14 The Respiratory System

IT'S A GAS

Without fuel, we wouldn't get very far on our trip. Our car won't start without gasoline, our plane would be grounded without jet fuel, and our bodies would die without glucose, the fuel necessary for metabolism. The respiratory system's primary function is to transport the oxygen from the atmosphere into the bloodstream to be used by cells, tissues, and organs for the processes necessary to sustain life. Remember, during cellular respiration, glucose is broken down to make adenosine triphosphate (ATP). Your body needs oxygen to "burn" glucose, just as your car needs oxygen to burn gasoline. This amazing system is often taken for granted. We don't even consciously realize that the respiratory system is moving 12,000 quarts of air a day into and out of our lungs. On our journey, the fuel for our means of transportation also produces a waste by-product, or exhaust. For example, our car produces waste gases that it eliminates through its exhaust system. The body also produces a waste gas, carbon dioxide, during metabolism that needs to be eliminated via the respiratory system so it does not build up to toxic levels. In this chapter, we explore the journey that oxygen molecules must take from our surrounding atmosphere to our cells and tissues. Hopefully, your journey through the respiratory system will be a "breathtaking" experience.

LEARNING OUTCOMES

At the end of the journey through this chapter, you will be able to:

- List the basic functions of the respiratory system.
- Differentiate between respiration and ventilation.
- Name and explain the functions of the structures of the upper and lower respiratory tracts.
- Discuss the process of gas exchange at the alveolar level.
- Describe the role of the pleura in protecting the lungs.
- Describe the various skeletal structures related to the respiratory system.
- Explain the actual process and regulation of ventilation.
- Describe pulmonary function testing.
- Discuss several common disorders of the respiratory system.

Pronunciation Guide

Pro•*nun*•ci•a•tion
Definitions/Parts

Correct pronunciation is important in any journey so that you and others are completely understood. Here is a "see-and-say" Pronunciation Guide for the more difficult terms to pronounce in this chapter. Please note that even though there are standard pronunciations, regional variations of the pronunciations can occur.

adenoid (AD eh noid)
alveoli (al VEE oh lye)
atelectasis (AT eh LEK tah sis)
bronchi (BRONG kye)
bronchioles (BRONG kee ohlz)
capillaries (KAP ih lair eez)
carina (kah RINE uh)
cilia (SILL ee ah)
conchae (KONG kay)
diaphragm (DIE ah fram)
emphysema (EM fih SEE mah)
empyema (EM pye EE mah)
epiglottis (ep ih GLAH tiss)
erythropoiesis (eh RITH roh poy EE sis)
esophagus (eh SOFF ah gus)
eustachian tubes (yoo STAY she ehn)
glottis (GLAH tiss)
hilum (HIGH lim)
larynx (LAIR inks)
lingula (LING gu lah)
mediastinum (MEE dee ah STY num)
medulla oblongata (meh DULL lah OB long GAH tah)
nasopharynx (NAY zoh FAIR inks)
oropharynx (OR oh FAIR inks)
palatine tonsils (PAL ah tine)
parietal pleura (pah RYE eh tal PLOO rah)
pneumocyte (NEW moh site)
respiration (res pir AY shun)
rima glottidis (RIE mah GLAH ti diss)
sternum (STER num)
surfactant (sir FAC tant)
thoracic cage (tho RASS ik)
trachea (TRAY kee ah)
tuberculosis (too BER kew LOH sis)
ventilation (ven tih LAY shun)
vibrissae (vie BRISS ee)
visceral pleura (VISS er al PLOO rah)

SYSTEM OVERVIEW

Along your journey, you will undoubtedly have plenty of exercise walking to see the sights. Have you ever wondered why you feel out of breath or why breathing faster and deeper helps you recover from strenuous exercise? Our body uses energy from the food we eat, but cells can obtain the energy from food only with the help of the vital gas *oxygen* (O_2), which allows for cellular respiration. Luckily, oxygen is found in relative abundance in the atmosphere and therefore in the air we breathe. However, when the cells use oxygen, they produce the gaseous waste *carbon dioxide* (CO_2). If allowed to build up in the body, carbon dioxide would become toxic, so the bloodstream carries the carbon dioxide to the lungs to be exhaled and eliminated from the body. The respiratory system's primary role, therefore, is to bring oxygen from the atmosphere into the bloodstream and to remove the gaseous waste by-product carbon dioxide. As you can see from this discussion, the respiratory system works closely with the heart and circulatory system. Because of this relationship, these two systems are often grouped together in medicine to form the **cardiopulmonary system**.

The respiratory system consists of the following major components:

- Two lungs, the vital organs of the respiratory system
- Upper and lower airways that *conduct*, or move, gas into and out of the system
- Terminal air sacs called *alveoli* surrounded by a network of capillaries that provide for *gas exchange*
- A thoracic cage that houses, protects, and facilitates the function of the system
- Muscles of breathing that include the main muscle, the diaphragm, and accessory muscles

Please take a few minutes to look at **FIGURE 14–1** ■. We explore each of these components as we travel through the respiratory system.

AMAZING FACTS

Autocontrol of the Cardiopulmonary System

The cardiovascular and the respiratory, or pulmonary, systems function without any conscious effort on your part. You probably didn't realize it, but as you read the previous paragraph and these last two sentences, your heart beat approximately 70 times and pumped approximately 5 liters of blood around your body. During that same time, you breathed approximately 12 times, moving over 6,000 milliliters of air. Homeostatic control mechanisms, including the autonomic nervous system and the hypothalamus, regulate ventilation rate, cardiac output, and blood pressure.

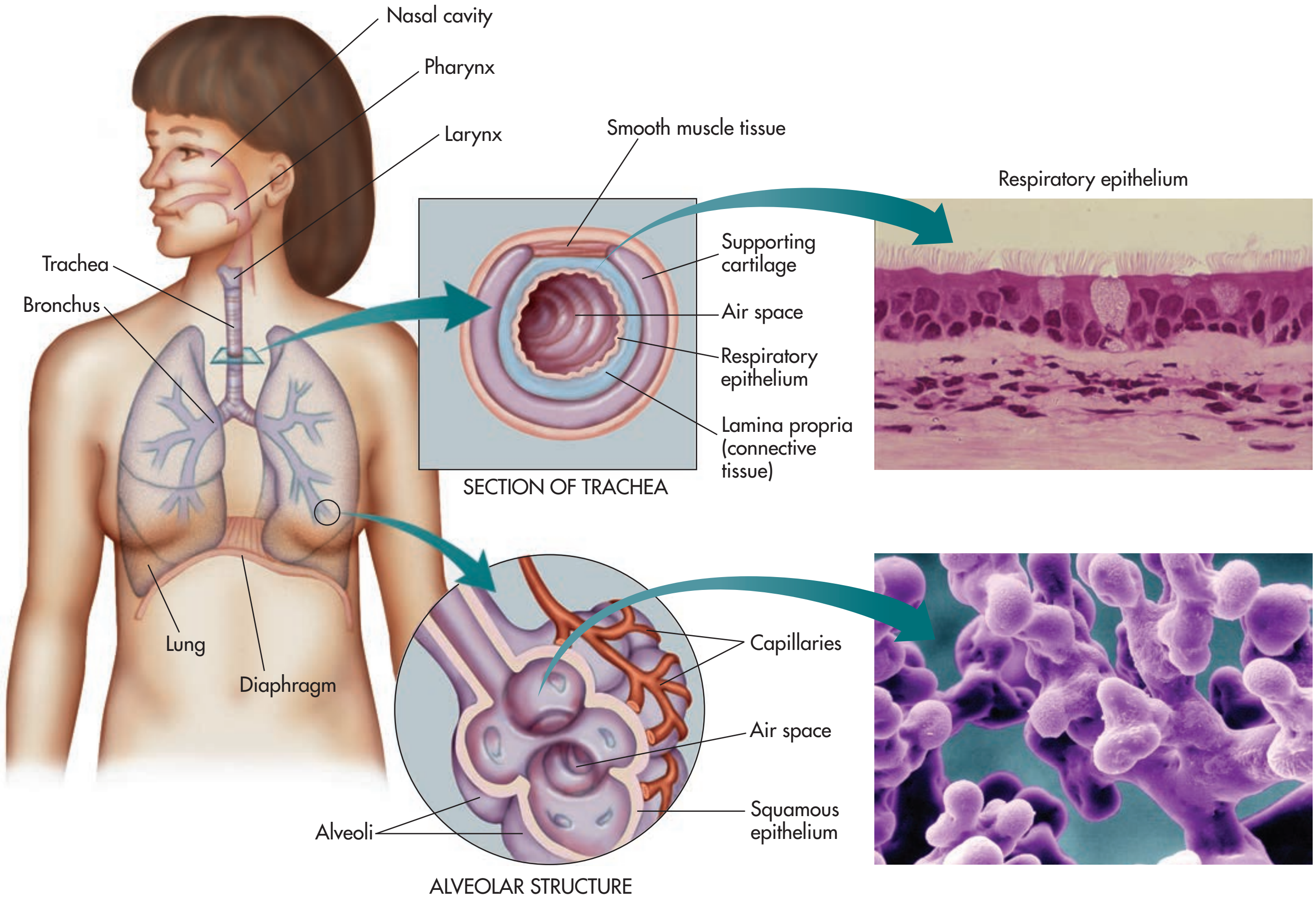


FIGURE 14–1 ■
The components of the respiratory system with micrographs of the respiratory epithelium and alveoli. (Source: Ed Reschke/Photolibrary/Getty Images; BSIP/Universal Images Group/Getty Images)

Ventilation versus Respiration

Before beginning our journey, it is important to pave the way with a solid understanding of some commonly confused concepts. The air we breathe is a mixture of several gases, as can be seen from **TABLE 14–1** ■. The predominant gas is nitrogen (N_2), but this is an *inert* gas, which means it does not combine or interact with anything in the body. Even though nitrogen travels into the respiratory system and comes out virtually unchanged, it is vitally important as a support gas that keeps the lungs open with its constant volume and pressure. The next greatest concentrated gas is oxygen, and it is very physiologically active within our bodies. You'll notice that carbon dioxide is in low concentration in the air we inhale, but it is in much higher concentration in the air we exhale.

The respiratory system contains a very intricate network of tubes that moves, or conducts, gas from the atmosphere to deep inside the lungs. This movement of gas is accomplished by breathing. However, a more precise look at the process of breathing shows that it is actually two separate processes. The first is **ventilation**, which is the bulk movement of the air in and out of the terminal ends of the airways. The process of *gas exchange*, which occurs deep within the lungs, in which oxygen is added to the blood and carbon dioxide is

Table 14–1 Gases in the Atmosphere

GAS	% OF ATMOSPHERE
Nitrogen (N_2)	78.08
Oxygen (O_2)	20.95
Carbon dioxide (CO_2)	.03
Argon	.93

Note: The atmosphere also contains trace gases such as neon and krypton.

removed, is termed **respiration**. (*Note:* The process by which cells make ATP by breaking down glucose is also called *respiration*: *cellular respiration*.) Because the gas exchange in the lungs occurs between the blood and the air in the external atmosphere, it is more precisely called **external respiration**. The oxygenated blood is transported internally via the cardiovascular system to the cells and tissues where gas exchange is now termed **internal respiration**, and oxygen moves into the cells as carbon dioxide is removed. Therefore, ventilation is not the same thing as respiration. When you watch a television show in which someone says to place the patient on a respirator, that term is incorrect. The person should say "ventilator" because the machine is only moving the gas mixture into the patient's lung (ventilating) and not causing gas exchange. See **FIGURE 14–2**, which contrasts these important processes.

The respiratory system is responsible for providing all the body's oxygen needs and removing carbon dioxide. In fact, the body's oxygen reserve lasts only about 4–6 minutes. If that reserve is used up and additional oxygen is unavailable, then death is the obvious outcome. Therefore, the body must continually replenish its oxygen by bringing in the oxygen molecules from the atmosphere.

In a general sense, the respiratory system is a series of branching tubes called **bronchi** and **bronchioles** that transport the atmospheric gas deep within our lungs to the small air sacs called **alveoli**, which represent the terminal end of the respiratory system. To better visualize this system, look at a stalk of broccoli held upside down. The stalk and its branches represent the airways, and the green bumpy stuff on the end is like the terminal alveoli. See? Not only is broccoli good for you but it can also be a learning tool!

