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EQA

CHAPTER 8

Respiratory System

CHAPTER CONCEPTS

Just before winning a gold metal for the 400-m race at the 2004 Olympic games, Jeremy Wariner (*center*) of the United States warmed up by stretching, sprinting, and jogging. Onlookers may have thought he was trying to prevent an injury when he ran the race. Maybe, but this type of warmup can also help a runner win the race, primarily because it causes an increase in blood flow to the leg muscles. A good warmup can increase the number of open capillary beds in the region as much as 1,000%. More blood flow brings the fuel and oxygen a runner's working muscles will need, and it also removes the waste products they generate during the race. When muscles contract, lots of CO_2, H^+, and lactic acid enter the bloodstream, and so does heat.

Hemoglobin, the respiratory pigment that carries oxygen, is well adapted to these conditions. As acidity and temperature rise, hemoglobin tends to release more oxygen than otherwise. In distance runners, the body temperature can rise from 98.6°F to 102°F, and pH can be reduced from 7.4 to 6.9, greatly facilitating the release of extra O_2 (20% or more) into the runner's exercising leg muscles.

World-class athletes, such as Jeremy Wariner, need every advantage in order to win a race. Therefore, a prerace warmup is critical, so that the cardiovascular and respiratory systems are ready to perform, even from the moment the race begins. Only if these systems are ready can an athlete hope to win a gold medal at the Olympic games. Even though you may not be a world-class athlete, your cardiovascular and respiratory systems still need to perform optimally when you exercise. Therefore, a warmup is essential for you also, regardless of your chosen sport.

8.1 The Respiratory System

The organs of the respiratory system ensure that oxygen enters the body and carbon dioxide leaves the body. During **inspiration,** or inhalation (breathing in), and **expiration,** or exhalation (breathing out), air is conducted toward or away from the lungs by a series of cavities, tubes, and openings, illustrated in Figure 8.1. **Ventilation** is another term for breathing that encompasses both inspiration and expiration.

The respiratory system also works with the cardiovascular system to accomplish these events:

1. external respiration: exchange of gases (oxygen and carbon dioxide) between air and blood.
2. internal respiration: exchange of gases between blood and tissue fluid.
3. transport of gases to and from the lungs and the tissues.

Cellular respiration uses the oxygen and produces the carbon dioxide that makes gas exchange with the environment necessary. Ventilation and the three events listed here allow cellular respiration to continue.

The Respiratory Tract

Table 8.1 traces the path of air from the nose to the lungs. As air moves along the airways, it is cleansed, warmed, and moistened. Cleansing is accomplished by coarse hairs, cilia, and mucus in the region of the nostrils and by cilia and mucus in the rest of the nasal cavity and the other airways of the respiratory tract. In the nose, the hairs and the cilia act as a screening device. In the trachea and other airways, the cilia beat upward, carrying mucus, dust, and occasional bits of food that "went down the wrong way" into the pharynx, where the accumulation can be swallowed or expectorated. The air is warmed by heat given off by the blood vessels lying close to the lining of the airways, and it is moistened by the wet surface of these passages.

Conversely, as air moves out during expiration, it cools and loses its moisture. As the air cools, it deposits its moisture on the lining of the trachea and the nose, and the nose may even drip as a result of this condensation. The air still retains so much moisture, however, that upon expiration on a cold day, it condenses and forms a small cloud.

