary bronchi and the larger bronchial tubes (Fig. 18-13). Most bronchoscopes are now attached to video recording equipment. The bronchoscope is passed into the respiratory tract by way of the nose or mouth and the pharynx. It may be used to remove foreign bodies, inspect and take tissue samples (biopsies) from tumors, or collect other specimens. Children inhale a variety of objects, such as pins, beans, pieces of nuts, and small coins, all of which a physician may remove with the aid of a bronchoscope. If such items are left in the lung, they may cause an abscess or other serious complication and may even lead to death.

Oxygen therapy is used to sustain life when a condition interferes with adequate oxygen supply to the tissues. The oxygen must first have moisture added by bubbling it through water that is at room temperature or

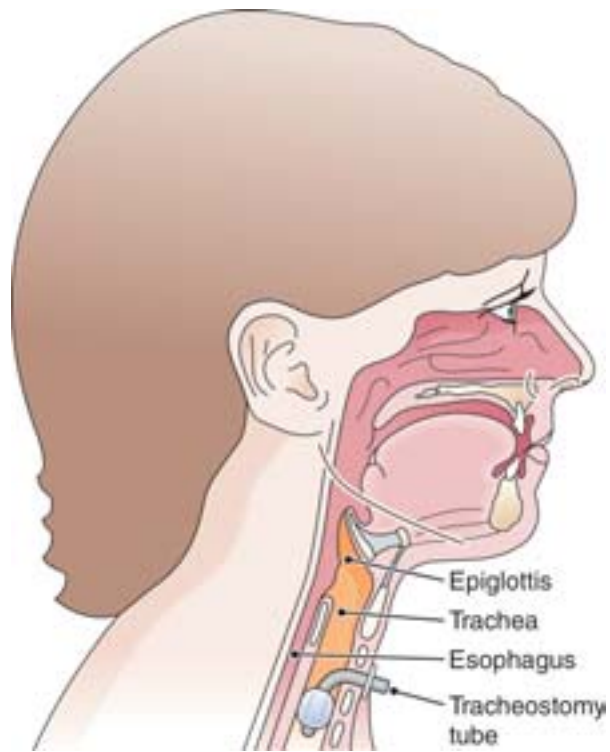


Figure 18-14 A tracheostomy tube in place. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.) **ZOOMING IN** ♦ What structure is posterior to the trachea?

heated. Oxygen may be delivered to the patient by mask, catheter, or nasal prongs. Because there is danger of fire when oxygen is being administered, no one in the room can smoke.

A **suction apparatus** is used for removing mucus or other substances from the respiratory tract by means of negative pressure. A container to trap secretions is located between the patient and the machine. The tube leading to the patient has an opening to control the suction. When

Box 18-3 • Health Professions

Careers in Respiratory Therapy

Respiratory therapists and respiratory therapy technicians specialize in evaluating and treating breathing disorders. Respiratory therapists evaluate the severity of their clients' conditions by taking complete histories and testing respiratory function with specialized equipment. Based on their findings, and in consultation with a physician, therapists design and implement individualized treatment plans, which may include oxygen therapy and chest physiotherapy. They also educate clients on the use of ventilators and other medical devices. Respiratory therapy technicians assist in carrying out evaluations and treatments.

To perform their duties, both types of practitioners need a thorough understanding of anatomy and physiology. Most respiratory therapists in the United States receive their training from an accredited college or university and take a national licensing exam. Respiratory therapists and technicians work in a variety of settings, such as hospitals, nursing care facilities, and private clinics. As the American population continues to age, the prevalence of respiratory ailments is expected to increase. Thus, job prospects are good. For more information about careers in respiratory therapy, contact the American Association for Respiratory Care.

suction is applied, the drainage flows from the patient's respiratory tract into the collection container.

A **tracheostomy** (tra-ke-OS-to-me) tube is used if the pharynx or the larynx is obstructed. It is a small metal or plastic tube that is inserted through a cut made in the trachea, and it acts as an artificial airway for ventilation (Fig. 18-14). The procedure for the insertion of such a tube is a *tracheostomy*. The word **tracheotomy** (tra-ke-OT-o-me) refers to the incision in the trachea.

