13 The Respiratory System

IT'S A GAS

Without fuel, we wouldn't get very far on our trip. Our car wouldn't start without gasoline, our plane would be grounded without jet fuel, and our bodies would die without the fuel necessary for metabolism. The respiratory system's primary function is to transport the vital oxygen, from the atmosphere to the bloodstream to be utilized by cells, tissues, and organs for the process of cellular respiration, which is necessary to sustain life. 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 waste by-products or exhaust. For example, our car produces waste gases, which 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 in toxic levels. In this chapter, we explore the journey oxygen molecules must take from the outside atmosphere to our cells and tissues. In addition, we travel with carbon dioxide as it leaves the respiratory system and is placed back into the atmosphere. 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 and state the basic functions of the components of the respiratory system.
- Differentiate between ventilation and respiration.
- 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 pulmonary function testing.
- 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.
- Discuss several common respiratory system diseases.

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 pronunciations given are referenced to medical dictionaries, and regional variations may exist.

adenoid (AD eh noid)
alveoli (al VEE oh lye)
asthma (AZ mah)
atelectasis (at eh LEK tah sis)
bronchi (BRONG kye)
bronchioles (BRONG kee ohlz)
bronchitis (brong KYE tis)
capillaries (KAP ih LAIR eez)
carina (kuh RINE uh)
cilia (SILL ee ah)
conchae (KONG kay)
diaphragm (DIE ah fram)
dyspnea (DISP nee ah)
emphysema (EM fih SEE mah)
empyema (EM pye EE mah)
epiglottis (ep ih GLOT tis)
erythrocytes (eh RITH roh sights)
erythropoiesis (eh RITH roh poy EE sis)
erythropoietin (eh RITH roh poy EH tin)
esophagus (eh SOFF ah gus)
Eustachian tubes (yoo STAY she ehn)
glottis (GLAH tiss)
hemoglobin (HEE moh GLOH binn)
hemothorax (HEEM oh THOH raks)
hilum (HIGH lim)
hydrothorax (HIGH dro THOH raks)
laryngitis (lair in JIGH tis)
laryngopharynx (lair IN goh FAIR inks)
larynx (LAIR inks)
lingula (LING gu lah)
mediastinum (MEE dee ah STY num)
medulla oblongata (meh DULL lah OB long GOT ah)
nasopharynx (NAY zoh FAIR inks)
palatine (PAL ah tine)
parietal pleura (pah RYE eh tal PLOO rah)
pharyngitis (FAIR in JIGH tis)
pharynx (FAIR inks)
pleural effusion (PLOO ral eh FYOO zhun)
pneumothorax (NOO moh THOH raks)
oropharynx (OR oh FAIR inks)
respiration (res pir AY shun)
sternum (STER num)
surfactant (sir FAC tent)
tuberculosis (too BER kew LOH sis)
trachea (TRAY kee ah)
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 to recover from strenuous exercise? Our body uses energy from the food we eat, but cells can only obtain the energy in the form of glucose from food 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.

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. The respiratory system, also called the **pulmonary system**, is closely connected with the heart and circulatory system. Due to their close 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 gas in 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 function for the system
- Muscles of breathing that include the main muscle, the diaphragm, and accessory muscles

Please take a few minutes to look at **FIGURE 13–1**. We explore each of these components as we travel through the respiratory system.

***AMAZING* BODY FACTS**

Autocontrol of Cardiopulmonary System

The cardiovascular and 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.

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, listed in **TABLE 13–1**. The predominant gas is nitrogen (N_2), but this is an inert gas, which means it does not interact 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; however, it is in much higher concentration in the air we exhale.

The respiratory system contains a very intricate set of tubes that conducts gas from the atmosphere to deep within 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 into and out of the lungs. Ventilation moves fresh air down into the terminal end of the lungs, where the gas exchange will take place. The second is **respiration**, the gas exchange process, in which oxygen is added to the blood and carbon

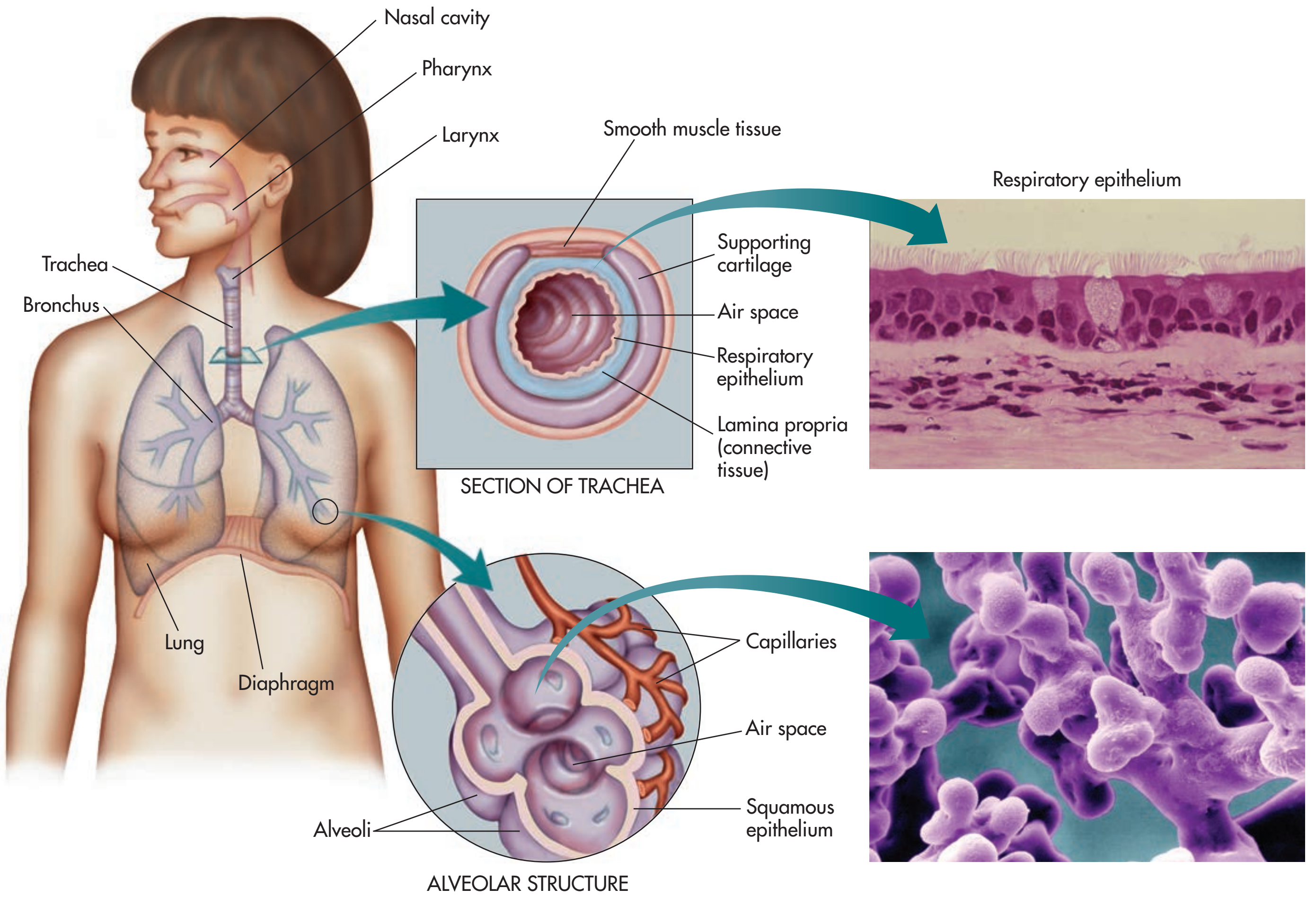


FIGURE 13–1

The various components of the respiratory system. (Source: Ed Reschke/Photolibrary/Getty Images; BSIP/Universal Images Group/Getty Images)

Table 13–1 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.

dioxide is removed. When an individual breathes, inspiration (breathing in) and expiration (breathing out) occurs, otherwise known as the ventilation process. The measurement of these ventilations per minute is typically referred to as the respiration rate and is approximately 14–20 respirations per minute. However, keep in mind respiration is the process of gas exchange. (*Note:* The process by which cells make ATP by breaking down glucose is also called respiration, but more specifically, 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. Ventilation, therefore, is not the same thing as respiration. When you watch a television show that says place the patient on a respirator, it is incorrect, and the person should say "a ventilator" because the machine is only moving the gas mixture (ventilating), not causing gas exchange. See FIGURE 13–2, which contrasts these important processes.

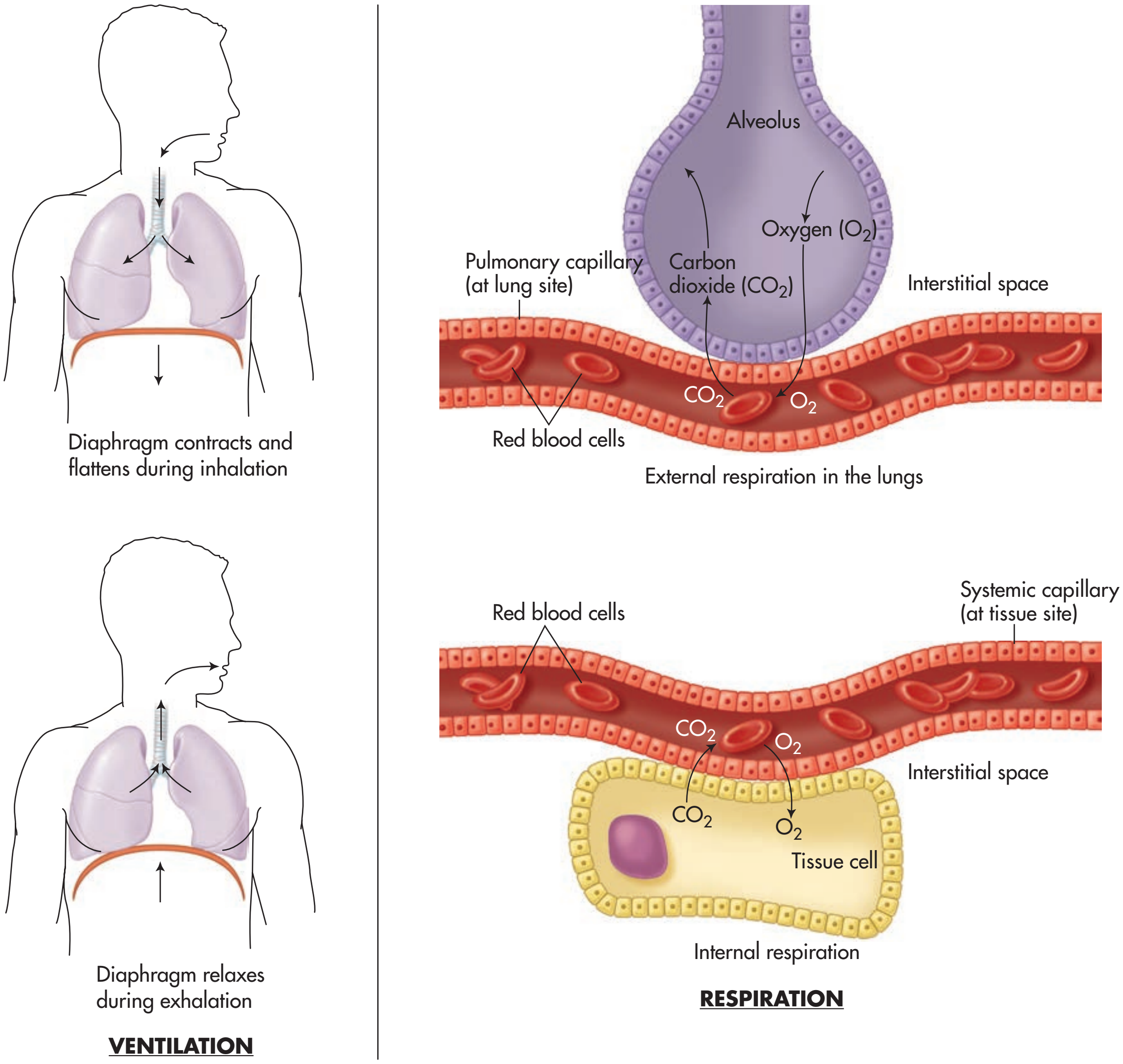


FIGURE 13–2
Contrast of ventilation and external and internal respiration.

The respiratory system is responsible for providing all the body's oxygen needs and removing carbon dioxide. Unlike cars that have large gas tanks for fuel storage, the human body has a very small reserve of oxygen. In fact, its 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. Again, this process is called ventilation. We now begin our breathtaking journey through the internal structures of the respiratory system by following the path oxygen molecules take.

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. The tissue of the lung is light, porous, and spongy. It floats if placed in water because of the air in the alveoli.

To better visualize this system, consider the shape of a stalk of broccoli held upside down. The stalk and its branchings 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.

Each alveolus is surrounded by a network of small blood vessels called **capillaries**. This combination of the alveolus and the capillary is called the **alveolar-capillary membrane** (respiratory membrane) and represents the connection between the respiratory and cardiovascular systems. This is where the vital process of gas exchange takes place. Before getting in depth into this process, let's trace the journey that oxygen molecules must take to arrive at the alveolar-capillary membrane.

FOCUS ON PROFESSIONS

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).

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

APPLIED SCIENCE

GAS EXCHANGE IN PLANTS

Fortunately for the earth's ecosystem, plant physiology of gas exchange is exactly opposite that of humans. Plants take in the CO_2 in the atmosphere and utilize it to help create energy, and then they 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 every day. We truly need a green earth to survive, so thank the next plant you see.

THE UPPER RESPIRATORY TRACT

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

The upper airways begin at the two openings of the nose, called **nostrils** or **nares**, and end at the **vocal cords** (see **FIGURE 13–3**). 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 our noses, for reasons that will become clear. The nose is a semi-rigid structure made of cartilage and bone. The **nasal cavity** is the space behind the nose and consists of three main regions: vestibular, olfactory, and respiratory. The two nasal cavities are separated by a wall called the **septal cartilage**, or **nasal septum**, which divides the nose into right and left sides. Please see **FIGURE 13–4**.

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 to 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. (*Gross* in this case means "large.") The vestibular region helps to filter out large particles so they do not enter the lungs, where they could irritate and clog the airways. You may also sneeze after inhaling particles, such as dust or allergens. Sneezing forces air quickly through the nose, to clear the upper respiratory tract.

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. Only four molecules of a substance are required for the olfactory senses to detect a gas. It is interesting to note that your ability to taste is related to your sense of smell. If you ever had a nasty head cold and could not taste your food as well, 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.)

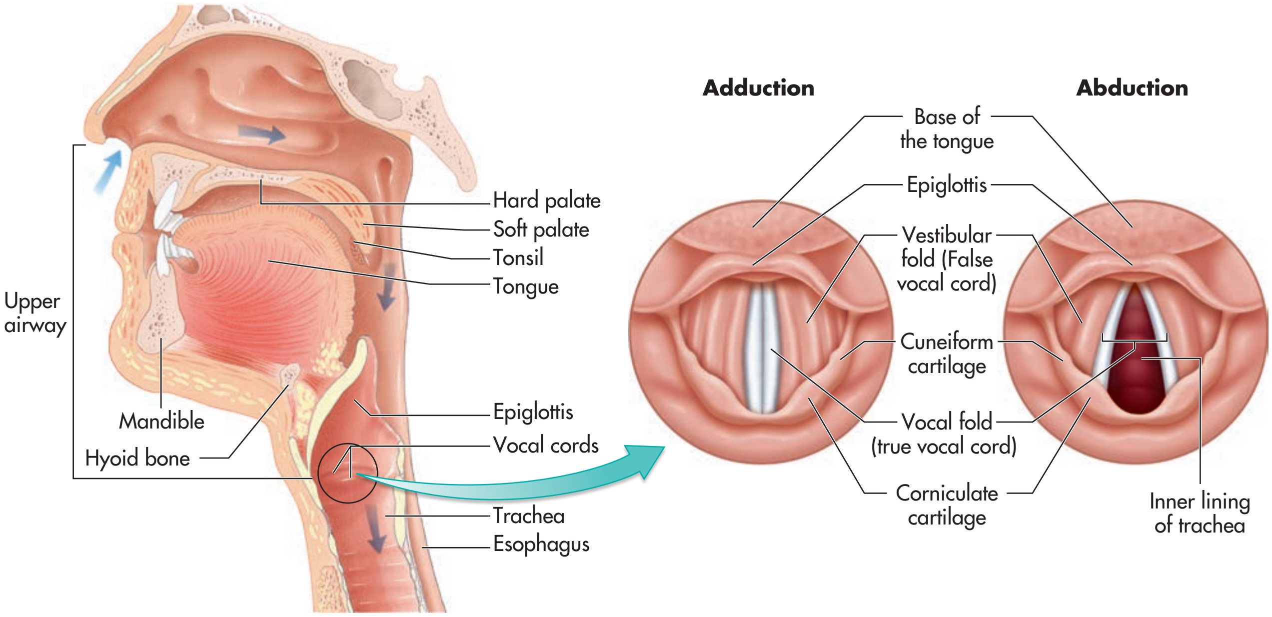


FIGURE 13–3
The upper airway and vocal cords.

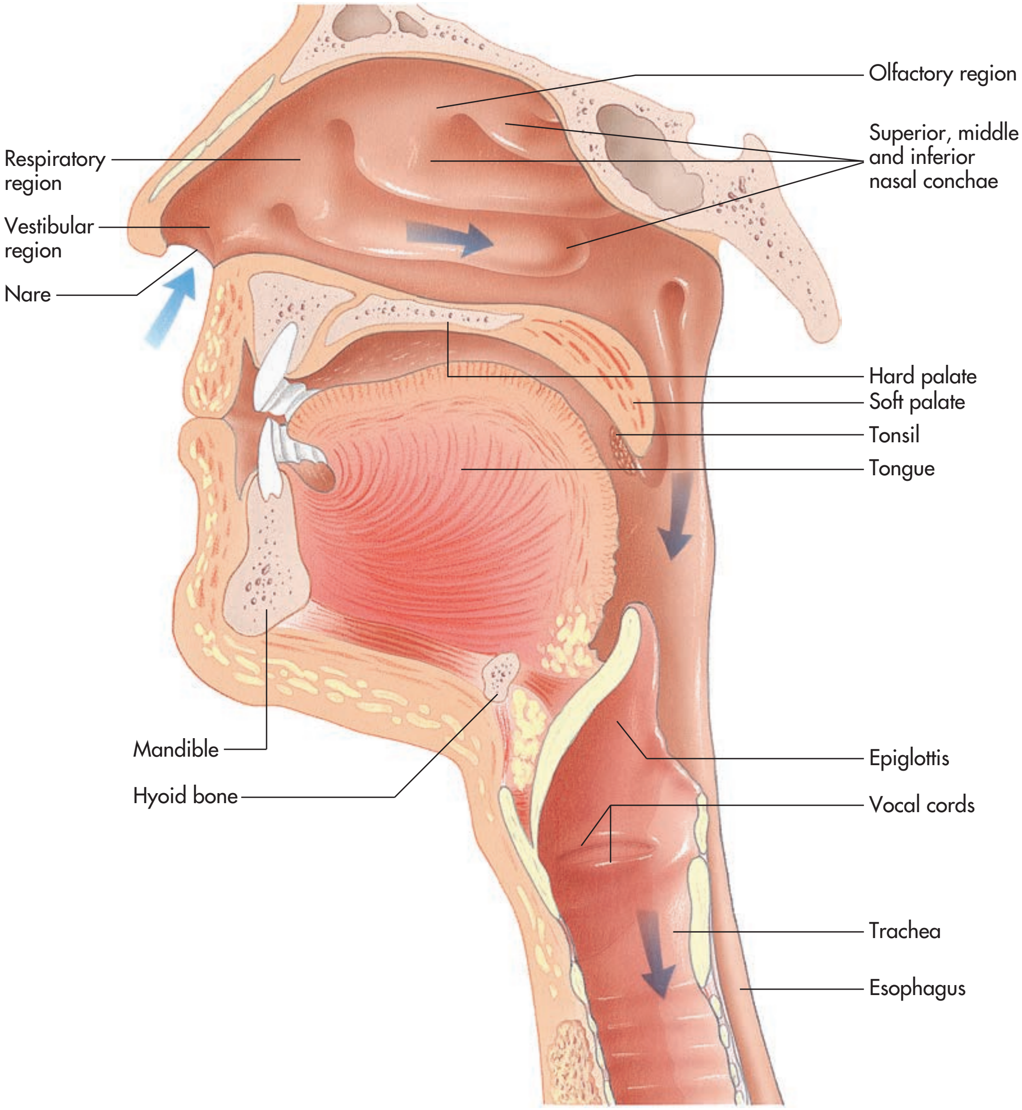


FIGURE 13–4
The nasal regions.

AMAZING BODY 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 that this is not so far-fetched. They are developing an electronic sensor that samples the breath and can detect lung, breast, bladder, and prostate cancers by chemical variations related to the specific tumors.

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 region** of the nose. Even though it is called the respiratory region, no respiration or gas exchange takes place here. Keep in mind that the respiratory region resides in 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 13–4). These split up the gas into three channels, thereby providing more surface area for incoming air to make contact with the nasal mucosa. Although 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)!

Because the nasal cavity is not 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 of water *each day* to moisten inspired air to 80% relative humidity within the respiratory region of the nose. 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.

AMAZING BODY FACTS

Why Do We Breathe Through Our Mouth?

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 thus less work involved in breathing. Therefore, mouth breathing predominates during stress and exercise because it is easier (less resistant) for the gas to travel through the larger oral opening. Of course, when you get a head cold and your nasal passages become blocked by secretions, it becomes necessary to breathe through the easier or open route of the mouth. On your journey, you must always be ready for detours.

PATHOLOGY CONNECTION

THE NOSE

Often the nose can indicate the body's sensitivity to certain airborne allergens such as seasonal pollens from grass or ragweed. **Allergic rhinitis** occurs when allergens trigger the nasal mucosa to secrete excessive mucus, causing the infamous runny nose. Because the release of histamine is often the culprit, antihistamines can be used to treat many cases. Some individuals can also take allergy injections to desensitize their reaction to the specific allergen. (For more on allergies, see Chapter 14, "The Lymphatic and Immune Systems.")

Nasal polyps are noncancerous growths within the nasal cavity. The exact cause is unknown but it is believed that they occur due to chronic inflammation. If they become large enough, they can obstruct the nasal passageway and make breathing difficult. In these cases, surgical removal is necessary.

TEST YOUR KNOWLEDGE 13–1

Choose the best answer.

1. Which gas is found in the atmosphere?
   a. Oxygen
   b. Nitrogen
   c. Carbon dioxide
   d. All 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.

(continued)

TEST YOUR KNOWLEDGE *(continued)*

3. The process of gas exchange at the tissue sites 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. heart.

5. The bones in the respiratory region of the nose are called:
   a. sinuses.
   b. turbinates.
   c. tectonic plates.
   d. bronchioles.

Complete the following.

1. Noncancerous nasal growths are called _______________, and seasonal _______________ can occur with the release of airborne pollens.

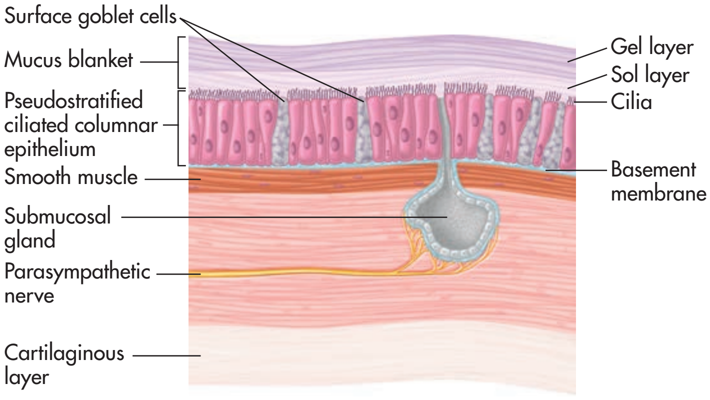
CLINICAL APPLICATION

EXCESSIVE MUCUS PRODUCTION

Some diseases, such as chronic bronchitis and cystic fibrosis, cause excess mucus to be produced, which must be expectorated (spit out) or swallowed. The color of the expectorant is clinically useful. In general, yellow and green sputum indicate an infection, but also indicate that the immune system is helping to fight an infection because the mucus becomes green when enzymes (from the defense cells) that fight bacteria are activated. Red or brown mucus indicates that bleeding has occurred, which is seen in lung cancer or advanced tuberculosis. Cystic fibrosis causes the exocrine glands to secrete very thick mucus. This blocks the airways and increases the susceptibility to bacterial infections.

Going to Ride the Mucociliary Escalator

The epithelial lining of the respiratory region of the nose plays a very important role in keeping this region of the nose clean and free of debris buildup. Cells in the epithelial layer (or respiratory mucosa) are called **pseudostratified ciliated columnar epithelium** and are found not only in the respiratory region of the nose but also throughout most of the airways. See **FIGURE 13–5**. The **epithelium** is a single layer of



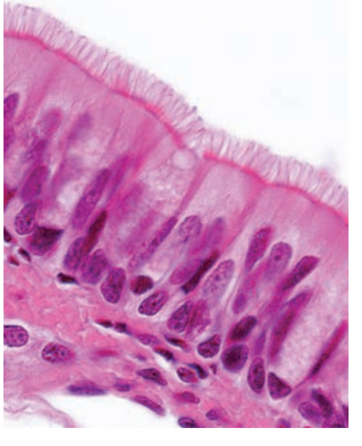


FIGURE 13–5
The mucociliary escalator. (Source: Jose Luis Calvo/Shutterstock)

tall, columnlike cells with nuclei located at different heights, giving the false appearance of two or more layers of cells when in fact there is only one—hence the term *pseudostratified columnar*. Each columnar cell has 200–250 **cilia** on its surface.

Goblet cells and submucosal glands are interspersed in the respiratory mucosa and produce about 100 milliliters (approximately ¼ pint) of mucus per day. The mucus actually forms in 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 mucus blanket, much like fly paper. Once debris is trapped on the mucus blanket, it must be removed from the lung.

So how does this mucus layer actually work? The microscopic, hairlike cilia act as tiny "oars," and in Figure 13–5, 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. When this process occurs in the nose, the debris-laden secretions are pushed toward the front of the nasal cavity to be expelled through the nose. 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—that is, unless something paralyzes it, such as smoking.

The Sinuses

Have you ever heard of someone being called an airhead? Technically, we are *all* airheads because the skull contains air-filled cavities (commonly called **sinuses**) that connect with the nasal cavity via small ducts (passageways). Because these are located around the nose, they are called **paranasal sinuses**. (*Para* means "around"; *sinus* means "hollow cavity.") They are lined with respiratory mucosa (mucous membranes) that continually drain their secretions into the nasal cavity, warming and moistening the air passing through it. The sinuses are named for the specific facial bones in which they are located. (See **FIGURE 13–6** ■.)

These cavities of air in the bones of the cranium are believed to help prolong and intensify 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 that the air-filled sinuses help to lighten your head.

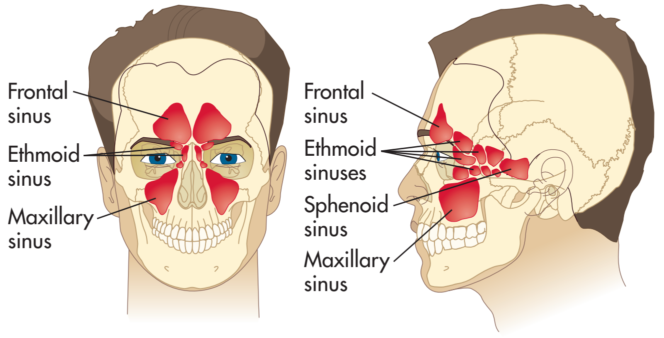


FIGURE 13–6 ■
The paranasal sinuses.

Imagine how heavy your head would be if those facial bones were solid!

Sinuses do not exist at birth, but develop as you grow. Facial changes are influenced by the sinuses as you mature. Sinuses also provide further warming and moisturizing of inhaled air.

The Pharynx

The **pharynx** is a hollow, muscular structure, about 2½ inches long, lined with epithelial tissues. It serves as a common passageway for both air and food. The pharynx begins behind the nasal cavities and is divided into the following three sections, as shown in **FIGURE 13–7** ■.

- Nasopharynx
- Oropharynx
- Laryngopharynx

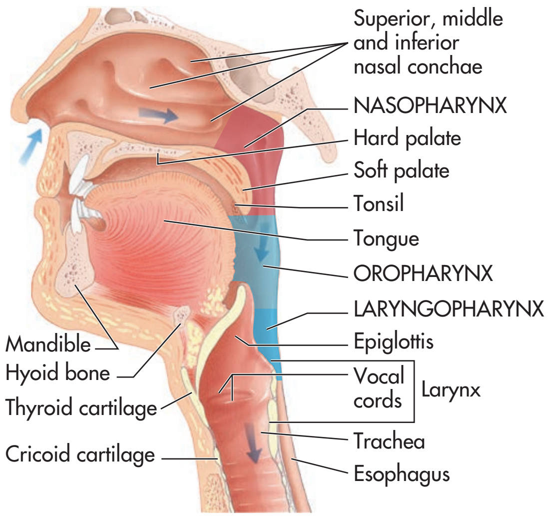


FIGURE 13–7 ■
The nasopharynx, oropharynx, and laryngopharynx and related structures.

The **nasopharynx** is the uppermost section of the pharynx and begins right behind the 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.

The **oropharynx** is the next structure, located right behind the oral or buccal cavity. The oropharynx conducts not only atmospheric gas but also food and liquid. Air breathed through both the nose and the mouth passes through here, as does anything that is swallowed. 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 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 prevent the nasopharynx and nasal cavity from allowing food or liquid to enter the respiratory system. 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 inferior 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, to be discussed soon.

The Larynx

The **larynx**, located in the neck, is a triangular chamber below the laryngopharynx that houses the important structures needed for speech. Commonly known as the voice box, the larynx is a semirigid structure composed of cartilage plates 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 a part of the thyroid cartilage and is more prominent in males than in females. This cartilage is also anatomically known as the **thyroid cartilage**, beneath which is the **cricoid cartilage**. Both cartilages in the exposed areas of airways found in the neck are necessary to provide structure and support for airways so they do not collapse and block the flow of air in and out of the lungs.

The space between the vocal cords is called the **rima glottis**, or simply the **glottis**. The glottis is the opening that leads into the larynx and eventually the lungs. There is a leaf-shaped, flaplike fibrocartilage, located above the glottis, called the **epiglottis**. The epiglottis closes over the opening to the larynx when you swallow and opens up when you breathe, as part of the swallowing reflex. This selective closure is called the *glottis* or *sphincter mechanism*. It facilitates the closing of the epiglottis over the glottic opening during swallowing, sealing it so food does not enter the lungs.

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

The **vocal cords** are the area of division between the upper and lower airways, representing the point of transition to the lower airways. The lower airways start below the vocal cords, and we soon 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. While 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. Referring back to Figure 13–7, you see a space between the thyroid and cricoid cartilages, and 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 about 2.5 centimeters 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. Adduction during expiration partially seals the vocal cords, whereas abduction during inspiration opens the cords, increasing the size of the glottic opening. 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 most 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 intubated because the vocal cords cannot function properly. If you ever see a TV soap opera or movie where someone is 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**, can be placed in the anterior portion of the neck.

PATHOLOGY CONNECTION

THE UPPER AIRWAY

The major pathologies of the upper airway are infections or allergies of the sinuses, nose, or throat. The **common cold** is familiar to everyone and is caused by over 200 different strains of viruses. A cold is a contagious disease with an acute inflammation of the mucous membranes of the upper airway, which causes swelling and congestion. You may become more susceptible to the cold virus if your immune system has been weakened by lack of sleep, poor nutrition, stress, or fatigue. Exposure to cigarette smoke can also make you more susceptible. There is no cure for the common cold, but the symptoms can be treated. The best way to prevent the spread of a cold is to wash your hands and cover your mouth when you sneeze or cough. Often colds, allergies, and the flu are confused and can lead to misdiagnosis and therefore mistreatment. See **TABLE 13–2** ■, which compares and contrasts the differences.

Sinusitis is an infection of the sinus cavities by viruses or bacteria with subsequent inflammation of the mucous membrane linings. Allergies can also affect the sinuses and cause inflammation. This inflammation causes pressure, pain, and often a headache. The tonsils, pharynx, and larynx can also be infected with viruses and bacteria and even other microorganisms such as yeast. Again, the resulting inflammation can lead to swelling, redness, and pain. **Tonsillitis** causes the tonsils to swell and become painful, especially when swallowing. If severe, a tonsillectomy may be needed. **Pharyngitis** (sore throat) can cause discomfort, especially when swallowing. **Strep throat** is caused by the *Streptococcus* bacteria and causes a red, purulent (forming pus), and painful throat. **Laryngitis**, or an inflamed voice box, is characterized by hoarseness and loss of speech. Laryngitis can also be caused by excessive use of the voice such as in prolonged singing. Please see **FIGURE 13–8** ■ for examples of locations of these infections. If bacteria are known to be the cause of any of these infections, an antibiotic can be used. However, if no bacterial infection is involved, the symptoms should be treated until the infection or allergy symptoms run their course.

Acute epiglottitis is a potential airway emergency in which the bacteria *Haemophilus influenzae type B* (often abbreviated *H. influenzae type B* or *Hib*) causes acute swelling of the epiglottis, which, if it swells large enough, can totally block the airway leading to the lungs. Its onset is rapid, with fever and sore throat usually the first symptoms. Acute epiglottitis is most prevalent in children ages 2–6 and requires rapid recognition and treatment. Since the introduction of the universal Hib vaccine, the incidences have been decreasing. Airway maintenance is the mainstay of treatment, with antibiotic therapy selective against *H. influenzae type B*, although other pathogens can still cause the disease.

LEARNING HINT

EPIGLOTTITIS

Respiratory distress, drooling, dysphagia, and dysphonia are the four Ds that are signs of epiglottitis.

(continued)

PATHOLOGY CONNECTION *(continued)*

Table 13–2 Comparison of Allergy, Cold, and Influenza

SYMPTOM/SIGN	ALLERGY	COLD	FLU
Onset	Response to allergen	Slow	Fast
Duration	> 1+ weeks	1 week	1–3 weeks
Season	Spring/Summer/Fall	Fall/Winter	Fall/Winter
Fever	None	Rare, < 100	102–104; lasts 3–4 days
Fatigue, weakness	Mild; varies	Quite mild	May last 2–3 weeks
Extreme exhaustion	Rare	Never	Early and prominent
General aches, pains	Varies	Slight	Usual; often severe
Headache	Usual	Rare	Prominent
Sneezing	Usual	Usual	Sometimes
Sore throat	Sometimes	Common	Sometimes
Stuffy nose	Common	Common	Sometimes
Nasal discharge	Clear	Yellow/greenish	Varies
Chest discomfort	Sometimes	Mild to moderate	Common; can be severe
Cough	None; dry	Yes	Yes; dry hacking
Vomit and/or diarrhea	Rare; varies	Rare	Common

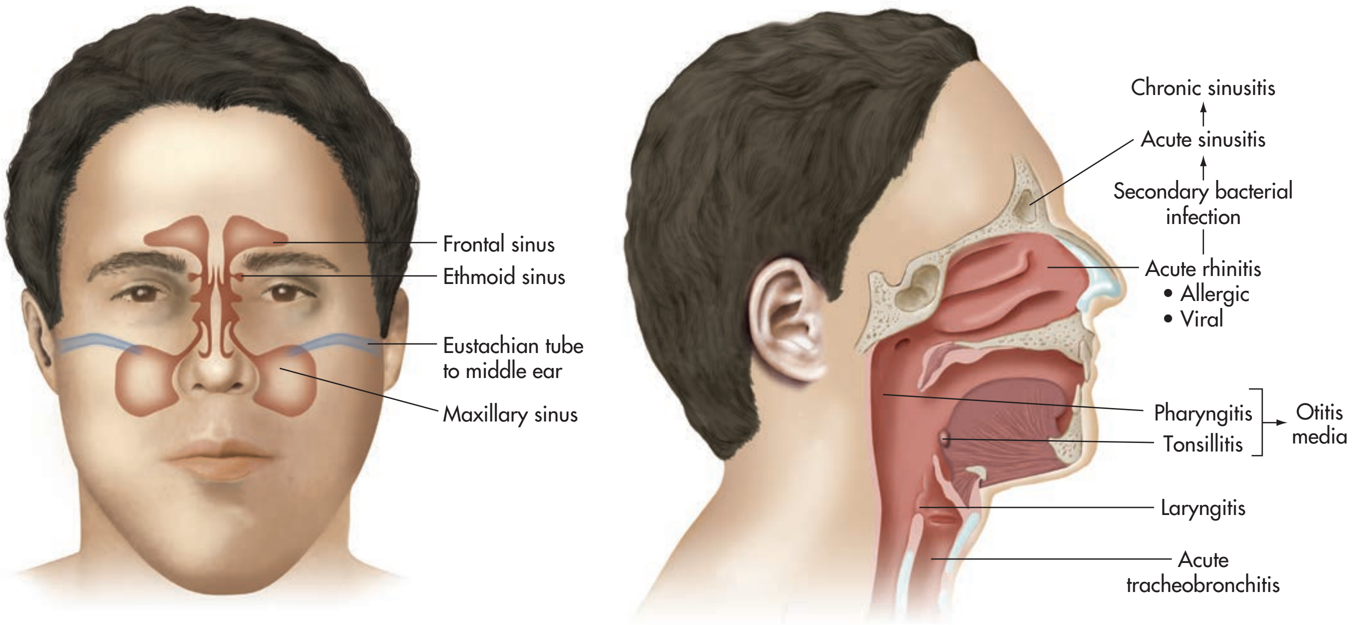


FIGURE 13–8
The upper airway and related infections.

Laryngotracheobronchitis (LTB) is different from epiglottitis but also results from an infection of the laryngeal area. It too can cause airway obstruction and is characterized by noisy breathing, especially on inspiration. LTB can be viral or bacterial, and the clinical presentation is that of a barking cough and inspiratory stridor (a harsh, high-pitched sound often heard without a stethoscope).

Croup was the former confusing term used for both LTB and acute epiglottitis, but it is clinically important to differentiate the two because of the life-threatening nature of acute epiglottitis.

Sleep apnea is a condition in which breathing stops during sleep. Sleep apnea is most commonly caused by soft tissue at the back of the throat relaxing and blocking the airway. This condition is called *obstructive* sleep apnea. A rarer form of sleep apnea is caused by failure of the brain to communicate with muscles involved in breathing so there is no attempt to breathe. This form is known as *central* sleep apnea. When a sleeping person stops breathing, the brain briefly wakes him or her up to trigger restored breathing. A person with sleep apnea may awaken briefly many times during the night but not remember waking up. This interrupted sleep can cause fatigue during the day. Long-term, undiagnosed sleep apnea can cause other health problems, such as high blood pressure, weight gain, and headaches. Sleep apnea can be diagnosed during a sleep study, where the patient is monitored while sleeping. Mild obstructive sleep apnea may be treated with special pillows and positioning the patient to help keep the airway open. Weight loss may reduce the severity of sleep apnea. More severe obstructive sleep apnea may be treated with oral appliances, breathing devices, or surgery. Central sleep apnea often requires pharmacologic treatment.

TEST YOUR KNOWLEDGE 13–2

Choose the best answer.

1. The hairlike structures that propel mucus in the airways are:
   a. the sol layer.
   b. the 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. nasal cavity.
   b. nasopharynx.
   c. pharynx.
   d. larynx.

5. When a patient is intubated, how far does the artificial tube sit above the carina?
   a. 3.5 cm
   b. 2.5 cm
   c. 1.5 cm
   d. 5.3 cm

Match the disease to its meaning.

1. _____ Common cold	a. sore throat will cause discomfort especially when swallowing
2. _____ Sinusitis	b. characterized by hoarseness and loss of speech
3. _____ Pharyngitis	c. caused by over 200 different strains of viruses
4. _____ Laryngitis	d. airway emergency distress, drooling, dysphagia, and dysphonia
5. _____ Acute epiglottitis	e. infection causing pressure, pain, and often a headache
6. _____ LTB	f. noisy breathing, barking cough, and inspiratory stridor

THE LOWER RESPIRATORY TRACT

The airway 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 13–9** ■.

Trachea and Bronchi

On leaving the vocal cords in the larynx, the inspired air enters the **trachea**, also known as the windpipe, a 4½-inch-long tube lined with ciliated mucous membrane. Any dust or mucus that also enters the trachea can be removed by expectoration. During expectoration, deep breaths followed by forceful air expulsion (coughing) moves substances out of the lower respiratory tract and into the mouth, where they can be spit out or swallowed. The trachea extends from the cricoid cartilage of the larynx to the sixth thoracic vertebrae (approximately to the midpoint of the chest). The cartilage found in the trachea is in the form of C-shaped structures in the anterior portion of the trachea to provide rigidity and protection for the exposed airway in the neck. 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 there is room for the esophagus to expand when you swallow larger chunks of food.

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, it begins its first branching, or bifurcation, into two bronchi (*bronchus* is the singular form), the **right mainstem** and the **left mainstem**. The site of bifurcation is called the **carina** (again, see Figure 13–9). 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** that correspond to 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 bronchi are all the same, only smaller, as they branch downward. The first layer is the epithelial layer, which contains the mucociliary escalator—or pseudostratified ciliated columnar cells—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 13–10** ■).

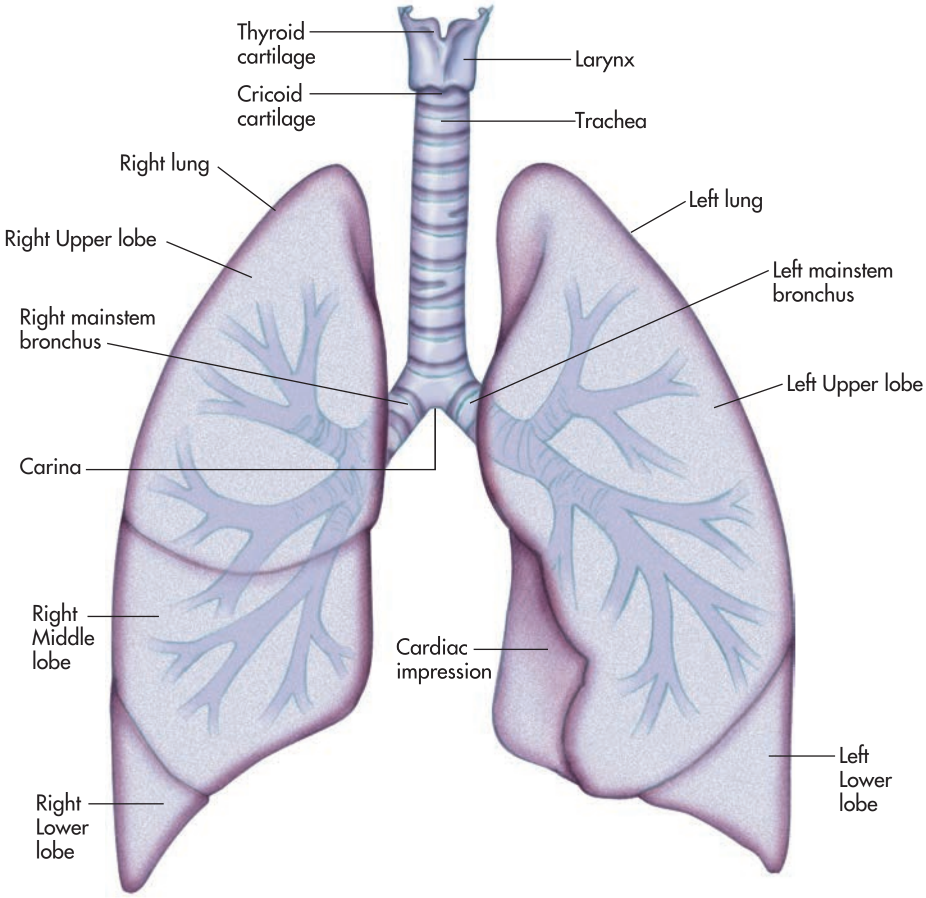


FIGURE 13–9 ■

The tracheobronchial tree.

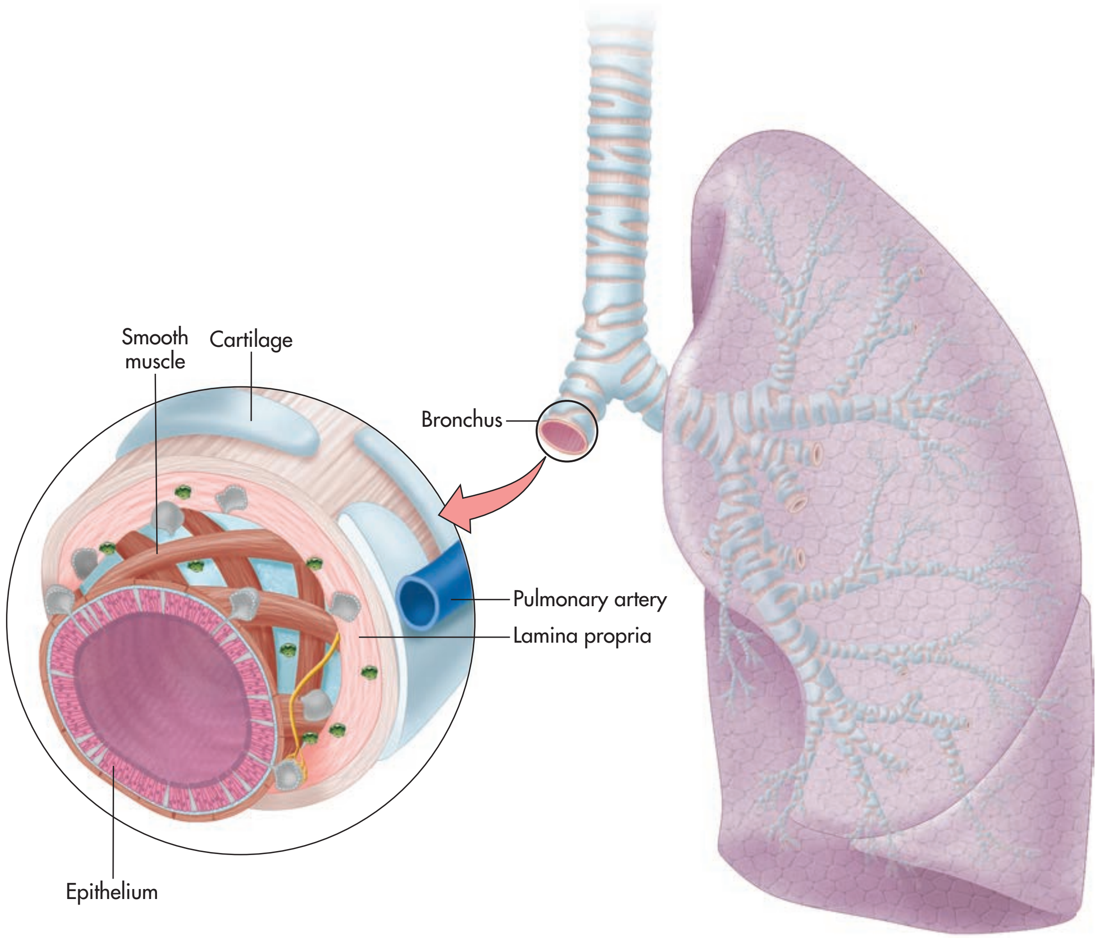


FIGURE 13–10
Tissue layers in the bronchi.

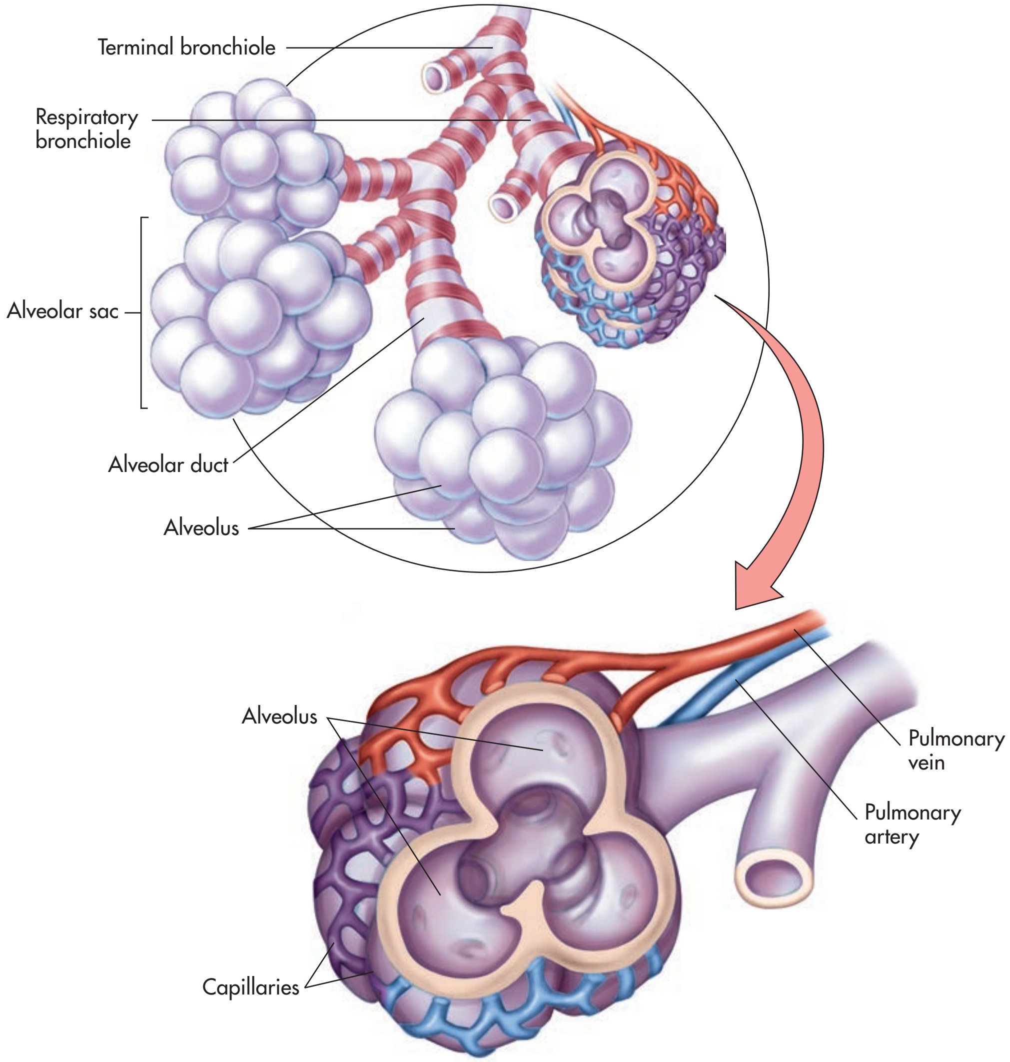
CLINICAL APPLICATION

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 nice 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 anatomic structure increases the probability that the object has lodged there. In addition, an *endotracheal tube* (breathing tube) may be placed too far into the lung, and instead of sitting above the carina so both lungs are ventilated, the tube will most likely 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** that branch 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. Next are the very tiny airways called **bronchioles**, which average only 1 millimeter in diameter. They have no cartilage layer, and the epithelial lining becomes ciliated cuboidal cells (short square cells as opposed to large columns). The cilia, goblet cells, and submucosal gland are almost all gone by this point. There is no gas exchange yet, just simple conduction of the gas mixture containing the oxygen molecules down the tree. The **terminal bronchioles**, which have an average diameter of 0.5 millimeters, no goblet cells, no cartilage, no cilia, and no submucosal glands, mark the end of the conducting areas. Finally, we 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 consists of simple cuboidal cells interspersed with actual alveoli-type cells, which are flat, pancakelike cells called **simple squamous 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 bunch–like structures of several connected alveoli, better known as the **alveolar sacs**. See **FIGURE 13–11**.



STRUCTURES OF THE LUNGS

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

FIGURE 13–11

Conduction and gas exchange structures and functions.

The Alveolar Capillary Membrane: Where the Action Is

The alveoli are the terminal air sacs that are surrounded by numerous pulmonary capillaries and together make up the functional 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 a total 80 square meters (m^2) surface area for the oxygen molecules to diffuse across (about the size of a tennis court!) into the surrounding pulmonary capillaries, which have about the same cross-sectional area (70 m^2). 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 capillaries 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 blood in the pulmonary capillaries 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.

AMAZING BODY FACTS

Exhaled CO_2 and Mosquitoes

Because mosquitoes are too small to carry flashlights, 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, they use their heat sensors to find an area of skin on which to begin their banquet!

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.

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

When the alveoli are small (during end-expiration), the surfactant layer lowers the surface tension, thereby preventing alveoli collapse. However, 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 the movement of air into and out of the lung and 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 to 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 simple squamous cells of two types. The main type (95%) comprising the alveolar surface is a flat, pancakelike cell called a **squamous pneumocyte** or Type I cell. This is where the gas molecules can easily pass through in the process of gas exchange. The alveoli also need to produce the valuable surfactant, and this is where the plump Type II, or **granular pneumocytes**, come in. These highly metabolic cells not only produce surfactant but also aid in cellular repair responsibilities.

In addition, 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 for gases and the macrophages to move from one alveolus to another.

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** (also known as the **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

THERAPEUTIC OXYGEN

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

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 millimeters 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 it 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 oxygen known as the PaO_2 goes down because less oxygen can get into the blood, and the $PaCO_2$ in the arterial blood goes up because less CO_2 crosses into the lungs to be exhaled.

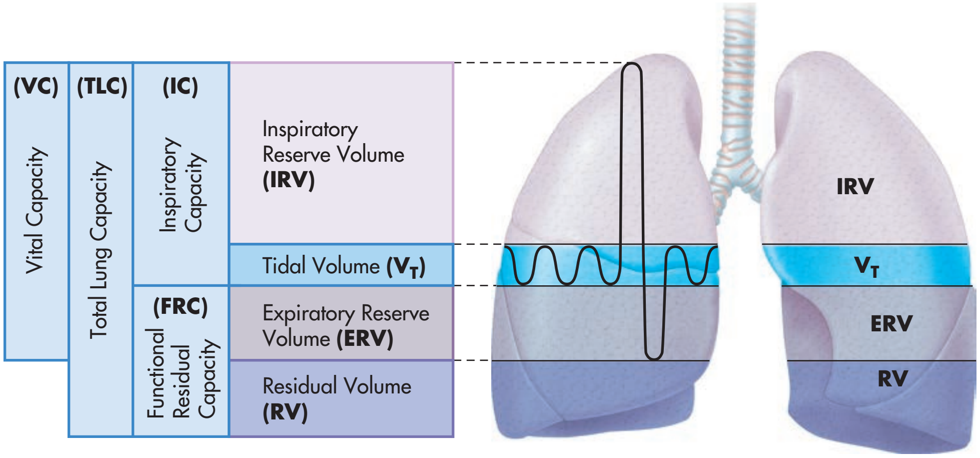
Changes in the bloodstream can also affect blood gases. Red blood cells, or **erythrocytes**, are responsible for the bulk of the transportation of oxygen and carbon dioxide in the blood via a protein- and iron-containing molecule called **hemoglobin**, which performs the actual transportation. It is estimated that there are about 280 million hemoglobin molecules found in *each* erythrocyte!

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 or may have a "bluish" tint. An obvious example of this can be seen when you look at the veins in your arm. 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) are important in oxygen delivery to your tissues.

Your body can attempt to respond to low hemoglobin levels by producing more red blood cells in a process called **erythropoiesis**. (*Poiesis* means "to make.") This process begins once 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. Once 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 onto 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.

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 is recorded as in **FIGURE 13–12** ■. 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 (IRV) is what you can breathe in beyond a normal inspiration. Likewise, your expiratory reserve volume (ERV) 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



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 13–12 Normal lung volumes and capacities.

these volumes to get various lung capacities, as shown in Figure 13–12 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)—sum of all 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 (FEV_1) and peak expiratory flow rate (PEFR). 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 to establish whether the airways have become "narrower" than normal (as would be seen in an asthma episode) is the 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. PEFR 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 monitor diseases such as asthma that affect these airways.

PATHOLOGY CONNECTION

THE LOWER AIRWAYS

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

Atelectasis and Pneumonia

Atelectasis, commonly found in the hospital setting, is a condition in which the air sacs of the lungs are either partially or totally collapsed. Atelectasis can occur in patients who cannot or will not take deep breaths to fully expand the lungs, stimulate surfactant production, and keep the air passageways open. Surgery, pain, 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 to 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 a virus, fungus, bacterium, aspiration, or chemical inhalation. Inflammation occurs in the infected areas, with an accumulation of cell debris and thick fluid in the alveoli. In certain pneumonias, lung tissue is destroyed. Pneumonias, if severe enough, can lead to death. It is interesting to note that secondary pneumonia is what often kills people following a flu illness and not the actual flu attack. Pneumonias can also be classified according to their location as illustrated in **FIGURE 13–13**.

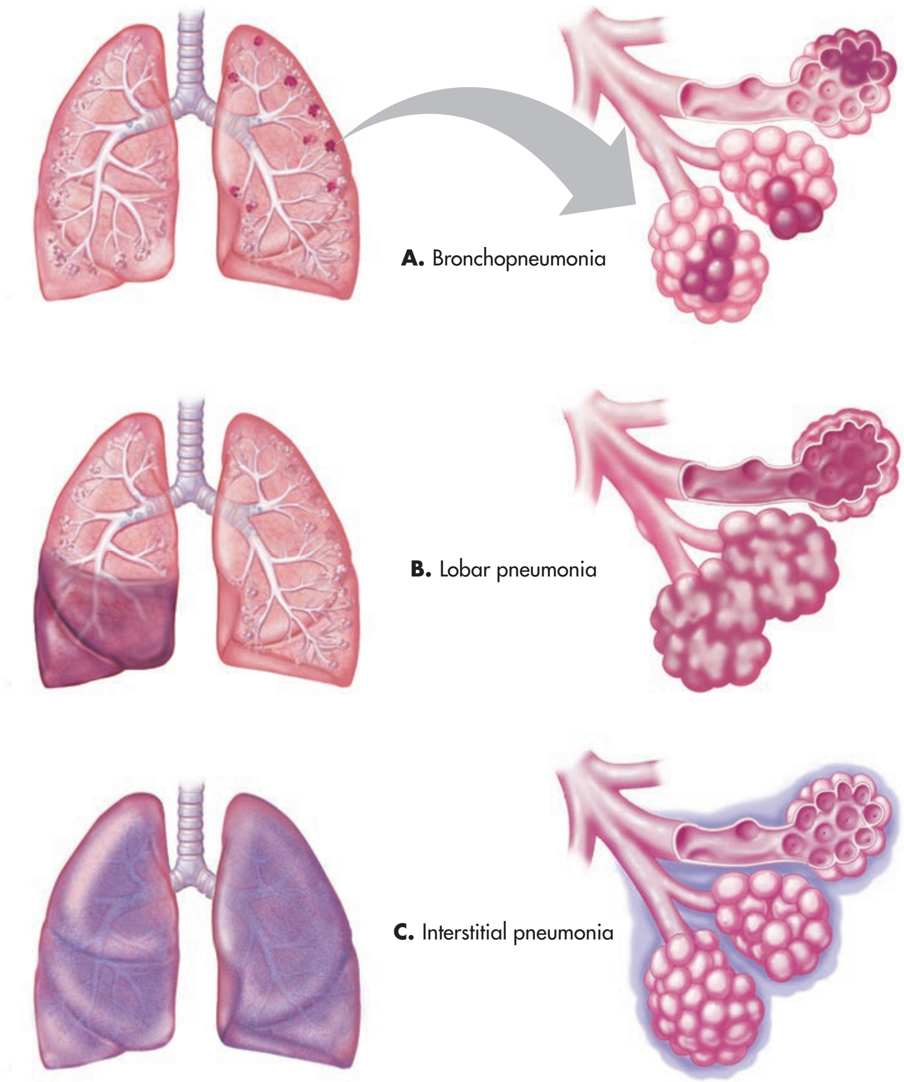


FIGURE 13–13 General locations for pneumonias.

Tuberculosis

Tuberculosis (TB) is a bacterial infection that has seen a recent rise in occurrence. Tuberculosis thrives in areas of the body that have high oxygen content such as in the lungs. A healthy immune system can destroy tuberculosis bacteria or encase the bacteria in lumplike structures called **tubercles**. Tubercles (lesions) form in the lungs. Within a tubercle, the bacteria remain inactive. Tuberculosis can lay dormant in the body for years. However, if the immune system weakens, tubercles can burst, and the bacteria can multiply. If the bacteria's spread is unchecked, vast lung damage can occur. There has been recent concern about a form of tuberculosis that is very resistant to the drugs normally used to treat TB and has a high mortality rate. Someone with tuberculosis may have a cough, low-grade fever in the afternoon, weight loss, and night sweats.

Chronic Obstructive Pulmonary Disease

Obstructive pulmonary disease is a general term used to describe abnormal pulmonary conditions associated with cough, sputum production, dyspnea, airflow obstruction, and impaired gas exchange. It is the fourth leading cause of death in the United States. **Chronic obstructive pulmonary disease (COPD)** is a group of diseases in which patients have difficulty getting all the air out of their lungs and often have large amounts of secretions and lung damage. COPD refers to one or a combination of emphysema and chronic bronchitis. Asthma used to be included in the COPD category but has become separate because it is distinguished by having reversible airway narrowing and airway hyperreactivity; it is most commonly characterized as an inflammatory process. **Emphysema** is characterized anatomically as the permanent, abnormal enlargement of distal airway spaces and destruction of the alveolar walls. **Chronic bronchitis** is associated with a productive cough, enlargement of mucous glands, and hypertrophy of the airway smooth muscle. Acute bronchitis is a temporary and very common lung condition that can affect people of any age. It differs from chronic bronchitis in that it is reversible and there are no permanent structural changes. All these illnesses share features of airway obstruction and therefore share some similar treatments. However, asthma is typically treated as a separate disease from COPD because of its reversibility. **TABLE 13–3** ■ summarizes each of the COPD-associated diseases, each of which is discussed in greater detail later in this chapter.

Asthma

Asthma is a chronic inflammatory illness of the airways affecting nearly 25 million people in the United States, including 6.2 million children. Asthma is the most common chronic disease of childhood and younger adults, with about 80% of cases developing before the age of 45. It is a potentially life-threatening lung condition in which the airways of the lungs constrict (**bronchospasm**), often in reaction to an allergy. See **FIGURE 13–14** ■. 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 person breathes the same air over and over. This lowers the amount of oxygen in the blood and increases the blood levels of carbon dioxide. Asthma can be controlled with the use of medication.

Table 13–3 Asthma and COPD Diseases

DISEASE	DESCRIPTION
Asthma	A chronic inflammatory disorder of the airways in which many cells and cellular elements play a role. In susceptible individuals, this inflammation causes recurrent episodes of wheezing, breathlessness, chest tightness, and cough, particularly at night and in the early morning. These episodes are usually associated with widespread but variable airflow obstruction that is often reversible either spontaneously or with treatment.
Chronic bronchitis	Usually defined in clinical terms as the presence of productive cough during 3 months of the year for 2 consecutive years, provided that other causes of chronic sputum production, such as tuberculosis, are excluded. Airway hyperreactivity may be present, but airflow limitation is not fully reversible.
Emphysema	A pathologic diagnosis marked by destruction of alveolar walls, with resultant loss of elastic recoil in the lung. Dyspnea on exertion is the predominant clinical feature, and airway hyperreactivity may also be present.

(continued)

PATHOLOGY CONNECTION *(continued)*

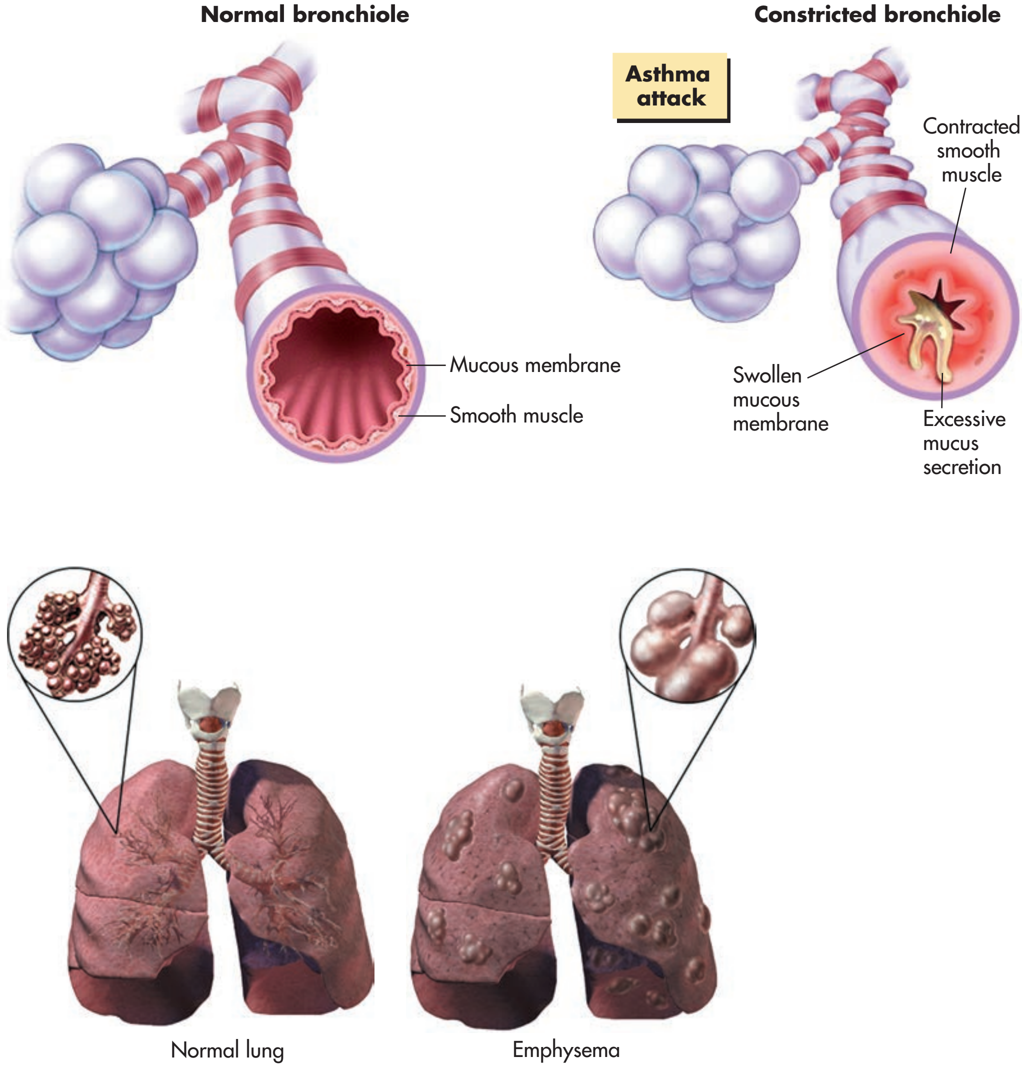


FIGURE 13–14
Asthma and emphysema.

The most common symptoms of asthma include episodic wheezing, shortness of breath, cough, and chest tightness. These symptoms are often worse at nighttime or in the early morning due to diurnal variations in muscle tone of the airways. (For more information about the relationship between asthma and allergies, see Chapter 14, "The Lymphatic and Immune Systems.")

Persons with asthma develop bronchospasm on exposure to specific sensitizing substances usually described as "triggers." Common triggers include allergens, inhalants, viruses, cold air, and exercise. **TABLE 13–4** provides a more complete list of asthma triggers. Asthma is a chronic disease, even though certain disease triggers may wax and wane, leading to episodic attacks. Therefore, patients and their caregivers need to understand the chronic nature of asthma and the underlying inflammatory process. It is important that patients be able to identify and control their exposure to environmental allergens or other types of triggers.

Table 13–4 Triggers for Asthmatic Attacks

Allergens	
Animal dander (pets with fur or feathers)	House dust mites (in mattresses, pillows, upholstered furniture, carpets)
Pollen (grass, trees, weeds)	Mold
Cockroaches	
Inhaled Irritants	
Tobacco smoke	Strong odors or sprays (perfumes, paint fumes, pesticides, hair sprays, cleaning agents)
Wood smoke	Occupational inhalants
Sulfur dioxide	
Air pollution	
Drugs	
Aspirin	Methacholine (used to provoke bronchoconstriction during diagnostic testing)
NSAIDs	Histamine (alternative agent to provoke bronchoconstriction during testing)
Beta-adrenergic blockers (oral or ophthalmic)	
Preservatives (sulfites and benzalkonium chloride)	
Other Factors	
Allergic rhinitis	Gastroesophageal reflux disease (GERD)
Cold air	Strong emotions
Exercise	Menses
Viral respiratory infections (rhinovirus, influenza, parainfluenza, *Corona* virus, RSV)	

CLINICAL APPLICATION

FAMILY HISTORY AND ASTHMA

The patient's history can be very helpful, as many asthmatic patients will have a family history of allergies such as asthma, eczema, or hay fever. Usually, the patient or his or her parents will be able to identify exposures or circumstances that trigger the patient's symptoms. According to a 2015 Centers for Disease Control and Prevention (CDC) survey, over 18 million people over age 18 suffer with asthma, which is approximately 7.6% of the U.S. population.

(continued)

PATHOLOGY CONNECTION *(continued)*

Emphysema

Emphysema is a nonreversible lung condition in which the alveolar air sacs are destroyed and the lung itself becomes "floppy" (again see Figure 13–14), much like a balloon that has been inflated and deflated many times. As the alveoli are destroyed, it becomes more difficult for gases to diffuse between the lungs and the blood. The lung tissue becomes fragile and can easily rupture (again, much like a worn tire), causing air to escape into the thoracic cavity and further inhibit gas exchange.

The work of breathing for the severely emphysemic patient expends energy similar to the energy spent jogging. They must continually work to maintain airway pressure in their abnormally large airspaces and must maintain a rapid respiratory rate. Weight loss is typical with severe emphysema. Think how much weight you'd lose if you ran a marathon each day!

About 2 million persons in the United States are estimated to have emphysema. The majority of cases were caused by smoking. However, 60,000–100,000 have a genetic deficiency of alpha$_1$-antitrypsin (α_1-AT) as their underlying etiology. α_1-AT is a glycoprotein that is essential in protecting the lungs against naturally occurring proteases that have the ability to destroy lung tissue. Patients with this deficiency tend to develop emphysema at a younger age (in their 40s or 50s) than do patients with emphysema from other causes. Most persons with α_1-AT deficiency are Caucasians of northern European descent.

Smoking further accelerates the process. Manifestations of severe α_1-AT deficiency involve the lungs, liver, and skin, and the major clinical feature is emphysema. The disorder is detected by a decreased level of α_1-AT to below a so-called protective value of 80 mg/dL. This is in comparison to normal serum levels of 150–350 mg/dL.

Chronic Bronchitis

Chronic bronchitis is a lung disease in which there are inflamed airways and large amounts of sputum produced. As inflammation occurs, the airways swell and the inner diameter of the airways get 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.

Chronic bronchitis is more common than emphysema, with a prevalence of over 9 million persons in the United States. Cigarette smoking is the major causative factor in up to 90% of cases. Patients with chronic bronchitis have an increase in size and number of the mucus-secreting glands, narrowing and inflammation of the small airways, obstruction of airways caused by narrowing and mucus hypersecretion, and bacterial colonization of the airways. Acute episodes are usually brought on by a respiratory tract infection. The usual clinical presentation of chronic bronchitis begins with morning cough productive of sputum. The patient may report a decline in exercise tolerance, although he or she may not have appreciated this decline until questioned. Wheezing may occur, and an increase in the anterior-posterior diameter of the chest (the classic "barrel chest") may be present in both emphysema and chronic bronchitis as a result of excessive accessory muscle use and gas trapping. The patient who has predominantly chronic bronchitis symptoms may undergo repeated episodes of respiratory failure and frequently develop right-sided heart failure.

CLINICAL APPLICATION

COPD DEMOGRAPHICS

Men have a higher incidence of COPD than women; however, women are catching up because more women are smoking in recent years.

AMAZING BODY FACTS

Smoking Kills

The major preventable cause of many of the respiratory diseases is smoking. It has been estimated that smoking kills more people than road accidents, suicides, and AIDS combined. This is the equivalent of one person dying every 15 minutes from a smoking-related illness.

The primary etiology for COPD is exposure to tobacco smoke. Smokers have higher death rates from both chronic bronchitis and emphysema. Smokers also have more lung-function abnormalities, show more respiratory symptoms, and experience all forms of COPD at a much higher rate than nonsmokers. Age of starting, total pack-years, puff volume, and current smoking status are predictive of COPD mortality.

Passive smoking (the exposure of nonsmokers to cigarette smoke) also seems to increase the risk of COPD-related disease. Children of parents who smoke have a higher prevalence of respiratory symptoms and ear infections than children of nonsmokers. Exposure to smoke at an early age may impair lung maturation and the attainment of maximal lung function in adult life. Air pollution, occupational exposure, asthma, and nonspecific airway hyperresponsiveness may all play a role in the development of COPD.

TABLE 13–5 ■ lists the differential diagnostic markers for COPD and asthma. No one marker is conclusive, so the entire clinical picture must be assessed for correct diagnosis and treatment.

Table 13–5 Diagnostic Markers to Differentiate COPD and Asthma

DIAGNOSTIC MARKERS	COPD	ASTHMA
Age of patient when diagnosed	Typically over 40	Often child or young adult
Smoking history	Smokers and ex-smokers	No direct correlation between smoking and asthma, although smoke will trigger attack
Dyspnea	Shortness of breath, especially on exertion	Episodic attacks, especially on exposure to allergen/irritant/exercise
Cough	Productive cough, typically in the morning	Cough typically precedes an episode
Triggers (allergens, exercise)	None usually identified for attacks	Exposure to temperature, humidity, etc., leads to attacks
Spirometry	FEV_1/FVC ratio < 70%	FEV_1/FVC ratio low during attacks only
Daily variation in peak expiratory	Little	Morning dip and day-to-day variability flow rate (PEFR)
Effect of corticosteroid trial	Inconclusive (< 20 % of patients are successful)	Improvement
Eosinophilia (increased number of eosinophils)	No	In allergic reaction forms of asthma
Chest x-ray	Overinflation	Overinflation during attacks

CLINICAL APPLICATION

SMOKING HISTORY

Smoking history is a very important initial screening procedure the clinician can perform, as it can help to clinically determine how much a person has actually smoked in his or her lifetime as well as estimate how much damage smoking has caused. A 10- to 20-pack-year history will cause changes in PFT findings. A 70-pack-year history of smoking or greater has been described as a specific finding suggestive of COPD. Pack-year history is calculated by multiplying the number of packs smoked per day by the number of years smoked.

TEST YOUR KNOWLEDGE 13–3

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.

Match the following.

1. _____ Function residual capacity (FRC)	a. the maximum amount of air that can be moved into and out of the respiratory system in a single respiratory cycle
2. _____ Inspiratory reserve volume (IRV)	b. the volume of air remaining in the lungs at the end of a normal expiration
3. _____ Expiratory reserve volume (ERV)	c. the amount of air that can be forcefully inhaled after a normal inspiration
4. _____ Residual volume (RV)	d. the amount of air that can be forcefully exhaled after a normal expiration
5. _____ Vital capacity (VC)	e. the volume of air remaining in the lungs after a maximum expiration

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, pulmonary vein, pulmonary artery, and aorta), and trachea (see FIGURE 13–15 ■).

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 sac, or serous membrane (see Chapter 4), called the **visceral pleura**. The thoracic cavity and the upper side of the diaphragm are lined with a continuation of this membrane called the **parietal pleura**. Between these two pleural layers is an intrapleural space (pleural cavity) that contains a slippery liquid called **pleural fluid**. This fluid greatly reduces the friction as an individual breathes.

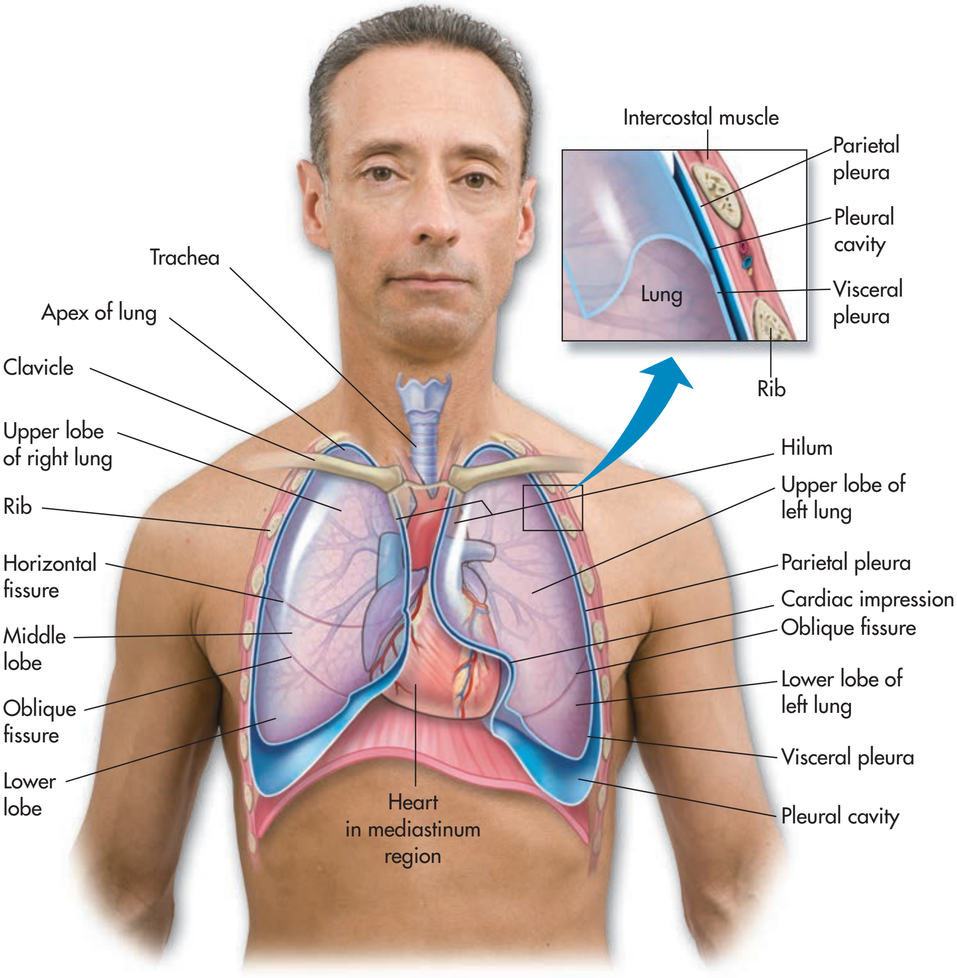


FIGURE 13–15 ■
Structures of the thoracic cavity.

PATHOLOGY CONNECTION

PLEURAL SPACE PROBLEMS

Trauma or certain disease states can interfere with the structure and therefore the function of the thoracic cavity. A **pneumothorax** is a condition in which there is air inside the thoracic cavity and outside the lungs. 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. Alternately, 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

(continued)

PATHOLOGY CONNECTION *(continued)*

the lung or lungs to expand when breathing. If the lungs are too greatly restricted to expand and begin to collapse, a life-threatening situation may occur.

A **pleural effusion** is a condition in which there is an excessive buildup of fluid in the pleural space between the parietal and the visceral pleura. This fluid may be pus (in which case it is known as **empyema**), 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 and lead to lung collapse. Because less air can flow in 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. This intervention often includes a chest tube inserted into the pleura space to allow drainage of fluid. This will allow for the lung to reexpand. See **FIGURE 13–16** for illustrations of a sucking chest wound and how to perform a thoracentesis to remove pleural fluid.