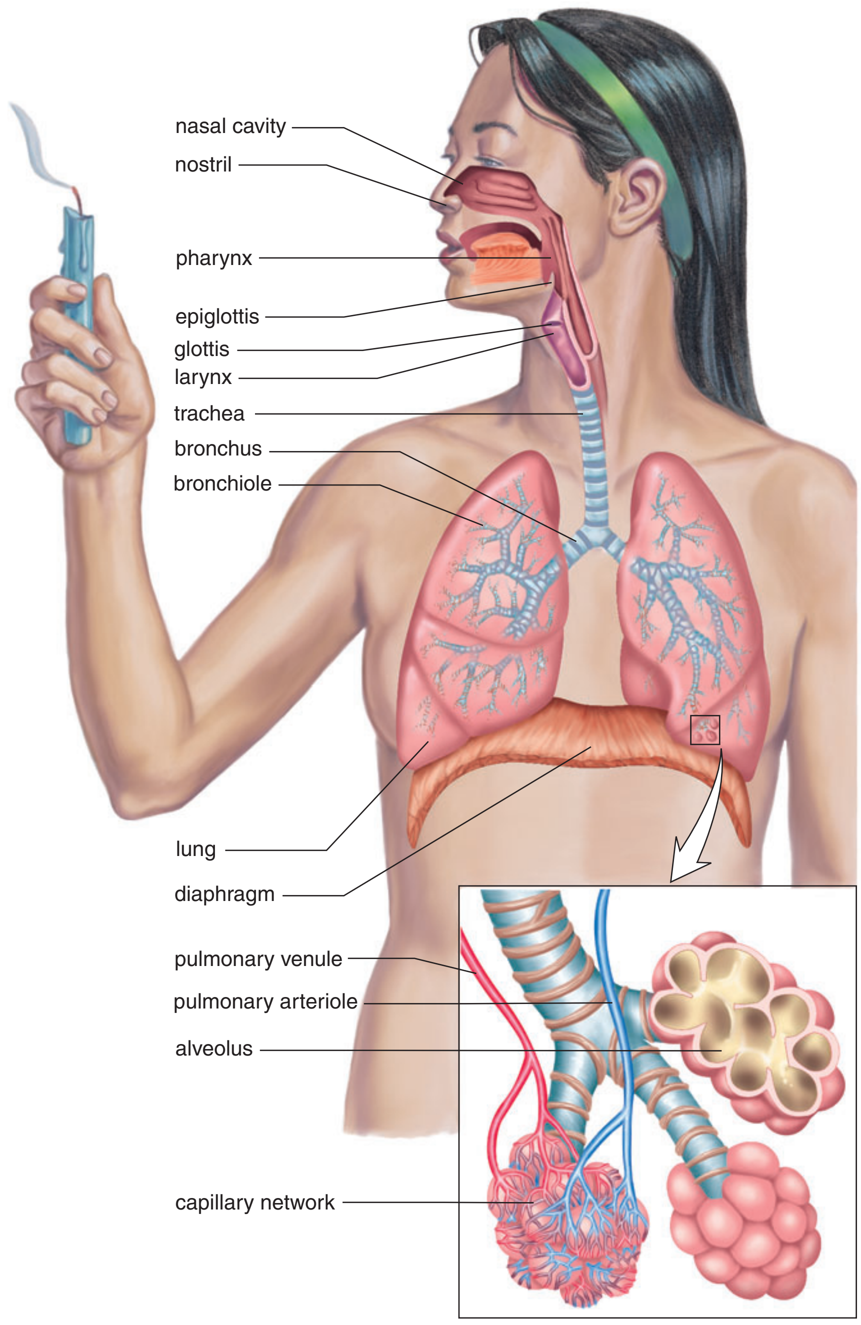


Figure 8.1 The respiratory tract.
The respiratory tract extends from the nose to the lungs. The lungs are composed of air sacs called alveoli. Gas exchange occurs between the air in the alveoli and the blood within a capillary network that surrounds the alveoli. Notice in the blowup that the pulmonary arteriole is colored blue—it carries O_2-poor blood away from the heart to the alveoli. Then, carbon dioxide leaves the blood, and oxygen enters the blood. The pulmonary venule is colored red—it carries O_2-rich blood from the alveoli toward the heart.

Table 8.1 Path of Air

Structure	Description	Function
The Upper Respiratory Tract		
Nares	Openings into the nasal cavities	Passage of air into nasal cavities
Nasal cavities	Hollow spaces in nose	Filter, warm, and moisten air
Pharynx	Chamber posterior to oral cavity; lies between nasal cavity and larynx	Connection to surrounding regions
Glottis	Opening into larynx	Passage of air into larynx
Larynx	Cartilaginous organ that houses vocal cords (voice box); composed of the nasopharynx, oropharynx, and the laryngopharynx	Sound production
The Lower Respiratory Tract		
Trachea	Flexible tube that connects larynx with bronchi	Passage of air to bronchi
Bronchi	Paired tubes inferior to the trachea that enter the lungs	Passage of air to lungs
Bronchioles	Branched tubes that lead from bronchi to alveoli (air sacs)	Passage of air to each alveolus
Lungs	Soft, cone-shaped organs that occupy lateral portions of thoracic cavity	Contain alveoli and blood vessels

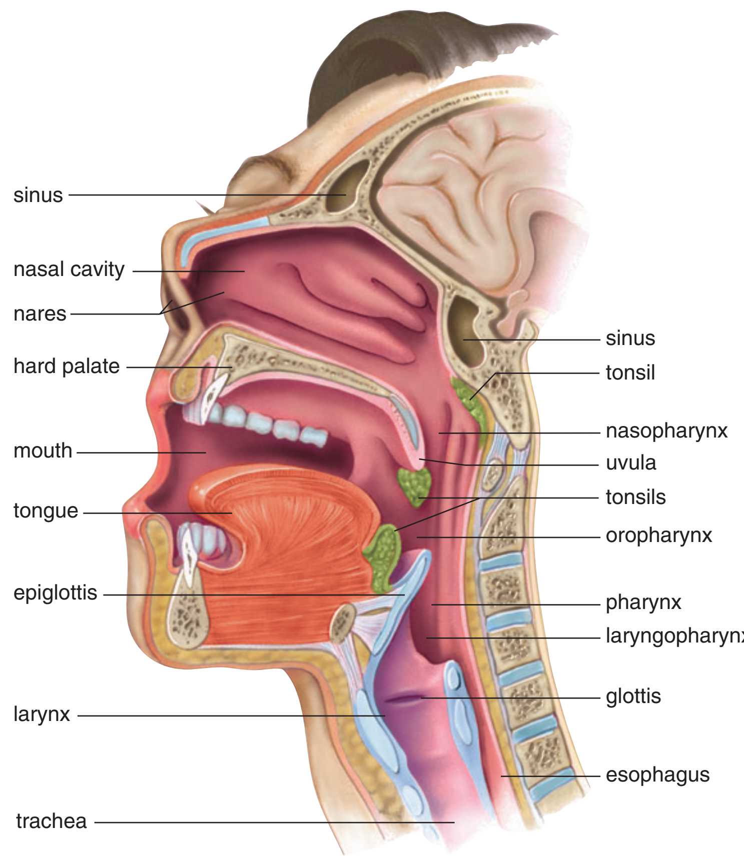


Figure 8.2 **The path of air.**
This drawing shows the path of air from the nasal cavities to the trachea, which is a part of the lower respiratory tract. The other organs are in the upper respiratory tract.

The Nose

The nose opens at the nares (nostrils) that lead to the **nasal cavities.** The nasal cavities are narrow canals separated from one another by a septum composed of bone and cartilage (Fig. 8.2). Special ciliated cells in the narrow upper recesses of the nasal cavities act as odor receptors. Nerves lead from these cells to the brain, where the impulses generated by the odor receptors are interpreted as smell.

The tear (lacrimal) glands drain into the nasal cavities by way of tear ducts. For this reason, crying produces a runny nose. The nasal cavities also communicate with the cranial sinuses, air-filled mucosa-lined spaces in the skull. If inflammation due to a cold or an allergic reaction blocks the ducts leading from the sinuses, fluid may accumulate, causing a sinus headache.

The nasal cavities empty into the nasopharynx, the upper portion of the pharynx. The auditory tubes lead from the nasopharynx to the middle ears.

The Pharynx

The **pharynx** is a funnel-shaped passageway that connects the nasal and oral cavities to the larynx. Therefore, the pharynx, which is commonly referred to as the "throat," has three parts: the nasopharynx, where the nasal cavities open above the soft palate; the oropharynx, where the oral cavity opens; and the laryngopharynx, which opens into the larynx.

The tonsils form a protective ring at the junction of the oral cavity and the pharynx. Being lymphatic tissue, the tonsils contain lymphocytes that protect against invasion of foreign antigens that are inhaled. In the tonsils, B cells and T cells are prepared to respond to antigens that may subsequently invade internal tissues and fluids. Therefore, the respiratory tract assists the immune system in maintaining homeostasis.

In the pharynx, the air passage and the food passage cross because the larynx, which receives air, is ventral to the esophagus, which receives food. The larynx lies at the top of the trachea. The larynx and trachea are normally open, allowing air to pass, but the esophagus is normally closed and opens only when a person swallows.

Air from either the nose or the mouth enters the pharynx and then continues to the lungs.

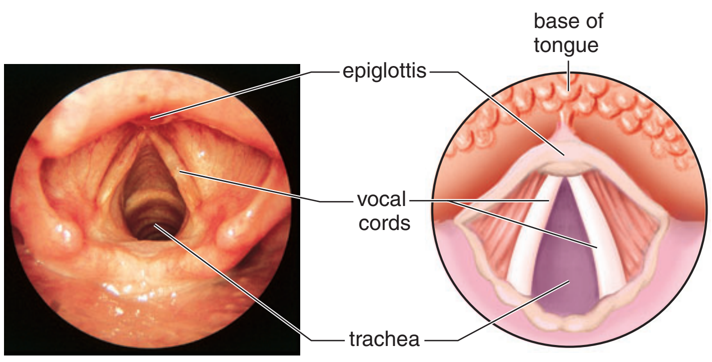


Figure 8.3 **Placement of the vocal cords.**
Viewed from above, the vocal cords can be seen to stretch across the glottis, the opening to the trachea. When air is expelled through the glottis, the vocal cords vibrate, producing sound. The glottis is narrow when we produce a high-pitched sound, and it widens as the pitch deepens.

The Larynx

The **larynx** is a cartilaginous structure that serves as a passageway for air between the pharynx and the trachea. The larynx can be pictured as a triangular box whose apex, the Adam's apple, is located at the front of the neck. At the top of the larynx is a variable-sized opening called the **glottis.** When food is swallowed, the larynx moves upward against the **epiglottis,** a flap of tissue that prevents food from passing into the larynx. You can detect this movement by placing your hand gently on your larynx and swallowing.

The larynx is called the voice box because it houses the vocal cords. The **vocal cords** are mucosal folds supported by elastic ligaments, which are stretched across the glottis (Fig. 8.3). When air passes through the glottis, the vocal cords vibrate, producing sound. At the time of puberty, the growth of the larynx and the vocal cords is much more rapid and accentuated in the male than in the female, causing the male to have a more prominent Adam's apple and a deeper voice. The voice "breaks" in the young male due to his inability to control the longer vocal cords. These changes cause the lower pitch of the voice in males.

The high or low pitch of the voice is regulated when speaking and singing by changing the tension on the vocal cords. The greater the tension, as when the glottis becomes narrower, the higher the pitch. When the glottis is wider, the pitch is lower (Fig. 8.3, *right*). The loudness, or intensity, of the voice depends upon the amplitude of the vibrations—that is, the degree to which the vocal cords vibrate.

The Trachea

Whereas the nasal cavities, pharynx, and larynx are a part of the upper respiratory tract, the trachea and the rest of the respiratory system are in the lower respiratory tract. The **trachea,** commonly called the windpipe, is a tube connecting the larynx to the primary bronchi. Its walls consist of connective tissue and smooth muscle reinforced by C-shaped cartilaginous rings.

The trachea lies ventral to the esophagus. The open part of the C-shaped rings faces the esophagus, and this allows the esophagus to expand when swallowing. The mucous membrane that lines the trachea has an outer layer of pseudostratified ciliated columnar epithelium. (*Pseudostratified* means that while the epithelium appears to be layered, actually each cell touches the basement membrane.) The cilia that project from the epithelium keep the lungs clean by sweeping mucus, produced by goblet cells, and debris toward the pharynx (Fig. 8.4). When one coughs, the tracheal wall contracts, narrowing its diameter. Therefore, coughing causes air to move more rapidly through the trachea, helping to expel mucus and foreign objects. Smoking is known to destroy the cilia, and consequently the soot in cigarette smoke collects in the lungs. Smoking is discussed more fully in the Health Focus on page 155.

If the trachea is blocked because of illness or the accidental swallowing of a foreign object, it is possible to insert a breathing tube by way of an incision made in the trachea. This tube acts as an artificial air intake and exhaust duct. The operation is called a **tracheostomy.**

Figure 8.4 **Trachea.**
Scanning electron micrograph of the surface of the mucous membrane lining the trachea consisting of goblet cells and ciliated cells. The cilia sweep mucus and debris embedded in it toward the pharynx, where it is swallowed or expectorated. Smoking causes the cilia to disappear; consequently, debris now enters the bronchi and lungs.

The Bronchial Tree

The trachea divides into right and left primary bronchi (sing., **bronchus**), which lead into the right and left lungs (see Fig. 8.1). The bronchi branch into a great number of secondary bronchi that eventually lead to **bronchioles.** The bronchi resemble the trachea in structure, but as the bronchial tubes divide and subdivide, their walls become thinner, and the small rings of cartilage are no longer present. During an asthma attack, the smooth muscle of the bronchioles contracts, causing bronchiolar constriction and characteristic wheezing. Each bronchiole leads to an elongated space enclosed by a multitude of air pockets, or sacs, called alveoli (sing., **alveolus**). The components of the bronchiole tree beyond the primary bronchi compose the lungs.

The Lungs

The **lungs** are paired, cone-shaped organs that occupy the thoracic cavity, except for the central area that contains the trachea, the heart, and esophagus. The right lung has three lobes, and the left lung has two lobes, allowing room for the heart, which points left. A lobe is further divided into lobules, and each lobule has a bronchiole serving many alveoli.

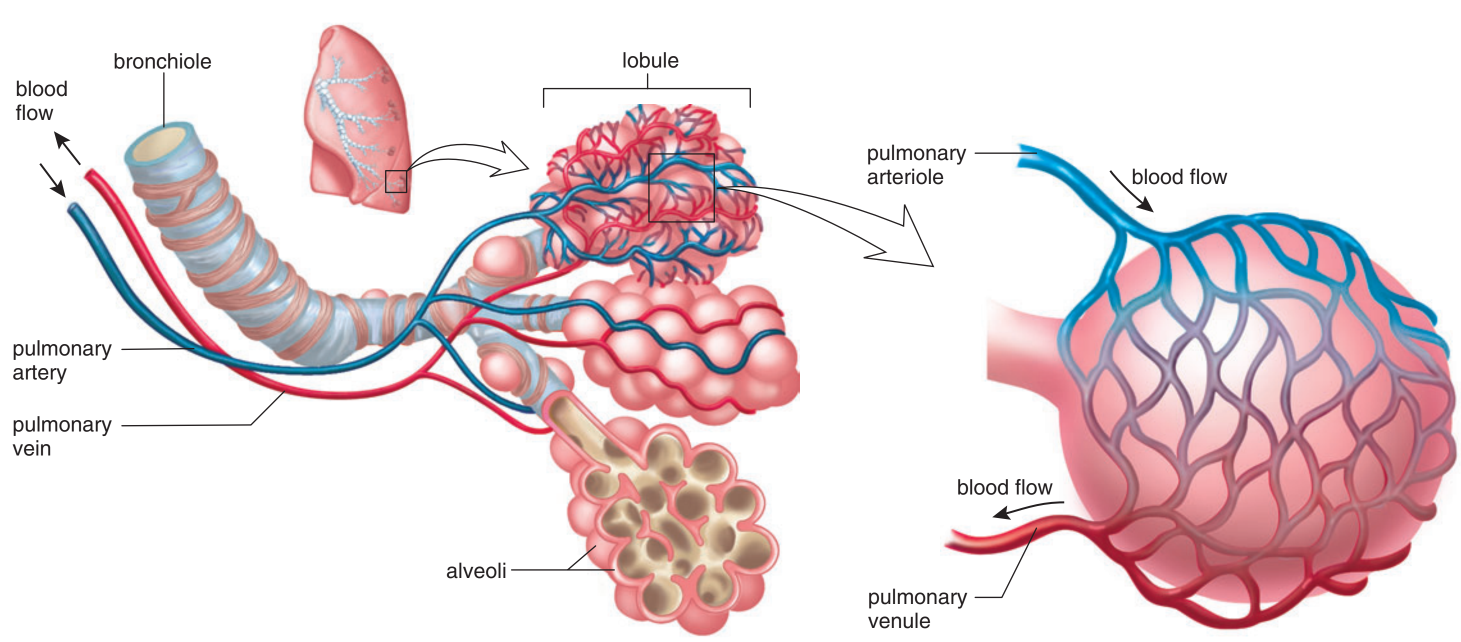
The lungs follow the contours of the thoracic cavity including the diaphragm, the muscle that separates the thoracic cavity from the abdominal cavity. Each lung is enclosed by pleura, a double layer of serous membrane that produces serous fluid. The parietal pleura adheres to the thoracic cavity and the visceral pleura adheres to the surface of the lung. Surface tension is the tendency for water molecules to cling to one another due to hydrogen bonding between molecules. Surface tension holds the two pleural layers together, and therefore the lungs must follow the movement of the thorax when breathing occurs.

The Alveoli

The lungs have about 300 million alveoli, with a total cross-sectional area of 50–70 m^2. Each alveolar sac is surrounded by blood capillaries. The wall of the sac and the wall of the capillary are largely simple squamous epithelium—thin flattened cells—and this facilitates gas exchange. Gas exchange occurs between air in the alveoli and blood in the capillaries (Fig. 8.5). Oxygen diffuses across the alveolar wall and enters the bloodstream, while carbon dioxide diffuses from the blood across the alveolar wall to enter the alveoli.

The alveoli of human lungs are lined with a **surfactant,** a film of lipoprotein that lowers the surface tension and prevents them from closing. The lungs collapse in some newborn babies, especially premature infants, who lack this film. The condition, called **infant respiratory distress syndrome,** is now treatable by surfactant replacement therapy.

Air passes through the nose, pharynx, larynx, trachea, and bronchial tree before reaching the lungs.



Blood supply of alveoli **Capillary network of one alveolus**

Figure 8.5 Gas exchange in the lungs.
The lungs consist of alveoli surrounded by an extensive capillary network. Notice that the pulmonary artery and arteriole carry O_2-poor blood (colored blue), and the pulmonary vein and venule carry O_2-rich blood (colored red).

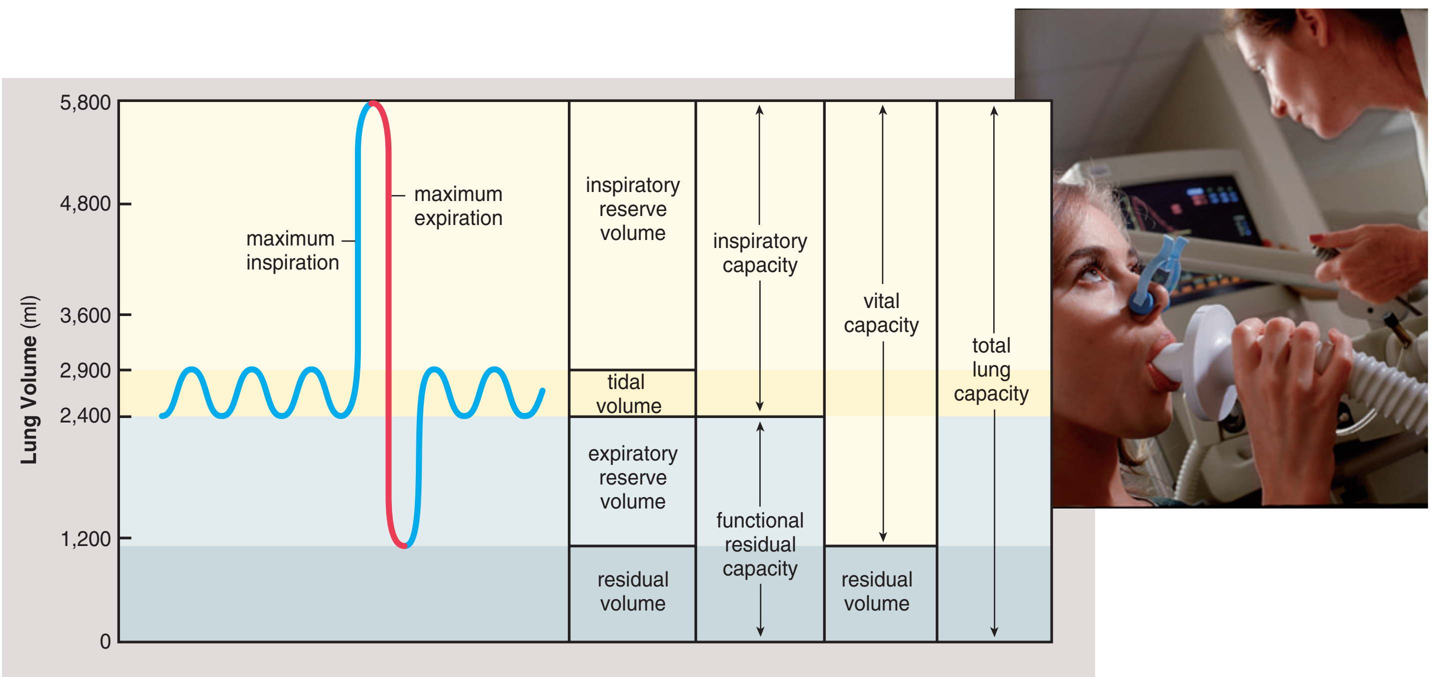


Figure 8.6 **Vital capacity.**
A spirometer measures the amount of air inhaled and exhaled with each breath. During inspiration, the pen moves up, and during expiration, the pen moves down. Vital capacity (red) is the maximum amount of air a person can exhale after taking the deepest inhalation possible.

8.2 Mechanism of Breathing

As ventilation occurs, air moves into the lungs from the nose or mouth during inspiration and then moves out of the lungs during expiration. A free flow of air from the nose or mouth to the lungs and from the lungs to the nose or mouth is vitally important. Therefore, a technique has been developed that allows physicians to determine if there is a medical problem that prevents the lungs from filling with air upon inspiration and releasing it from the body upon expiration. This technique is illustrated in Figure 8.6, which shows the measurements recorded by a spirometer when a person breathes as directed by a technician.

Respiratory Volumes

Normally when we are relaxed, only a small amount of air moves in and out with each breath. This amount of air, called the **tidal volume,** is only about 500 mL.

It is possible to increase the amount of air inhaled, and therefore the amount exhaled, by deep breathing. The maximum volume of air that can be moved in plus the maximum amount that can be moved out during a single breath is called the **vital capacity.** It's called vital capacity because your life depends on breathing, and the more air you can move, the better off you are. A number of different illnesses, discussed at the end of this chapter, can decrease vital capacity.

Vital capacity varies by how much we can increase inspiration and expiration over the tidal volume amount. We can increase inspiration by expanding the chest and therefore, the lungs. Forced inspiration **(inspiratory reserve volume)** usually increases by 2,900 mL, and that's quite a bit more than a tidal volume of only 500 mL! We can increase expiration by contracting the abdominal and thoracic muscles. This so-called **expiratory reserve volume** is usually about 1,400 mL of air. You can see from Figure 8.6 that vital capacity is the sum of tidal, inspiratory reserve, and expiratory reserve volumes.

It's a curious fact that some of the inhaled air never reaches the lungs; instead, it fills the nasal cavities, trachea, bronchi, and bronchioles (see Fig. 8.1). These passages are not used for gas exchange, and therefore they are said to contain **dead air space.** To ensure that inhaled air reaches the lungs, it is better to breathe slowly and deeply. Also, note in Figure 8.6 that even after a very deep exhalation, some air (about 1,000 mL) remains in the lungs; this is called the **residual volume.** This air is no longer useful for gas exchange. In some lung diseases to be discussed later, the residual volume builds up because the individual has difficulty emptying the lungs. This means that the vital capacity is reduced because the lungs are filled with useless air.

The air used for gas exchange excludes both the air in the dead space of the respiratory tract and the residual volume in the lungs.

Ecology Focus

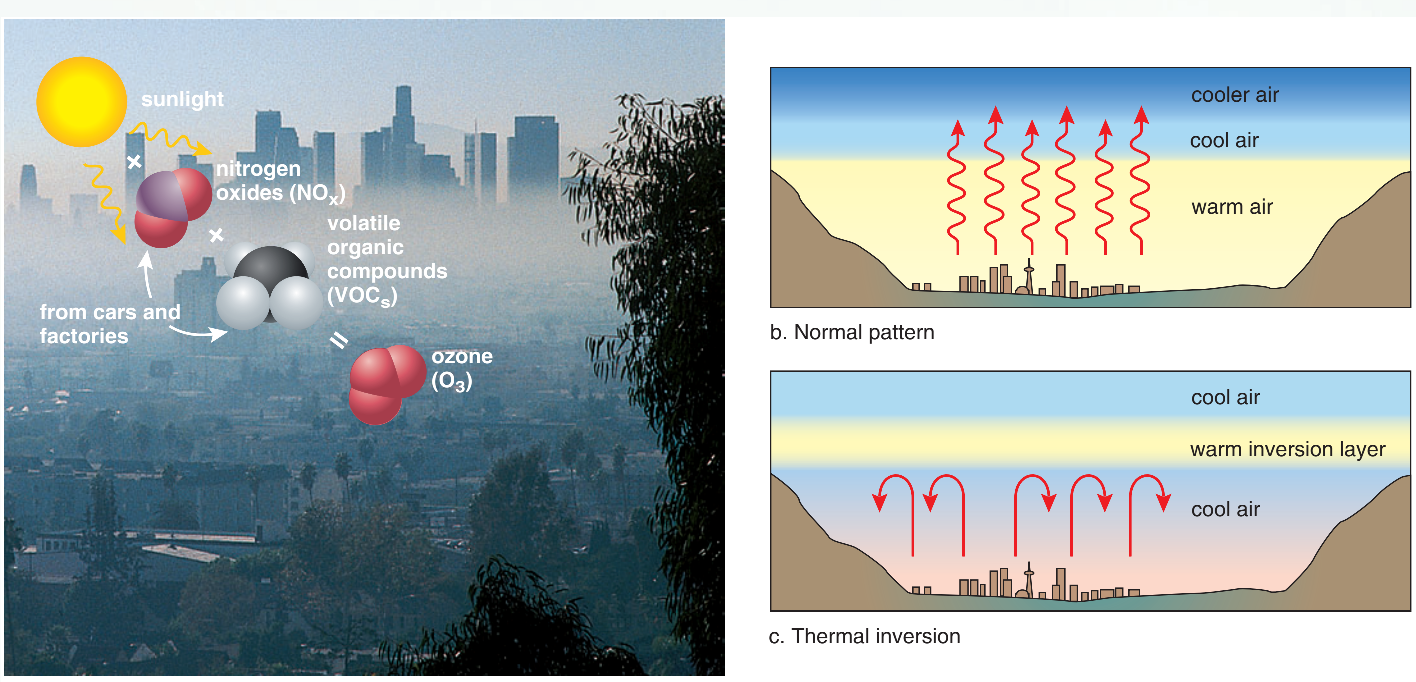
Photochemical Smog Can Kill

Most industrialized cities have photochemical smog, at least occasionally. Photochemical smog arises when primary pollutants react with one another under the influence of sunlight to form a more deadly combination of chemicals. For example, two primary pollutants, nitrogen oxides (NO_x) and volatile organic compounds (VOCs) including hydrocarbons, as well as alcohols, aldehydes, and ethers, react with one another in the presence of sunlight to produce nitrogen dioxide (NO_2), ozone (O_3), and PAN (peroxyacetylnitrate). Ozone and PAN are commonly referred to as oxidants. Breathing oxidants affects the respiratory and nervous systems, resulting in respiratory distress, headache, and exhaustion.

Cities with warm, sunny climates that are large and industrialized, such as Los Angeles, Denver, and Salt Lake City in the United States, Sydney in Australia, Mexico City in Mexico, and Buenos Aires in Argentina, are particularly susceptible to photochemical smog. If the city is surrounded by hills, a thermal inversion may aggravate the situation. Normally, warm air near the ground rises, so that pollutants are dispersed and carried away by air currents. But sometimes during a thermal inversion, smog gets trapped near the Earth by a blanket of warm air (Fig. 8A). This may occur when a cold front brings in cold air, which settles beneath a warm layer. The trapped pollutants cannot disperse, and the results are dangerous to one's respiratory health. Even healthy adults experience a reduction in lung capacity when exposed to photochemical smog for long periods or during vigorous outdoor activities. Repeated exposures to high concentrations of ozone are associated with respiratory problems, such as an increased rate of lung infections and permanent lung damage. Children, the elderly, asthmatics, and individuals with emphysema or other similar disorders are particularly at risk.

Even though we have federal legislation to bring air pollution under control, more than half the people in the United States live in cities polluted by too much smog. In the long run, pollution prevention is usually easier and cheaper than pollution cleanup. Some prevention suggestions are as follows:

- Encourage use of public transportation and burn fuels that do not produce pollutants.
- Increase recycling in order to reduce the amount of waste that is incinerated.
- Reduce energy use so that power plants need to provide less.
- Use renewable energy sources, such as solar, wind, or water power.
- Require industries to meet clean-air standards.



a. Ground-level ozone formation

b. Normal pattern

c. Thermal inversion

Figure 8A **Thermal inversion.**
a. Los Angeles is the "air pollution capital" of the world. Its millions of cars and thousands of factories make it particularly susceptible to photochemical smog, which contains ozone due to the chemical reaction shown. **b.** Normally, pollutants escape into the atmosphere when warm air rises. **c.** During a thermal inversion, a layer of warm air (warm inversion layer) overlies and traps pollutants in cool air below.

Inspiration and Expiration

To understand ventilation, the manner in which air enters and exits the lungs, it is necessary to remember the following facts:

1. Normally, there is a continuous column of air from the pharynx to the alveoli of the lungs.
2. The lungs lie within the sealed-off thoracic cavity. The rib cage, consisting of the ribs joined to the vertebral column posteriorly and to the sternum anteriorly, forms the top and sides of the thoracic cavity. The intercostal muscles lie between the ribs. The diaphragm and connective tissue form the floor of the thoracic cavity.
3. The lungs adhere to the thoracic wall by way of the pleura. Any space between the two pleurae is minimal due to the surface tension of the fluid between them.

Inspiration

Inspiration is the active phase of ventilation because this is the phase in which the diaphragm and the external intercostal muscles contract (Fig. 8.7*a*). In its relaxed state, the diaphragm is dome-shaped; during deep inspiration, it contracts and lowers. Also, the external intercostal muscles contract, and the rib cage moves upward and outward.

Following contraction of the diaphragm and the external intercostal muscles, the volume of the thoracic cavity will be larger than it was before. As the thoracic volume increases, the lungs expand. Now the air pressure within the alveoli decreases, creating a partial vacuum. Because alveolar pressure is now less than atmospheric pressure (air pressure outside the lungs), air naturally flows from outside the body into the respiratory passages and into the alveoli.

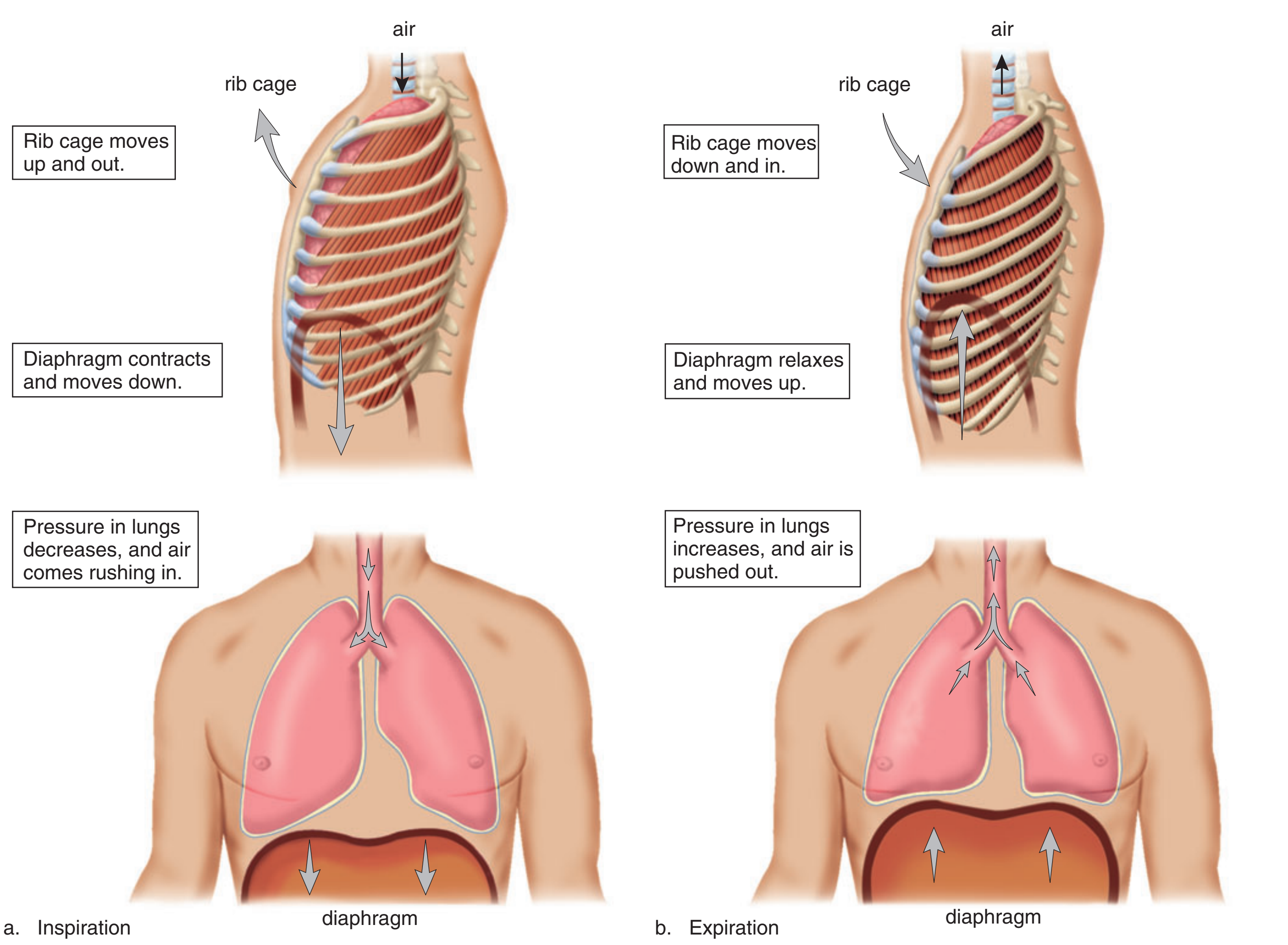


Figure 8.7 **Inspiration versus expiration.**
To understand ventilation, it is necessary to realize that the lungs adhere to the thoracic cavity by way of the pleura. **a.** During inspiration, the thoracic cavity and, therefore, the lungs expand so that air is drawn in. **b.** During expiration, the thoracic cavity and, therefore, the lungs resume their original positions and pressures. Now air is forced out.

It is important to realize that air comes into the lungs because they have already opened up; air does not force the lungs open. This is why it is sometimes said that *humans inhale by negative pressure.* The creation of a partial vacuum in the alveoli causes air to enter the lungs. While inspiration is the active phase of breathing, the actual flow of air into the alveoli is passive.

Expiration

Usually, expiration is the passive phase of breathing, and no effort is required to bring it about. During expiration, the elastic properties of the thoracic wall and lungs cause them to recoil. In addition, the lungs recoil because the surface tension of the fluid lining the alveoli tends to draw them closed. During expiration, the abdominal organs press up against the diaphragm, and the rib cage moves down and inward (Fig. 8.7*b*). What keeps the alveoli from collapsing as a part of expiration? Recall that the presence of surfactant lowers the surface tension within the alveoli. Also, as the lungs recoil, the pressure between the pleura decreases, and this tends to make the alveoli stay open. The importance of the reduced intrapleural pressure is demonstrated when, by design or accident, air enters the intrapleural space. Now the lung collapses.

The diaphragm and external intercostal muscles are usually relaxed when expiration occurs. However, when breathing is deeper and/or more rapid, expiration can be active. Contraction of the internal intercostal muscles can force the rib cage to move downward and inward. Also, when the abdominal wall muscles contract, they push on the viscera, which push against the diaphragm, and the increased pressure in the thoracic cavity helps expel air.

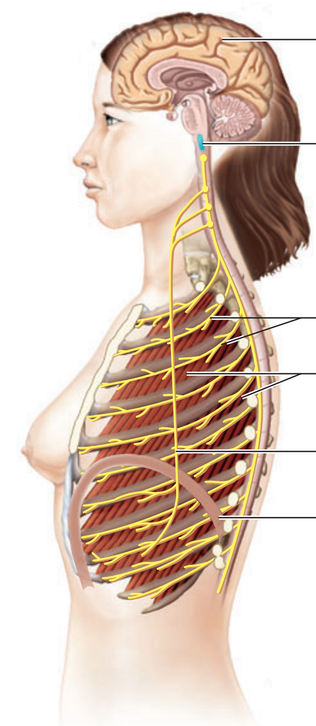


Figure 8.8 **Nervous control of breathing.**
During inspiration, the respiratory center, located in the medulla oblongata, stimulates the external intercostal (rib) muscles to contract via the intercostal nerves and stimulates the diaphragm to contract via the phrenic nerve. The thoracic cavity, and then the lungs, expand and air comes rushing in. Expiration occurs due to a lack of stimulation from the respiratory center to the diaphragm and intercostal muscles. Now, as the thoracic cavity, and then the lungs, resume their original size, air is pushed out.

Control of Ventilation

Normally, adults have a breathing rate of 12 to 20 ventilations per minute. The rhythm of ventilation is controlled by a **respiratory center** located in the medulla oblongata of the brain.