Artificial respiration is used when a patient has temporarily lost the capacity to perform the normal motions of respiration. Such emergencies include cases of gas or smoke inhalation, electric shock, drowning, poisoning or paralysis

of the breathing muscles. A number of different apparatuses are used for artificial respiration in a clinical setting. There are also some techniques that can be used in an emergency.

Many public agencies offer classes in the techniques of mouth-to-mouth respiration and cardiac massage to revive people experiencing respiratory or cardiac arrest. This technique is known as **cardiopulmonary resuscitation**, or **CPR**. These classes also include instruction in emergency airway clearance using abdominal thrusts (Heimlich maneuver), chest thrusts, or back blows to open obstructed airways.

Box 18-3 provides information on the work of respiratory therapists.

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART

MEANING

EXAMPLE

The Respiratory System

nas/o
or/o
laryng/o
pleur/o

nose
mouth
larynx
side, rib

The *nasopharynx* is behind the nasal cavity.
The *oropharynx* is behind the mouth.
The *laryngeal* pharynx opens into the pharynx.
The *pleura* covers the lung and lines the chest wall (rib cage).

The Process of Respiration

spir/o
capn/o
-pnea
orth/o-

breathing
carbon dioxide
breathing
straight

A *spirometer* is an instrument used to record breathing volumes.
Hypercapnia is a rise in the blood level of carbon dioxide.
Hypopnea is a decrease in the rate and depth of breathing.
Orthopnea can be relieved by sitting in an upright position.

Disorders of the Respiratory System

pneumon/o
atel/o
pneum/o
-centesis

lung
incomplete
air, gas
tapping, perforation

Pneumonia is inflammation of the lung.
Atelectasis is incomplete expansion of the lung.
Pneumothorax is accumulation of air in the pleural space.
In *thoracentesis* a needle is inserted into the pleural space to remove fluid.

Summary

I. Phases of Respiration

- A. Pulmonary ventilation
- B. External gas exchange
- C. Internal gas exchange

II. The respiratory system

- A. Nasal cavities—filter, warm, and moisten air
- B. Pharynx (throat)—carries air into respiratory tract and food into digestive tract
- C. Larynx (voice box)—contains vocal cords
 1. Glottis—space between the vocal cords
 2. Epiglottis—covers larynx on swallowing to help prevent food from entering
- D. Trachea (windpipe)
- E. Bronchi—branches of trachea that enter lungs and then subdivide
 1. Bronchioles—smallest subdivisions
- F. Lungs

1. Organs of gas exchange
2. Lobes: three on right; two on left
3. Alveoli
 - a. Tiny air sacs where gases are exchanged
 - b. Surfactant—reduces surface tension in alveoli; eases expansion of lungs
4. Pleura—membrane that encloses the lung
 - a. Visceral pleura—attached to surface of lung
 - b. Parietal pleura—attached to chest wall
 - c. Pleural space—between layers
5. Mediastinum—space and organs between lungs

III. The process of respiration

- A. Pulmonary ventilation
 1. Inhalation—drawing of air into lungs
 - a. Compliance—ease with which lungs and thorax can be expanded
 2. Exhalation—expulsion of air from lungs
 3. Lung volumes—used to evaluate respiratory function

- B. Gas exchange**
1. Gases diffuse from area of higher concentration to area of lower concentration
 2. In lungs—oxygen enters blood and carbon dioxide leaves (external exchange)
 3. In tissues—oxygen leaves blood and carbon dioxide enters (internal exchange)
- C. Oxygen transport**
1. Almost totally bound to heme portion of hemoglobin in red blood cells
 2. Separates from hemoglobin when oxygen concentration is low (in tissues)
 - a. Carbon monoxide replaces oxygen on hemoglobin
- D. Carbon dioxide transport**
1. Most carried as bicarbonate ion
 2. Regulates pH of blood
- E. Regulation of respiration**
1. Nervous control—centers in medulla and pons
 2. Chemical control
 - a. Central chemoreceptors respond to CO_2 , which decreases pH
 - b. Peripheral chemoreceptors—respond to low levels of O_2
- F. Abnormal ventilation**
1. Hyperventilation—rapid, deep respiration
 2. Hypoventilation—inadequate air in alveoli
- G. Breathing patterns**
1. Normal—12 to 20 times per minute in adult
 2. Types of altered breathing
 - a. Hyperpnea—increase in depth and rate of breathing
 - b. Tachypnea—excessive rate of breathing
 - c. Apnea—temporary cessation of breathing
 - d. Dyspnea—difficulty in breathing
 - e. Orthopnea—difficulty relieved by upright position