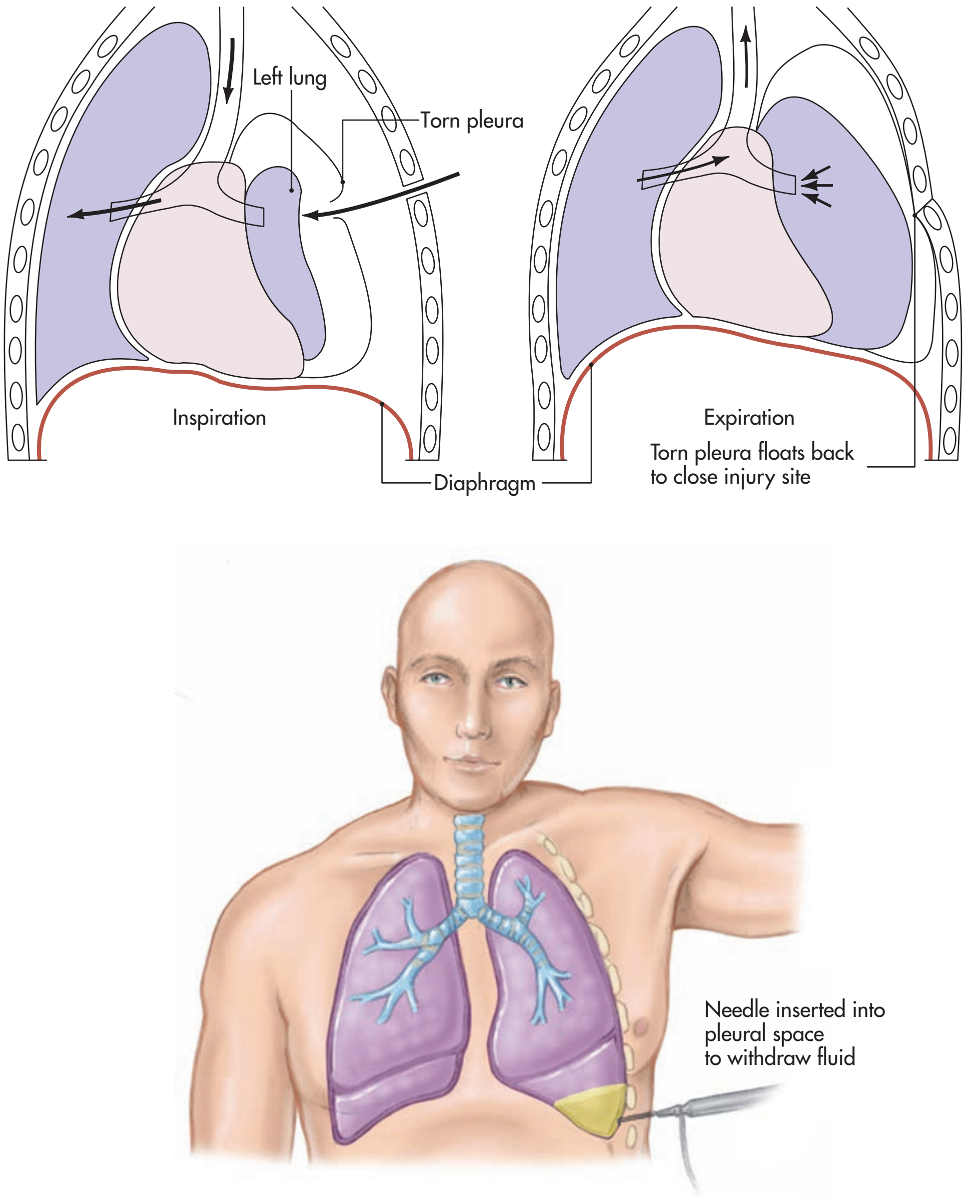


FIGURE 13–16
Pneumothorax (sucking chest wound) and technique for performing thoracentesis.

The Lungs

The right and left lungs are conical-shaped organs; the rounded peak is called the **apex** of the lung. The apices of the lung 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 a deep, concave cavity that contains the heart and therefore is called the **cardiac impression**; it is deeper on the left side. The **hilum** is the area where the root of each lung is attached. 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 left upper and left lower lobes. Why only two lobes in the left, you may ask? Remember that the heart is located in the left anterior area of the chest and therefore takes up some space of the left lung. The right lung is larger, and about 60% of gas exchange occurs there. The term **lingula** refers to the area of the left lung that corresponds with the right middle lobe. 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.

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 13–17**).

The **sternum**, or breastbone, 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. The hand is placed over the body of the 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 and only attach to the vertebral column.

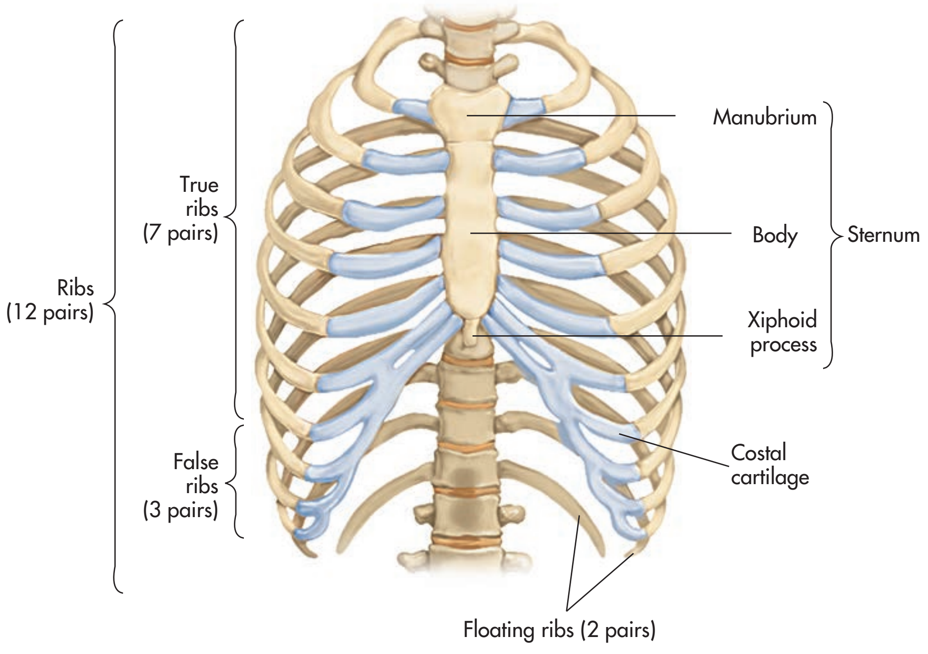


FIGURE 13–17
The thoracic cage.

HOW WE BREATHE

The control center that tells us to breathe is located in the brain in an area known as the **medulla oblongata**. 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** and contracts and flattens downward, thereby increasing the space in the thoracic cavity (see FIGURE 13–18 ■). The increase in volume in the thoracic cavity causes a decrease in pressure because volume and pressure are inversely related. This creates a lower than atmospheric pressure in the lungs, allowing air to rush into the lungs, down the pressure gradient (from high to low). The external intercostal muscles also assist by moving the sternum and ribs up and outward during inspiration to increase the total volume in the thoracic cavity. By the way, a hiccup happens when your diaphragm muscle has an involuntary spasm that causes the glottis to close suddenly. As you probably know, these spasms can last for awhile, and it might be hard to figure out how to stop them.

To achieve changes in volume and pressure, the diaphragm flattens and thereby increases the volume of the thoracic cavity. At the same time, the ribs move upward and outward via the external intercostal muscles, which also increases the thoracic volume. Because the lungs adhere to the pleural membranes, they are moved upward and outward. This increases the volume of the lungs and decreases their internal pressure. Air then flows from the relative high pressure of the atmosphere, down the trachea, and into the low pressure of the alveoli. Because air is a gas, it will fill all the available alveoli and therefore facilitate gas exchange.

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. This becomes clinically significant when assessing people who have asthma, emphysema, chronic bronchitis, or any other lung disease. In emphysema, the bronchioles become damaged and wider, allowing air into the lungs, increasing compliance but making it much more difficult to breathe out.

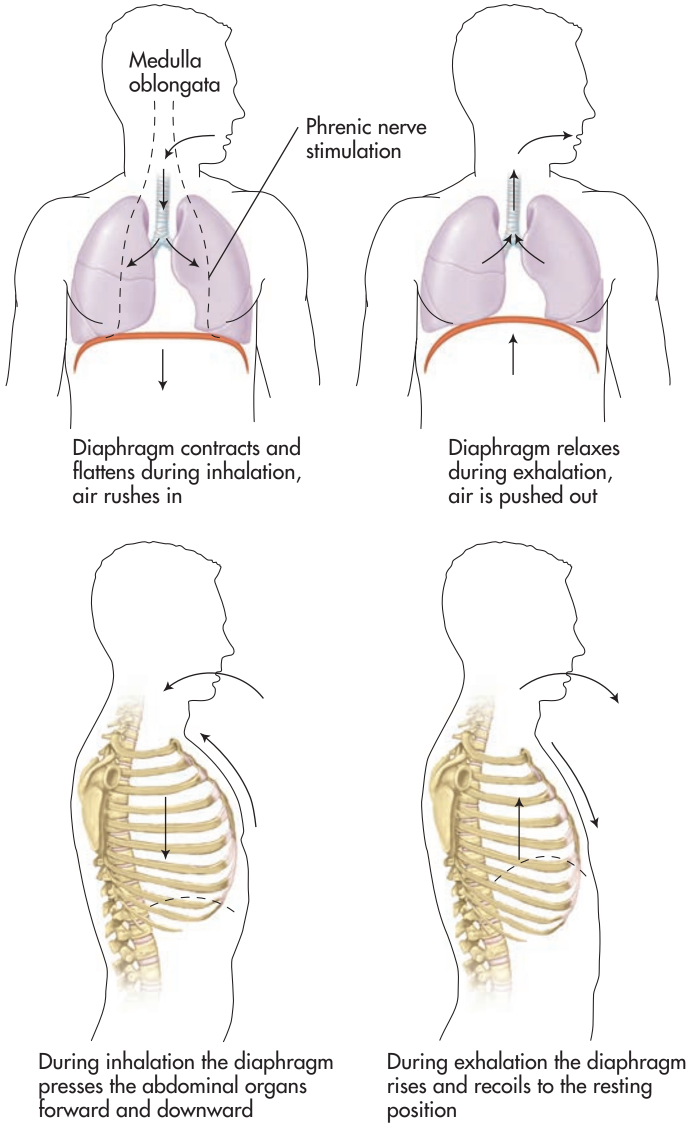


FIGURE 13–18 ■
How we breathe.

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 tissue that is stretched during inspiration also aids in expiration because this elastic tissue now wants to return to rest, much like a stretched rubber band that is released.

What makes the brain tell the lungs how quickly or 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 carbon dioxide levels rise, it means that not enough CO_2 is being ventilated. When this occurs, chemoreceptors in the

APPLIED SCIENCE

BOYLE'S LAW

The process of ventilation takes place because there is an inverse relationship between pressure and volume, which means that if there is a decrease in the volume of a gas, the pressure will rise; if you increase the volume of a gas, its pressure will fall. This was first recognized by Robert Boyle in the 1600s and is now called Boyle's law.

medulla oblongata send signals to the respiratory muscles to increase the rate and depth of breathing. Chemoreceptors in the carotid arteries and aortic arch are also sensitive to high CO_2 levels and low blood pH and can trigger increased ventilation.

APPLIED SCIENCE

PH AND VENTILATION

CO_2 levels are directly related to hydrogen ion concentration. When CO_2 levels rise, so does hydrogen ion concentration. Consequently, pH falls; that is, blood becomes more acidic. Because of this relationship, your body interprets any decrease in blood pH, no matter the cause, as if it were due to increased CO_2, and ventilation increases. For example, when Maria's diabetes is poorly controlled, she might have lower blood pH (increased hydrogen ion concentration) due to metabolic acidosis. In an attempt to bring her blood pH back to normal, her ventilation rate would increase.

Other factors can change breathing rate as well. Our breathing rate changes as we grow and mature into adults. A developing newborn has a breathing rate of 40–60 breaths/minute. This slows to 14–20 breaths/minute in adulthood. When we sleep, our breathing rate slows down because body cells are using less oxygen and producing less carbon dioxide. Breath rate increases with exercise, when body cells are rapidly producing carbon dioxide. It can also increase when we feel strong emotions. We may yawn when we are tired and need more oxygen. Yawning is a deep breath that fills the lungs and brings oxygen to the blood.

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 muscles in the neck, the sternocleidomastoid, and 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. See FIGURE 13–19 for the specific accessory muscles of exhalation.

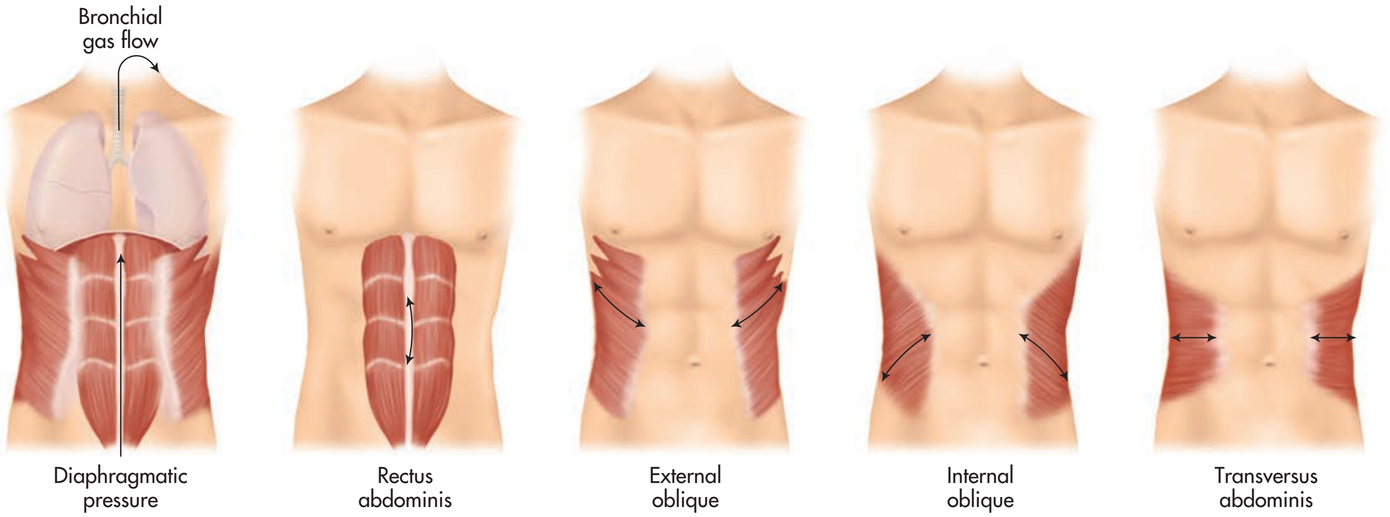


FIGURE 13–19
The accessory muscles of exhalation.

A QUICK TRIP THROUGH THE DISEASES OF THE RESPIRATORY SYSTEM

DISEASE	ETIOLOGY	SIGNS AND SYMPTOMS	DIAGNOSTIC TEST(S)	TREATMENTS
Lung cancer	Cause not known but linked to smoking and inhalation of carcinogens; metastasis	Obstruction of airways interfering with ventilation, weight loss, weakness, cough, or change in cough	Bronchoscopy, imaging studies, biopsy, sputum exam, patient exam, and history	Radiation, chemotherapy, surgery immunotherapy and oxygen therapy
Asbestosis	Prolonged exposure to airborne asbestos particles	Dyspnea, chest pain, productive cough in smokers, decreased lung inflation	Chest x-rays find irregular linear infiltrates; may have a honeycomb appearance on x-ray; decreased pulmonary function tests and hypoxemia	No cure, and the goal is to relieve symptoms and treat any complications such as infections
Infections				
Acute bronchitis	Viral or bacterial	Inflamed mucous membranes of trachea and bronchi; expectorating or dry cough, shortness of breath, fever, *rales* (raspy sound)	Physical exam	Antibiotics if bacterial
Common cold	Viral	Upper airway congestion, cough, sore throat	History and physical exam	Treat symptoms; pain medication, bedrest, drink fluids, proper nutrition
Pharyngitis	Viral or bacterial	Red, sore swollen throat, pus	History and physical exam, throat culture	If bacterial use antibiotics, antiseptic gargle
Laryngitis	Viral or bacterial, allergies, overuse of voice	Dysphonia, sore throat, trouble swallowing	History and physical exam	Rest voice, drink fluids, keep throat moist; if bacterial use antibiotics
Tonsillitis	Viral or bacterial	Sore throat, swollen tonsils, and dysphagia	History and physical exam, culture	Antibiotics for bacterial, surgery if needed
Influenza	Viral	Fever, cough, body aches, and headaches	History and physical exam	Rest, fluids, pain medication; treat symptoms

DISEASE	ETIOLOGY	SIGNS AND SYMPTOMS	DIAGNOSTIC TEST(S)	TREATMENTS
Pneumonia	Viral, bacterial, or fungal chemical inhalation and aspiration.	Productive cough, chest pain, weakness, malaise, dyspnea	Imaging, bloodwork, sputum culture	Antibiotics if confirmed bacterial infection; antifungal drugs if confirmed fungal infection
Pulmonary tuberculosis	Bacterial	Primary, may be asymptomatic; secondary, cough (may be blood tinged), fever (night sweats), weight loss	Imaging, TB skin test, sputum test	Antibiotic agents and oxygen therapy
Inflammations and Allergies				
Seasonal allergic rhinitis (hay fever)	Allergic agents	Upper airway congestion, watery nose and eyes, sneezing	History and physical exam, allergy testing	Antihistamines, preventative allergy shots
Asthma	Many triggers such as allergens, food, exercise, cold air, inhaled irritants, smoking	Dyspnea, wheezing, productive cough, hypoxia	History and physical exam, lung function tests	Bronchodilators, steroids, and antiasthmatic agents; oxygen if needed
COPD				
Chronic bronchitis	Cigarette smoking and long-term exposure to air pollutants, middle or old age	Dyspnea, wheezing, productive cough, hypoxia	History and physical exam, lung function tests	Antibiotics if bacterial, bronchodilators; oxygen and mucolytics if needed
Emphysema	Cause not fully known but associated mostly with smoking and also associated with one genetic form from alpha 1–antitrypsin deficiency	Dyspnea, tachypnea, wheezing, productive cough, hypoxia	History and physical exam, lung function tests	Oxygen therapy, bronchodilators, alpha 1–antitrypsin replacement

(continued)

A QUICK TRIP *(continued)*

DISEASE	ETIOLOGY	SIGNS AND SYMPTOMS	DIAGNOSTIC TEST(S)	TREATMENTS
Other Respiratory Diseases				
Acute respiratory distress syndrome (ARDS)	Form of pulmonary edema that has a high mortality rate and very noncompliant (stiff) lungs; many causes but most often caused by shock, sepsis, and trauma	Rapid shallow breathing with dyspnea; hypoxemia and fluid accumulation in lungs with rhonchi and crackles	Arterial blood gases showing respiratory acidosis and severe hypoxemia, bilateral infiltrates on x-rays with white-outs in lung fields	Intubation and mechanical ventilation; sedatives and diuretics and in some cases high doses of corticosteroids
Cystic fibrosis	Hereditary disease transmitted via a recessive gene	Excessive thick mucus secretion, repeated infections, large salt losses, difficult digestion	Sweat test, genetic testing	Respiratory hygiene therapy, mucus thinning agents, antibiotics, pancreatic enzyme supplements

PHARMACOLOGY CORNER

Although oxygen is often not thought of as a drug, it is the major drug used in treating respiratory diseases as well as cardiac disease. The basic purpose is to reduce the work of breathing, increase the oxygen content of the blood, and reduce the work of the heart. Oxygen therapy comes in various forms of delivery such as nasal cannulas and oxygen masks.

Problems with the airway are usually due to inflammatory processes that narrow the airways, making it difficult to breathe. For rapid relief of an acute situation of airway narrowing, aerosolized bronchodilators can be given. For long-term treatment of chronic airway inflammation, inhaled steroids have been used because they have less systemic effects than oral or injectable steroids.

The only method known to prevent or slow the progression of COPD is to stop smoking or eliminate the occupational source. All patients who smoke need to be regularly encouraged to stop. Cigarette smoking kills nearly 450,000 Americans each year and debilitates nearly one-half of all long-term smokers. Tobacco dependence is a powerful addiction and one that is extremely difficult to break, often requiring four to six attempts. Even after quitting, patients sometimes have a lifelong craving that does decrease with time. Some patients will be successful on their own, but most will require behavioral counseling and encouragement in addition to pharmacological therapy. This treatment usually consists of nicotine replacement therapy in the form of gum, skin patches, or inhaled forms. In addition, drugs can be given to decrease the desire such as Chantix or Wellbutrin.

In many cases premature infants have underdeveloped lungs that do not have adequate surfactant maturation to breathe on their own. Natural and synthetic surfactant forms have been developed that can be instilled into the lungs. This can buy time until the infant develops adequate amounts on his or her own.

Bacterial lung infections can be treated with systemic antibiotics. Although not related to lung disease, new research has allowed for the development of aerosolized insulin that can be inhaled for the treatment of diabetes. Many antiviral medications are available to reduce the length and severity of a viral infection such as the cold or flu. The possibility of developing the flu is greatly reduced through the use of annual flu vaccinations. See **FIGURE 13–20** for an illustration of drugs used to treat the respiratory system.

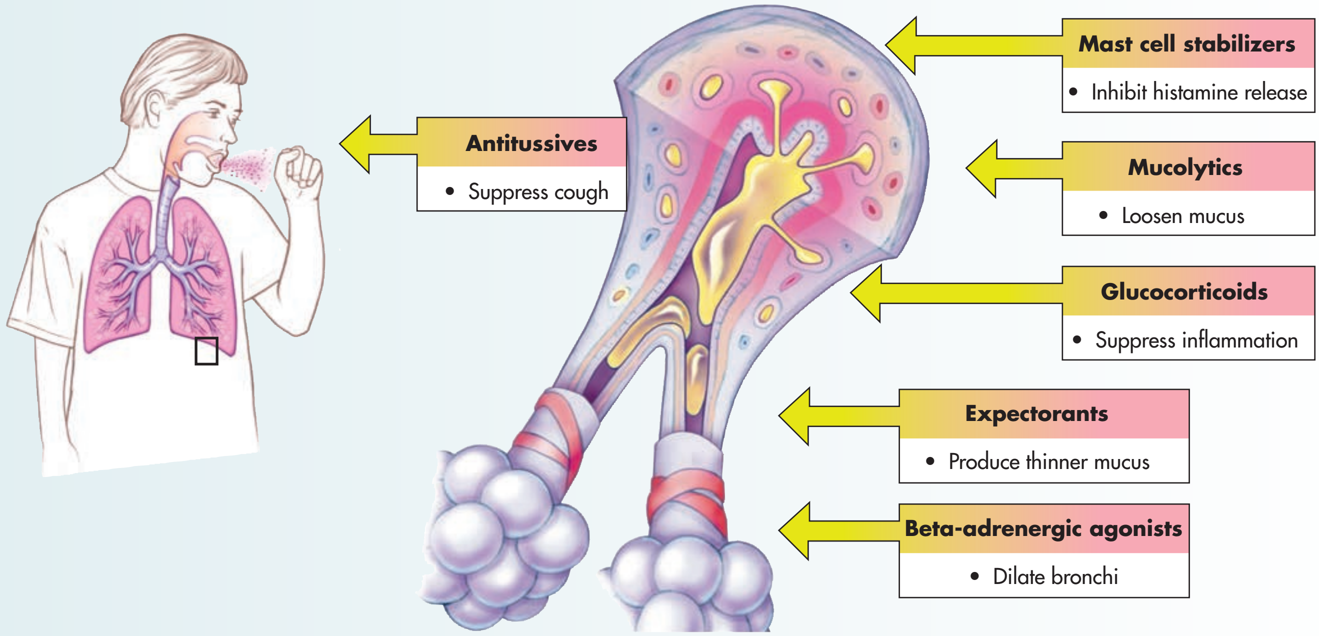


FIGURE 13–20
Classes of drugs used to treat respiratory disorders.

TEST YOUR KNOWLEDGE 13–4

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. Rib pairs 1–7 are attached to:
   a. the vertebral column only.
   b. the vertebral column and the sternum.
   c. the sternum only.
   d. are free floating.

Complete the following.

5. Ventilation takes place due to a(n) ___________ relationship between pressure and volume, which means that if there is a _____________ in the volume of a gas, the pressure will ______; if you ________ the volume of a gas, its pressure will fall.

6. ______________ is a condition in which air leaks out of the lung into the thoracic cavity.

7. ______________ is a disease in which there are excessive airway secretions, often as the result of smoking.

8. ______________ is a condition that leads to wheezing and shortness of breath, often allergy related.

SUMMARY

Snapshots from the Journey

- 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 in 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 ends 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 airways is to filter, warm, and moisten inhaled air for its journey to the lungs.
- In addition, the upper airways 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 airways 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.

RAY'S STORY

Ray, a quadriplegic, was brought into the emergency room with thick secretions and a fever. His heart rate and blood pressure are increased, and his lungs do not sound clear on examination. The carbon dioxide levels in his blood are greatly increased, and the oxygen levels are well below normal, even given his dependence on a ventilator.

a. What possible respiratory diseases or conditions could he have?

____

____

____

____

b. What are some recommended treatments for this patient?

____

____

____

____

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. Which of the following structures of the lungs is located in the respiratory zone?
   a. Bronchioles
   b. Terminal bronchioles
   c. Respiratory bronchioles
   d. Segmental bronchi

7. Which of the following structures is *not* found in the region where gas exchange takes place?
   a. Alveolar sacs
   b. Respiratory bronchioles
   c. Alveolar ducts
   d. Segmental bronchi

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. The _______________ and the _______________ are part of the immune system and are found in the nasopharynx and oropharynx.

6. The term _______________ is used to describe the vocal fold when it is open.

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. Caused by bacteria or viruses and will affect your voice
5. _______ Cystic fibrosis	e. Cigarette smoking causes large amounts of secretions and inflamed airways
6. _______ Tuberculosis	f. Occurs when air sacs in the lungs are either partially or totally collapsed
7. _______ Atelectasis	g. Caused by a bacterial infection that thrives in areas of the body that have high oxygen concentrations

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.

Suggested Activities

1. Research the effects of secondhand smoking and smokeless tobacco, and share results with the class or develop posters on these subjects.

2. Working as a group, research occupational causes of lung diseases and see how long a list you can develop.