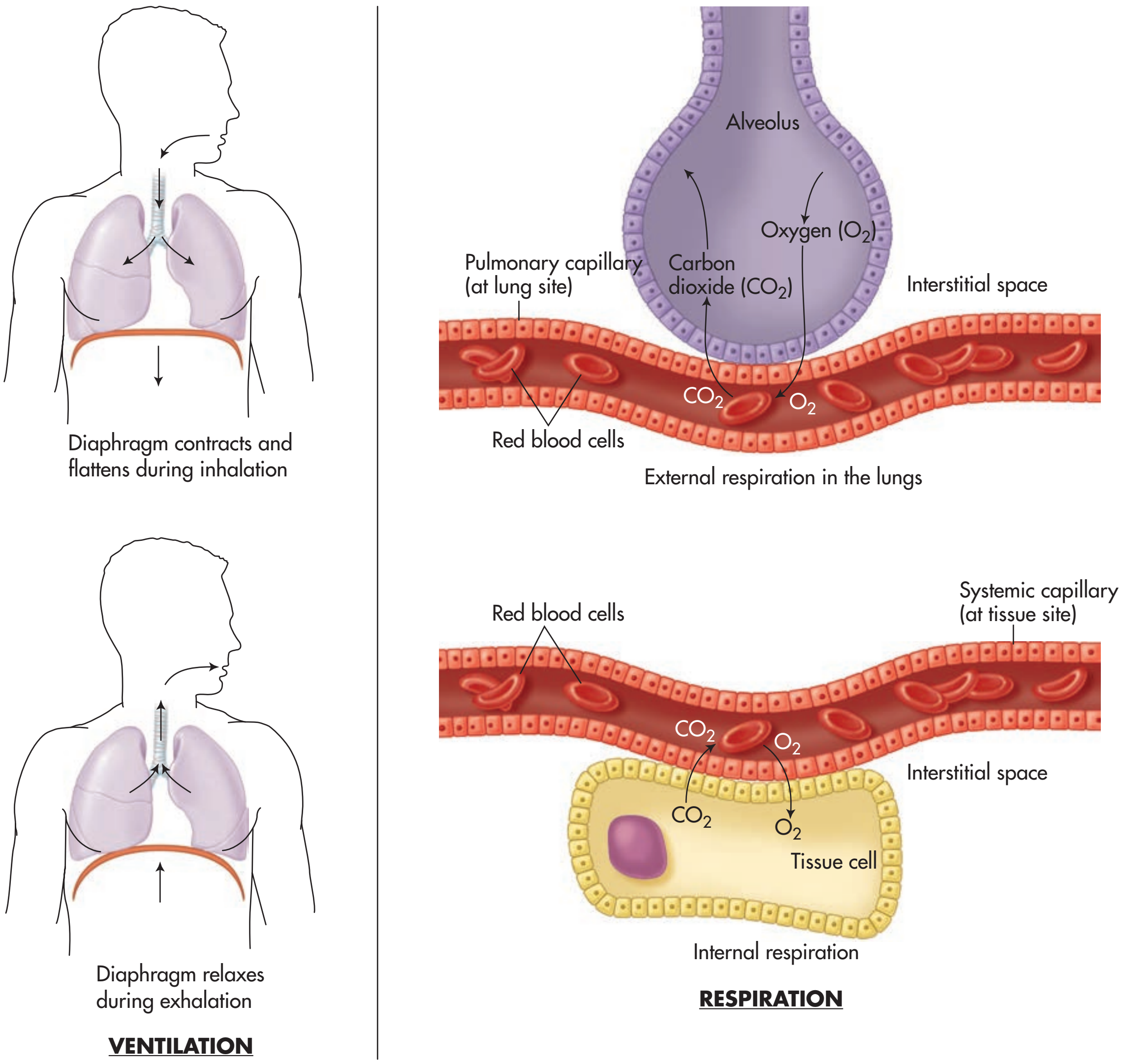


FIGURE 14–2
Contrast of ventilation and external and internal respiration.

Each alveolus is surrounded by a network of small blood vessels called **capillaries**. This combination of the alveolar wall and the capillary wall is called the *alveolar–capillary membrane* and represents the connection, or for you computer buffs, the interface, between the respiratory and cardiovascular systems. This is where the vital process of gas exchange takes place and therefore it is also referred to as the respiratory membrane. Before getting deeper into this process, let's trace the journey that oxygen molecules must take to arrive at the alveolar–capillary membrane.

APPLIED SCIENCE

GAS EXCHANGE IN PLANTS

Fortunately for us, the physiology of gas exchange in plants is exactly opposite that of humans. Plants take in the CO_2 in the atmosphere and use it for energy, then release oxygen into our atmosphere. The earth's largest source of oxygen released is the Amazon rainforest, which is unfortunately being destroyed at a high rate. We truly need a green earth to survive, so thank the next plant you see.

FOCUS ON PROFESSIONS

(Source: Phanie/RGB Ventures/ SuperStock/Alamy Stock Photo)

The **respiratory therapist**'s main job is to ensure proper ventilation of the respiratory system through a variety of treatment modalities. **Perfusionists**, on the other hand, run a machine that actually performs gas exchange. For example, during a heart or lung transplant, the blood supply is temporarily rerouted through a respirator until the new heart or lung is transplanted. Because this procedure requires a lot of time, the rerouted blood must be oxygenated and carbon dioxide removed via a special mechanical membrane. Learn more about these two related and exciting professions by visiting the websites of national organizations, including the American Association for Respiratory Care (AARC), the National Board for Respiratory Care (NBRC), the American Society of Extracorporeal Technology (AmSECT), and the National Association for Medical Direction of Respiratory Care (NAMDRC).

THE UPPER RESPIRATORY TRACT

The upper airway is responsible for initially conditioning the inhaled air. It consists of the nose, mouth, pharynx, and larynx and performs several other important functions.

The upper airway begins at the two openings of the nose, called **nares**, or **nostrils**, and ends at the **vocal cords** (see **FIGURE 14–3** ■). The functions of the upper airway include:

- Heating or cooling inspired (inhaled) gases to body temperature (98.6°F [37°C])
- Filtering particles from the inspired gases
- Humidifying inspired gases to a relative humidity of 100%
- Providing for the sense of smell, or **olfaction**
- Producing sounds, or **phonation**
- Ventilating, or conducting, the gas down to the lower airways

The Nose

Although some people do breathe in through their mouths, under normal circumstances we were meant to breathe in through the nose for reasons that will become clear as this discussion progresses. The nose is a semirigid structure made of cartilage and bone. Three main regions are contained within the space behind the nose, called the **nasal cavity**. The nasal cavity is separated into right and left halves by a wall called the *nasal septum* (or septal cartilage), made of bone and cartilage. The regions contained within each nasal cavity are the vestibular, olfactory, and respiratory regions. See **FIGURE 14–4** ■.

The vestibular region is located inside the nostrils and contains the coarse nasal hairs that act as the first line of defense for the respiratory system. These hairs, called **vibrissae**, are covered with sebum, a greasy substance secreted by the sebaceous glands of the nose. Sebum helps trap large particles and also keeps the nose hairs soft and pliable—those unwanted nose hairs really do have a role as a gross particle filter. (By the way, *gross* in this case means "large.") The vestibular region helps filter out large particles so they do not enter the lungs, where they could irritate and clog the airways.

The air from the atmosphere must be warmed to body temperature and must also be moistened so the airways and the lungs do not dry out. This is a job for the respiratory

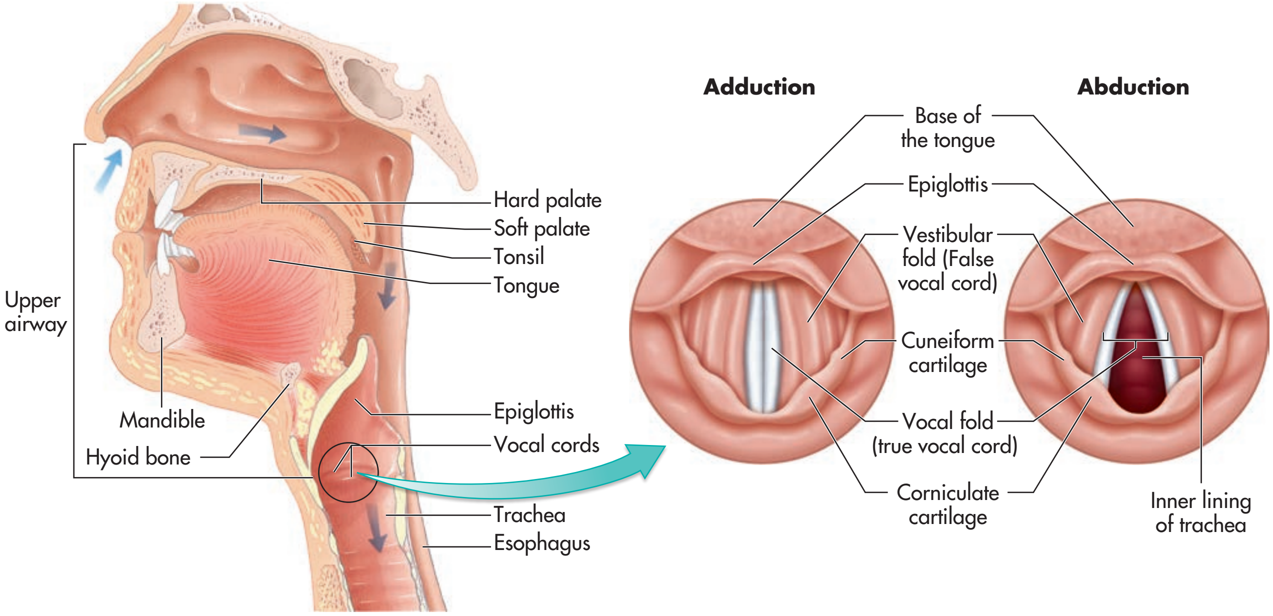


FIGURE 14–3

The upper airway and vocal cords.

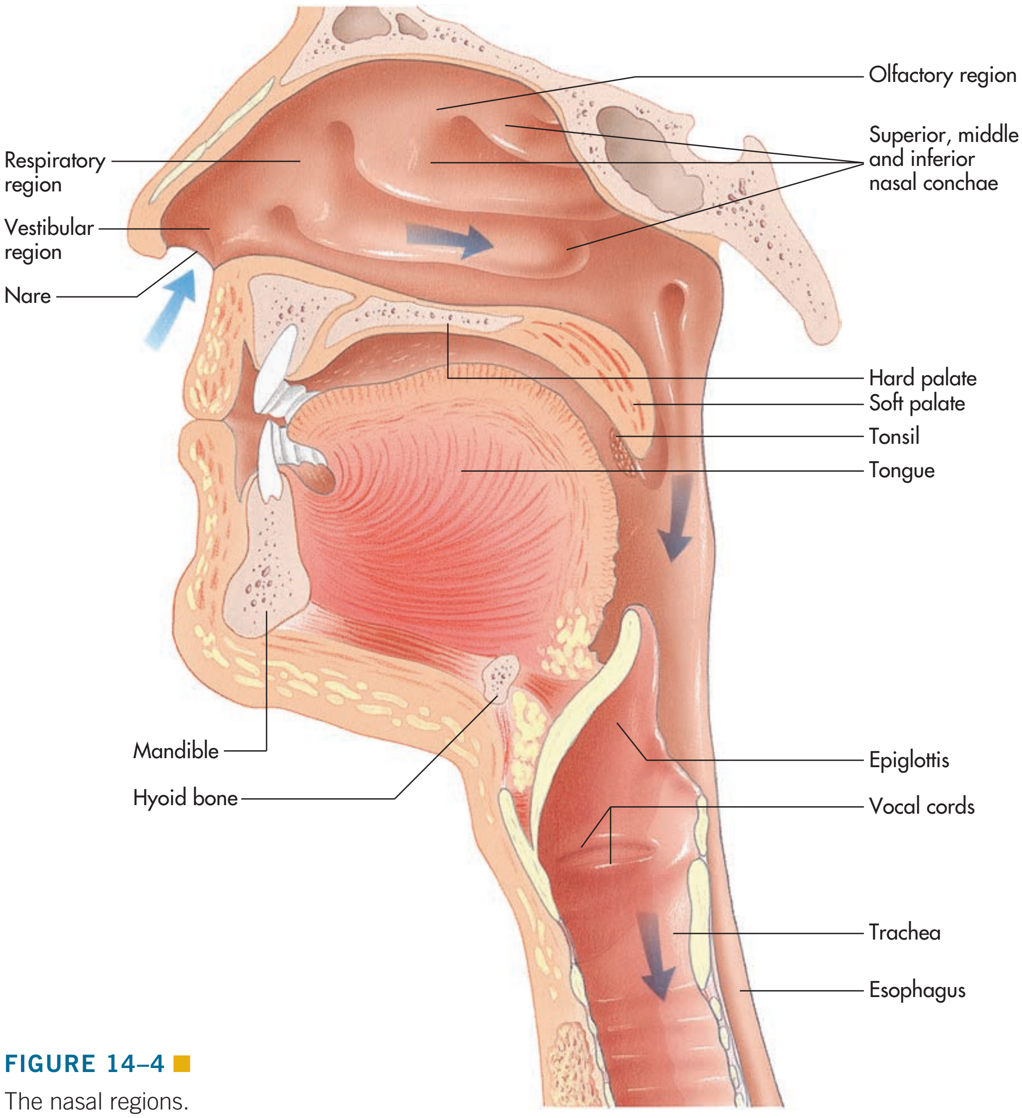


FIGURE 14–4

The nasal regions.

region of the nasal cavity, which is lined with mucous membranes that are richly supplied with blood. The respiratory region possesses three scroll-like bones known as **turbinates**, or **conchae** (again see Figure 14–4). These split the cavity into three channels, thereby providing more surface area for incoming air to make contact with the warm, moist nasal mucosa. Whereas the respiratory region has a small volume of 20 milliliters, if you could unfold the turbinates, you would have a surface area of *106 square centimeters* (about the size of a 3 × 5-inch index card).

AMAZING FACTS

Why Do We Breathe through Our Mouths?

You may have seen your favorite football player wearing an odd-looking strip of plastic across the nose. This is to help make breathing easier by increasing the diameter of the nostrils. The nose is responsible for one-half to two-thirds of the total airway resistance in breathing. Airway resistance represents the work required to move the gas down the tube. The larger the tube, the less resistance and therefore less work involved in breathing. Therefore, mouth breathing predominates during stress and exercise because it is easier for the gas to travel through the larger oral opening, due to less resistance. Of course, when you get a head cold and your nasal passages become blocked by secretions, it becomes necessary to breathe through the easier, open route of the mouth. On your journey, you must always be ready for detours.

In addition, because the nasal cavity is no longer a straight passageway, the air current becomes turbulent, so more air makes contact with these richly vascularized mucous membranes that transmit heat and moisture to the inspired gas. Incredibly, these moist mucous membranes add 650–1,000 milliliters (almost 3–4 cups) of water *each day* to moisten inspired air to 80% relative humidity within the respiratory region of the nasal cavity. In such a short distance, this is a pretty impressive humidification process. When the furnace in your house turns on in cold weather, this may dry the inspired air significantly and make it harder for your respiratory region to work. Therefore, humidifying this dry gas with water, such as from a room humidifier, may keep added stress off your body's natural humidification system. The nasal cavity is lined with pseudostratified ciliated columnar epithelium. (See the discussion of the mucociliary escalator in the next section.)

AMAZING FACTS

Breath Test May Detect Cancer

In the past, people have reported dogs that were able to sniff out cancerous (malignant) growths. Recent research by Israeli scientists is proving this to be not so "far-fetched." They are developing an electronic sensor that samples the breath and can detect lung, breast, bowel, and prostate cancers by chemical variations related to the specific tumors.

The olfactory region is strategically placed on the roof of the nasal cavity. The advantage to this is that sniffing inspired gas into this region keeps it there and does not allow the gas to reach deeper into your lungs. This is a relatively safe way to sample a potentially noxious or dangerous gas without taking a deep breath into the lungs, where it could cause severe damage. It is interesting to note that your ability to taste is related to your sense of smell. If you have ever had a nasty head cold and could not taste your food, now you know why. (Remember that we can only sense five different tastes, but recent research indicates we may be able to differentiate up to a trillion different odors.)

TEST YOUR KNOWLEDGE 14–1

Choose the best answer.

1. Which gas is found in the atmosphere?
   a. Oxygen
   b. Nitrogen
   c. Carbon dioxide
   d. All of the above
2. The process of moving gas into and out of the respiratory system is:
   a. ventilation.
   b. external respiration.
   c. internal respiration.
   d. diffusion.
3. The process of gas exchange at the body tissues is called:
   a. ventilation.
   b. external respiration.
   c. internal respiration.
   d. osmosis.
4. Gas exchange takes place across the:
   a. bronchi.
   b. bronchioles.
   c. alveolar–capillary membrane.
   d. nasal cavity.
5. Which of the following takes place in the upper airways?
   a. Olfaction
   b. Warming of air
   c. Filtering of air
   d. All of the above
6. Which of the following separates the nasal cavity into right and left halves?
   a. Nasal septum
   b. Hard palate
   c. Olfactory region
   d. Inferior nasal conchae
7. Which of the following is not a role of the sinuses?
   a. Intensifies voice sound
   b. Makes the head lighter
   c. Required for speech
   d. Assists in moisturizing inhaled air

Answer the following.

8. The medical term for the sense of smell is ______________ and for producing sound is ______________.

Going to Ride the Mucociliary Escalator

The epithelial lining of the nasal cavity plays a very important role in keeping the respiratory system clean and free of debris. Cells in the epithelial layer (or respiratory mucosa) are *pseudostratified* (*pseudo* = false, *stratified* = layered) *ciliated columnar cells* and are found not only in the respiratory region of the nasal cavity but also throughout most of the airways. See **FIGURE 14–5**. Remember that the pseudostratified epithelium is a single layer of tall, columnlike cells with nuclei located at different heights, giving the false appearance of two layers of cells, when in fact there is only one—hence the term *pseudostratified columnar*. Now all we need to add is the cilia. Each columnar cell has 200–250 cilia on its surface. **Cilia** are hairlike projections that can beat at a fantastic rate. Think of them as super rowers in a boat.

Goblet cells and submucosal glands are interspersed in the respiratory mucosa and produce about 100 milliliters (about 3 ounces) of **mucus** per day. The mucus actually resides as two layers. The cilia reside in the *sol layer*, which contains thin, watery fluid that allows them to beat freely. The *gel layer* is on top of the sol layer; as its name suggests, it is more viscous or gelatinous in nature. This sticky gel layer traps small particles, such as dust or pathogens, on the mucous blanket, much like flypaper. Once the debris is trapped on the mucous blanket, it must be removed from the respiratory system.

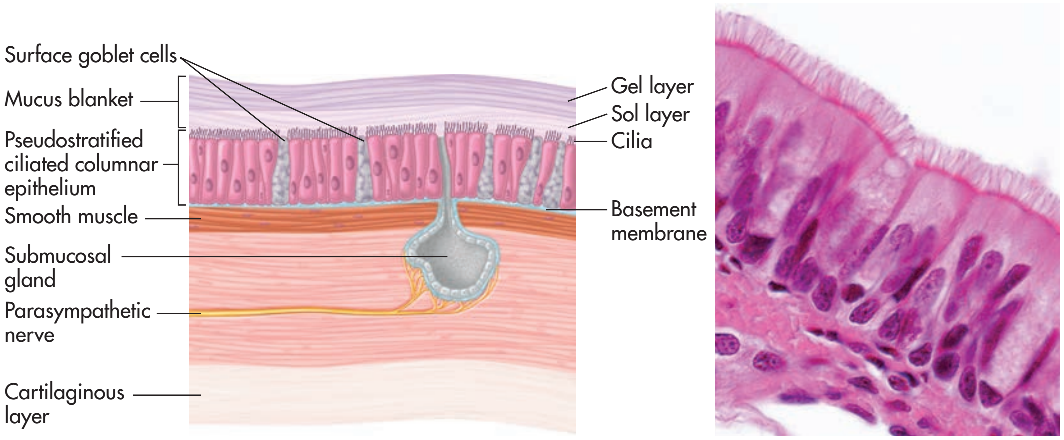


FIGURE 14–5
The mucociliary escalator with corresponding micrograph. (Source: Jose Luis Calvo/Shutterstock)

So how does this layer of mucus actually work? The microscopic, hairlike cilia act as tiny "oars," and in Figure 14–5, you can see that these oars rest in the watery sol layer. They beat at an incredible rate of 1,000–1,500 times per minute and propel the gel layer and its trapped debris onward and upward about 1 inch per minute to be expelled from the body. The pseudostratified ciliated columnar epithelium, located in the airways of the lungs, propels the gel layer toward the oral cavity to be either expectorated with a cough or swallowed into the stomach. Some texts refer to this epithelial layer as the *mucociliary escalator*, which gives a better picture of what it does. This escalator works 24/7, unless something paralyzes it, such as smoking.

CLINICAL APPLICATION

EXCESSIVE MUCUS PRODUCTION

In some diseases—for example, chronic bronchitis and cystic fibrosis—excess mucus is produced that will need to be expectorated or swallowed. The color of the expectorant is clinically useful. In general, clear mucus is usually normal unless there is an excessive amount, which may indicate irritation or the beginning of an inflammatory process. Look if there are other symptoms that may indicate infections. Yellow and green sputum indicates an infection but also indicates that the immune system is helping to fight an infection. Mucus turns green when enzymes (from the defense cells) that fight bacteria are activated. Mucus that is red or brown could indicate the presence of fresh or old blood and tends to indicate that bleeding has occurred, which is often seen in lung cancer or advanced tuberculosis. Cystic fibrosis is an inherited disease that affects the glands and causes them to secrete very thick mucus. This blocks the airways and increases the susceptibility to bacterial infections.

The Sinuses

Have you ever heard of someone being called an airhead? Technically, we are all airheads because the skull contains hollow, air-filled cavities (commonly called **sinuses**) that connect with the nasal cavity via small passageways. Because these are located around the nose, they are called *paranasal* sinuses. They are lined with a respiratory mucosa layer that continually drains its secretions into the nasal cavity. The sinuses are named for the specific facial bones in which they are located: the ethmoid, sphenoid, maxilla, and frontal bones (see **FIGURE 14–6** ■).

These cavities of air in the bones of the cranium are believed to help in the prolongation and intensification of sound produced by the voice. If you ever shouted inside a cave, you noticed a more resonant quality to the sound. In addition, it is theorized the air-filled sinuses help to lighten the heavy head that sits atop the neck. Not all of the sinuses exist at birth; rather, they develop as you grow and influence facial changes as you mature. Sinuses also provide further warming and moisturizing of inhaled air.

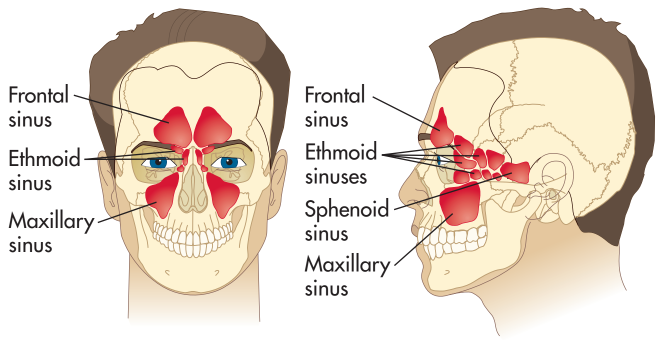


FIGURE 14–6 ■
The paranasal sinuses.

The Pharynx

The pharynx is a hollow, muscular structure about 2½ inches long, lined with epithelial tissues. The **pharynx** begins posterior to the nasal cavities and is divided into the following three sections, as shown in **FIGURE 14–7** ■ by the different-colored segments.

- Nasopharynx
- Oropharynx
- Laryngopharynx

The **nasopharynx** is the uppermost section of the pharynx and begins just posterior to the two nasal cavities. Air that is breathed through the nose passes through the nasopharynx. This section also contains lymphatic tissue of the immune system, called the **adenoids**, and passageways to the middle ear, called **eustachian tubes** (or *auditory tubes*). You can understand how an infection located in the nasal cavities can lead to an ear infection, and vice versa. The nasopharynx is lined with respiratory mucosa.

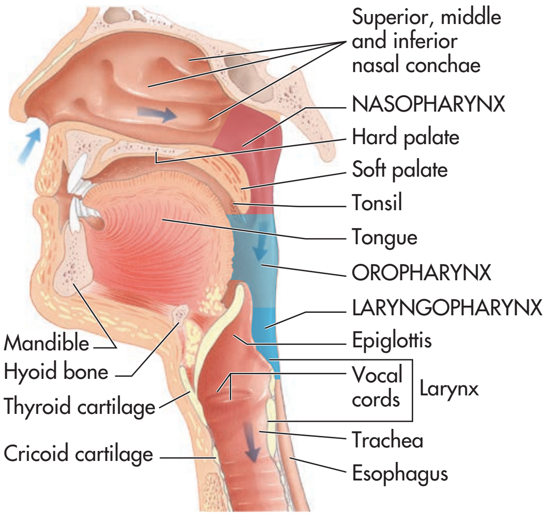


FIGURE 14–7

The nasopharynx, oropharynx, and laryngopharynx and related structures.

The **oropharynx** is the next region and is located posterior to the oral (buccal) cavity. Air that is breathed through the mouth as well as air that is breathed through the nose passes through here. It is important to note that anything that is swallowed also passes through this section. Therefore, the oropharynx conducts not only air but also food and liquid. For added protection, the oropharynx is lined with stratified squamous epithelium.

The oral entrance is a strategic area to place "guardians" for the immune system because this is where pathogens can easily enter the body. Lymphoid tissue, or **tonsils**, such as the **palatine tonsils**, are located in this area. Another set of tonsils, the **lingual tonsils**, are found at the back of the tongue. During the process of swallowing, the uvula and soft palate move in a posterior and superior position to protect the nasopharynx and nasal cavity from allowing food or liquid to enter. Actually swallow and feel this happening within your oral cavity. This protection can be overcome by forceful laughter, and that is why when you laugh with liquid or food in your mouth, the food or liquid can sometimes come up through your nose.

The **laryngopharynx** is the lowermost portion of the pharynx; an older term for it was the hypopharynx because of its position. Air that is breathed and anything that is swallowed passes through the laryngopharynx. Swallowed materials pass through the **esophagus** to get to the stomach, and air travels through the **larynx** (the next part of the respiratory system) and then the trachea on its way to the lungs. What directs the flow of "traffic" (air to the lungs and food and liquid to the stomach)? Is it a tiny highway worker directing traffic? No, it is directed by the swallowing reflex, which is discussed shortly.

The Larynx

The larynx, located in the neck, is a triangular chamber inferior to the pharynx that houses the important structures needed for speech. Commonly known as the *voice box*, the larynx is a semirigid structure composed of several types of cartilage connected by muscles and ligaments that provide for movement of the vocal cords to control speech. The thyroid cartilage is the largest of the cartilages found in the larynx. The "Adam's apple" is part of the thyroid cartilage and is more prominent in males. Inferior to the thyroid cartilage, forming the inferior border of the larynx, is the cricoid cartilage. Both of these cartilages found in the neck are necessary to provide structure and support for airways so they do not collapse and block the flow of air into and out of the lungs. A third cartilage, the epiglottal cartilage, is a leaf-shaped, flaplike structure located above the opening into the larynx called the **epiglottis**. The epiglottis covers the larynx during swallowing. The other cartilages in the larynx are supportive structures for the vocal cords.

The vocal cords are paired membranes located inside the larynx. The **glottis** is the sound-producing structure containing the vocal cords. The space between the vocal cords is called the **rima glottidis**. The glottis allows gas to travel to the trachea and eventually the lungs. Your voice is produced when air is forced past the partially closed vocal cords, causing them to vibrate. You normally speak during an exhalation.

Air that is breathed and anything that is swallowed passes through the laryngopharynx. Then a choice must be made. Swallowed materials *should* pass through the esophagus to get to the stomach, and air *should* travel through the larynx and then the trachea on its way to the lungs. Food and air are directed by a mechanism termed the *glottic* or *sphincter mechanism* (swallowing reflex). The epiglottis closes over the opening to the larynx when you swallow and opens up when you breathe. The glottic mechanism facilitates the closing of the epiglottis over the glottic opening, thus sealing it so food does not enter the lungs. In addition, the soft palate blocks the nasal cavity, and the tongue blocks the oral cavity during swallowing so food can only travel in one direction, into the esophagus.

Thus, the lungs are closed to traffic when you swallow, and the food and liquid travel down the only open tube or route, the esophagus, leading into the stomach. When we breathe in, the gas preferentially travels into the lungs through a process that actually draws it there because of pressure differences. More on this later.

The vocal cords are the area of division between the upper and lower airways. The lower airways start inferior to the vocal cords. Now we continue our journey down the lower airways all the way down to the end point, or alveoli.

CLINICAL APPLICATION

KEEPING THE VITAL AIRWAY OPEN

Just like any vital highway, the airway needs to remain open to a flow of traffic, or the oxygen molecules will cease to flow into the alveoli and therefore not get into the bloodstream to supply the tissues. Whereas a traffic jam can last for hours, oxygen flow can be disrupted for only a few minutes without tragic results. For example, if the upper airway swells shut from a severe allergic reaction to a bee sting, an emergency airway must be established. Remember, we only have 4–6 minutes of oxygen reserve. Review Figure 14–7, and you will see a space between the thyroid and cricoid cartilages. This is where an emergency cricoidthyroidotomy is performed. This space has few blood vessels or nerves, which makes it ideal in an emergency situation to place a temporary breathing tube.

Sometimes a longer-term breathing tube must be inserted into the lungs via a technique called *intubation*. This tube passes through the vocal cords and sits above the juncture (carina) between the right and left lung. A machine called a *ventilator* can move air into and out of the damaged lungs at this juncture. The tube has an inflatable cuff to seal the airway once it is in place. Knowledge that the vocal cords open and close during breathing becomes clinically significant when intubating a patient. Adduction partially seals the vocal cords and occurs during expiration, whereas abduction opens the cords, increasing the size of the glottic opening during inspiration. If the patient is breathing, it is better to pass the tube with the deflated cuff through the narrow opening of the vocal cords during an inhalation when the cords are maximally open. Conversely, when removing the tube (extubation), the health care professional must always remember to deflate the cuff so it doesn't damage the cords as the tube is pulled back through them. It should go without saying (no pun intended) that a patient cannot talk when properly intubated because the vocal cords cannot function. If you ever see a TV soap opera or movie where someone is plainly talking with a tube going down his or her mouth into the lungs, you will know it is impossible. More permanent airways, called *tracheostomy tubes*, are placed in the neck. Some patients can learn to talk with a specialized tracheostomy tube in place.

TEST YOUR KNOWLEDGE 14–2

Choose the best answer.

1. The hairlike structures that propel mucus in the airways are:
   a. sol layer.
   b. gel layer.
   c. pathogens.
   d. cilia.

2. Which of the following is *not* true about the sinuses?
   a. They are air-filled cavities.
   b. They are located in the skull and around the nose.
   c. They help to lighten the head.
   d. Gas exchange occurs there.

3. Food is prevented from entering the ______________ when eating by the closure of the ______________.
   a. esophagus; uvula
   b. esophagus; epiglottis
   c. trachea; epiglottis
   d. epiglottis; glottis

4. The vocal cords are found in the:
   a. laryngopharynx.
   b. nasopharynx.
   c. oropharynx.
   d. larynx.

5. The oropharynx is lined with ______________, whereas the nasopharynx is lined with ______________.
   a. respiratory mucosa; stratified squamous epithelium
   b. stratified squamous epithelium; respiratory mucosa
   c. respiratory mucosa; pseudostratified ciliated epithelium
   d. simple cuboidal epithelium; pseudostratified ciliated epithelium

6. Voice is normally produced by vibration of the closed vocal cords during:
   a. inspiration.
   b. exhalation.
   c. internal respiration.
   d. external respiration.

7. The upper airway begins at the ______________ and ends at the ______________.
   a. tonsils, alveoli
   b. nares, bronchi
   c. nares, vocal cords
   d. vocal cords, alveoli

8. The pharynx can be divided into three sections. Which of the following is one of the three sections?
   a. Trachea
   b. Esophagus
   c. Larynx
   d. Oropharynx

THE LOWER RESPIRATORY TRACT

The airway network that leads to the lungs and then branches out into the various lung segments resembles an upside-down tree and is sometimes called the *tracheobronchial tree*. See **FIGURE 14–8** ■.

Trachea and Bronchi

After leaving the larynx, the inspired air enters the **trachea**, also known by the lay term *windpipe*. The trachea extends from the cricoid cartilage of the larynx to the fifth thoracic vertebrae (approximately to the midpoint of the chest). The cartilage found in the anterior portion of the trachea is in the form of C-shaped structures to provide rigidity and protection for the exposed airway in the neck. The posterior parts of the rings are smooth muscle. This C shape also serves another important purpose. The esophagus lies in the area where the C opens up posteriorly. Without the cartilage, there is some "give" in the posterior aspect of the larynx and trachea, so the esophagus can expand when you swallow larger chunks of food, and the food won't get stuck against the rigid cartilage of the trachea. The trachea is lined with respiratory mucosa.

The trachea is the largest bronchus and can be thought of as the trunk of the tracheobronchial tree. Once the trachea reaches the center of the chest approximately at the level of vertebrae T5, it begins its first branching, or bifurcates, into two bronchi (*bronchus* is the singular form), the *right mainstem* and the *left mainstem*. The site of bifurcation into the right and left lung is called the **carina** (again, see Figure 14–8). One bronchus goes to the right lung and the other bronchus goes to the left lung. The mainstem bronchi are sometimes also referred to as the *primary bronchi*. Now the bronchi must branch into the five lobar bronchi, one in each of the five lobes of the lungs.

Each lung lobe is further divided into specific segments, and the next branching of bronchi is called the *segmental bronchi*. At the point from the trachea down to the segmental bronchi, the tissue layers of the bronchial walls are all the same, only smaller, as they branch downward. The first layer is the epithelial layer (remember the mucociliary escalator?) that keeps the area clean of debris. A middle **lamina propria** layer contains smooth muscle, lymph, and nerve tracts. The third layer is the protective and supportive cartilaginous layer (see **FIGURE 14–9** ■).

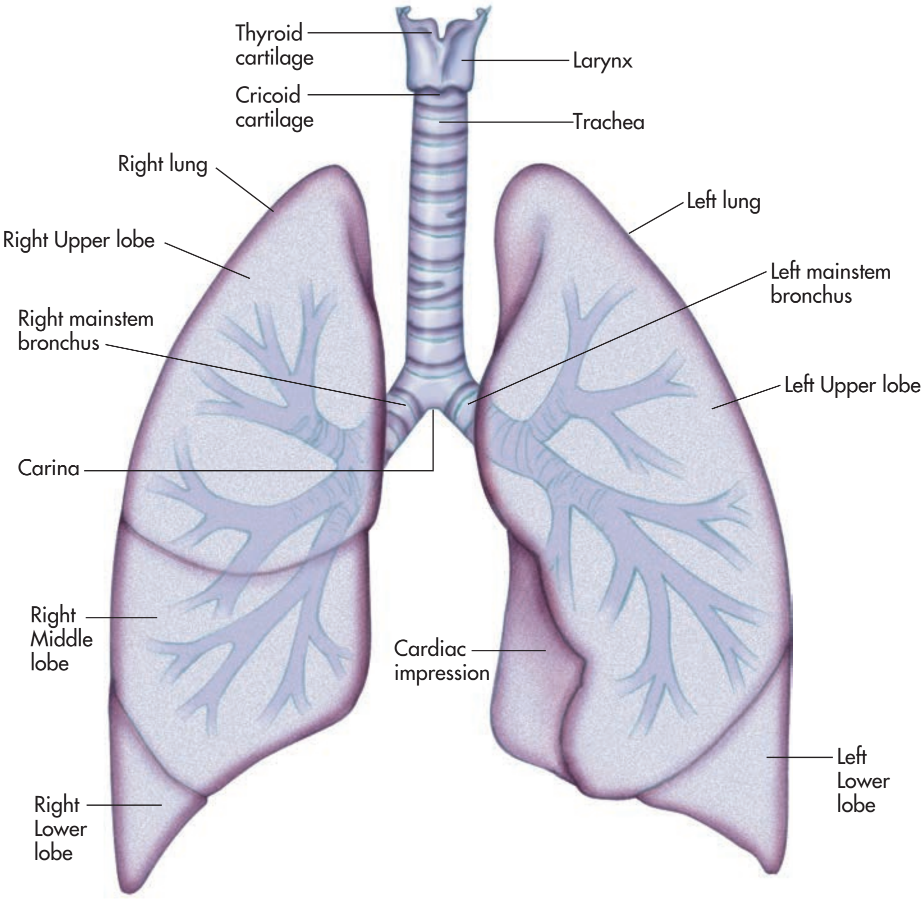


FIGURE 14–8 ■
The tracheobronchial tree.

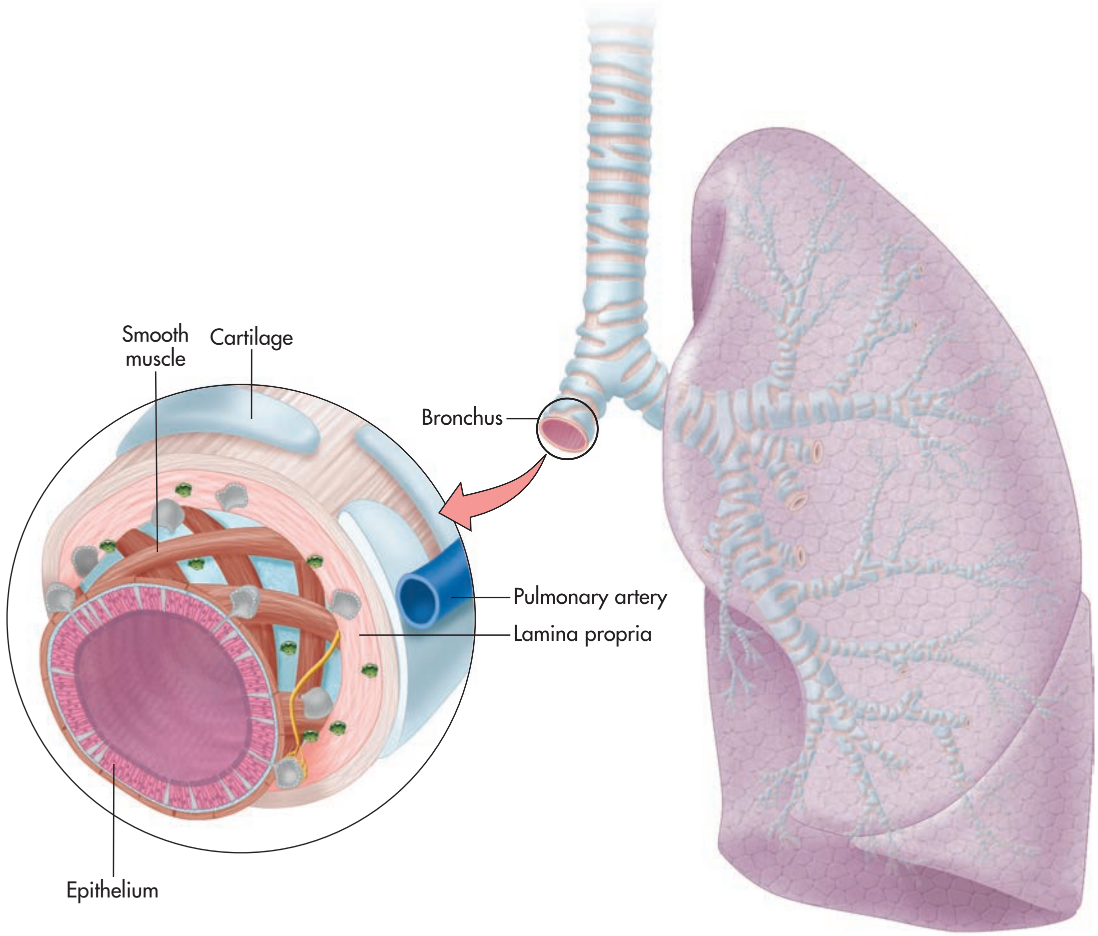


FIGURE 14–9
Tissue layers in the bronchi.

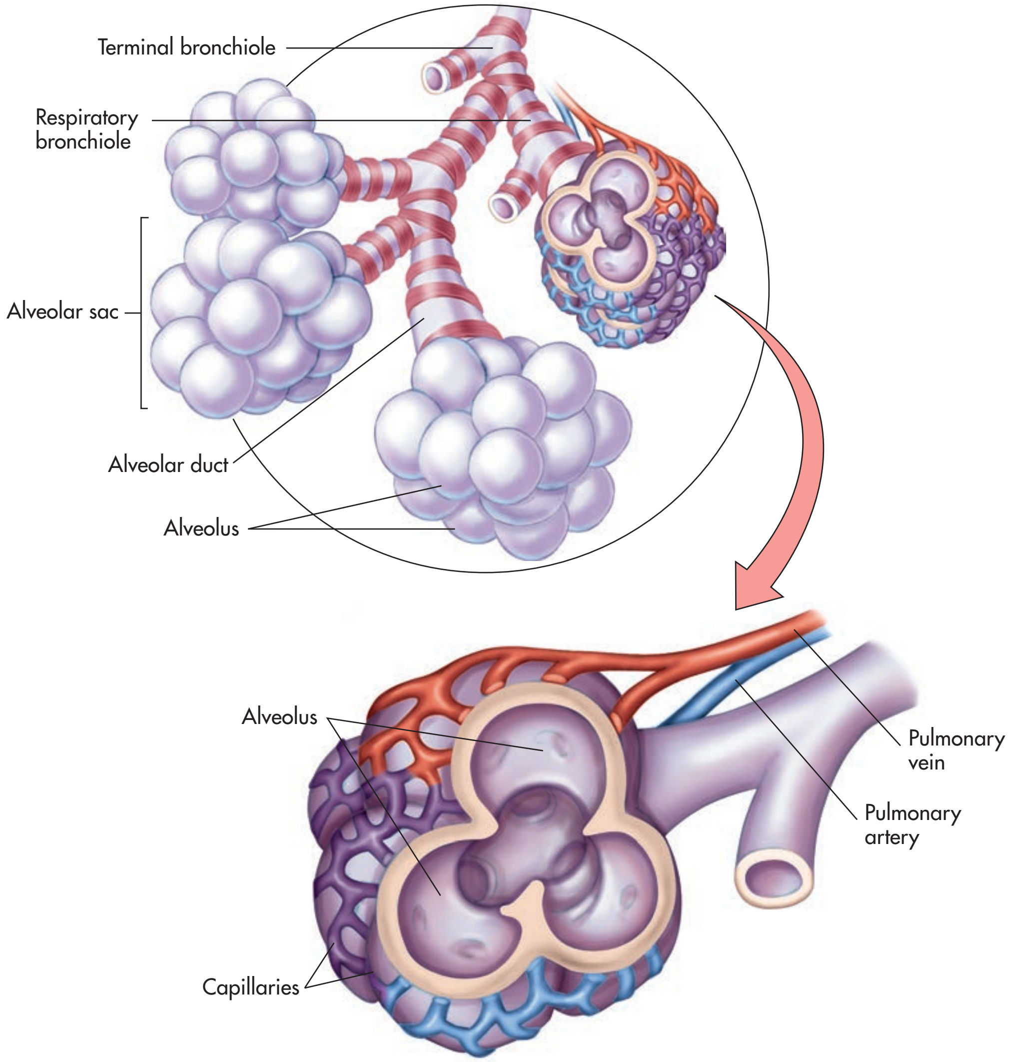
CLINICAL APPLICATION

THE ANGLE MAKES A DIFFERENCE

The angle of branching is not the same for both sides of the tracheobronchial tree. The right mainstem branches off at a 20- to 30-degree angle from the midline of the chest. The left mainstem branches off at a more pronounced 40- to 60-degree angle. This is important because the lesser angle of the right mainstem branching allows foreign bodies that are accidentally breathed in to more often lodge in the right lung. This is useful to know if a child has aspirated (taken into the lung) an object, and the physician must enter the lung with a bronchoscope to remove the object. Time may be critical, and it may make a difference if the search is begun immediately in the right lung because its structure increases the probability that the object has lodged there. In addition, a breathing tube or endotracheal tube may be placed too far into the lung, and instead of sitting above the carina so both lungs are ventilated, the tube most likely will pass into and ventilate only the right lung. This is why an x-ray for proper tube placement is so important.

The branching becomes more numerous with tiny subsegmental bronchi branching deep within each lung segment. The diameter of subsegmental bronchi ranges from 1 to 6 millimeters. Cartilaginous rings are now irregular pieces of cartilage and will soon fade away completely. Notice as we move toward the gas exchange regions that the airways simplify to make it easier for gas molecules to pass through. Now we reach the very tiny airways called *bronchioles*; they average only 1 millimeter in diameter. They have no cartilage layer, and the epithelial lining becomes ciliated cuboidal (short square cells as opposed to large columns). The bronchioles have smooth muscle in their walls. The cilia, goblet cells, and submucosal gland are almost all gone at this point. There is no gas exchange yet—just simple conduction of the gas mixture containing the oxygen molecules down the tree. Now we reach the terminal bronchioles, which have an average diameter of 0.5 millimeter, no goblet cells, no cartilage, no cilia, and no submucosal glands. This marks the end of the conducting zone. We now journey into the gas exchange or respiratory zone of the lung.

The next airway beyond the terminal bronchiole is called the respiratory bronchiole because a small portion of gas exchange takes place here. The epithelial lining is simple cuboidal cells interspersed with actual alveoli-type cells, which are flat, pancakelike cells called simple squamous epithelial cells known as **pneumocytes**. Alveolar ducts originate from the respiratory bronchioles wherein the walls of the alveolar ducts are completely made up of simple squamous cells arranged in a tubular configuration. The alveolar ducts give way to the grape bunchlike structures of several connected alveoli, better known as the *alveolar sacs*. See **FIGURE 14–10**.



STRUCTURES OF THE LUNGS

Conducting zone	Trachea	Cartilaginous airways
	Main stem bronchi	
	Lobar bronchi	
	Segmental bronchi	
	Subsegmental bronchi	
	Bronchioles	Noncartilaginous airways
	Terminal bronchioles	
Respiratory zone	Respiratory bronchioles	Gas exchange region
	Alveolar ducts	
	Alveolar sacs	

FIGURE 14–10
Conduction and gas exchange structures and functions.

At this point, the walls are simple squamous epithelium—no muscle, no cartilage, no cilia, no mucus; in other words, as simple as possible to allow for gas exchanges.

The alveoli are the terminal air sacs that are surrounded by numerous pulmonary capillaries and together make up the gas exchange unit of the lung known as the **alveolar capillary membrane**. The average number of alveoli in an adult lung ranges from 300 million to 600 million. This gives it a massive surface area (about the size of a tennis court) for the oxygen molecule to diffuse across into the surrounding pulmonary capillaries, which have about the same cross-sectional area. Once again, we see an example of the body increasing surface area by dividing a structure into millions of tiny segments. The blood entering the pulmonary capillaries comes from the right side of the heart and is low in oxygen and high in carbon dioxide because it just came from the body tissues. Gas exchange or external respiration takes place, and the blood leaving the pulmonary capillary is high in oxygen and travels to the left side of the heart to be pumped around to the tissues. Conversely, carbon dioxide molecules are in high concentration in the pulmonary capillary blood and very low in the lung (remember, there is little CO_2 in the atmosphere), so CO_2 leaves the blood and enters the lung to be exhaled.

CLINICAL APPLICATION

THERAPEUTIC OXYGEN

Often, a distressed respiratory system and sometimes the cardiac system need supplemental oxygen to assist its function and meet its needs. There are many ways to deliver an enriched oxygen supply to the lungs, including an oxygen mask, nasal cannula (prongs), and specialized devices to deliver both oxygen and extra humidity to the lungs to assist their function.

There are three types of cells in the alveoli. The majority (95%) of the alveolar surface consists of flat, thin, pancake-like cells called *squamous pneumocytes*, or Type I cells. Gas molecules can easily pass through these cells in the process of gas exchange. The alveoli also need to produce surfactant. This is where the Type II *granular pneumocytes* come in. These highly metabolic cells not only produce surfactant but they also aid in cellular repair responsibilities. Finally, this area needs to be free of debris that would act as barriers to the vital process of gas exchange. The "cleanup" cells, called Type III cells or wandering **macrophages**, ingest foreign particles as the macrophages wander throughout the alveoli. There are even small holes between the alveoli called *pores of Kohn* that allow the macrophages to move from one alveolus to another.

On closer inspection of the alveolar capillary membrane, you will see four distinct components. The first layer is the liquid **surfactant** layer that lines the alveoli. This phospholipid helps lower the surface tension in these very tiny spheres (alveoli) that would otherwise collapse due to the high surface tension.

APPLIED SCIENCE

THE AMAZING SURFACTANT

Not only does surfactant lower the surface tension when the alveoli are small (end-expiration), thereby preventing alveoli collapse, but when you take a deep breath (end-inspiration), your alveoli get larger and the surfactant layer thins and becomes less effective, its surface tension increasing because of its thinning. This prevents overexpansion or rupture of the alveoli. Lack of surfactant can cause stiff lungs that resist expansion. Surfactant develops late in fetal development, and premature babies therefore may not have sufficient levels. Without immediate intervention, their tiny lungs would collapse (**atelectasis**) and thus prevent vital gas exchange. If they are given too much volume to re-expand their stiff lungs, the alveoli may rupture, again because surfactant is not there to prevent overexpansion. Surfactant also has an antibacterial property that helps fight harmful pathogens. Fortunately, medical science has developed surfactant replacement therapy that can instill surfactant into the lungs to maintain their function until babies have matured and can produce it on their own.

The second component is the actual tissue layer, or *alveolar epithelium*, comprised of type I and type II pneumocytes. The third component of the alveolar capillary membrane is the *interstitial space*. This is the area that separates the basement membrane of alveolar epithelium from the basement membrane of the capillary endothelium and contains interstitial fluid. This space is so small that the membranes of the alveoli and capillary appear fused. However, if too much fluid gets into this space (interstitial edema), the membranes separate, which makes it harder for gas exchange to occur because the gas has to travel a greater distance and through a congested, fluid-filled space.

The fourth component is the *capillary endothelium* (simple squamous epithelium) that forms the wall of the capillary. The capillary contains the blood with the red blood cells that carry the precious gas cargo to its destination.

CLINICAL APPLICATION

WHAT CAN GO WRONG WITH GAS EXCHANGE?

The membrane between the alveoli and the capillaries is quite thin. In fact, it is only 0.004-millimeter thick. The thinness of this membrane aids in the diffusion of the gases between the lungs and the blood. Anything that would act as a barrier to oxygen molecules getting to or through this barrier would decrease the amount of oxygen that gets into the blood. For example, excessive secretions and fluid such as in pneumonia act as a barrier and reduce the oxygen levels in the blood, which can be measured by sampling arterial blood and analyzing the amount of each gas dissolved in it. This is called an *arterial blood gas*, or *ABG*. In the case of severe pneumonia, the level of arterial oxygen known as the PaO_2 decreases because less oxygen can get into the blood, and the $PaCO_2$ in the arterial blood increases because less CO_2 crosses into the lungs to be exhaled.

Red blood cells, or **erythrocytes**, are responsible for the bulk of the transportation of oxygen and a little carbon dioxide in the blood via a protein- and iron-containing molecule called **hemoglobin**, which performs the actual transportation. It is estimated that there are about *280 million* hemoglobin molecules found in *each* erythrocyte. Carbon dioxide is mainly carried in your blood as bicarbonate ions. For more information on the bicarbonate buffering system of your blood, see Chapter 17.

CLINICAL APPLICATION

ASSESSING VENTILATION AND BLOOD pH

Carbon dioxide levels are the best indicator of ventilation. Due to the rapid diffusion of carbon dioxide to the lungs and its subsequent exhalation, it can be used as a measure of the efficiency of ventilation. In many lung diseases, carbon dioxide levels can rise in the blood and initially form carbonic acid (H_2CO_3). This acid quickly breaks down into its ionic parts, H^+ (hydronium ion) and HCO_3^- (bicarbonate ion). To prevent too much acidity from building up in the blood, H^+ will be excreted by the kidneys, and more bicarbonate (base) will be formed to buffer the blood to maintain normal pH.

In general, if the hemoglobin is carrying large amounts of oxygen, the blood will be bright red. If there is less oxygen and more carbon dioxide being carried, then the blood will be darker in color. Venous blood has lower levels of oxygen and higher levels of carbon dioxide. As a result, venous blood has a dark red tint. Low levels of red blood cells or anemia would limit the number of hemoglobin molecules that could transport oxygen and thus greatly reduce the amount in the blood available for the tissues. Therefore, the number of red blood cells and the amount of hemoglobin in your blood (both of which can be measured) is important in oxygen delivery to your tissues.

Your body can attempt to respond to low oxygen levels by producing more red blood cells by a process called **erythropoiesis**. This process begins when the kidneys detect low levels of oxygen coming to them from the blood. The kidneys release into the bloodstream a hormone called **erythropoietin**. This substance travels through the blood and eventually reaches specialized cells found in the red bone marrow. When stimulated, these specialized cells begin to increase their production of erythrocytes until demand is met. Having too little iron in the body can also affect oxygen delivery because the iron in the hemoglobin is what holds on to the oxygen molecules. The terms *iron-poor* blood and *tired* blood come from the fact that a patient with low levels of iron tires easily due to low oxygen levels.

TEST YOUR KNOWLEDGE 14–3

Choose the best answer.

1. The largest bronchus or trunk of the tracheobronchial tree is the:
   a. right mainstem bronchus.
   b. left mainstem bronchus.
   c. bronchiole.
   d. trachea.

2. The site of bifurcation of the right and left lungs is called the:
   a. alveoli.
   b. carina.
   c. trachea.
   d. capillary.

3. If an object is aspirated into the airways, it is most likely to go to the:
   a. right lung.
   b. left lung.
   c. stomach.
   d. oropharynx.

4. The first portion of the airway where gas exchange begins is the:
   a. terminal bronchiole.
   b. trachea.
   c. mainstem bronchus.
   d. respiratory bronchiole.

5. The alveolar layer that lowers surface tension to keep the alveoli expanded is the:
   a. surfactant layer.
   b. capillary layer.
   c. epithelium layer.
   d. macrophage layer.

6. The alveolar cell that allows for gas exchange is the:
   a. squamous cell.
   b. granular cell.
   c. macrophage cell.
   d. Kohn cell.

7. What are the three types of cells found in the alveoli?
   a. Squamous pneumocytes, granular pneumocytes, and macrophages
   b. Type II, Type III, and Type VI cells
   c. Simple squamous epithelium, pseudostratified epithelium, and ciliated columnar epithelium
   d. Simple squamous epithelium, pseudostratified epithelium, and pseudostratified columnar epithelium

Complete the following.

8. The iron-containing molecule responsible for transporting oxygen in the blood is _______________.

THE HOUSING OF THE LUNGS AND RELATED STRUCTURES

The lungs reside in the thoracic cavity and are separated by a region called the **mediastinum**, which contains the esophagus, heart, great vessels (superior and inferior vena cava and aorta), and trachea (see **FIGURE 14–11** ■).

Breathing in and out causes the lungs to move within the thoracic cavity. Over time, an irritation could occur as the lungs rub the inside of the thoracic cage. To prevent such damage, each lung is wrapped in a serous membrane called the *pleura*. The inner layer of the pleura covering the lungs is called the **visceral pleura**. The thoracic cavity and the upper side of the diaphragm are lined with the outer layer of this membrane, the **parietal pleura**. Between these two pleural layers is a microscopic intrapleural space (pleural cavity) that contains a slippery liquid called **pleural fluid** that greatly reduces the friction as an individual breathes. Remember that serous membranes have only a *potential* space between them. The visceral and parietal pleura are essentially "layered" together. There is practically no space between them. (This is the second serous membrane we have seen; the *pericardium* is also a serous membrane.)

The Lungs

The right and left lungs are cone-shaped organs; the rounded peak is called the apex of the lung. The apices (plural of *apex*) of the lungs extend 1–2 inches above the clavicle. The bases of the lungs rest on the right and left hemidiaphragm. The right lung base is a little higher than the left to accommodate the large liver lying underneath. The medial surface of the lung has

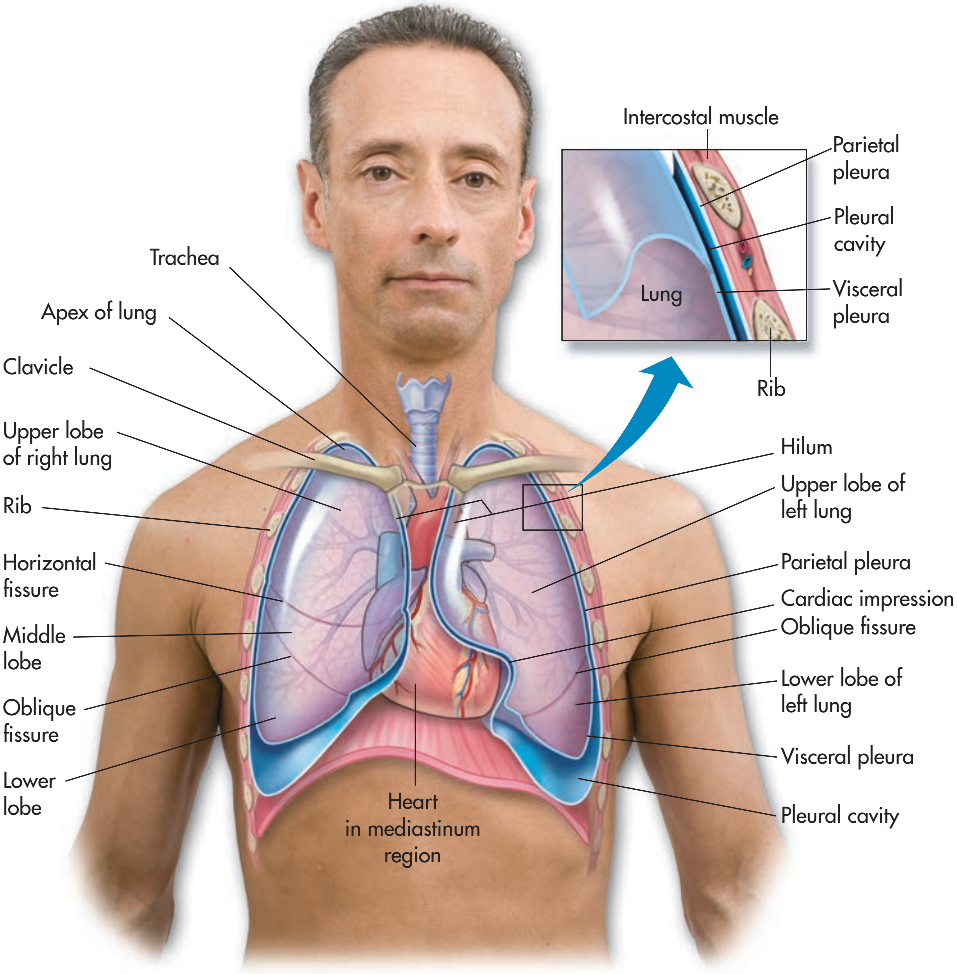


FIGURE 14–11

Structures of the thoracic cavity.

a deep, concave cavity that contains the heart and is therefore called the *cardiac impression* and is deeper on the left side. The **hilum** is the area where the two mainstem bronchi and associated structures attach to each lung. This is also referred to as the *root* of each lung. Each root contains the mainstem bronchus, pulmonary artery and vein, nerve tracts, and lymph vessels.

The right lung has three lobes—the upper, middle, and lower lobes—that are divided by the horizontal and oblique fissures. The left lung has only one fissure, the oblique fissure, and therefore only two lobes, called the upper and lower lobes. You may hear the term **lingula**. This is an area of the left lung that corresponds with the right middle lobe. Why only two lobes in the left, you may ask? Remember that the heart is located in a space (cardiac impression) in the left anterior area of the chest and therefore takes up some space of the left lung. In fact, the right lung is larger, and about 60% of gas exchange occurs there. The lobes are even further divided into specific segments related to their anatomical position. For example, the apical segment of the right upper lobe is the top portion or tip of the right upper lobe. Remember, the segmental bronchi enter each lung segment. See **FIGURE 14–12**.

The Protective Bony Thorax

The lungs, heart, and great vessels are all protected by the *bony thorax*. This bony and cartilaginous frame provides protection and also movement of the thoracic cage to accommodate breathing. The bony thorax includes the rib cage, the sternum (or breastbone), and the corresponding thoracic vertebrae to which the ribs attach (see **FIGURE 14–13**).

The **sternum** is centrally located at the anterior portion of the thoracic cage and is comprised of the manubrium, body, and xiphoid process. This anatomical landmark is very important for proper hand placement in CPR (cardiopulmonary resuscitation). The hand is placed over the body of the

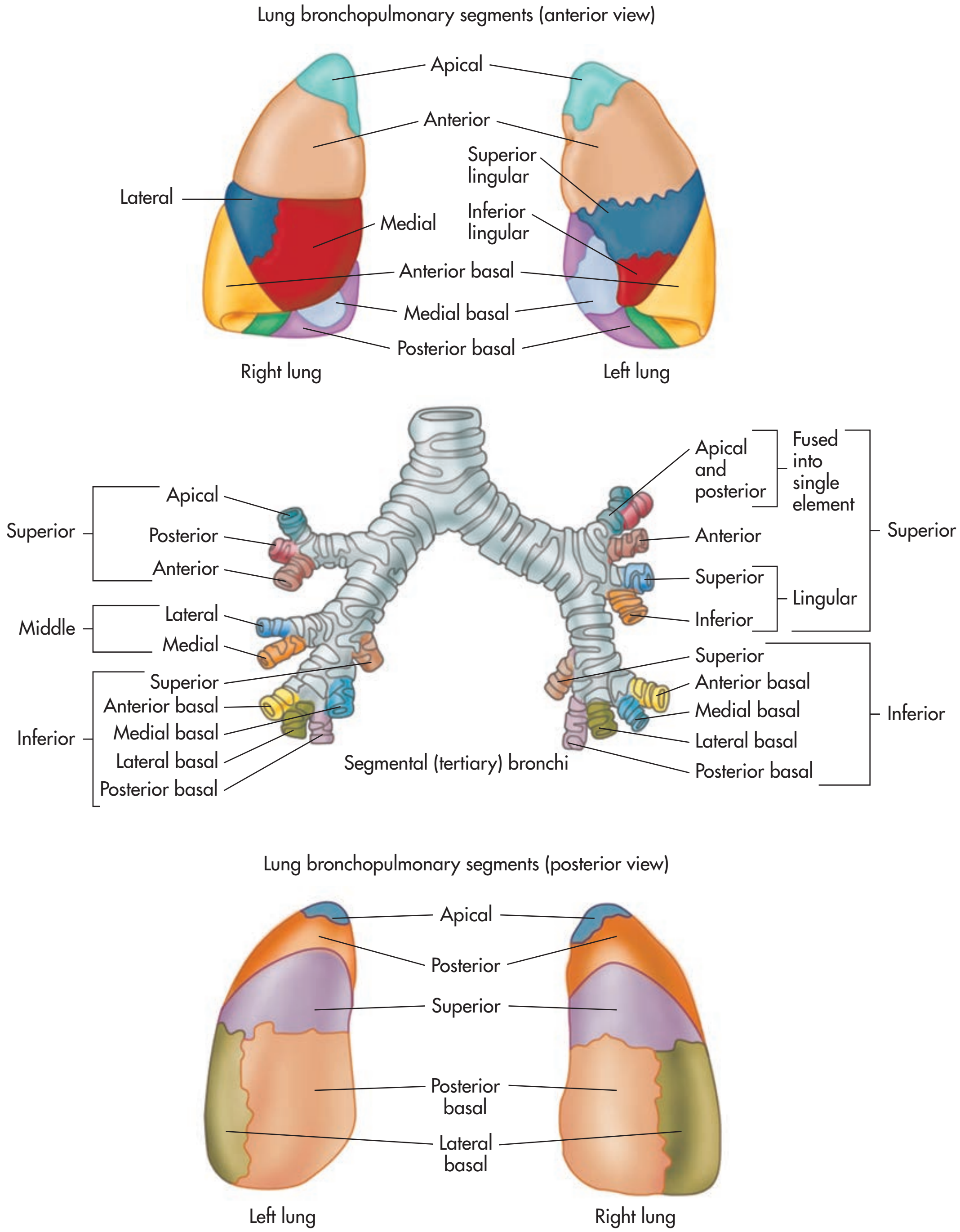


FIGURE 14–12

Bronchopulmonary segments.

sternum where compressions squeeze the heart between the body of the sternum and the thoracic vertebrae. If the hand placement is too low on the xiphoid process, it can break off and lacerate the internal organs.

The **thoracic cage** consists of 12 pairs of elastic arches of bone called *ribs*. The ribs are attached by cartilage to allow for their movement while breathing. The true ribs are pairs 1 through 7 and are called *vertebrosternal* because they connect anteriorly to the sternum and posteriorly to the thoracic vertebrae of the spinal column. Pairs 8, 9, and 10 are called the false ribs, or *vertebrocostal*, because they connect to the costal cartilage of the superior rib and again posterior to the thoracic vertebrae. Rib pairs 11 and 12 are called the *floating ribs* because they have no anterior attachment.

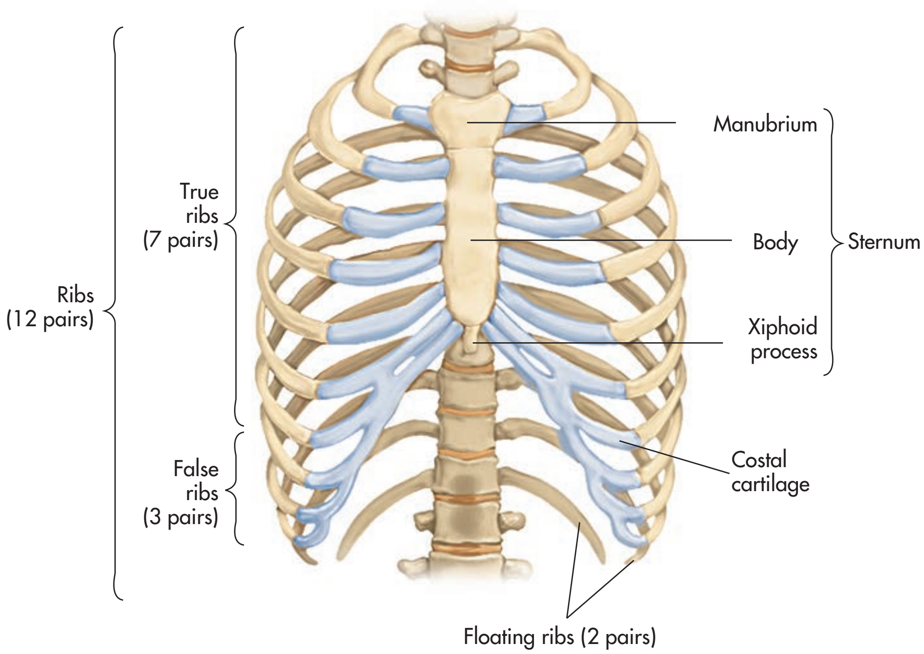


FIGURE 14–13

The thoracic cage.

HOW WE BREATHE

The control center that tells us to breathe is located in the brain, specifically in the **medulla oblongata**. There is also another respiratory area in the pons. *Inspiration* is an active process of ventilation in which the main breathing muscle, the **diaphragm** (a dome-shaped muscle when at rest), is sent a signal via the phrenic nerve, from the cervical plexus of the spinal cord. The diaphragm contracts and flattens, thereby increasing the space in the thoracic cavity (see **FIGURE 14–14**). The increase in volume in the thoracic cavity causes a decrease in pressure in the thoracic cavity that is transmitted to the lungs. Keep in mind that volume and pressure are inversely related. Because the pressure in the lungs is now lower than atmospheric pressure, air rushes into

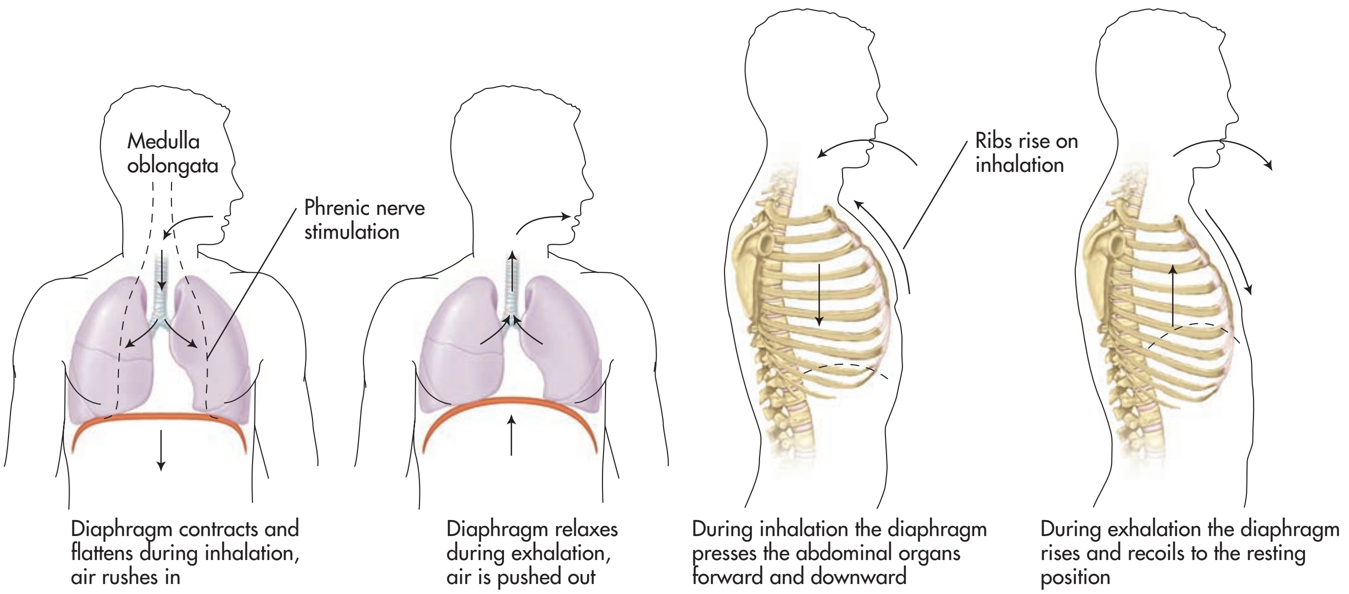


FIGURE 14–14

How we breathe.

the lungs, down the pressure gradient (from high to low). The external intercostal muscles also assist by moving the ribs up and outward during inspiration to increase the total volume in the thoracic cavity.

Exhalation, on the other hand, is usually a passive act. As the diaphragm relaxes, it forms a dome shape, which decreases the amount of space in the thoracic cavity. As a result, pressure in the lungs becomes greater than the atmospheric pressure, and the air is pushed out of the lungs. The fact that the lungs are elastic and are stretched during inspiration also aids in expiration because this tissue returns to rest (recoils), much as a stretched rubber band that is released.

The ease by which ventilation occurs is referred to as **compliance**. Low compliance means that it is more difficult to expand the lungs, whereas high compliance means that less effort is required to expand the lungs. For example, this becomes clinically significant when assessing people who have fibrotic diseases of the lung that decrease compliance and make it difficult to breathe in a sufficient volume of air.

What makes the brain tell the lungs how rapidly or how slowly to breathe? Although we can consciously speed up or slow down our breathing, our breathing rate is normally controlled by the level of carbon dioxide in our blood. If blood carbon dioxide levels rise, it means that not enough CO_2 is being ventilated, so the medulla oblongata sends signals to the respiratory muscles to increase the rate and depth of breathing. Sensory receptors in the aorta and carotid arteries and the medulla oblongata constantly monitor blood chemistry. These chemoreceptors actually sense blood pH. As CO_2 levels rise, blood pH falls, as the blood becomes more acidic. So any time blood becomes more acidic, say in untreated diabetes, the ventilation rate will increase to “blow off” excess CO_2.

AMAZING FACTS

Exhaled CO_2 and Mosquitoes

Mosquitoes are too small to carry flashlights, so how do they find you in the dark? They do it by using carbon dioxide sensors to locate increased concentrations of CO_2 emitted by—you guessed it—your exhaled breath. Once they detect your exhaled CO_2 (which can be up to 164 feet away), they use their heat sensors to find an area of skin on which to begin their banquet. You have an increased chance of being bitten during and right after exercising or doing any strenuous labor. This is because increases of lactic acid and body heat when you are active appear to attract mosquitoes, as does an increase in uric acid. Also, if you have blood type O, you are twice as likely to get bitten as a person with blood type A (type B is somewhere in the middle). Certain skin bacteria also attract mosquitoes; this is why your ankles and feet, which have greater bacterial colonies, seem to be targeted more so than other parts of the body. Finally, pregnant women are twice as likely to be bitten because they exhale about 21% more carbon dioxide and their body temperature is approximately 1.26°F warmer than normal.

Another amazing carbon dioxide fact is that many people believe swimmers hyperventilate to get more oxygen in their systems before a sustained underwater dive. In reality, they are “blowing off” CO_2 to get their levels low. Because higher levels of CO_2 cause us to want to breathe, the body is fooled into believing it doesn’t need to for a while longer, so swimmers can remain underwater longer. Unfortunately, the body still uses up its oxygen at a regular rate and sometimes uses enough of the reserve that swimmers risk losing consciousness.

Sometimes the body needs help to breathe beyond resting or normal breathing. For example, during increased physical activity or in disease states in which more oxygen is required, **accessory muscles** are used to help pull up your rib cage to make an even larger space in the thoracic cavity. The accessory muscles used are the scalene and the sternocleidomastoid muscles in the neck and the pectoralis major and pectoralis minor muscles of the chest.

Although exhalation is a passive process, there are times, especially with certain disease states, when exhalation may need to be assisted. Again, the body has accessory muscles of exhalation that assist in a more forceful and active exhalation by increasing abdominal pressure. The main accessory muscles of exhalation are the various abdominal muscles that push up the diaphragm or the back muscles that pull down and thus compress the thoracic cage. The next time you blow a candle, put your hand on your abdomen. You will feel the abdominal muscles tighten to increase the force of expiration to blow out the candle. See **FIGURE 14–15** ■ for the specific accessory muscles of exhalation.

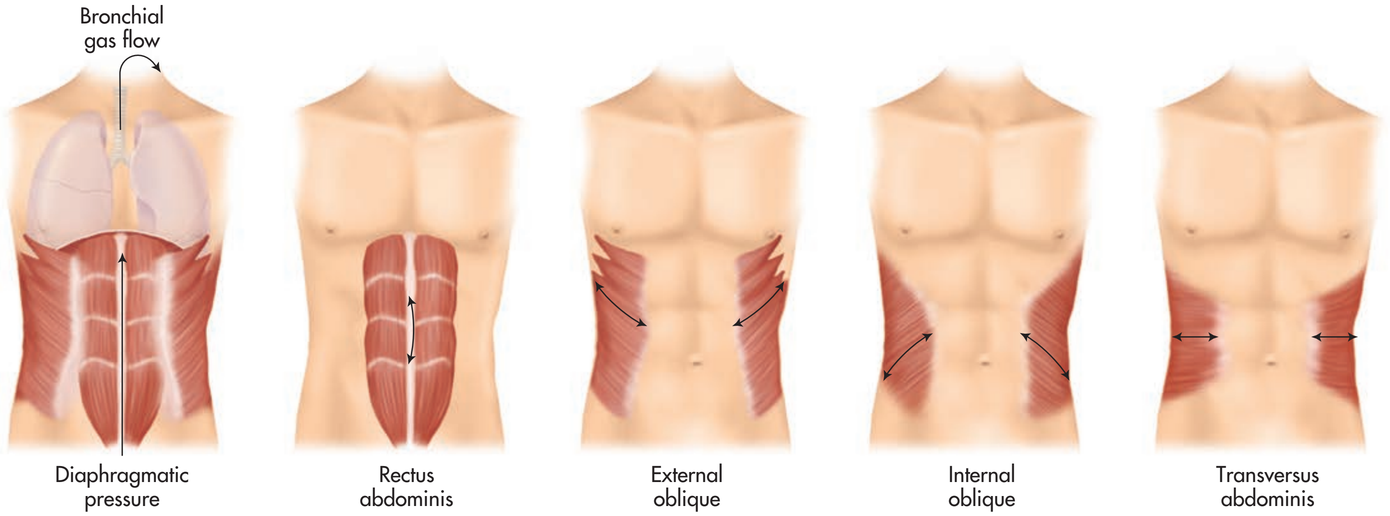


FIGURE 14–15

The accessory muscles of exhalation.

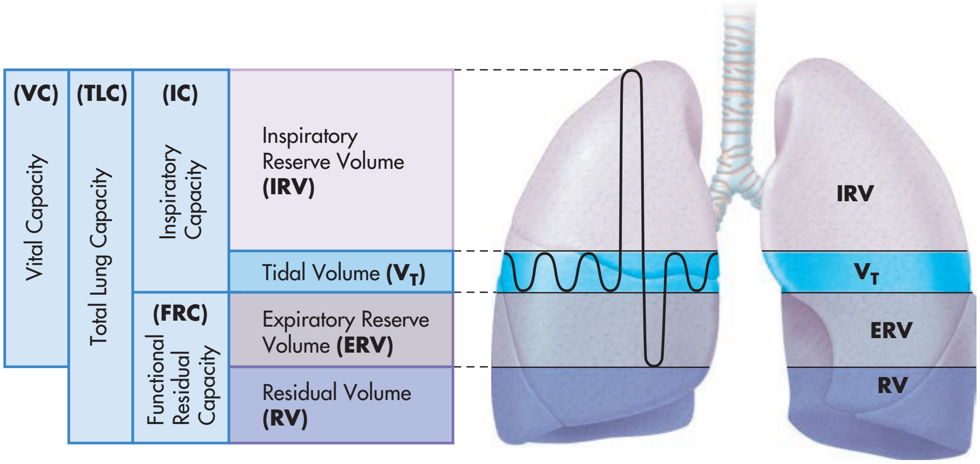
Pulmonary Function Testing

Lung function can be measured in terms of volumes and flows using pulmonary function testing (PFT). First, the various volumes can be measured by having the patient breathe normally and then take a maximum deep breath followed by a maximum exhalation. The tracing of this breath is recorded as in **FIGURE 14–16**. For example, tidal volume (V_T) is the amount of air moved into or out of the lungs at rest during a single breath. The normal tidal volume is 500 mL, although there is considerable variation depending on age, sex, height, and general fitness. Your inspiratory reserve volume is what you can breathe in beyond a normal inspiration. Likewise, your expiratory reserve volume is what you can exhale beyond a normal exhalation. You can never totally exhale all the air out of your lungs; your residual volume (RV) prevents total lung collapse. We can combine these volumes to get various lung capacities, as shown in Figure 14–16 and below.

- Function residual capacity (FRC)—the volume of air remaining in the lungs at the end of a normal expiration
- Inspiratory reserve volume (IRV)—the amount of air that can be forcefully inhaled beyond a normal inspiration
- Expiratory reserve volume (ERV)—the amount of air that can be forcefully exhaled beyond a normal expiration
- Residual volume (RV)—the volume of air remaining in the lungs after a maximum expiration
- Vital capacity (VC)—the maximum amount of air that can be moved into and out of the respiratory system in a single respiratory cycle.
- Total Lung Capacity (TLC)—the sum of all the lung volumes

Besides volumes and capacities, we can also measure the flow rates coming out of the lung at various points during a forced (maximum patient effort) vital capacity (FVC). For example, we can measure the forced expiratory volume in 1 second, or FEV_1. Normally, one can exhale 75–85% of their FVC in 1 second. However, someone with an obstructive disease would take longer to exhale and get less than 70% of their total FVC out in 1 second and therefore have a reduced FEV_1.

Another test that helps establish whether the airways have become "narrower" than normal (as would be seen in an asthma episode) is peak expiratory flow rate, or PEFR, which is the maximum flow rate or speed of air a person can rapidly expel after taking the deepest possible breath. The PEFR test is measured in liters per minute and should be within a predicted range. This a good test to reflect how the larger airways are functioning and to monitor diseases such as asthma that affect these airways.



Lung volume measurements	Male (in milliliters)	Female (in milliliters)
Tidal Volume (V_T): The volume of gas in and out of the lungs during one normal breath	500	400–500
Inspiratory Reserve Volume (IRV): The volume of air forcefully inspired beyond a normal inspiration	3100	1900
Expiratory Reserve Volume (ERV): Volume of gas forcefully exhaled beyond a normal expiration	1200	800
Residual Volume (RV): The volume of gas still remaining in the lungs after a forced expiration	1200	1100
Lung Capacities (combination of two or more volumes)		
Vital Capacity (VC): VC = IRV + V_T + ERV	4800	3200
Inspiratory Capacity (IC): IC = V_T + IRV	3600	2400
Functional Residual Capacity (FRC): FRC = ERV + RV	2400	1800
Total Lung Capacity (TLC): TLC = IRV + V_T + ERV + RV	6000	4200

FIGURE 14–16

Normal lung volumes and capacities.

TEST YOUR KNOWLEDGE 14–4

Choose the best answer.

1. The _______________ pleura lines the thoracic cavity.
   a. visceral
   b. parietal
   c. mediastinum
   d. chest

2. The portion of the sternum where CPR is performed is the:
   a. xiphoid process.
   b. ribs.
   c. manubrium.
   d. body.

3. The _______________ nerve innervates the main breathing muscle, called the _______________.
   a. thoracic; internal intercostals
   b. thoracic; diaphragm
   c. phrenic; external intercostals
   d. phrenic; diaphragm

4. The amount of air moved during typical resting ventilation is called:
   a. inspiratory reserve volume.
   b. vital capacity.
   c. expiratory reserve volume.
   d. tidal volume.

5. As CO_2 rises, chemoreceptors send signals to the _______________ to _______________ ventilation.
   a. cerebrum; decrease
   b. heart; increase
   c. medulla oblongata; increase
   d. spinal cord; decrease

Complete the following.

6. The process of producing red blood cells is called _______________.

Match the following.

1. Function residual capacity (FRC) ___
2. Inspiratory reserve volume (IRV) ___
3. Expiratory reserve volume (ERV) ___
4. Residual volume (RV) ___
5. Vital capacity (VC) ___

a. the maximum amount of air that can be moved into and out of the respiratory system in a single respiratory cycle
b. the volume of air remaining in the lungs at the end of a normal expiration
c. the amount of air that can be forcefully inhaled after a normal inspiration
d. the amount of air that can be forcefully exhaled after a normal expiration
e. the volume of air remaining in the lungs after a maximum expiration

COMMON DISORDERS OF THE RESPIRATORY SYSTEM

Respiratory disease is one of the most common disease groups seen in health care settings. The following sections is a review of some of these.

Atelectasis and Pneumonia

Atelectasis, commonly occurring in hospitalized patients, is a condition in which the air sacs of the lungs are either partially or totally collapsed. Atelectasis usually occurs in patients who cannot or will not take deep breaths to fully expand the lungs and keep the passageways open. Surgery or an injury of the thoracic cage (such as broken ribs) often makes deep breathing painful. Taking periodic deep breaths is important not only to expand the lungs but also to stimulate the production of surfactant, which helps keep the small alveolar sacs open between breaths.

Patients with large amounts of secretions who cannot cough them up are also at risk for atelectasis because the secretions block airways and lead to areas of collapse. Quite often, if atelectasis is not corrected and secretions are retained, **pneumonia** can develop within 72 hours. Pneumonia is a lung infection that can be caused by either viruses, fungi, protists, or bacteria. Inflammation occurs in the infected areas, with an accumulation of cell debris and fluid. In certain pneumonias, lung tissue is destroyed. Pneumonias, if severe enough, can lead to death.

Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) is a group of diseases in which patients have difficulty getting all the air out of their lungs. Often, large amounts of secretions and lung damage are involved. The diseases involved in COPD are **emphysema** and **chronic bronchitis**. **Asthma**, formerly considered a COPD-type disease, is now separated into its own category due to its special characteristics such as its reversibility with proper treatment.

Asthma

Asthma is a potentially life-threatening lung condition in which the body reacts to an allergy by causing constriction of the airways of the lungs, known as **bronchospasm** (see **FIGURE 14–17**). It is difficult to get air in and even more difficult to get air out of the lungs. The inability to get air out of the lungs is known as *gas trapping*. As a result of gas trapping, fresh air cannot get into the lungs, so the victim breathes the same air over and over. This lowers the amount of oxygen in the blood and increases the blood levels of carbon dioxide. Because this is an inflammatory process of the airways, there is also an increase in the amount of mucus that the airways produce. These increased secretions can block the airways (a phenomenon known as *mucus plugging*) and further reduce the flow of fresh air to the lungs. Although asthma can be a life-threatening disease, it can be controlled with the use of medication.

Emphysema

Emphysema is a nonreversible lung condition in which the alveolar air sacs are destroyed and the lung itself becomes "floppy" (see Figure 14–17), much like a balloon that has been inflated and deflated too many times. As the alveoli are

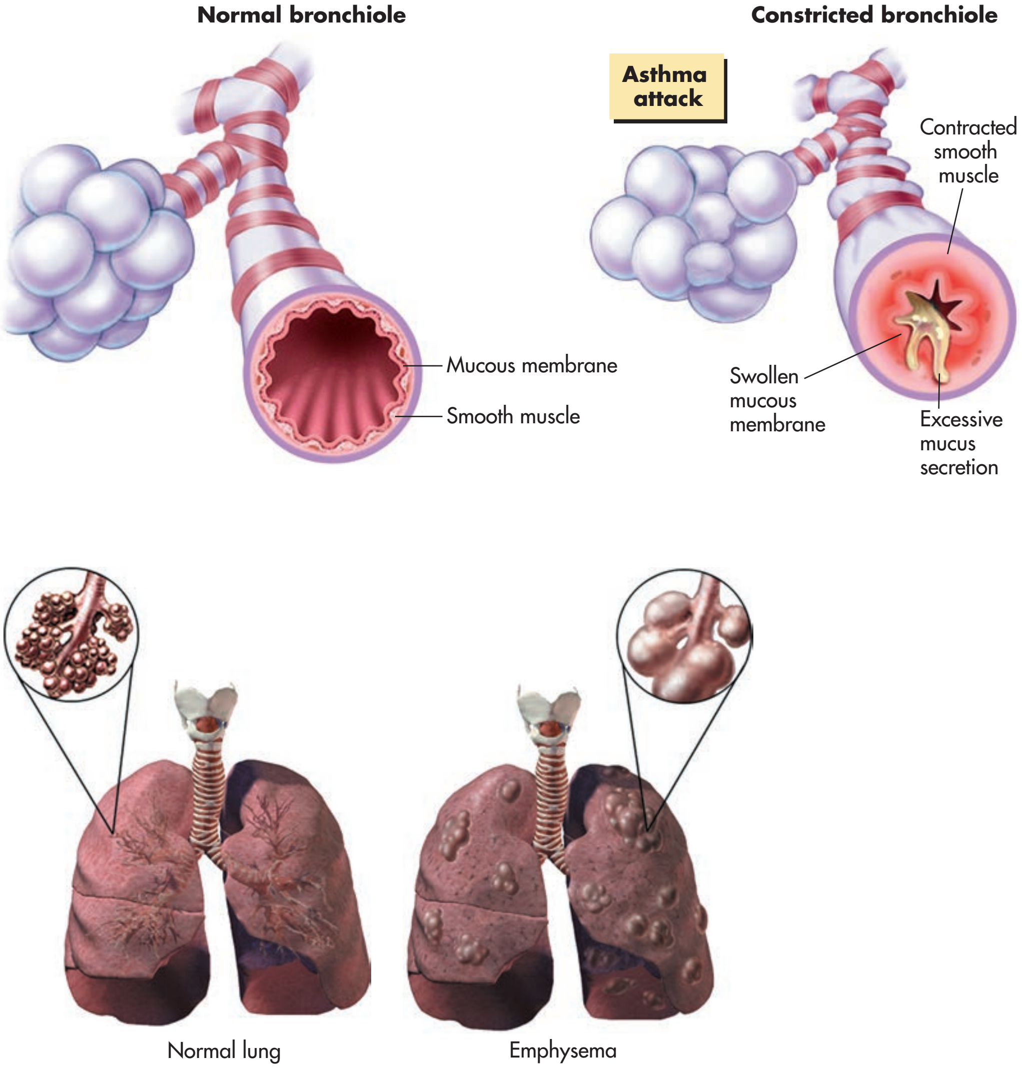


FIGURE 14–17
Asthma and emphysema.

destroyed, it becomes more difficult for gases to diffuse between the lungs and the blood. The lung tissue becomes fragile and can easily rupture (much like a worn tire), causing air to escape into the thoracic cavity and further inhibit gas exchange. This causes a pneumothorax, which is discussed below.

Chronic Bronchitis

Chronic bronchitis is a lung disease in which there are inflamed airways and large amounts of sputum are being produced. As inflammation occurs, the airways swell, and the inner diameter of the airways become smaller. As they get smaller, it becomes difficult to move air in and out, which increases the work of breathing. Because of this increased work level, more oxygen is used, and more carbon dioxide is produced.

Pneumothorax

A **pneumothorax** is a condition in which there is air inside the thoracic cavity and outside the lungs, often in the pleural cavity. Remember that the pleural cavity is a *potential* space. Gas or fluid may be forced into the cavity, separating the layers of the membrane. Air can enter the thoracic cavity from two directions. A stab wound or gunshot wound to the chest would allow air to rush into the thoracic cavity from the outside. The lung might develop a leak as a result of either a structural deformity or a disease process (such as in emphysema). In this situation, air would enter the thoracic cavity from the lung as air is breathed in. In either case, if the gas cannot escape, it will continue to fill a space in the thoracic cavity and provide less space for the lung or lungs to expand when breathing. If the lungs are too greatly restricted to expand, a life-threatening situation may occur.

Pleural Effusion

A **pleural effusion** is a condition in which an excessive buildup of fluid develops in the pleural cavity between the parietal and the visceral pleura. This fluid may be pus (in which case it is known as **empyema**), lymphatic fluid (called a **chylothorax**), serum from the blood (called a **hydrothorax**), or blood (called a **hemothorax**). Because fluids are affected by gravity, pleural effusions tend to move to the lowest point in the pleural space. If a pleural effusion is large enough, it can have the same effect as a large pneumothorax. It can restrict the amount of expansion of a lung or lungs. Because less air can flow into and out of the lungs, the patient has to work harder by breathing in and out more rapidly to meet the body's demands for more oxygen and the removal of carbon dioxide. This additional work of breathing may exhaust an individual to the point that he or she can no longer breathe without intervention. These conditions may progress to atelectasis.

Tuberculosis

Tuberculosis (TB) is a bacterial infection that has seen a recent rise in occurrence. It thrives in areas of the body that have high oxygen content such as the lung. Tuberculosis bacilli can remain dormant in the body for years before beginning to multiply. If it continues unchecked, vast lung damage can occur. There has been recent concern about a multidrug-resistant form of tuberculosis that is very resistant to the antibiotics that are normally used to treat TB, and this strain has a high mortality rate.

Patients with lung disease may exhibit signs and symptoms such as dyspnea, tachypnea, cyanosis due to low oxygen levels, and use of accessory muscles of ventilation to assist normal breathing. In addition, the cardiac system may exhibit tachycardia to speed up oxygen delivery and may increase the number of red blood cells that carry oxygen.

The major preventable cause of many respiratory diseases is smoking. The annual number of smoking-related deaths in the United States is equivalent to one jumbo jet filled with passengers crashing every day with no survivors, or 450,000 deaths per year.

SUMMARY

Points of Interest

- Moving approximately 12,000 quarts of air each day, the respiratory system is responsible for providing oxygen for the blood to take to the body's tissues and removing carbon dioxide, one of the waste products of cellular metabolism.
- Ventilation is the movement of gases into and out of the lungs; during respiration, oxygen is added to the blood and carbon dioxide is removed.
- The lungs contain continually branching airways called bronchi and bronchioles.
- At the end of bronchioles are alveolar sacs.
- Each alveolar sac is surrounded by a capillary network where gas exchange occurs with the blood.
- The purpose of the upper airway is to filter, warm, and moisten inhaled air for its journey to the lungs.

- In addition, the upper airway provides for olfaction (sense of smell) and phonation (speech).
- The mucociliary escalator captures foreign particles, and the hairlike cilia constantly move a layer of mucus up to the upper airway to be swallowed or expelled.
- Adenoids and tonsils aid in preventing pathogens from entering the body.
- Because activities of breathing and swallowing share a common pathway, the epiglottis protects the airway to the lungs from accidental aspiration of food and liquids.
- Vocal cords are the gateway between the upper and lower airways.
- The tracheobronchial tree is like an upside-down tree with ever-branching airways, where the trunk of the tree is represented by the trachea and the leaves by the alveoli.
- The alveolar capillary membrane is where external respiration or gas exchange occurs.
- The bony thorax provides support and protection for the respiratory system.
- The main muscle of breathing is the diaphragm, and accessory muscles assist in times of need such as exercise and disease.
- The medulla oblongata in the brain is the control center for breathing and sends impulses via the phrenic nerve to the diaphragm.

CASE STUDY

A patient comes to the emergency department with wheezing and thick secretions. His heart rate, breathing rate, and blood pressure are all increased. He is using accessory muscles of ventilation to breathe and has peripheral cyanosis. He has a history of allergies and has had a "bad cold" for several days.

a. What are two possible respiratory conditions he may have?

____

____

b. Can you think of some recommended treatments for this patient?

____

____

c. What would be some positive indicators that your treatment is working? For example, after the treatment, you notice less accessory muscle use. Can you think of at least two more?

____

____

REVIEW QUESTIONS

Multiple Choice

1. The process of gas exchange between the alveolar area and capillary is:
   a. external ventilation.
   b. internal ventilation.
   c. internal respiration.
   d. external respiration.

2. The bulk movement of gas into and out of the lung is called:
   a. internal respiration.
   b. ventilation.
   c. diffusion.
   d. gas exchange.

3. Which of the following is *not* a function of the upper airway?
   a. Humidification
   b. Gas exchange
   c. Filtration
   d. Heating or cooling gases

4. The largest cartilage in the upper airway is the:
   a. cricoid.
   b. eustachian.
   c. mega cartilage.
   d. thyroid.

5. Which structure controls the opening to the trachea?
   a. Esophagus
   b. Hypoglottis
   c. Epiglottis
   d. Hyperglottis

6. Cells need oxygen to:
   a. make ATP.
   b. get rid of CO_2.
   c. use gasoline.
   d. breathe.

7. The lung capacity that includes tidal volume, inspiratory reserve volume, and expiratory reserve volume is called your:
   a. total lung capacity.
   b. functional residual capacity.
   c. inspiratory capacity.
   d. vital capacity.

Matching

1. ______ Asthma	a. An inherited disease transmitted by a recessive gene, causing excessive mucus production
2. ______ Chronic bronchitis	b. Causes permanent destruction of alveolar walls and surrounding capillaries
3. ______ Laryngitis	c. Has many triggers that include pet dander, food allergies, and cold air
4. ______ Emphysema	d. Occurs when air sacs in the lungs are either partially or totally collapsed
5. ______ Cystic fibrosis	e. Caused by bacteria or viruses and will affect your voice
6. ______ Tuberculosis	f. Cigarette smoking causes large amounts of secretions and inflamed airways
7. ______ Atelectasis	g. Caused by a bacterial infection that thrives in areas of the body that have high oxygen concentrations

Fill in the Blank

1. Small bronchi are called ________________.
2. The sense of smell is termed ________________, and the act of speech is called ________________.
3. The hairlike projections called ________________ beat within the ________________ layer and propel the ________________ layer toward the oral cavity to be expectorated.
4. The ________________ are thought to lighten the head and provide resonance for the voice.
5. When the diaphragm contracts, lung volume ________________ and air flows ________________.

Short Answer

1. Describe the tissue layers in the bronchi.

____

____

____

____

2. Explain how gas exchange takes place in the lungs.

____

____

____

____

3. Discuss the importance of surfactant.

4. Describe the process of normal breathing beginning with the brain.

5. Explain the changes in the wall of the tracheobronchial tree as you move from conducting zone to respiratory zone.