- f. Kussmaul—characterizes acidosis
 - g. Cheyne-Stokes—irregularity found in critically ill
3. Possible results—cyanosis, hypoxia (anoxia), hypoxemia, suffocation

IV. Disorders of the respiratory system

- A.** Disorders of the nasal cavities and related structures—sinusitis, polyps, deviated septum, nosebleed (epistaxis)
- B.** Infection—colds, RSV, croup, influenza, pneumonia, tuberculosis
- C.** Hay fever and asthma—hypersensitivity (allergy)
- D.** COPD—involves emphysema and bronchitis
- E.** SIDS—sudden infant death syndrome
- F.** Respiratory distress syndrome (RDS)
1. Acute (ARDS)—due to other medical problem or direct injury to lung
 2. RDS of newborn—due to lack of surfactant
- G.** Cancer—smoking a major causative factor
- H.** Disorders involving the pleural space
1. Pleurisy—inflammation of pleura
 2. Pneumothorax—air in pleural space
 3. Hemothorax—blood in pleural space

V. Age and the respiratory tract

VI. Special equipment for respiratory treatment

- A.** Bronchoscope—tube used to examine air passageways and remove foreign bodies
- B.** Oxygen therapy
- C.** Suction apparatus—removes mucus and other substances
- D.** Tracheostomy—artificial airway
1. Tracheotomy—incision into trachea
- E.** Artificial respiration—cardiopulmonary resuscitation (CPR)

Questions for Study and Review

Building Understanding

Fill in the blanks

1. The exchange of air between the atmosphere and the lungs is called _____.
2. The space between the vocal cords is the _____.
3. The ease with which the lungs and thorax can be expanded is termed _____.
4. A lower than normal level of oxygen in the tissues is called _____.
5. Inflammation of the pleura is termed _____.

Matching

Match each numbered item with the most closely related lettered item.

- | | |
|--|--------------|
| ___ 6. A decrease in the rate and depth of breathing | a. dyspnea |
| ___ 7. An increase in the rate and depth of breathing | b. hyperpnea |
| ___ 8. A temporary cessation of breathing | c. orthopnea |
| ___ 9. Difficult or labored breathing | d. hypopnea |
| ___ 10. Difficult breathing that is relieved by sitting up | e. apnea |

Multiple choice

- ___ 11. The bony projections in the nasal cavities that increase surface area are called
- nares
 - septae
 - conchae
 - sinuses
- ___ 12. Which of the following structures produces speech?
- pharynx
 - larynx
 - trachea
 - lungs
- ___ 13. The leaf-shaped cartilage that covers the larynx during swallowing is the
- epiglottis
 - glottis
 - conchae
 - sinus
- ___ 14. Respiration is centrally regulated by the
- cerebral cortex
 - diencephalon
 - brain stem
 - cerebellum
- ___ 15. Incomplete expansion of a lung or portion of a lung is called
- effusion
 - adhesion
 - epistaxis
 - atelectasis
- internal and external gas exchange
 - pleura and diaphragm
 - inhalation and exhalation
 - spirometer and spirogram
17. Trace the path of air from the nostrils to the lung capillaries.
18. What is the function of the cilia on cells that line the respiratory passageways?
19. Compare and contrast the transport of oxygen and carbon dioxide in the blood.
20. Define hyperventilation and hypoventilation. What is the effect of each on blood CO₂ levels and blood pH?
21. What are chemoreceptors and how do they function to regulate breathing?
22. Describe the structural and functional changes that occur in the respiratory system in chronic obstructive pulmonary disease.
23. Compare and contrast the following disease conditions:
- Kussmaul and Cheyne-Stokes respiration
 - acute coryza and influenza
 - bronchopneumonia and lobar pneumonia
 - pneumothorax and hemothorax

Conceptual Thinking

24. Jake, a sometimes exasperating 4-year-old, threatens his mother that he will hold his breath until “he dies.” Should his mother be concerned that he might succeed?
25. Why is it important that airplane interiors are pressurized? If the cabin lost pressure, what physiological adaptations to respiration might occur in the passengers?

Understanding Concepts

16. Differentiate between the terms in each of the following pairs: