Respiratory System

chapter 22

evolve

http://evolve.elsevier.com/Herlihy

Key Terms

alveolus (p. 406)
bronchioles (p. 406)
bronchus (p. 404)
compliance (p. 410)
epiglottis (p. 401)
exhalation (p. 411)
glottis (p. 401)
inhalation (p. 411)
intrapleural pressure (p. 409)
larynx (p. 401)
partial pressure (p. 415)
pharynx (p. 401)
pleurae (p. 407)
surfactants (p. 408)
tidal volume (p. 416)
trachea (p. 404)
ventilation (p. 411)
vital capacity (p. 417)

Objective

1. Describe the structure and functions of the organs of the respiratory system and trace the movement of air from the nostrils to the alveoli.
2. Describe why lungs collapse or expand and the role of pulmonary surfactants.
3. Discuss the three steps in respiration, including:
   - Describe the relationship of Boyle's law to ventilation.
   - Explain how respiratory muscles affect thoracic volume.
   - List three conditions that make the alveoli well-suited for the exchange of oxygen and carbon dioxide.
4. List lung volumes and capacities.
5. Discuss the voluntary and involuntary control of breathing, including:
   - Explain the neural and chemical control of respiration.
   - Describe common variations and abnormalities of breathing.

Is he breathing? This is the first question asked about a person who has been seriously injured. The question indicates the importance of each breath. To breathe is to live; not to breathe is to die. Each breath is a breath of life.

Because of its close connection with life, ancient peoples attributed the act of breathing to the divine. Even the phases of breathing are called *inspiration* and *expiration*, references to a divine spirit moving into and out of our lungs. The creation story in Genesis, in which God breathes life into the little clay figure of Adam, vividly expresses an image of divine breath. Poetry also describes breathing as the life force. For example, the great Persian poet Sa'di echoed the sacredness of breath in a prayer: "Each respiration holds two blessings. Life is inhaled, and stale, foul air is exhaled. Therefore, thank God twice every breath you take."

STRUCTURE: ORGANS OF THE RESPIRATORY SYSTEM

UPPER AND LOWER RESPIRATORY TRACTS

The respiratory system contains the upper and lower respiratory tracts (Figure 22-1). The upper respiratory tract contains the respiratory organs located outside the chest cavity: the nose and nasal cavities, pharynx, larynx, and upper trachea. The lower respiratory tract consists of organs located in the chest cavity: the lower trachea, bronchi, bronchioles, and alveoli. The lower parts of the bronchi, bronchioles, and alveoli are located in the lungs. The pleural membranes and the muscles that form the chest cavity are also part of the lower respiratory tract.

Most of the respiratory organs are concerned with conduction, or movement, of air through the respiratory passages. The alveoli are the tiny air sacs located at the end of the respiratory passages. They are concerned with the exchange of oxygen and carbon dioxide between the air and the blood across the walls of the pulmonary capillaries. It is critical that the airway remains open; airway obstruction is life threatening!

NOSE AND NASAL CAVITIES

The nose includes an external portion that forms part of the face and an internal portion called the *nasal cavities*. The nasal cavities are separated into right and left halves by a partition called the *nasal septum*, which is made of bone and cartilage. Air enters the nasal cavities through two openings called the *nostrils*, or *nares*. Nasal hairs in the nostrils filter large particles of dust

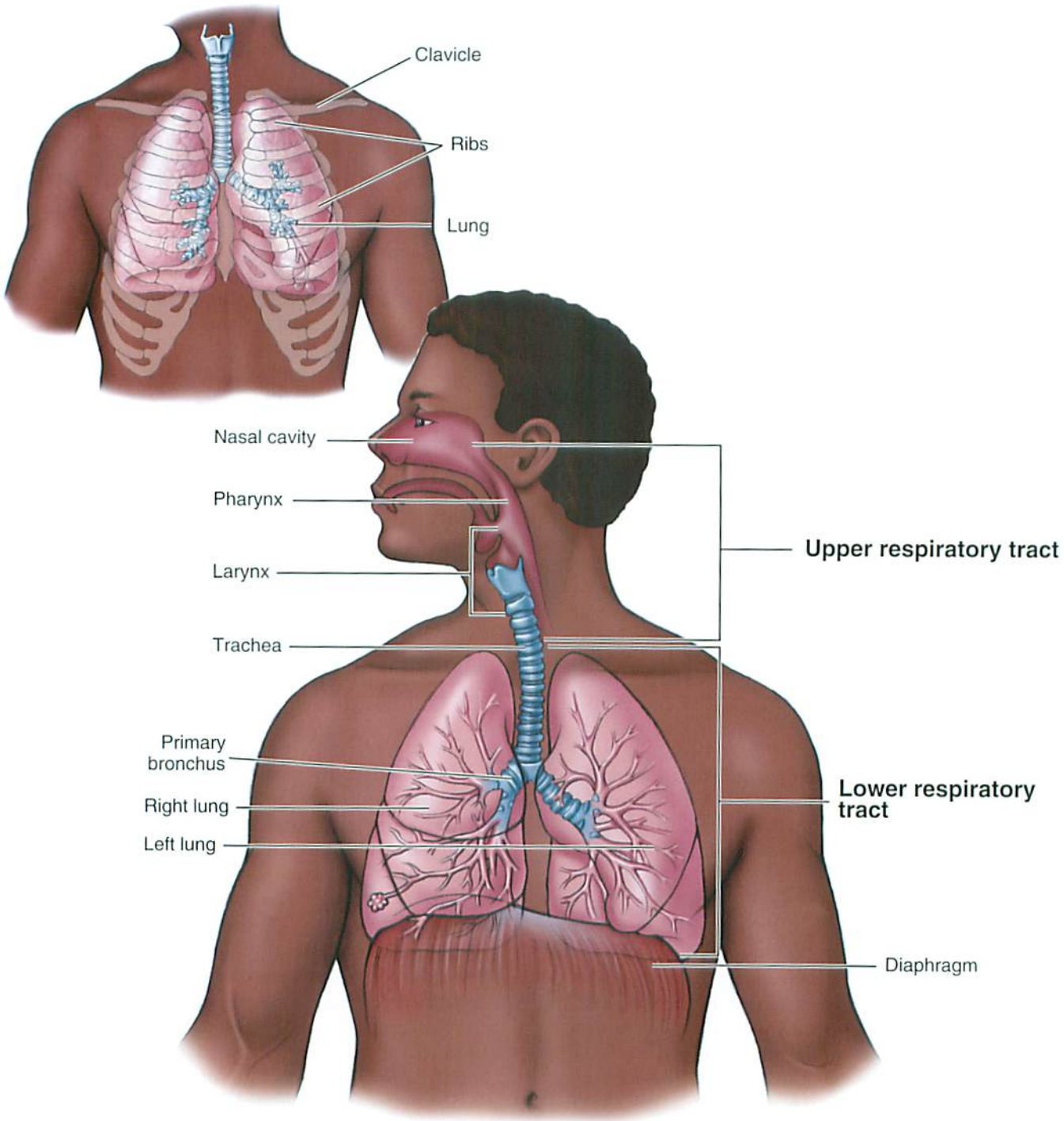


FIGURE 22-1 Organs of the respiratory system: upper respiratory tract and lower respiratory tract.

that might otherwise be inhaled. In addition to its respiratory function, the nasal cavity contains the receptor cells for the sense of smell. The olfactory receptors cover the mucous membrane of the upper parts of the nasal cavity and a part of the nasal septum.

Three bony projections called *nasal conchae* (KONCH-ay) appear on the lateral walls of the nasal cavities. The conchae increase the surface area of the nasal cavities and support the ciliated mucous membranes, which line the nasal cavities. Mucous membranes contain many blood vessels and mucus-secreting cells. The rich supply of blood warms and moistens the air, and the sticky mucus traps dust, pollen, and other small particles, thereby cleansing the air as it is inhaled. Because the nose helps warm, moisten, and cleanse the air, breathing through the nose is better than mouth breathing.

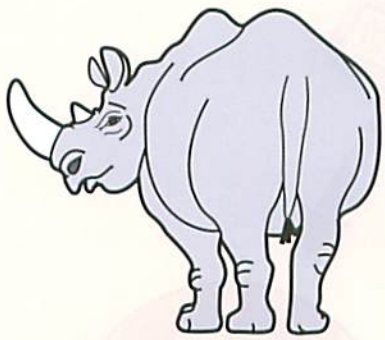
The nasal cavities contain several drainage openings. Mucus from the paranasal sinuses (see Figure 8-8) drains into the nasal cavities. The paranasal sinuses

include the maxillary, frontal, ethmoidal, and sphenoidal sinuses. Tears from the nasolacrimal ducts also drain into the nasal cavities. (Cry and your nose runs.)

Do You Know...

That Your Nose Is More Than Just a Smeller?

The nose does a few things real well; as you know, the nose knows smells. It also "nose" how to clean and humidify air. Equally important, the nose plays a big cosmetic role: it makes us look good and, if it doesn't, we simply rearrange it surgically until it is fashioned into a great-looking nose. Nose-related medical conditions or procedures are named after the rhino, who sports the mother of all noses. For instance, a *rhinoplasty* refers to the surgical reshaping, resizing, or realigning of the nose. *Rhinorrhea* refers to a runny nose, as in the common cold or the discharge of cerebrospinal fluid from the nose. *Rhinokyphosis* is a humpback nose, and, of course, you can have a pain in the nose—*rhinodynia*. It is interesting that the rhino has captured the nose words, since the rhino's nose is merely hardened hair; it doesn't sniff or drip, and it certainly doesn't check itself in for a nose job.



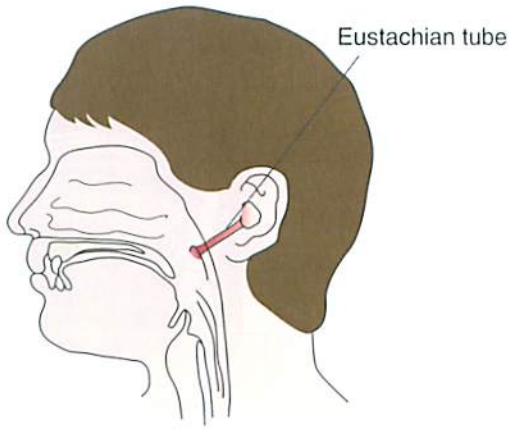
In some persons, the nasal septum may bend toward one side or the other, thereby obstructing the flow of air and making breathing difficult. This abnormal positioning of the septum is called a *deviated septum*. Surgical repair of the deviated septum (septoplasty) corrects the problem.

And for the nose that snorts cocaine? Chronic exposure to the drug causes intense vasoconstriction of the blood vessels that supply the septum. The septal cartilage dies, thereby creating a hole in the septum and giving the nose a collapsed or "caved-in" appearance. Not a good look!

PHARYNX

The **pharynx** (FAIR-inks), or throat, is located behind the oral cavity and between the nasal cavities and the larynx (Figure 22-2). The pharynx includes three parts: the nasopharynx (upper section), the oropharynx (middle section), and the laryngopharynx (lower section). The oropharynx and the laryngopharynx are part of both the digestive and respiratory systems and function as a passageway for both food and air. The pharynx conducts food toward the esophagus (tube for food to enter the stomach). The pharynx also conducts air to the larynx as it moves toward the lungs.

The pharynx contains two other structures: the openings from the eustachian tubes (auditory tubes) and the tonsils. The eustachian tube connects the nasopharynx with the middle ear.



LARYNX

WHERE AND WHAT IS YOUR VOICE BOX?

The **larynx** (LAIR-inks), also called the *voice box*, is located between the pharynx and trachea (see Figure 22-2, *A*). The larynx has three functions: it acts as a passageway for air during breathing, it produces sound (your voice), and it prevents food and other foreign objects from entering the distal respiratory structures. The larynx is a triangular structure made primarily of cartilage, muscles, and ligaments (see Figure 22-2, *C* and *D*).

The largest of the cartilaginous structures in the larynx is the thyroid cartilage. It is a tough hyaline cartilage and protrudes in the front of the neck. The thyroid cartilage is larger in men and is called the *Adam's apple* (see Figure 22-2, *B*).

The **epiglottis** (ep-i-GLOT-iss) is another cartilaginous structure, located at the top of the larynx (see Figure 22-2, *A* and *B*). The epiglottis acts as a flap, a very important flap. It covers the opening of the trachea during eating so food does not enter the lungs.

VOCAL CORDS

The larynx is called the *voice box* because it contains the vocal cords (see Figure 22-2, *A* and *C*). The vocal cords are folds of tissue composed of muscle and elastic ligaments and covered by mucous membrane. The cords stretch across the upper part of the larynx. The **glottis** is the space between the vocal cords.

TRUE OR FALSE

The two types of vocal cords are the false and true vocal cords. The false vocal cords are called "false" because they do not produce sounds. Instead, the muscles in this structure help to close the airway during swallowing. The true vocal cords produce

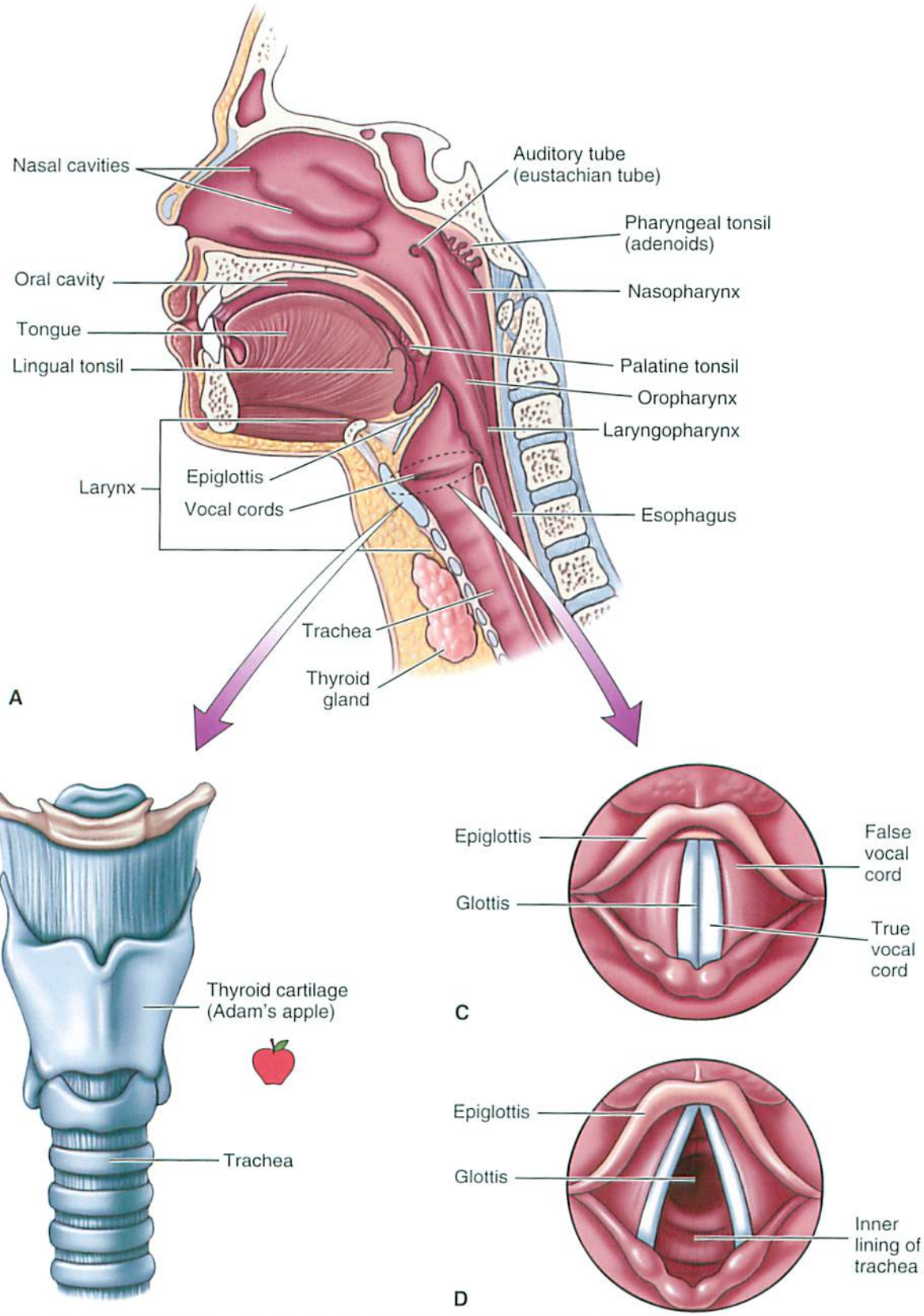


FIGURE 22-2 **A,** Organs of the upper respiratory tract. **B,** Larynx, showing the thyroid cartilage (Adam's apple). **C,** Vocal cords and glottis (closed). **D,** Vocal cords and glottis (open).

sound. Air flowing from the lungs through the glottis during exhalation causes the true vocal cords to vibrate, thereby producing sound.

The loudness of your voice depends on the force with which the air moves past the true vocal cords. The pitch of your voice depends on the tension exerted on the muscles of the true vocal cords. You form sound into words with your pharynx, oral cavity, tongue, and lip movement. The nasal cavities, sinuses, and pharynx act as resonating chambers, thereby altering the quality of your voice. Listen to the different voices of your friends. One voice may sound high and squeaky, whereas another may sound low and booming.

DOWN THE WRONG WAY

As shown in Figure 22-2, *A*, the pharynx acts as a passageway for food, water, and air. Food and water in the pharynx, however, should not enter the larynx. How is food and water normally kept out of the larynx? When you breathe in air, the glottis opens, and air moves through the glottis into tubes that carry it to the lungs.

When you swallow food, however, the epiglottis covers the glottis, thereby preventing food from entering the lower respiratory passages. Instead, the food enters the esophagus, the tube that empties into the stomach. How does this happen? During swallowing, the larynx moves upward and forward while the epiglottis moves downward. If you place your fingers on your larynx as you swallow, you can feel the larynx move upward and forward. In addition to the movement of the epiglottis, the glottis closes. Compare the size of the glottis in Figure 22-2, *C* and *D*.

Note that swallowing plays a key role in preventing the entrance of food or water into the respiratory tubes. Some patients develop difficulty in swallowing, particularly those who have suffered neurological damage such as a stroke. Any patient who experiences difficulty in swallowing is at risk for aspiration (entrance of food or water into the lungs). Aspiration is a large clinical problem.

FROM BOY TO YOUNG MAN

Why is Jack's voice lower than Jill's? At puberty, under the influence of testosterone, the male larynx enlarges and the vocal cords become longer and thicker. The larger vocal cords deepen the male voice. Changes in the larynx and vocal cords cause the boy's voice to "break" as he matures into a young man. In an earlier period in history, young choir boys with beautiful high voices were castrated. Castration, the surgical excision of the testes, removes the source of testosterone and prevents thickening of the vocal cords. These unfortunate castrated boys continued to sing beautifully as members of the castrati choir. For obvious reasons, this practice eventually disappeared.

Re-Think

1. Trace the flow of air from the nose to the trachea.
2. Explain why food and water do not enter the respiratory structures during swallowing.

Do You Know...

Who Heimlich Is and What He Maneuvered?

Dr. Heimlich is a physician who developed a procedure designed to dislodge the obstructing object in a choking person. The Heimlich maneuver, or abdominal thrust, is a simple technique. The "bear hug" procedure is demonstrated on an adult below. Here are the steps for the adult:

1. Stand behind the choking person and wrap your arms around the person's waist.
2. Position your hands (fist position) between the person's navel and the bottom of the rib cage.
3. Press your fist into the abdomen with a quick upward movement.
4. Repeat several times as necessary.

Heimlich maneuver (adult)

Do You Know...

How "Dumb Plant" Was Used to Control Gossip (Without, of Course, Killing the Gossiper)?

A tea made from dieffenbachia ("dumb plant") was given to Roman slaves before they were sent to the market to shop. The tea caused the slave's tongue and mouth to swell and paralyzed the throat. The slave was therefore unable to speak and gossip about household affairs. It is still used by some African tribes as a punishment for gossip. An overdose of the poison causes excessive swelling, obstruction of the respiratory passageways, and death by suffocation. On an updated note, acute respiratory obstruction can be induced when a patient is given a drug or food to which she is allergic. "Dumb plant ingestion" may be dead, but the anaphylactic response (respiratory obstruction) is very much alive and well.

TRACHEA

WHERE IT SITS AND WHERE IT SPLITS

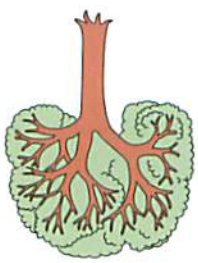
The **trachea** (TRAY-kee-ah), or windpipe, is a tube 4 to 5 inches (10 to 12.5 cm) long and 1 inch (2.5 cm) in diameter (Figure 22-3). The trachea extends from the larynx downward into the thoracic cavity, where it splits into the right and left bronchi (sing., **bronchus**). The trachea splits, or bifurcates, at a point called the *carina* (kah-RYE-nah) at the manubriosternal junction (where the manubrium of the sternum meets the sternal body). Why is the carina so important clinically? The carina is very sensitive; touching it during suctioning causes vigorous coughing. The purpose of the trachea? It conducts air to and from the lungs.

KEEPING IT OPEN

The trachea lies in front of the esophagus, the food tube. C-shaped rings of cartilage partially surround the trachea for its entire length and serve to keep it open. The rings are open on the back side of the trachea so that the esophagus can bulge forward as food moves along the esophagus to the stomach. You can feel the cartilaginous rings if you run your fingers along the front of your neck. Without this strong cartilaginous support, the trachea would collapse and shut off the flow of air through the respiratory passages. Because of the cartilaginous rings, a tight collar or necktie does not collapse the trachea. A severe blow to the anterior neck, however, can crush the trachea and cause an acute respiratory obstruction. The trachea must be kept open.

BRONCHIAL TREE: BRONCHI, BRONCHIOLES, AND ALVEOLI

The bronchial tree consists of the bronchi, the bronchioles, and the alveoli. It is called a *tree* because the bronchi and their many branches resemble an upside-down tree. Most of the bronchial tree is in the lungs.



Bronchial tree

BRONCHI

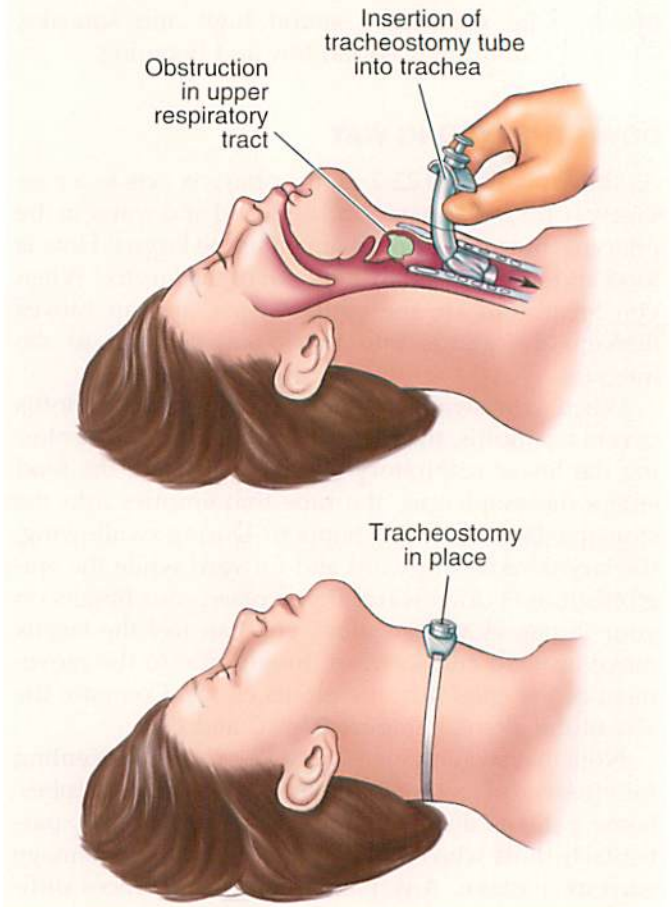
The right and left primary bronchi are formed as the lower part of the trachea divides into two tubes. The primary bronchi enter the lungs at a region called the *hilus*. The primary bronchi branch into secondary bronchi, which branch into smaller tertiary bronchi. Because the heart lies toward the left side of the chest, the left bronchus is narrower and positioned more horizontally than the right bronchus. The right bronchus is shorter and wider than the left bronchus and extends downward in a more vertical direction. Because of the differences in the size and positioning of the bronchi, food particles and small objects are more easily inhaled, or aspirated, into the right bronchus.

Why are tiny toys not good for tiny tots? Young children generally put toys in their mouths. The tiny toy may become lodged in the larynx or bronchus, causing an acute respiratory obstruction. Unless relieved immediately, the obstruction can be fatal. Tiny toys are responsible for many toy recalls.

Do You Know...

What a Tracheostomy Is?

Sometimes a part of the upper respiratory tract becomes blocked, thereby obstructing the flow of air into the lungs. To restore air flow, an emergency tracheostomy may be performed. This procedure is the insertion of a tube through a surgical incision into the trachea below the level of the obstruction. The tracheostomy bypasses the obstruction and allows air to flow through the tube into the lungs.



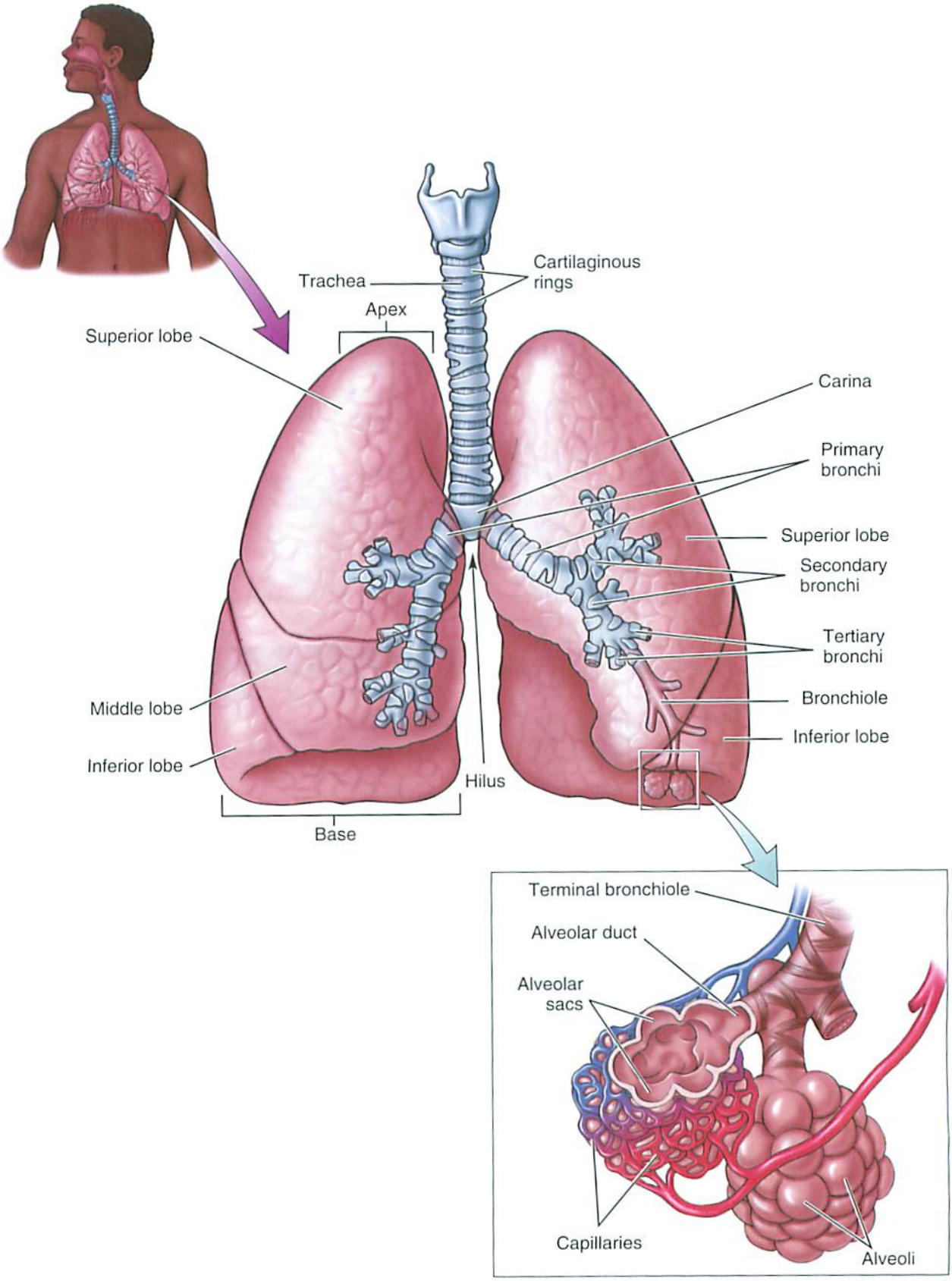


FIGURE 22-3 Trachea and bronchial tree (bronchi, bronchioles, and alveoli).

The upper segments of the bronchi have C-shaped cartilaginous rings, which help keep the bronchi open. As the bronchi extend into the lungs, however, the amount of cartilage decreases and finally disappears. The finer and more distal branches of the bronchi contain no cartilage.

BRONCHIOLES

The bronchi divide repeatedly into smaller tubes called **bronchioles** (BRON-kee-ohls). The walls of the bronchioles contain smooth muscle and no cartilage. The bronchioles regulate the flow of air to the alveoli. Contraction of the bronchiolar smooth muscle causes the bronchioles to constrict, thereby decreasing the bronchiolar lumen (opening) and thus decreasing the flow of air. Relaxation of the bronchioles causes the lumen to increase, thereby increasing the flow of air.

An asthma attack illustrates the effect of bronchiolar smooth muscle constriction. In a person with asthma, the bronchioles hyperrespond to a particular stimulus. The bronchiolar smooth muscle then constricts, decreasing the flow of air into the lungs. The person complains of a tight chest and expends much energy trying to force air through the constricted bronchioles into the lungs. Forced air causes a wheezing sound. Bronchiolar smooth muscle relaxants are medications that cause bronchodilation, thereby improving air flow and relieving the wheezing.

Let's translate this into autonomic pharmacology. The bronchioles contain $beta_2$-adrenergic receptors. Stimulation of these receptors causes relaxation of the bronchiolar smooth muscle, thus inducing bronchodilation and improved air flow. Albuterol, a $beta_2$-adrenergic agonist, is a bronchodilator drug. Conversely, a $beta_2$-adrenergic blocker, such as propranolol, causes bronchoconstriction and is therefore contraindicated in asthmatic patients.

? Re-Think

1. Explain why the trachea remains open.
2. What is the "problem" caused by bronchoconstriction?

ALVEOLI

The bronchioles continue to divide and give rise to many tubes called *alveolar ducts* (see Figure 22-3). These ducts end in very small, grapelike structures called *alveoli* (sing., **alveolus**). The alveoli are tiny air sacs that form at the ends of the respiratory passages. A pulmonary capillary surrounds each alveolus. The alveoli function to exchange oxygen and carbon dioxide across the alveolar-pulmonary capillary membrane. Oxygen diffuses from the alveoli into the blood; carbon dioxide diffuses from the blood into the alveoli. The term *atelectasis* refers to collapsed and airless alveoli. Atelectasis occurs commonly as a postoperative complication and as a result of conditions such as pneumonia and cancer of the lung.

Do You Know...

Why You May Diagnose Cystic Fibrosis by Kissing Your Baby's Face?

Cystic fibrosis (CF) is a hereditary disease that is characterized by thickened secretions of most exocrine glands. Consequently CF affects many organs including the liver, pancreas, and especially the lungs. The production of thick bronchial secretions is of particular concern because the secretions block narrow breathing passages, causing atelectasis and pulmonary infections. Eventually lung tissue is destroyed; for this reason the clinical picture of CF is dominated by lung dysfunction. In addition, sweat glands and salivary glands produce a very salty secretion; mothers often notice the salty taste of their infants upon kissing them.

Certain respiratory diseases may destroy alveoli or cause a thickening of the alveolar wall. As a result, the exchange of gases is slowed. Oxygenation of the blood may decrease, causing hypoxemia and cyanosis, and the blood may retain carbon dioxide, causing a disturbance in acid–base balance (acidosis).

Do You Know...

Why Your Fingers Go "Clubbing"?

Patients who experience chronic hypoxemia, such as those with impaired lung and heart function, often develop clubbing of the fingers and toes. Clubbing is characterized by enlarged fingertips and toes and changes in the thickness and shape of the nails. The enlargement is due to the formation of additional capillaries and tissue hypertrophy in an attempt to deliver oxygen to the oxygen-deprived cells.

LUNGS

RIGHT AND LEFT

The two lungs, located in the pleural cavities, extend from an area just above the clavicles to the diaphragm. The lungs are soft cone-shaped organs so large that they occupy most of the space in the thoracic cavity (see Figure 22-3). The lungs are subdivided into lobes. The right lung has three lobes: the superior, middle, and inferior lobes. Because of the location of the heart in the left side of the chest, the left lung has only two lobes: the superior lobe and the inferior lobe.

The upper rounded part of the lung is called the *apex*, and the lower portion is called the *base*. The base of the lung rests on the diaphragm. The amount of air the lungs can hold varies with a person's body build, age, and physical conditioning. For instance, a tall person has larger lungs than a short person. A swimmer generally has larger lungs than a "couch potato," and the trained singer has larger lungs than the typical "shower singer."

Do You Know...

That Charles Dickens "Nailed It" in His Novel *The Pickwick Papers?*

Yup, the creator of our beloved Tiny Tim in *A Christmas Carol* was the first to accurately describe (but not name) the syndrome of obesity-associated alveolar hypoventilation, or Pickwickian syndrome. In Dickens' description in *Pickwick Papers*, he refers to "a fat boy and red-faced boy in a state of somnolency" (extreme sleepiness). He subsequently addresses the boy as "Young Dropsy" (a reference to his obesity), Young Opium-eater (a reference to his somnolency), and Young Boa Constrictor (a reference to his excessive appetite). Physiologically, this is what Dickens meant to say: The boy's immense abdominal girth causes ventilatory insufficiency (periodic respirations and hypoventilation) and hypoxemia, explaining his extreme sleepiness (somnolence). The hypoxemia also stimulates RBC production and polycythemia (through erythropoietin) in an attempt to increase oxygen in the blood; this accounts for the boy's red appearance. Had Dickens known a little pathophysiology, he would have thrown into the mix a probable hematocrit of 65, expanded blood volume, hypercapnia with mild respiratory acidosis, alveolar hypoventilation, and an enlarged right heart. He would have explained that right heart failure, in turn, causes distention of the neck veins (JVD), hepatomegaly and pedal edema.

Although Dickens didn't throw around much medical terminology, Young Dropsy's appearance described the syndrome quite accurately. So why is Pickwickian syndrome of such concern today? Because of the prevalence of obesity in our society and the wide varieties of obesity-related health conditions! Our increasing girth continues to "expand" upward. The short-term solution may be to increase the size of clothes, chairs, and caskets, but the real solution is to waste the waist. The good news? Weight loss appears to reverse the signs and symptoms of Pickwickian syndrome, including the "obesity heart disease."

Re-Think

1. What is the primary function of the alveoli?
2. Reviewing the structures of the respiratory tract, identify at least three ways that a patient can develop an acute respiratory obstruction.

PLEURAL MEMBRANES

PLEURA

The outside of each lung and the inner chest wall are lined with a continuous serous membrane called the **pleurae** (Figure 22-4). The pleurae are named according to their location. The membrane on the outer surface of each lung is called the *visceral pleura;* the membrane lining the chest wall is called the *parietal pleura*. The visceral pleura and the parietal pleura are attracted to each other like two flat plates of glass whose surfaces are wet. The plates of glass can slide past one another but offer some resistance when you try to pull them apart.

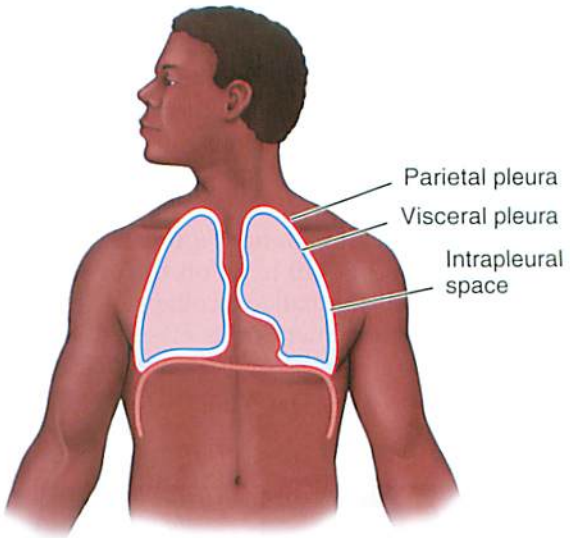


FIGURE 22-4 Lungs, pleural membranes, and the intrapleural space.

PLEURAL CAVITY: A POTENTIAL SPACE

Between the visceral pleura and the parietal pleura is a space called the *intrapleural space*. The pleural membranes secrete a small amount of serous fluid (approximately 25 mL). The fluid lubricates the pleural membranes and allows them to slide past one another with little friction or discomfort. Under abnormal conditions, the intrapleural space has the potential to accumulate excess fluid, blood, and air. An excess secretion of pleural fluid is called *pleural effusion*. Purulent (pus) pleural effusion is called *empyema*.

2+2 Sum It Up!

Air moves through the following structures—from the nasal cavities, to the pharynx, to the larynx, to the trachea, to the bronchi, to the bronchioles, and finally to the alveoli. When the air reaches the alveoli (the tiny air sacs at the end of the bronchial tree), the respiratory gases oxygen and carbon dioxide diffuse across the alveolar–pulmonary capillary membrane. Most of the respiratory structures conduct air to and from the lungs. Only the alveoli function in the exchange of the respiratory gases between the outside air and the blood. The lungs contain the structures of the lower respiratory tract. Pleural membranes surround the lungs and line the thoracic cavity, creating the intrapleural space or pleural cavity.

COLLAPSED AND EXPANDED LUNGS

Figure 22-1 shows that the lungs occupy most of the thoracic cage, but this statement must be qualified: the *expanded* lungs occupy most of the thoracic cage. Under normal conditions, the lungs expand like inflated balloons. Under abnormal conditions, however, a lung may collapse. What determines whether or not the lungs collapse or expand?

WHY LUNGS COLLAPSE

If the thoracic cavity is entered surgically, the lungs collapse. There are two reasons why the lungs collapse: elastic recoil and surface tension.

ELASTIC RECOIL

Consider a balloon and a lung (Figure 22-5, *A*). If you blow up a balloon but fail to tie off the open end, the air rushes out and the balloon collapses. It collapses because of the arrangement of its elastic fibers. When these fibers stretch, they remain stretched only when tension is applied (the air blown into the balloon stretches the balloon). If the end of the balloon is not tied off, the elastic fibers recoil, forcing air out and collapsing the balloon. The same can be said of the lung. The arrangement of the lung's elastic tissue is similar to the arrangement of the elastic fibers in the balloon. The elastic tissue of the lung can stretch, but it recoils and returns to its unstretched position if tension is released (see Figure 22-5, *B*). This is called *elastic recoil*.

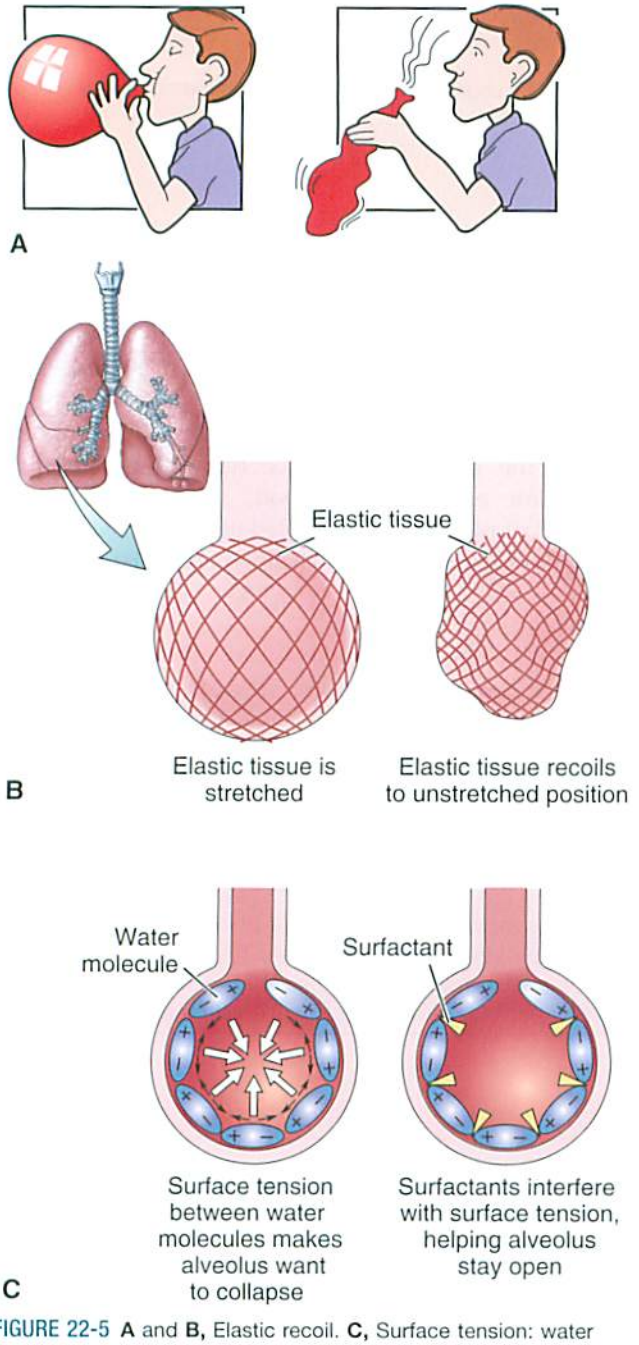


FIGURE 22-5 **A** and **B**, Elastic recoil. **C**, Surface tension: water and the effect of surfactants.

SURFACE TENSION

The lung also collapses for a second reason, a force called *surface tension*. The single alveolus in Figure 22-5, *C*, illustrates surface tension. A thin layer of water lines the inside of the alveolus. Water is a polar molecule; one end of the water molecule has a positive (+) charge, whereas the other end of the molecule has a negative (–) charge. Note how the water molecules line up. The positive (+) end of one water molecule is attracted to the negative (–) charge on the second water molecule. Each water molecule pulls on the other and on the water molecules beneath them. The electrical attraction of the water molecules is the surface tension. As the water molecules pull on one another, they tend to make the alveolus smaller; in other words, they tend to collapse the alveoli.

NOTE: The surface tension of pure water is normally very high. In the mature normal lung, special alveolar cells secrete pulmonary surfactants. **Surfactants** (sur-FAK-tants) are detergent-like lipoproteins that decrease surface tension by interfering with the electrical attraction between the water molecules on the inner surface of the alveolus (see Figure 22-5, *C*). The secretion of surfactant is stimulated by a sigh. After every five or six breaths, a person takes a larger than normal breath (a sigh); the sigh stretches the alveoli, promoting the secretion of surfactant. Surfactants lower surface tension but do not eliminate it. Surface tension remains a force that acts to collapse the alveoli.

Do You Know...

Why a Premature Infant Is More Apt Than a Full-Term Infant to Develop Respiratory Distress Syndrome?

Surfactant-secreting cells appear only during the later stages of fetal development. An infant born 2 to 3 months prematurely generally has insufficient surfactant-secreting cells. As a result, surface tension within the alveoli is excessively high, the alveoli collapse, and the infant experiences respiratory distress. The infant may die in respiratory failure. This condition is commonly called *respiratory distress syndrome*. Before delivery the mother may be given steroids to hasten the development of surfactant-secreting cells. In addition, a premature infant is given surfactants through inhalation in an attempt to prevent this life-threatening condition.

Re-Think

1. List two reasons that the lungs want to collapse.
2. Why does water have a high surface tension?
3. Why does a deficiency of surfactants increase the "work" of breathing?

WHY LUNGS EXPAND

If elastic recoil and surface tension collapse the lungs, why do they remain expanded in the normal closed thorax? Lung expansion depends on pressure within the intrapleural space. A series of diagrams in Figure 22-6 illustrates this point. In Figure 22-6, *A*, the three pressures are labeled P1, P2, and P3. P1 is the pressure outside the chest (the pressure in the room), also called the *atmospheric pressure*. P2 is the pressure in the lung, also called the *intrapulmonic pressure*. P3 is the pressure in the intrapleural space, also called the **intrapleural pressure**. Note in Figure 22-6, *A*, that the lungs are normally expanded.

Figure 22-6, *B* and *C*, shows why the lungs expand. To illustrate this point, a hole is created in the right chest wall so that the right lung collapses. Note the pressures. Because of the hole in the chest wall, all the pressures are equal. In other words, P1 = P2 = P3. In Figure 22-6, *C*, a tube is inserted through the hole of the right chest wall into the intrapleural space. The tube is attached to a pump, which removes air from the intrapleural space. As air moves from the intrapleural space, the intrapleural pressure (P3) decreases and becomes negative. This negative intrapleural pressure (P3) merely means that it is lower than the atmospheric pressure (P1) or the intrapulmonic pressure (P2).

What is the effect of a negative intrapleural pressure? Because P2 (intrapulmonic pressure) is greater than P3 (intrapleural pressure), the lung is pushed toward the chest wall, causing the lung to expand. Also, because P1 (atmospheric pressure) is higher than P3, the chest wall is pushed inward toward the lung. When the chest wall and the lungs meet, the lung is

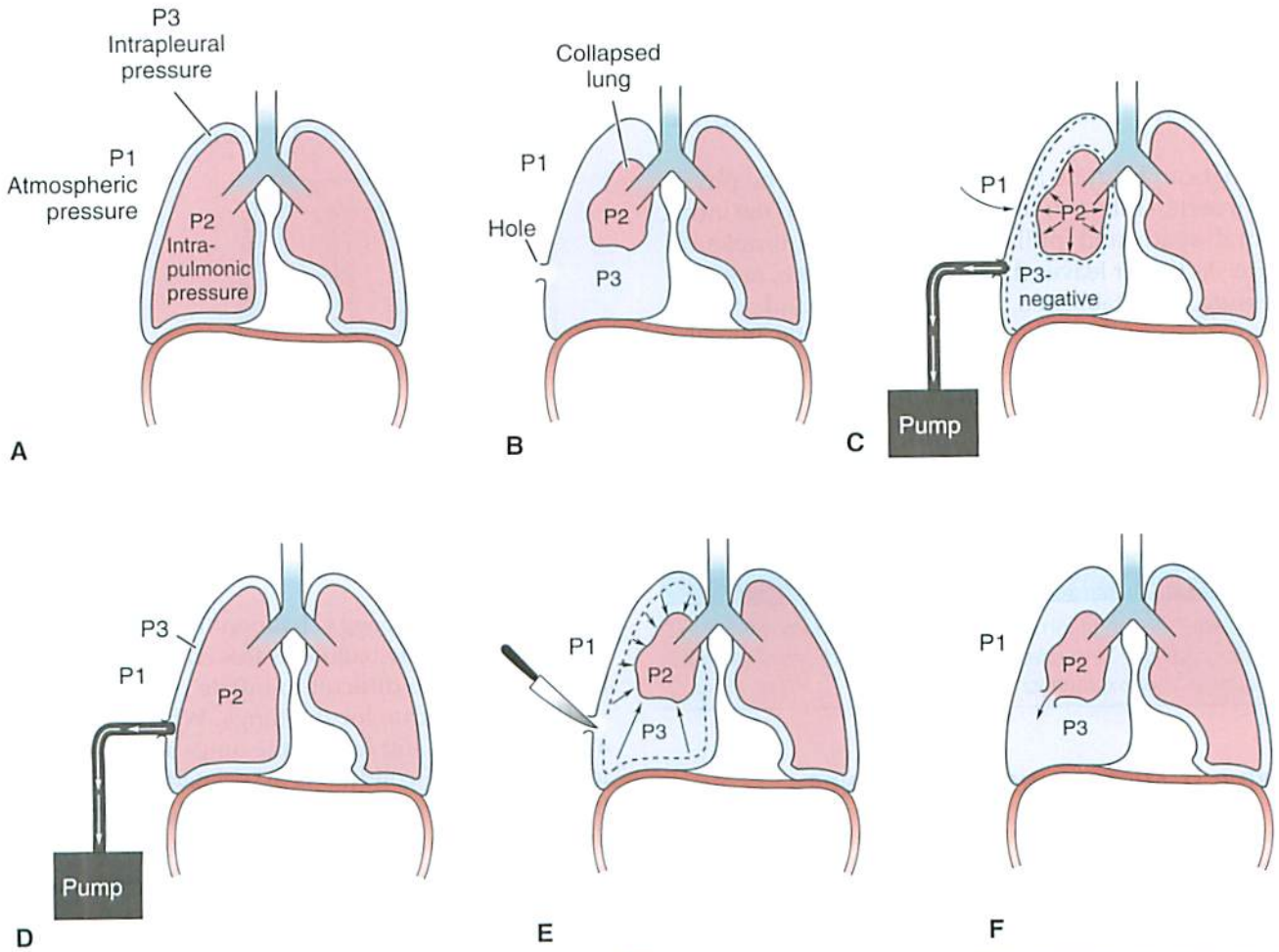


FIGURE 22-6 Lung expansion and collapse. **A,** The lungs expand. **B,** The right lung collapses because of the hole in the chest wall. **C,** Air is pumped out of the intrapleural space, creating a negative intrapleural pressure. **D,** The lung expands because of the negative intrapleural pressure. **E,** The lung collapses because of the hole (knife wound) in the chest wall. **F,** The lung collapses because of a hole in the lung.

expanded (see Figure 22-6, *C* and *D*). The important point is that the lung expands and remains expanded because the intrapleural pressure is negative.

What happens if the pump is removed, thereby recreating the hole in the chest wall? Because P1 is higher than P3, air rushes into the intrapleural space through the hole and eliminates the negative intrapleural pressure. As a result, the lung collapses. Remember that the lung expands only when the intrapleural pressure is negative.

Figure 22-6, *E*, illustrates the effects of a stab wound to the chest. The hole created by the knife allows the air to rush into the intrapleural space and eliminate the negative intrapleural pressure. The introduction of air into the intrapleural space and subsequent collapse of the lung is called a *pneumothorax* (*pneumo-* means air; *thorax* means chest). Air in the intrapleural space is also why the lungs collapse when a surgical incision is made into the chest wall.

Figure 22-6, *F*, shows the effect of a hole in the lung. Because the intrapulmonic pressure (P2) is higher than the intrapleural pressure (P3), air rushes into the intrapleural space through the hole in the lung, thereby eliminating the negative intrapleural pressure and collapsing the lung. Sometimes, people with emphysema develop blebs, or blisters, on the outer surface of their lungs. The blebs rupture and create a hole between the intrapulmonic and intrapleural spaces, causing air to rush into the intrapleural space and collapsing the lung.

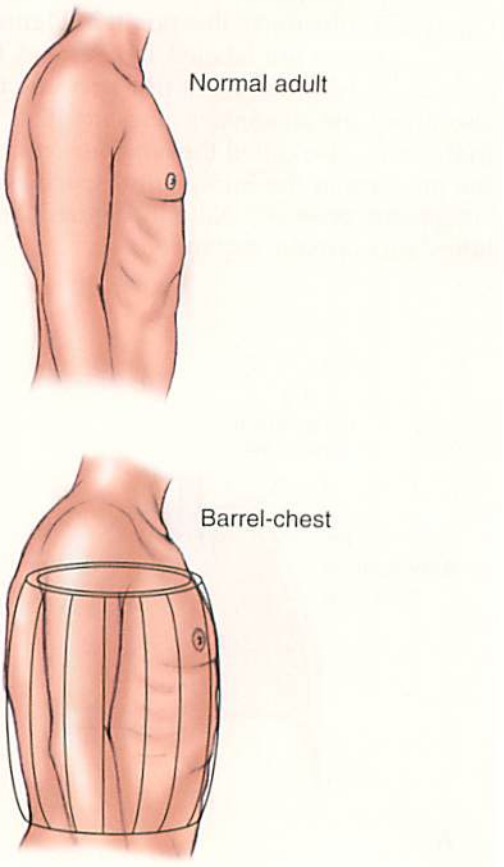
What can be done for a collapsed lung? The physician inserts a tube through the chest wall into the intrapleural space and pulls air out of the intrapleural space. As the air leaves the intrapleural space, negative pressure is reestablished, and the lung expands. Sometimes, the physician inserts a large needle into the intrapleural space to aspirate, or withdraw, air, blood, and pus in a procedure called a *thoracentesis*. It facilitates lung expansion.

NOTE: The intrapleural pressure remains negative only when no hole exists in the chest wall or the lungs.

Do You Know...

Why This Person's Chest Looks Like a Barrel?

This person has emphysema, a condition characterized by damaged tissue in the lower respiratory structures and overinflated alveoli. As a result, the lungs cannot exhale the proper amount of air, and the air remains trapped in the alveoli. (*Emphysema* means "puffed up" alveoli.) Consequently, the alveoli and lungs become overinflated and cause the chest to be shaped like a barrel, so a person with severe emphysema is described as barrel-chested.



Re-Think

Explain why the lungs remain expanded. Use the terms *atmospheric pressure*, *intrapleural pressure*, and *intrapulmonic pressure* in your explanation.

SAYING IT ANOTHER WAY: COMPLIANCE

Compliance is the measure of elastic recoil and can be illustrated by two balloons. One balloon has never been inflated and is stiff. A second balloon has been inflated many times and has lost some of its elasticity (elastic recoil); it appears baggy. Which balloon is easier to inflate? The baggy balloon is easier to inflate because it has lost some of its elasticity and is less stiff.

Translation: The baggy balloon is more compliant (stretchy). The new balloon is less compliant (stiff) and is therefore more difficult to inflate.

The same is true for the lungs. When lung compliance decreases (stiff lungs), the lungs are more difficult to inflate. Some conditions associated with decreased lung compliance are pulmonary edema, respiratory distress syndrome (deficiency of surfactants), and pulmonary fibrosis. Decreased lung compliance is not good!

What about increased lung compliance? Lungs that are too stretchy also cause problems. For example, the patient with emphysema has damaged lung structure and reduced elastic recoil. Lung compliance has

increased too much; there is not enough elastic recoil to completely expel air on exhalation. The increased compliance also contributes to the formation of the barrel chest appearance that characterizes a person with chronic lung disease.

? Re-Think

Explain compliance using the example of two springs: a heavy duty spring used on garage doors and the tiny springs found in ball-point pens.

2+2 Sum It Up!

The expanded lungs normally fill the thoracic cavity. Unless pressure conditions in the pleural cavity are correct, the lungs collapse. The tendency of the lungs to collapse is due to the result of two factors: elastic recoil and alveolar surface tension. The expansion of the lungs is caused by a negative intrapleural pressure within the intrapleural space. If the negative intrapleural pressure is eliminated, the lungs collapse.

RESPIRATORY FUNCTION

THREE STEPS IN RESPIRATION

Most of us equate breathing with respiration. Respiration includes breathing, but it is more than breathing; it involves the entire process of gas exchange between the atmosphere and the body's cells. Respiration includes the following three steps:

- Ventilation, or breathing
- Exchange of oxygen and carbon dioxide
- Transport of oxygen and carbon dioxide by the blood

STEP 1: VENTILATION OR BREATHING

What It Is

Movement of air into and out of the lungs is called **ventilation**; it is more commonly called *breathing*. The two phases of ventilation are inhalation and exhalation. **Inhalation**, also called *inspiration*, is the breathing-in phase. During inhalation, oxygen-rich air moves into tiny air sacs in the lungs. **Exhalation**, also called *expiration*, is the breathing-out phase. During exhalation, air rich in carbon dioxide is moved out of the lungs. One inhalation and one exhalation make up one respiratory cycle.

Boyle's Law: Pressure and Volume

To understand ventilation, you need some background information. You need to know the relationship between pressure and volume, a relationship called *Boyle's law*. Note the two tubes in Figure 22-7. Tube A is a small tube that fits into a bicycle tire. When filled, the tube can hold 1 liter (L) of air. Tube B is larger and fits into a truck tire. When filled, it can hold 10 L of air. Thus, the volume of the truck tube (B) is 10 times greater than the volume of the bicycle tube.

In the upper panel of Figure 22-7, both tubes are empty. Let's add 1 L of air to each tube and measure the pressure in each tube. By touching the surfaces of the tubes, you can get a rough estimate of the pressures. Tube A feels firm, whereas tube B feels soft. In other words, the pressure in tube A is higher than the pressure in tube B. Both tubes received the same amount of air, so why are the pressures different? The different volumes of the tubes cause the different pressures. The pressure is higher in tube A because the volume of tube A is small; 1 L of air completely fills the tube. The pressure in tube B is lower because its volume is large (10 L). One L of air only partially fills the truck tube. The smaller the volume, the higher the pressure; the greater the volume, the lower the pressure. If volume changes, the pressure changes. This is Boyle's law, the principle on which ventilation is based.

Do You Know...

About the Pink Puffers and Blue Bloaters?

Both Pink Puffers and Blue Bloaters suffer from breathing difficulties, such as asthma, emphysema, or chronic obstructive pulmonary disease (COPD). Pink Puffers gasp for breath and, in doing so, turn red in the face. Blue Bloaters, having suffered from poor pulmonary function for a longer time, are accustomed to struggling for air and so don't gasp and struggle like the Pink Puffers. The Blue Bloaters, with weakened respiratory muscles, don't have the energy to puff away and turn red; rather, they tend to inhale a large volume of air, hold it, and become bloated. This type of respiratory activity causes their oxygen levels to decline, thereby causing hypoxemia and cyanosis (blueness). Complicating the hypoxemia is an accumulation of carbon dioxide in the blood, which in turn causes respiratory acidosis. Of the two, Blue Bloaters are generally the most seriously ill and in need of treatment. Furthermore, their already depleted oxygen levels decline quickly if they develop an acute complication such as pneumonia.

Boyle's Law and Breathing

What does Boyle's law have to do with ventilation? On inhalation (breathing in), air flows into the lungs. What is the force that causes the air to flow in? Place your hands on your rib cage. Inhale. Notice that the thoracic cage moves up and out on inhalation (Figure 22-8, *A* and *C*). This movement increases the volume of the thoracic cavity and lungs. As the volume in the lung increases, the pressure in the lung (P2) decreases (satisfying Boyle's law). As a result, P2 becomes less than P1 (atmospheric pressure, the air you breathe). Air flows from higher pressure to lower pressure, through the nose into the lungs.

What happens on exhalation? Another change in lung volume. Place your hands on your rib cage and exhale. The thoracic and lung volumes decrease as the rib cage returns to its resting position (see Figure 22-8,

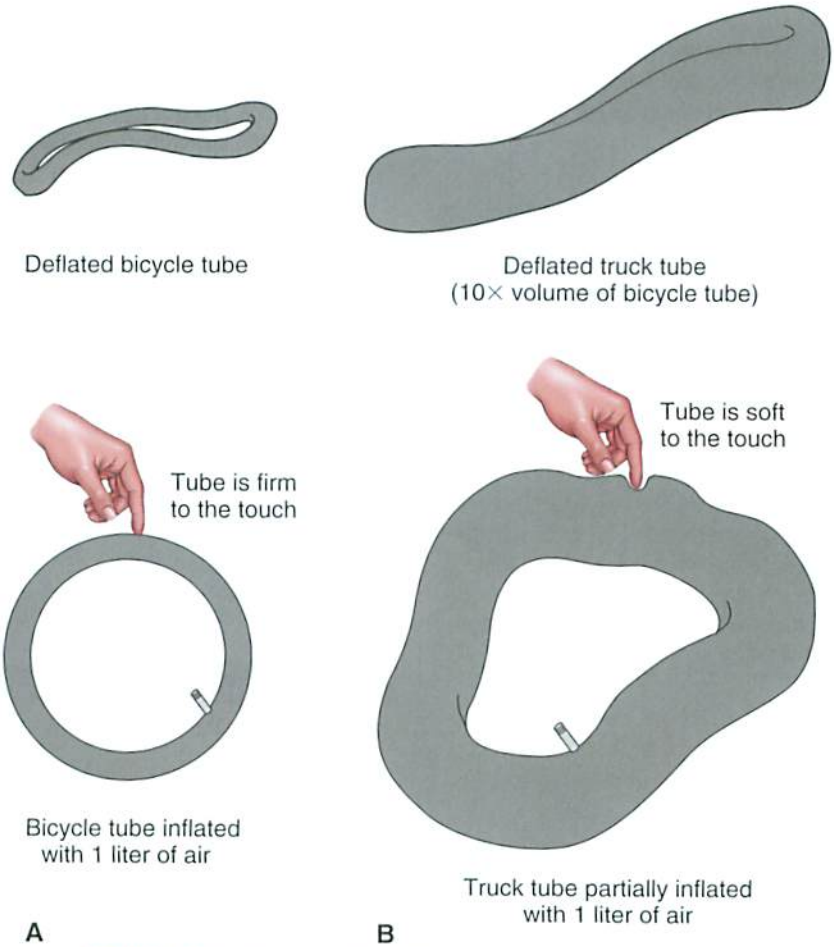


FIGURE 22-7 Boyle's law: relationship between pressure and volume.

B and *D*). The decreased lung volume causes the pressure within the lungs (P2) to increase. Now P2 is higher than P1, and air flows out of the lungs through the nose. Let us clarify the relationship between Boyle's law and ventilation:

- Air flows in response to changes in pressure. As the lung volume increases on inhalation, the intrapulmonic pressure (P2) decreases, and air flows into the lungs.
- On exhalation, lung volume decreases, intrapulmonic pressure (P2) increases, and air flows out of the lungs.
- Air flows in response to pressure changes. Pressure changes occur in response to changes in volume. Inhalation is associated with an increase in thoracic volume; exhalation is associated with a decrease in thoracic volume.

? Re-Think

Explain ventilation in terms of Boyle's law.

The Muscles of Respiration

What causes the thoracic volume to change? The change in thoracic volume is caused by the contraction and relaxation of the respiratory muscles. On inhalation, the respiratory muscles, diaphragm, and intercostal muscles contract (see Figure 22-8, *A* and *C*). The diaphragm is a dome-shaped muscle that forms the floor of the thoracic cavity and separates the thoracic cavity from the abdominal cavity. The diaphragm is the chief muscle of inhalation. Contraction of the diaphragm flattens the muscle and pulls it downward, toward the abdomen. This movement increases the length of the thoracic cavity. During quiet breathing, the diaphragm accounts for most of the increase in the thoracic volume.

The two intercostal muscles, the external and internal intercostals, are located between the ribs. When the external intercostal muscles contract, the rib cage moves up and out, thereby increasing the width of the thoracic cavity. Note that the size of the thoracic cavity increases in three directions: from front to back, from side to side, and lengthwise. Why is this increase in thoracic volume so important? As the thoracic volume increases, so does the volume of the lungs. According to Boyle's law, the increase in volume decreases the pressure in the lungs and, as a result, air flows into the lungs. Some of the accessory muscles of respiration, located in

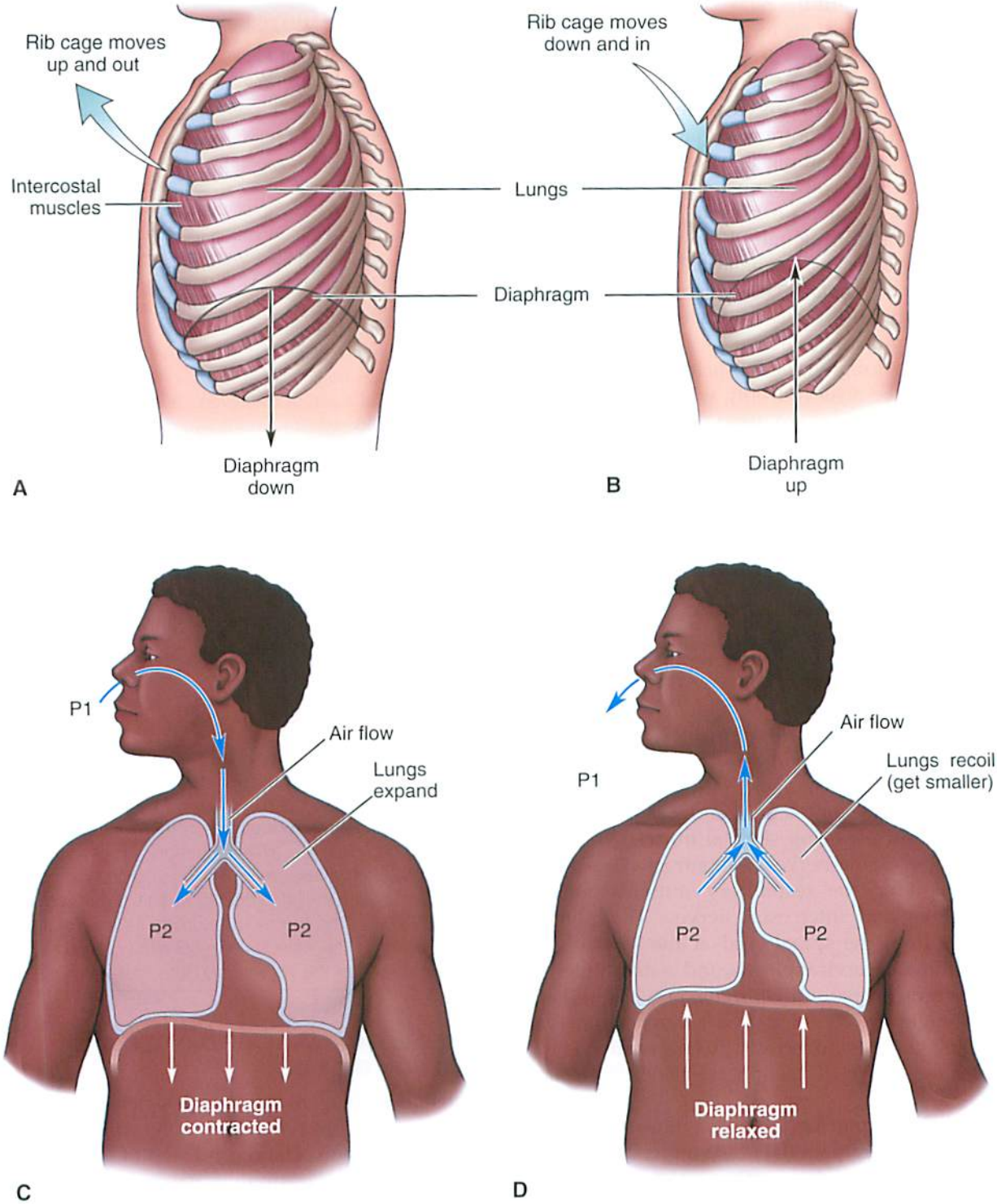


FIGURE 22-8 Inhalation and exhalation. The thoracic volume increases, and air rushes into the lungs **(A** and **C).** The thoracic volume decreases, and air rushes out of the lungs **(B** and **D).**

the neck and chest, can move the rib cage even farther during exertion.

On exhalation, the muscles of respiration relax and allow the ribs and diaphragm to return to their original positions (see Figure 22-8, *B* and *D*). This movement decreases thoracic and lung volume and increases pressure in the lungs. Consequently, air flows out of the lungs. Elastic recoil of lung tissue and surface tension within the alveoli aid with exhalation. Forced exhalation uses the accessory muscles of respiration. These include the muscles of the abdominal wall and the internal intercostal muscles. Contraction of the accessory muscles of respiration pulls the bottom of the rib cage down and in, and it forces the abdominal

viscera upward toward the relaxed diaphragm. These actions force additional air out of the lungs.

How much energy does it take to breathe? Inhalation is a result of the contraction of the respiratory muscles, so it is an active process. The muscles use up energy (ATP) as they contract. Exhalation associated with normal quiet breathing is passive. Exhalation is caused by muscle relaxation; no energy is required for muscle relaxation. Thus, in normal quiet breathing, we use up energy during half of the respiratory cycle (inhalation). We rest on exhalation. During forced exhalation (as in exercise), however, the accessory muscles of respiration must contract, and exhalation becomes energy using, or active.

With certain lung diseases such as emphysema, exhalation can be achieved only when the accessory muscles of respiration are used. The patient with emphysema therefore uses energy during both inhalation and exhalation. This process is physically exhausting, and these patients usually complain of being very tired.

Re-Think

1. What muscles are used for inhalation?
2. Explain why different muscles are used in exhalation and forced exhalation. Why might a person force exhale?

Nerves That Supply the Respiratory Muscles

Ventilation occurs in response to changes in the thoracic volume, and the changes in thoracic volume are caused by muscle contraction and relaxation. The respiratory muscles, being skeletal muscles, must be stimulated by motor nerves to contract. The motor nerves supplying the respiratory muscles are the phrenic nerve and intercostal nerves. The phrenic nerve exits from the spinal cord at the level of C4, travels within the cervical plexus, and is distributed to the diaphragm. Firing of the phrenic nerve stimulates the diaphragm to contract. The intercostal nerves supply the intercostal muscles. Thus, inhalation is initiated by the firing of the phrenic and intercostal nerves.

You will be caring for patients whose nerve and muscle function is impaired. For example, if the spinal cord is severed above C4, the phrenic nerve cannot fire. As a result, the skeletal muscles (diaphragm and intercostals) cannot contract. The person not only is quadriplegic, but also can breathe only with the assistance of a ventilator. Other patients experience difficulty in breathing because of the effects of certain drugs. Curare, for example, is a drug commonly used during surgery to cause muscle relaxation. It is a neuromuscular blocking agent that interferes with the transmission of the electrical signal from nerve to muscle. The block occurs within the neuromuscular junction. The patient is not only unable to move the body voluntarily, but also is unable to breathe.

Do You Know...

That a Boa Constrictor Knows More about Boyle's Law Than the Early Corset Makers?

The boa knows that by wrapping itself around an animal's chest, it can suffocate the victim by preventing chest expansion and inhalation (Boyle's law). Early corset makers, however, ignored this basic information. Corsets were designed to constrict the waist—the tighter the corset, the smaller the waist. A successfully corseted young lady might boast of a 12-inch–diameter waist! Problem was, the upper part of the corset included the lower part of the rib cage. What was the result of this constant binding? The corset prevented adequate ventilation and caused a permanent deformity of the rib cage, to say nothing of the displaced abdominal organs. The corseted young lovely couldn't breathe and often fainted. Herein lies the physiological basis of the swoon and delicate weakness that characterized wealthy young women. They were not weak because of their female X chromosomes; they were merely hypoxemic—no oxygen going to the brain. Fortunately, only the wealthiest could make a fashion statement by fainting.

Re-Think

What is the respiratory consequence of an injured or severed phrenic nerve?

2+2 Sum It Up!

The three steps in respiration are ventilation, exchange of oxygen and carbon dioxide in the lungs and cells, and transport of oxygen and carbon dioxide by the blood. Ventilation occurs in response to changes in thoracic volumes, which in turn cause changes in intrapulmonic pressures. Inhalation occurs when the respiratory muscles contract and enlarge the thoracic cage. Exhalation occurs when the respiratory muscles relax, allowing the thorax to return to its smaller, resting thoracic volume. The muscles of respiration contract in response to stimulation of the phrenic and intercostal nerves.

STEP 2: EXCHANGE OF OXYGEN AND CARBON DIOXIDE

Inhalation delivers fresh oxygen-rich air to the alveoli and exhalation removes carbon dioxide–laden air from the alveoli. The second step of respiration is the exchange of the respiratory gases. Exchange occurs at two sites: in the lungs and at the cells (Figure 22-9).

Why the Lungs Are Good Gas Exchangers

Gas exchange occurs in the lungs, specifically across the membranes of the alveoli and pulmonary capillaries. Three conditions make the alveoli well suited for the exchange of oxygen and carbon dioxide: a large surface area, thin alveolar and pulmonary capillary walls, and a short distance between the alveoli and pulmonary capillaries.

- *Large surface area.* Millions of alveoli, approximately 350 million per lung, create a total surface area

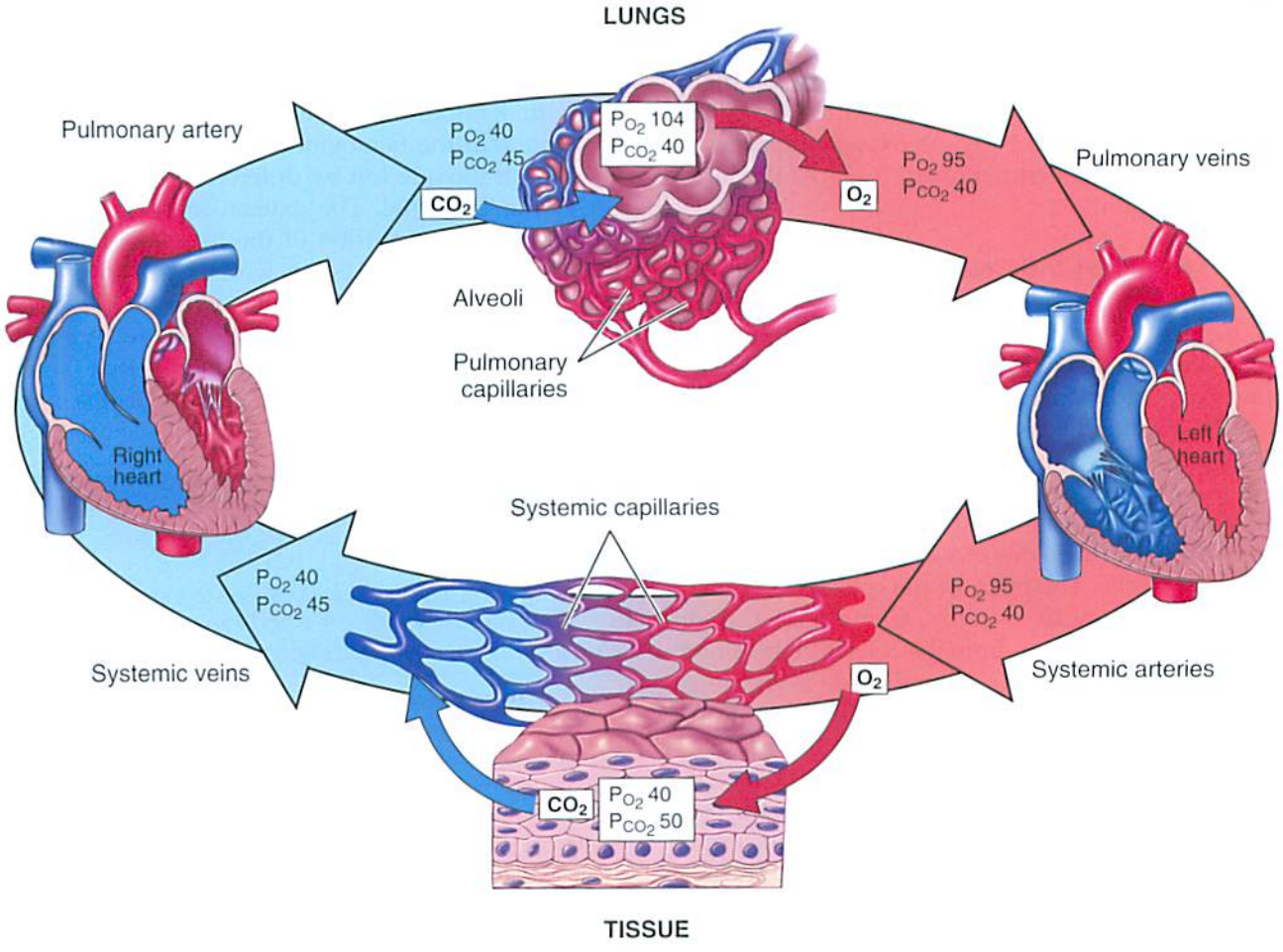


FIGURE 22-9 Partial pressures of oxygen (pO_2) and carbon dioxide (pCO_2) within the lungs and at the cellular level (in mm Hg).

about half the size of a tennis court. The large surface increases the amount of oxygen and carbon dioxide exchanged across the alveolar membranes.

- *Thin alveolar and pulmonary capillary walls.* The thin walls favor diffusion because they do not offer much resistance to the movement of oxygen and carbon dioxide across the membranes.
- *Closeness of the alveoli to the pulmonary capillaries.* Each alveolus is very close to a pulmonary capillary. For diffusion, closeness ensures a high rate of diffusion.

Partial Pressures and the Diffusion of Gases

What Causes the Respiratory Gases to Diffuse?

Chapter 3 describes how molecules diffuse from an area of higher concentration to an area of lower concentration. For gases such as oxygen and carbon dioxide, however, concentration is related to pressure. When the molecules of a gas are highly concentrated, the gas creates a high pressure. Consequently, we can talk about diffusion from areas of higher pressure to areas of lower pressure.

Ordinary room air is a gas composed of 78% nitrogen, 21% oxygen, and 0.04% carbon dioxide. Each part of the gas contributes to the total pressure. The amount of pressure each gas contributes is called the **partial pressure**. The symbol for the partial pressure of oxygen is pO_2; the symbol for the partial pressure of carbon dioxide is pCO_2. (Because the body does not use nitrogen gas, we can ignore it.)

Partial Pressures within the Lungs. Let us analyze the partial pressures of the respiratory gases in the alveoli and pulmonary capillaries (see Figure 22-9). The pO_2 of air in the alveoli is 104 mm Hg, whereas the pO_2 of venous blood (the blue end of the pulmonary capillary) is 40 mm Hg. Oxygen diffuses from the area of higher pressure (the alveolus) to the area of lower pressure (the pulmonary capillary). Note that the pO_2 in the blood goes from 40 mm Hg (blue) to 95 mm Hg (red). The partial pressure of oxygen increases because the blood has been oxygenated.

As for the waste, the carbon dioxide, the pCO_2 in the blood (blue capillary) is 45 mm Hg, whereas the pCO_2 in the alveolus is only 40 mm Hg. Carbon dioxide diffuses from the capillary, the area of higher pressure, to the alveolus, the area of lower pressure. Because of the diffusion of carbon dioxide out of the blood, the pCO_2 of the blood goes from 45 mm Hg at the blue end of the capillary to 40 mm Hg at the red end of the

capillary. What has been accomplished? The blood coming from the right side of the heart (blue) has been oxygenated and the oxygenated blood (red) eventually returns to the left side of the heart so that it can be pumped throughout the body. As oxygenation occurs, carbon dioxide has been removed; it leaves the lungs during exhalation.

Partial Pressure at the Cells. What happens to the gases at the tissues, or body cells? Two events occur. First, oxygen leaves the blood and diffuses into the cells, where it can be used during cell metabolism. Second, carbon dioxide, a consequence of cell metabolism, diffuses into the blood.

What partial pressures cause these events to happen? The pO_2 of the arterial blood is 95 mm Hg, whereas the cellular pO_2 is only 40 mm Hg. During gas exchange, oxygen diffuses from the blood into the space surrounding the cells. The pCO_2 of the cells is 50 mm Hg and the arterial pCO_2 is only 40 mm Hg. Carbon dioxide therefore diffuses from the cells into the blood. The blood then carries the carbon dioxide to the lungs for excretion. Thus, oxygenated blood from the lungs carries the oxygen to the cells; the oxygen then diffuses from the blood into the cells. The carbon dioxide, or the waste produced by the metabolizing cells, diffuses into the blood, which carries it to the lungs for excretion. Note the venous blood leaving the cells. The pO_2 is 40 mm Hg because the oxygen has been used up by the cells. The pCO_2 is 45 mm Hg because the waste was removed from the cells.

STEP 3: TRANSPORT OF OXYGEN AND CARBON DIOXIDE

The third step in respiration is the blood's mechanism for transporting oxygen and carbon dioxide between the lungs and body cells. Although the blood transports both oxygen and carbon dioxide, the way in which blood transports each gas differs.

Oxygen Transport

Almost all the oxygen (98%) is transported by the hemoglobin in the red blood cells. The remaining 2% of the oxygen is dissolved in the plasma. As soon as oxygen enters the blood in the pulmonary capillaries, it immediately forms a loose bond with the iron portion of the hemoglobin molecule. This new molecule is oxyhemoglobin. As the oxygenated blood travels to the cells throughout the body, the oxygen unloads from the hemoglobin molecule and diffuses across the capillary walls to the cells. The oxygen is eventually used up by the metabolizing cells.

Carbon Dioxide Transport

Blood carries carbon dioxide from the metabolizing cells to the lungs, where it is exhaled. Blood carries carbon dioxide in the following three forms:

- Ten percent of the carbon dioxide is dissolved in plasma.
- Twenty percent of the carbon dioxide combines with hemoglobin to form carbaminohemoglobin. Note that the hemoglobin carries both oxygen and carbon dioxide but by different parts of the hemoglobin molecule. The oxygen forms a loose bond with the iron portion of the hemoglobin, whereas the carbon dioxide bonds with the globin, or protein (amino acids) portion, of the hemoglobin.
- Seventy percent of the carbon dioxide is converted to the bicarbonate ion (HCO_3^-). Note that the blood carries most of the carbon dioxide in the form of bicarbonate.

? Re-Think

1. What is the pO_2 in the alveoli, pulmonary veins, tissue, and vena cava?
2. What is the driving force for oxygen to move from the alveoli into the blood? From the blood into the tissues?
3. How does the blood transport oxygen? Carbon dioxide?

2+2 Sum It Up!

The exchange of the respiratory gases occurs at two sites: the lungs and the cells. Oxygen diffuses from the alveoli into the pulmonary capillaries. Carbon dioxide diffuses from the pulmonary capillaries into the alveoli. At the cellular sites, oxygen diffuses from the capillaries into the cells; carbon dioxide diffuses from the cells into the capillaries. Blood transports oxygen and carbon dioxide. Hemoglobin carries most of the oxygen as oxyhemoglobin. The blood carries most of the carbon dioxide in the form of a bicarbonate ion (HCO_3^-).

AMOUNTS OF AIR

LUNG VOLUMES

Think about all the ways that you can vary the amount of air you breathe. For example, you can inhale a small amount of air or you can take a deep breath. How are you breathing now? Probably slowly and effortlessly. With strenuous exercise, you would breathe more rapidly and deeply. If you become anxious, your breathing pattern becomes more rapid and shallow. With certain diseases, your respirations might increase or decrease. In other words, the amount, or volume, of air you breathe can vary significantly.

The different volumes of air you breathe have names. The four pulmonary volumes are *tidal volume*, *inspiratory reserve volume*, *expiratory reserve volume*, and *residual volume*. A spirometer (spih-ROM-eh-ter) is a device that measures pulmonary volumes. The patient blows into the spirometer, which measures the amount of air and prints the results on graph paper. A recording of the volumes appears in Figure 22-10 and is summarized in Table 22-1:

- *Tidal volume.* Breathe in and out. The amount of air moved into or out of the lungs with each breath is called the **tidal volume**. The average tidal volume

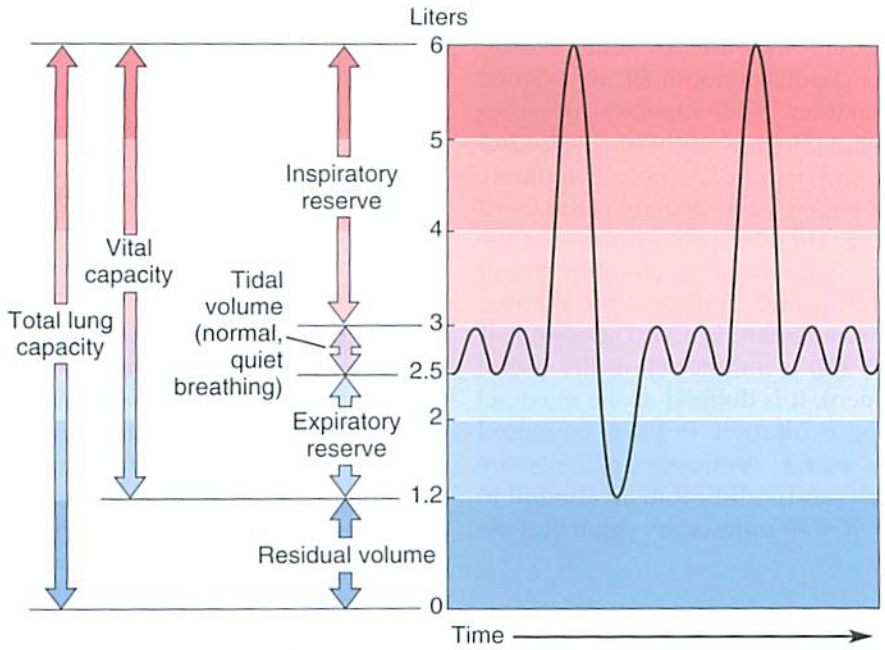


FIGURE 22-10 Pulmonary volumes and capacities.

during normal quiet breathing is about 500 mL. Tidal volume increases with exercise.

- *Inspiratory reserve volume.* Inhale a normal volume of air. Now, in addition to this normal amount of air, inhale as much as you possibly can. The additional volume of air is called the *inspiratory reserve volume.* This extra volume is approximately 3000 mL.
- *Expiratory reserve volume.* Exhale a normal amount of air. Now, in addition to this normal amount of air, exhale as much as you possibly can. The extra volume of exhaled air is called the *expiratory reserve volume.* It is about 1100 mL.
- *Residual volume.* Even after a forced exhalation, about 1200 mL of air remains in the lungs. This remaining air is the *residual volume.* Residual air remains in the lungs at all times, even between breaths. Note in Figure 22-10 that the four pulmonary volumes add up to the total lung capacity.

LUNG CAPACITIES

In addition to four pulmonary volumes, there are four pulmonary capacities (two described here). A pulmonary capacity is a combination of pulmonary volumes. For example, **vital capacity** (4600 mL) refers to the combination of tidal volume (500 mL), inspiratory reserve volume (3000 mL), and expiratory reserve volume (1100 mL). The measurement of vital capacity is a commonly used pulmonary function test.

You can measure vital capacity as follows. Take the deepest breath possible. Exhale all the air you possibly can into a spirometer. The spirometer measures the

Table 22-1 Lung Volumes and Capacities

NAME	DESCRIPTION	AMOUNT (mL)
Volumes		
Tidal volume	The volume of air moved into or out of the lungs during one respiratory cycle	500
Residual volume	The volume of air that remains in the lungs after a forceful exhalation	1200
Inspiratory reserve volume	The volume of air that can be forcefully inhaled after normal inhalation	3000
Expiratory reserve volume	The volume of air that can be forcefully exhaled after normal exhalation	1100
Capacities		
Vital capacity	The maximum volume of air that can be exhaled following maximal inhalation	4600
Functional residual capacity	The volume of air remaining in the lungs following exhalation during quiet breathing	2300
Total lung capacity	The volume of air in the lungs following a maximal inhalation	5800

amount of air you forcibly exhale. The amount exhaled should be approximately 4600 mL. In other words, vital capacity is the maximal amount of air exhaled after a maximal inhalation. Vital capacity measures pulmonary function in patients with lung diseases such as emphysema and asthma. A more commonly used clinical term for forced vital capacity is the *forced expiratory volume* (FEV). The FEV is the fraction of the forced vital capacity exhaled in a specific number of seconds. The subscript in FEV_1 indicates the number of seconds that the measurement lasted. The term *peak expiratory flow rate* (PEFR) is another clinically useful respiratory measurement. It is defined as the maximal rate of air flow during expiration. PEFR is measured by a handheld flow meter. Asthmatic patients are taught to measure FEV_1 and/or PEFR in an attempt to manage their asthma. (Other pulmonary capacities are listed in Table 22-1.)

DEAD SPACE

Some of the air you inhale never reaches the alveoli. It stays in the conducting passageways of the trachea, bronchi, and bronchioles. Because this air does not reach the alveoli, it is not available for gas exchange and is said to occupy anatomical dead space. The dead space holds about 150 mL of air. Breathing slowly and deeply increases the amount of well-oxygenated air that reaches the alveoli. Conversely, rapid panting delivers a poorer quality of air to the alveoli because a greater percentage of the inhaled volume of air remains in the anatomical dead space. Therefore, when you encourage your patients to take deep breaths, you are also helping supply the alveoli with well-oxygenated air.

? Re-Think

1. Differentiate between tidal volume and vital capacity.
2. Explain to your patient in two to three sentences what to do in order to measure vital capacity.

CONTROL OF BREATHING

Normal breathing is rhythmic and involuntary. For example, as you read, you are breathing effortlessly, about 16 times/min. (The normal respiratory rate ranges from 12 to 20 breaths/min in an adult and from 20 to 40 breaths/min in a child, depending on the age and size of the child.) You do not have to remember to breathe in and out, nor do you have to calculate how deeply to breathe. Fortunately, breathing occurs automatically.

You can voluntarily control breathing up to a point. Hold your breath for 5 seconds. Now try to hold your breath for 3 minutes. You can't do it; you must breathe. The need to breathe means that Sammy should not hold you hostage with his temper tantrums. No matter how good his performance and how long he holds his breath, he will eventually take a really deep breath and live.

NEURAL CONTROL OF RESPIRATION

How does the body control breathing? The two means of controlling breathing are nervous and chemical mechanisms. The nervous mechanism involves several areas of the brain, the most important being the brain stem. Special groups of neurons are widely scattered throughout the brain stem, particularly in the medulla oblongata and the pons (Figure 22-11). The main control center for breathing, in the medulla oblongata, is called the *medullary respiratory control center*. It sets the basic breathing rhythm.

Inhalation occurs when the inspiratory neurons in the medulla oblongata fire, giving rise to nerve impulses. The nerve impulses travel from the medulla oblongata along the phrenic and intercostal nerves to the muscles of respiration. Contraction of the respiratory muscles causes inhalation. Exhalation occurs when the expiratory neurons in the medulla oblongata fire and shut down the inspiratory neurons. This process inhibits the formation of nerve impulses and causes the respiratory muscles to relax. Thus, breathing is the result of the alternate firing of the inspiratory and expiratory neurons.

Although the medulla oblongata is the main control center for breathing, the pons also plays an important role. The pons contains the pneumotaxic center and the apneustic center. These areas in the pons modify and help control breathing patterns.

The medullary respiratory center is very sensitive to the effects of narcotics. Narcotics (opioids), such as morphine, depress the medulla oblongata and slow respirations. If the narcotic overdose is large enough, respirations may even cease, causing respiratory arrest and death. Because of the profound effect of narcotics on respirations, you must check a patient's respiratory rate before administering narcotics.

? Re-Think

1. What part of the brain stem exerts the greatest control of respiration?
2. Why will a downward herniation of the brain stem through the foramen magnum cause respiratory arrest?

Although the brain stem normally determines the basic rate and depth of breathing, other areas of the brain, including the hypothalamus and cerebral cortex, can also affect breathing patterns. For example, the hypothalamus processes our emotional responses, such as anxiety and fear. The hypothalamus, in turn,

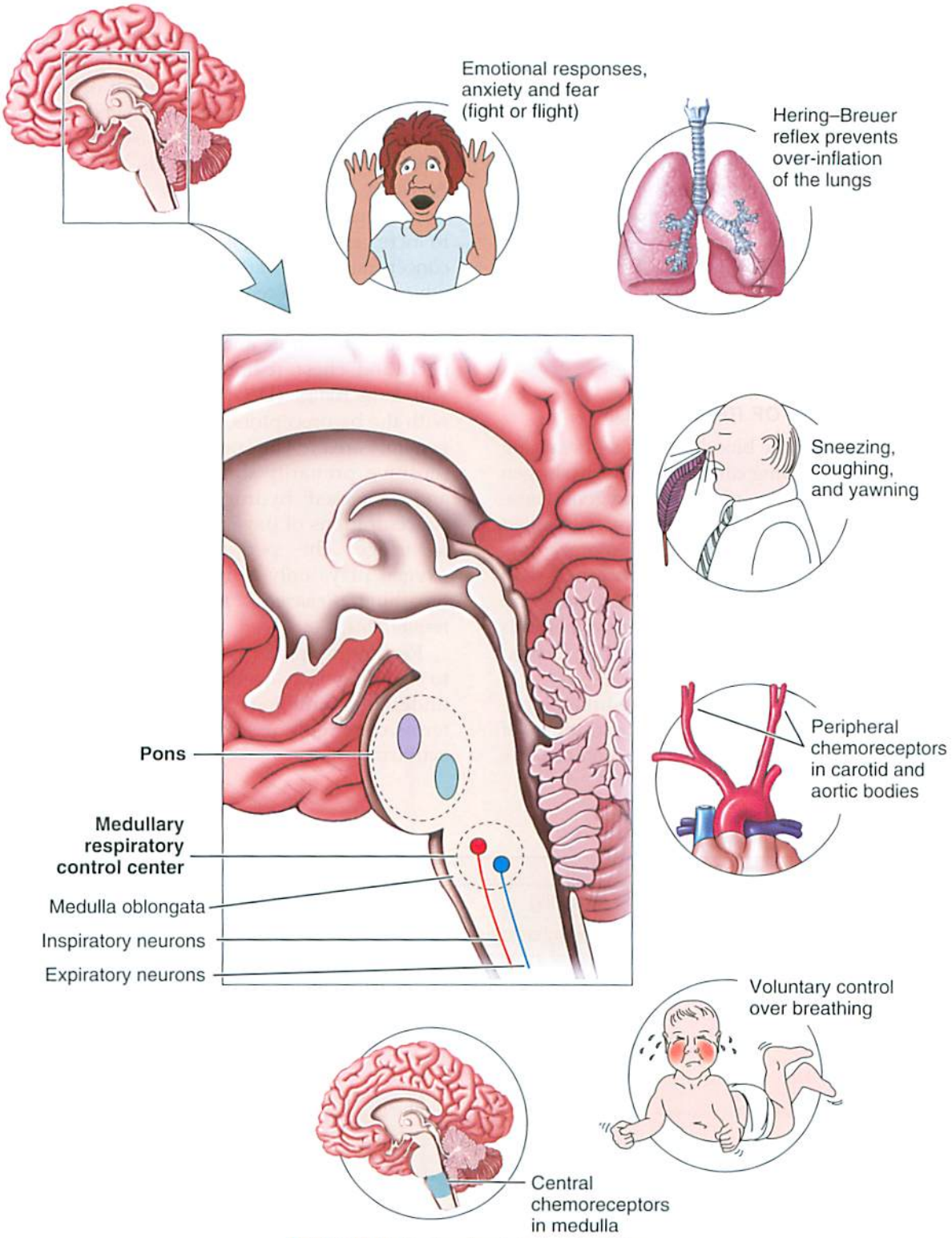


FIGURE 22-11 Factors that influence breathing.

stimulates the brain stem and changes the breathing pattern. Rapid breathing, a response to anxiety or fear, is part of the fight-or-flight response. The cerebral cortex can also affect respiration; cortical activity allows us to control the depth and rate of breathing voluntarily.

Several other nervous pathways affect the respiratory system. For example, the vagus nerve carries nerve impulses from the lungs to the brain stem. When the lungs become inflated, nerve impulses travel to the brain stem, inhibiting the inspiratory neurons. This response is called the *Hering-Breuer reflex*. It prevents overinflation of the lungs. The nervous structures not only control breathing patterns, but also affect several reflexes associated with the respiratory system. These include coughing, sneezing, and yawning.

CHEMICAL CONTROL OF RESPIRATION

Chemicals dissolved in the blood also affect breathing (see Figure 22-11), including carbon dioxide, hydrogen ion (which determines the pH), and oxygen. These chemicals are detected by chemosensitive cells called *chemoreceptors*. When activated, the chemoreceptors stimulate the areas of the brain stem concerned with respiration. The two types of chemoreceptors are central chemoreceptors, located in the central nervous system (CNS), and peripheral chemoreceptors, located outside the CNS.

The central chemoreceptors in the medulla oblongata detect changes in the blood concentrations of carbon dioxide and hydrogen ions. If carbon dioxide or hydrogen ion concentration increases, the central chemoreceptors signal the respiratory center to increase its activity. This response causes an increase in the rate and depth of breathing. As a result of the increase in breathing, carbon dioxide is exhaled and the blood levels of carbon dioxide decrease. Conversely, if the blood levels of carbon dioxide and hydrogen ions decrease, breathing decreases, thereby allowing concentrations of both carbon dioxide and hydrogen ions to increase. Breathing is controlled primarily by blood concentrations of carbon dioxide and hydrogen ions, which trigger the central chemoreceptors.

The peripheral chemoreceptors are in the walls of the carotid arteries and the walls of the aorta in the neck and chest region. They are called the *carotid* and *aortic bodies*. (Do not confuse the chemoreceptors with the baroreceptors, which are located in the same general area.) The peripheral chemoreceptors are sensitive primarily to low concentrations of oxygen and increased hydrogen ion concentration. Blood concentrations of oxygen, however, must be very low to trigger the peripheral chemoreceptors. Thus, oxygen plays only a minor role in the regulation of breathing. *Remember: pCO_2 is the major regulator of respirations.*

Respiratory patterns change, most often in response to changing body needs and sometimes in response to underlying pathology. Table 22-2 includes respiratory terms commonly used to describe altered respiratory activity.

Table 22-2 Common Respiratory Terms

TERM	DESCRIPTION
Apnea	Temporary cessation of breathing
Cheyne-Stokes respirations	An irregular breathing pattern characterized by a series of shallow breaths that gradually increase in depth and rate; the series of increased respirations is followed by breaths that gradually decrease in depth and rate. A period of apnea lasting 10 to 60 seconds follows; the cycle then repeats.
Cyanosis	A bluish color of the skin or mucous membrane caused by a low concentration of oxygen in the blood
Dyspnea	Difficult or labored breathing
Eupnea	Normal, quiet breathing
Hypoxia	An abnormally low concentration of oxygen in the tissues
Hypoxemia	An abnormally low concentration of oxygen in the blood
Hypercapnia	An abnormally high concentration of carbon dioxide in the blood
Hypocapnia	An abnormally low concentration of carbon dioxide in the blood
Hyperventilation	An increase in the rate and depth of respiration. Hyperventilation causes an excess exhalation of carbon dioxide and alkalosis.
Hypoventilation	A decrease in the rate and depth of respiration. Hypoventilation causes a retention of carbon dioxide and acidosis.
Kussmaul breathing	An increase in rate and depth of respiration stimulated by metabolic acidosis
Orthopnea	Difficulty in breathing that is relieved by a sitting-up position
Rales	Crackles (as in snap, *crackle*, and pop) are small clicking sounds in the lungs that resemble rubbing hair together next to the ear. They are typically inspiratory and are believed to occur when air opens closed air spaces. Rales or crackles can be further described as moist, dry, fine, and coarse.

Table 22-2 Common Respiratory Terms—cont'd

TERM	DESCRIPTION
Rhonchi	Snoring-like sounds that generally occur with obstruction of air in the large airways (trachea and bronchi)
Stridor	High-pitched, wheezelike sound that can be heard on both inhalation and/or exhalation. It is caused by an obstruction of air flow in the upper airway, such as the trachea, or in the back of the throat.
Tachypnea	Rapid breathing
Wheezes	High-pitched sounds typically on exhalation. Wheezing and other abnormal sounds can sometimes be heard without a stethoscope. Wheezing occurs when air is forced through narrow airways. Although commonly associated with asthma, wheezing may also be caused by other obstructing conditions (e.g., tumors, swelling, foreign bodies).

Re-Think

Explain how pCO_2 affects respiratory rate.

2+2 Sum It Up!

Normal breathing is rhythmic and involuntary. Nervous and chemical mechanisms control breathing. The nervous mechanism involves several areas of the brain, the most important of which is the brain stem. The inspiratory and expiratory neurons in the medulla oblongata determine the basic breathing pattern, which can be modified by the apneustic center and pneumotaxic center in the pons. Chemicals in the blood help control respirations. The central chemoreceptors in the brain are sensitive to carbon dioxide and hydrogen ions, and the peripheral chemoreceptors are sensitive to low blood levels of oxygen and an increase in the hydrogen ion concentration. pCO_2 is the major regulator of respirations.

As You Age

1. As a person ages, lung capacity decreases. The decrease in lung capacity is caused by the loss of elasticity of the lung tissue and diminished efficiency of the respiratory muscles. By the age of 70 years, vital capacity has decreased 33%.
2. With aging, many of the protective mechanisms of the respiratory system decline. The ciliary activity of the mucosa decreases, for example, and the phagocytes in the lungs become less effective. As a result, older adults are at greater risk for respiratory infections, especially pneumonia and bronchitis.
3. With age-related structural changes, the number of alveoli diminishes. The resulting decrease in oxygenation ultimately diminishes the capacity for physical activity.
4. Respiratory control is altered; consequently, the pO_2 drops to a lower level whereas the pCO_2 increases to a higher level.
5. Having breathed a lifetime's worth of various harmful substances (e.g., cigarette smoke, pollutants, pollens, pathogens), the lungs of an older person often show evidence of wear and tear, leading to emphysema and other respiratory disorders.

MEDICAL TERMINOLOGY AND DISORDERS Disorders of the Respiratory System

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
Words			
epistaxis		From a Greek word meaning "to drip"	**Epistaxis** is *a nosebleed.*
eupnea (and other "-pnea" words)	eu-	normal	**Eupnea** means *normal breathing.* To contrast, **bradypnea** (brady- = slow) is slow breathing, whereas **tachypnea** (tachy- = rapid) means rapid breathing. **Apnea** (a- = without) refers to the temporary cessation of breathing, **dyspnea** (dys- = difficult) is difficulty in breathing, and **orthopnea** (ortho- = straight) is the inability to breathe unless in an upright position.
	-pnea	breathing	
inspiration	in-	in	**Inspiration** refers to *breathing in or inhalation;* **expiration** (ex- = out) refers to *breathing out or exhalation.*
	-spir/o	breathing	
oximeter	-ox/i-	oxygen	A pulse **oximeter** is *a mechanical device used to measure oxygen levels in the blood.*
	-meter	measure	

Continued

MEDICAL TERMINOLOGY AND DISORDERS Disorders of the Respiratory System—cont'd

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
thoracentesis	thorac/o-	chest	A **thoracentesis** is *the incision through the chest wall in order to aspirate fluid or air for therapeutic or diagnostic purposes.*
	-centesis	surgical puncture	
Disorders			
influenza		From an Italian word meaning "influence of the cold"	*A respiratory infection (also known as* ***the flu****) that can be caused by several influenza viruses.*
pharyngitis	pharyng/o-	pharynx or throat	*Also called a sore throat; refers to an inflammation of the pharynx or throat.* Approximately 70% of the cases are virally induced. Infection by beta-hemolytic streptococcus is called *strep throat.*
	-itis	inflammation of	
rhinitis	rhin/o-	nose	Refers to the inflammation of the nasal mucosa. **Allergic rhinitis** refers to the response of the nasal mucosa to an allergen. **Seasonal allergic rhinitis** is triggered by high pollen counts. **Perennial allergic rhinitis** is present constantly throughout the year and is triggered by pet dander, cockroaches, and dust mites. **Acute viral rhinitis** is the **common cold** or **acute coryza.**
	-itis	inflammation of	
sinusitis (acute)	sinus/o-	sinus	*Refers to inflammation of the sinuses and is most often due to a swelling and narrowing of passages that drain the sinuses.*
	-itis	inflammation of	
Lower Respiratory Disorders			
asthma		From a Greek word meaning "to breathe hard" or "to pant"	*A chronic immune-mediated airway inflammation, characterized by breathlessness, tightness of the chest, dyspnea, wheezing, and coughing.* The inflammatory process produces **bronchial hyperreactivity,** so that milder stimuli, such as exercise, act as triggers.
bronchiectasis	bronch/o-	bronchus	*Refers to the permanent and abnormal dilation of the bronchi.* The characteristic sign of bronchiectasis is a persistent or recurrent cough and the production of purulent sputum.
	-ectasis	stretching or dilation	
bronchocarcinoma	bronch/o-	bronchus	A common cause of cancer-related deaths in the United States. It is especially common in persons >50 years with a long history of cigarette smoking. More than 90% of lung cancers are bronchogenic and arise from the bronchial epithelium.
	-carcin/o-	cancer	
	-oma	tumor	
tuberculosis	tubercul/o-	tubercle	Commonly called TB. It is known historically as "consumption" and was responsible for the "white plague." Globally TB is responsible for more deaths than any other infectious disease. TB is caused by *Mycobacterium tuberculosis,* or the "acid-fast" bacillus, and is generally spread by droplet infection through inhalation of the pathogen. It usually affects the upper lobes of the lungs, but can infect many other organs and spread or seed throughout the body (miliary TB). Following inhalation, the mycobacteria continue to multiply without any resistance from the host. In about 10 to 20 days a cellular immune response limits the growth and spread of the infection by the formation of a granuloma. The inner core of the granuloma is called the *Ghon tubercle;* it undergoes caseous necrosis, thereby forming a cheesy mass of dead cells and debris. The lesion may also liquefy and drain into surrounding bronchi, causing cavitation. The primary lesion often becomes fibrotic and calcifies. The infection enters a latent period during which mycobacteria become dormant. The activation of the dormant mycobacteria can occur at any time, particularly in an immunosuppressed person and in patients taking steroids.
	-osis	condition of	

MEDICAL TERMINOLOGY AND DISORDERS Disorders of the Respiratory System—cont'd

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
Restrictive Lung Disorders			
Disorders characterized by decreased "stretchiness" of the lungs and/or chest wall. They are classified as extrapulmonary and intrapulmonary disorders. Extrapulmonary causes of restrictive disorders include disorders of the CNS, the neuromuscular junction, and the chest wall. The intrapulmonary disorders are described as follows.			
pleuritis	pleur/o- -itis	pleura inflammation	*Also called* **pleurisy** *and refers to an inflammation of the pleura.* Pleurisy is classified as **dry pleurisy** (fibrinous) and **wet pleurisy** (serofibrinous, with an increased secretion of pleural fluid).
pleural effusion	pleur/o- -al effusion	pleura pertaining to From a Latin word meaning "to pour out"	*Refers to the accumulation of excess fluid between the two pleural membranes.* (An effusion is an escape of a fluid into a body cavity.) The two types of pleural effusion are the transudative and the exudative.
pneumothorax	pneum/o- -thorac/o-	air or lung chest	*Refers to the accumulation of air within the pleural space, causing the lung to collapse.* A pneumothorax can be opened or closed. An open pneumothorax occurs when the chest wall is penetrated, as in stabbing or gunshot wounds. A **closed pneumothorax** is not caused by an external wound; its cause originates within, as in a ruptured bleb (air bubble or blister) in a person with emphysema, ventilator-induced lung injury, and lung injury from broken ribs. A **tension pneumothorax** is due to a rapid accumulation of air in the pleural space. In addition to air, the lung may also collapse in response to the accumulation of blood in the pleural space (**hemothorax;** hem/o- = blood) or lymph (**chylothorax;** chyl/o- = lymph).
interstitial lung diseases (ILDs)			*A general term that includes many disorders characterized by inflammation and fibrosis.* The largest group of disorders appears in occupations and environments where there is significant inhalation of dust, gas, or fumes. ILDs also occur in response to infections and as a result of connective tissue disorders such as rheumatoid arthritis and scleroderma. **Sarcoidosis** and **idiopathic pulmonary fibrosis** are the two most common ILDs with an unknown etiology.
pneumonia	pneum/o- -ia	air or lung condition of	*Refers to an inflammation of lung tissue.* Pneumonia is the leading cause of death by infectious disease in the United States and has the highest mortality rate of all nosocomial (hospital-acquired) infections. There are many types of pneumonia. Pneumonia may be classified according to its cause: bacterium, virus, fungus, *Mycoplasma,* parasite, and chemical. Pneumonia is also classified according to whether it is community-acquired pneumonia or hospital-acquired pneumonia. **Community-acquired pneumonia (CAP)** is most commonly caused by *Streptococcus pneumoniae* and has its onset in the community or during the first 48 hours of hospitalization. **Hospital-acquired pneumonia (HAP)** occurs after 48 hours of admission to a hospital. The causative organisms of HAP are primarily bacterial, and differ from those involved with CAP. **Aspiration pneumonia** refers to the response of lung tissue to the entry of a foreign substance from the mouth or stomach. It usually occurs in persons with a diminished gag or cough reflex as occurs with loss of consciousness. **Opportunistic pneumonia** refers to pneumonia that develops in immunosuppressed persons. Immunosuppression is common in persons receiving cancer chemotherapy and radiation therapy.

Continued

MEDICAL TERMINOLOGY AND DISORDERS Disorders of the Respiratory System—cont'd

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
acute respiratory distress syndrome (ARDS)			**Adult respiratory distress syndrome,** or ARDS, is *a syndrome that leads to multiple organ failure and death.* **Infant respiratory distress syndrome (IRDS)** occurs in the premature infant and is due to the lack of pulmonary surfactants. (IRDS was formerly called **hyaline membrane disease.**)
Chronic Obstructive Pulmonary Diseases			
Called COPD and includes diseases (chronic bronchitis and emphysema) characterized by increased air flow obstruction. The major risk factor is cigarette smoking.			
emphysema		From a Greek word meaning "puffed up or bloated"	*Characterized by hyperinflation and destruction of the alveoli, obstruction of the small airways, and loss of elasticity of the lung tissue.*
chronic bronchitis	bronch/o- -itis	bronchus inflammation of	*The excessive production of mucus in the bronchi and the development of a recurrent and productive cough.* Chronic bronchitis is characterized by hyperplasia of the mucus-secreting cells in the trachea and bronchi; this causes narrowing of the airways and alters the functioning of the macrophages.
Vascular Lung Disorders			
pulmonary edema			*A collection of fluid within the alveolar and interstitial spaces of the lungs.* The presence of fluid impairs the diffusion of respiratory gases causing dyspnea, hypoxemia, CO_2 retention, and respiratory acidosis.
pulmonary embolism			*The lodging of an embolus or emboli in the pulmonary arterial circulation.* The affected part of the lung is therefore ventilated, but not perfused (with blood). The most common causes of pulmonary embolus are a blood clot arising from a thrombus in the deep veins of the legs or a clot originating in the right side of the heart in a person with atrial fibrillation.
pulmonary artery hypertension			*An elevation in pulmonary artery pressure.* Pulmonary hypertension increases the workload of the right ventricle causing ventricular hypertrophy and cor pulmonale.

Get Ready for Exams!

Summary Outline

The respiratory system is primarily concerned with the delivery of oxygen to every cell in the body and the elimination of carbon dioxide.

I. Structures: Organs of the Respiratory System

A. Consists of the upper and lower respiratory tracts

B. Nose and nasal cavities
   1. The nose and nasal cavities warm and humidify inhaled air.
   2. Olfactory receptors are located in the nose.
   3. The nasal cavities receive drainage from the paranasal sinuses and tear ducts.

C. Pharynx (throat)
   1. The nasopharynx forms a passage for air only.
   2. The oropharynx and laryngopharynx form passageways for both air and food.

D. Larynx (voice box)
   1. The larynx is a passage for air.
   2. The epiglottis is the uppermost cartilage and covers the larynx during swallowing.

E. Trachea (windpipe)
   1. It bifurcates into the right and left bronchi.
   2. C-shaped rings of cartilage keep the trachea open.

F. Bronchial tree
   1. The bronchial tree contains the bronchi, bronchioles, and alveoli.
   2. The bronchioles determine the radius of the respiratory air passages and therefore affect the amount of air that can enter the alveoli.
   3. The alveoli are tiny grapelike air sacs surrounded by pulmonary capillaries.
   4. Gas exchange occurs across the thin walls of the alveoli.

G. Lungs
1. The right lung has three lobes and the left lung has only two lobes.
2. The lungs contain the structures of the lower respiratory tract.

H. Pleural membranes
1. The serous membranes in the chest cavity are the parietal pleura and the visceral pleura.
2. Serous fluid between the pleural membranes prevents friction.
3. For the lungs to remain expanded, pressure in the intrapleural space must be negative.

II. Respiratory Function

A. Respiration includes three steps: ventilation, exchange of respiratory gases, and transport of respiratory gases in the blood.
1. Ventilation (breathing)
   a. The two phases of ventilation are inhalation and exhalation.
   b. Ventilation occurs in response to changes in the thoracic volume (Boyle's law).
   c. Thoracic volume changes because of the contraction and relaxation of the respiratory muscles.
   d. The phrenic and intercostal nerves are motor nerves that supply the diaphragm and the intercostal muscles.
   e. Inhalation is an active process (ATP is used during muscle contraction). Unforced exhalation is passive (no ATP used).
2. Exchange of gases
   a. Exchange of respiratory gases occurs by diffusion across the alveoli and pulmonary capillaries.
   b. Oxygen diffuses from the air in the alveoli into the blood while carbon dioxide diffuses from the blood into the alveoli.
   c. At the cellular layer, oxygen diffuses from the capillaries to the cells. Carbon dioxide diffuses from the cells into the capillaries, where it is transported to the lungs for excretion.
3. Transport of gases in the blood
   a. Most of the oxygen is transported by the red blood cell (oxyhemoglobin).
   b. The blood transports most carbon dioxide in the form of bicarbonate ion (HCO_3^-).

B. Amounts of air
1. Pulmonary volumes
   a. Refers to the amounts of air moved into and out of the lungs
   b. Pulmonary volumes are illustrated in Figure 22-10 and summarized in Table 22-1.
2. Vital capacity and anatomical dead space
   a. Lung capacities are combinations of pulmonary volumes.
   b. Vital capacity is the amount of air that can be exhaled after a maximal inhalation.
   c. Anatomical dead space refers to air remaining in the large conducting passageways that is unavailable for gas exchange, approximately 150 mL of air.

C. Control of breathing
1. Neural control of breathing
   a. The respiratory center is located in the brain stem.
   b. The medullary respiratory center contains inspiratory and expiratory neurons. Nerve impulses travel along the phrenic and intercostal nerves to the muscles of respiration.
   c. The pneumotaxic center and apneustic center are in the pons. These centers help control the medullary respiratory center to produce a normal breathing pattern.
   d. Two other areas of the brain can affect respirations: the hypothalamus and cerebral cortex.
2. Chemical control of respiration
   a. Central chemoreceptors are stimulated by carbon dioxide (pCO_2) and [H^+].
   b. Peripheral chemoreceptors are sensitive to low concentrations of oxygen and increased hydrogen ion concentration in the blood.

Review Your Knowledge

Matching: Structures of the Respiratory Tract

Directions: Match the following words with their descriptions below. Some words may be used more than once.

a. pharynx
b. trachea
c. larynx
d. bronchus
e. paranasal sinuses
f. bronchioles
g. carina
h. alveoli

1. ___ The trachea branches into a right and left _____
2. ___ Called the *voice box* because it contains the vocal cords
3. ___ Mucus drains from these mucous membrane-lined structures into the nasal passages.
4. ___ The respiratory structure connected to the middle ear by the eustachian tube
5. ___ Large tube supported by rings of cartilage; called the *windpipe*
6. ___ The respiratory structure(s) concerned with the exchange of the respiratory gases
7. ___ Structure closest to the pulmonary capillaries
8. ___ Tiny respiratory passages that deliver air to the alveoli
9. ___ Respiratory passage that delivers air to the bronchioles
10. ___ The point at which the trachea splits; causes intense coughing when stimulated by a suction catheter

Matching: Thoracic Cavity and Ventilation

Directions: Match the following words with their descriptions below. Some words may be used more than once.

a. parietal pleura
b. thoracic cavity
c. intrapleural space
d. visceral pleura
e. phrenic
f. diaphragm

1. ___ Membrane on the outer surface of each lung
2. ___ Contains the pleural cavity, pericardial cavity, and mediastinum
3. ___ The lung collapses when air or fluid collects in this space.
4. ___ The motor neuron that innervates the diaphragm
5. ___ Dome-shaped muscle that is the chief muscle of inhalation
6. ___ Membrane that lines the walls of the pleural cavity
7. ___ Must have a negative pressure here

Multiple Choice

1. Inhalation and exhalation are
   a. caused by contraction of the diaphragm and intercostal muscles.
   b. caused by contraction and relaxation of the bronchiolar smooth muscle.
   c. referred to as *ventilation*.
   d. caused by the relaxation of the diaphragm and intercostal muscles.
2. The bronchi, bronchioles, and alveoli are
   a. concerned with the exchange of respiratory gases.
   b. upper respiratory structures.
   c. collectively referred to as the *bronchial tree*.
   d. surrounded by rings of cartilage.
3. The diameter of the bronchioles determines the
   a. amount of mucus secreted by the respiratory membranes.
   b. rate of surfactant secretion.
   c. air flow to the alveoli.
   d. ventilatory rate.
4. Which of the following best describes the visceral and parietal pleura?
   a. They line the inner wall of the trachea and bronchi.
   b. They line the mediastinum.
   c. They are serous membranes.
   d. They are surfactant-secreting membranes.
5. If intrapleural pressure equals or exceeds intrapulmonic pressure,
   a. surfactant secretion ceases.
   b. the lung collapses.
   c. the larynx can no longer generate sound.
   d. pulmonary edema develops.
6. Which of the following does not occur on inhalation?
   a. Air moves into the lungs.
   b. Thoracic volume increases.
   c. The diaphragm contracts.
   d. Pressure within the intrapleural space becomes positive.
7. Which of the following describes Boyle's law?
   a. An increase in thoracic volume causes an increase in intrapleural pressure.
   b. There is no relationship between intrapulmonic pressure and thoracic volume.
   c. An increase in thoracic volume decreases intrapulmonic pressure.
   d. An increase in thoracic volume forces air out of the lungs.

Go Figure

1. **According to Figure 22-1**
   a. All respiratory structures distal to the larynx are located within the lung.
   b. The alveoli are the most distal of all structures of the bronchial tree.
   c. The bronchioles have cartilaginous rings similar to the trachea.
   d. Gas exchange occurs across all respiratory structures located in the lung.
2. **According to Figure 22-2**
   a. The glottis is also called the *true vocal cords*.
   b. The epiglottis prevents the entrance of food and water into the respiratory structures.
   c. The esophagus is "covered" by the epiglottis during swallowing.
   d. The larynx is part of both the respiratory system and the digestive system.
3. **According to Figure 22-3**
   a. The carina is located within the larynx.
   b. Alveoli are composed of a single layer of cells held open by cartilaginous rings.
   c. The alveoli are proximal to the bronchioles.
   d. The left lung has two lobes whereas the right lung has three lobes.
4. **Which statement is not true about Figure 22-5?**
   a. Elastic recoil wants to collapse the lungs.
   b. The surface tension of water wants to collapse the lungs.
   c. Surfactants want to collapse the lungs.
   d. Surfactants decrease the surface tension of water.
5. **According to Figures 22-4 and 22-6**
   a. The lung collapses when the intrapulmonic pressure exceeds intrapleural pressure.
   b. The lung collapses when intrapulmonic pressure exceeds atmospheric pressure.
   c. The lung collapses when intrapleural pressure is lower than intrapulmonic pressure.
   d. Pressure is normally negative in the space between the visceral and parietal pleurae.
6. **According to Figure 22-7 and Boyle's Law**
   a. When volume increases, pressure increases.
   b. When volume decreases, pressure decreases.
   c. There is no relationship between volume and pressure.
   d. When volume increases, pressure decreases.