The respiratory center automatically sends out impulses by way of nerves to the diaphragm and the external intercostal muscles of the rib cage, causing inspiration to occur (Fig. 8.8). When the respiratory center stops sending neuronal signals to the diaphragm and the rib cage, the diaphragm relaxes and resumes its dome shape. Now expiration occurs.

Although the respiratory center automatically controls the rate and depth of breathing, its activity can also be influenced by nervous input and chemical input. Following forced inspiration, stretch receptors in the alveolar walls initiate inhibitory nerve impulses that travel from the inflated lungs to the respiratory center. This stops the respiratory center from sending out nerve impulses.

Chemical Input The respiratory center is directly sensitive to the levels of hydrogen ions (H^+). However, when carbon dioxide (CO_2) enters the blood, it reacts with water and releases hydrogen ions. In this way, carbon dioxide participates in regulating the breathing rate. When hydrogen ions rise in the blood, the respiratory center increases the rate and depth of breathing. The center is not affected directly by low oxygen (O_2) levels. However, chemoreceptors in the **carotid bodies,** located in the carotid arteries, and in the **aortic bodies,** located in the aorta, are sensitive to the level of oxygen in the blood. When the concentration of oxygen decreases, these bodies communicate with the respiratory center, and the rate and depth of breathing increase.

During inspiration, due to nervous stimulation, the diaphragm lowers, and the rib cage lifts up and out. During expiration, due to a lack of nervous stimulation, the diaphragm rises, and the rib cage lowers.

8.3 Gas Exchanges in the Body

Gas exchange is critical to homeostasis. The act of breathing brings oxygen in air to the lungs and carbon dioxide from the lungs to outside the body. As mentioned previously, respiration includes not only the exchange of gases in the lungs, but also the exchange of gases in the tissues (Fig. 8.9).

The principles of diffusion, alone, govern whether O_2 or CO_2 enters or leaves the blood in the lungs and in the tissues. Gases exert pressure, and the amount of pressure each gas exerts is called its partial pressure, symbolized as P_{O_2} and P_{CO_2}. If the partial pressure of oxygen differs across a membrane, oxygen will diffuse from the higher to lower partial pressure.

External Respiration

External respiration refers to the exchange of gases between air in the alveoli and blood in the pulmonary capillaries (see Fig. 8.5). Blood in the pulmonary capillaries has a higher P_{CO_2} than atmospheric air. Therefore, *CO_2 diffuses out of the plasma into the lungs.* Most of the CO_2 is carried as **bicarbonate ions** (HCO_3^-). As the little remaining free CO_2 begins to diffuse out, the following reaction is driven to the right:

$$\underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-} \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3} \xrightarrow{\text{carbonic anhydrase}} \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2}$$

The enzyme **carbonic anhydrase,** present in red blood cells, speeds the breakdown of carbonic acid (H_2CO_3).

What happens if you hyperventilate (breathe at a high rate), and therefore push this reaction far to the right? The blood will have fewer hydrogen ions, and alkalosis, a high blood pH, results. In that case, breathing will be inhibited, but in the meantime, you may suffer various symptoms from dizziness to tetanic contractions of the muscles. What happens if you hypoventilate (breathe at a low rate) and this reaction does not occur? Hydrogen ions build up in the blood, and acidosis will occur. Buffers may compensate for the low pH, and breathing will most likely increase. Otherwise, you may become comatose and die.

The pressure pattern for O_2 during external respiration is the reverse of that for CO_2. Blood in the pulmonary capillaries is low in oxygen, and alveolar air contains a higher partial pressure of oxygen. Therefore, *O_2 diffuses into plasma and then into red blood cells in the lungs.* Hemoglobin takes up this oxygen and becomes **oxyhemoglobin** (HbO_2):

$$\underset{\text{deoxyhemoglobin}}{Hb} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{oxyhemoglobin}}{HbO_2}$$

Internal Respiration

Internal respiration refers to the exchange of gases between the blood in systemic capillaries and the tissue fluid. In Figure 8.9, internal respiration is shown in the upper body and the lower body; however, the same events occur in both regions. Blood in the systemic capillaries is a bright red color because red blood cells contain oxyhemoglobin. Because the temperature in the tissues is higher and the pH is lower, oxyhemoglobin naturally gives up oxygen. After oxyhemoglobin gives up O_2, it diffuses out of the blood into the tissues:

$$\underset{\text{oxyhemoglobin}}{HbO_2} \longrightarrow \underset{\text{deoxyhemoglobin}}{Hb} + \underset{\text{oxygen}}{O_2}$$

Oxygen diffuses out of the blood into the tissues because the P_{O_2} of tissue fluid is lower than that of blood. The lower P_{O_2} is due to cells continuously using up oxygen in cellular respiration. *Carbon dioxide diffuses into the blood from the tissues* because the P_{CO_2} of tissue fluid is higher than that of blood. Carbon dioxide, produced continuously by cells, collects in tissue fluid.

After CO_2 diffuses into the blood, it enters the red blood cells, where a small amount is taken up by hemoglobin, forming **carbaminohemoglobin** ($HbCO_2$). Most of the CO_2 combines with water, forming carbonic acid (H_2CO_3), which dissociates to hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). The increased concentration of CO_2 in the blood drives the reaction to the right:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \xrightarrow{\text{carbonic anhydrase}} \underset{\text{carbonic acid}}{H_2CO_3} \longrightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-}$$

The enzyme carbonic anhydrase, mentioned previously, speeds the reaction. Bicarbonate ions diffuse out of red blood cells and are carried in the plasma. The globin portion of hemoglobin combines with excess hydrogen ions produced by the overall reaction, and Hb becomes HHb, called **reduced hemoglobin.** In this way, the pH of blood remains fairly constant. Blood that leaves the systemic capillaries is a dark maroon color because red blood cells contain reduced hemoglobin.

Hemoglobin activity is essential to the transport of gases, and therefore to external and internal respiration. External and internal respiration are the movement of gases between pulmonary capillaries and alveoli and between the systemic capillaries and body tissue fluid, respectively. Both processes depend on the process of diffusion.

Visual Focus

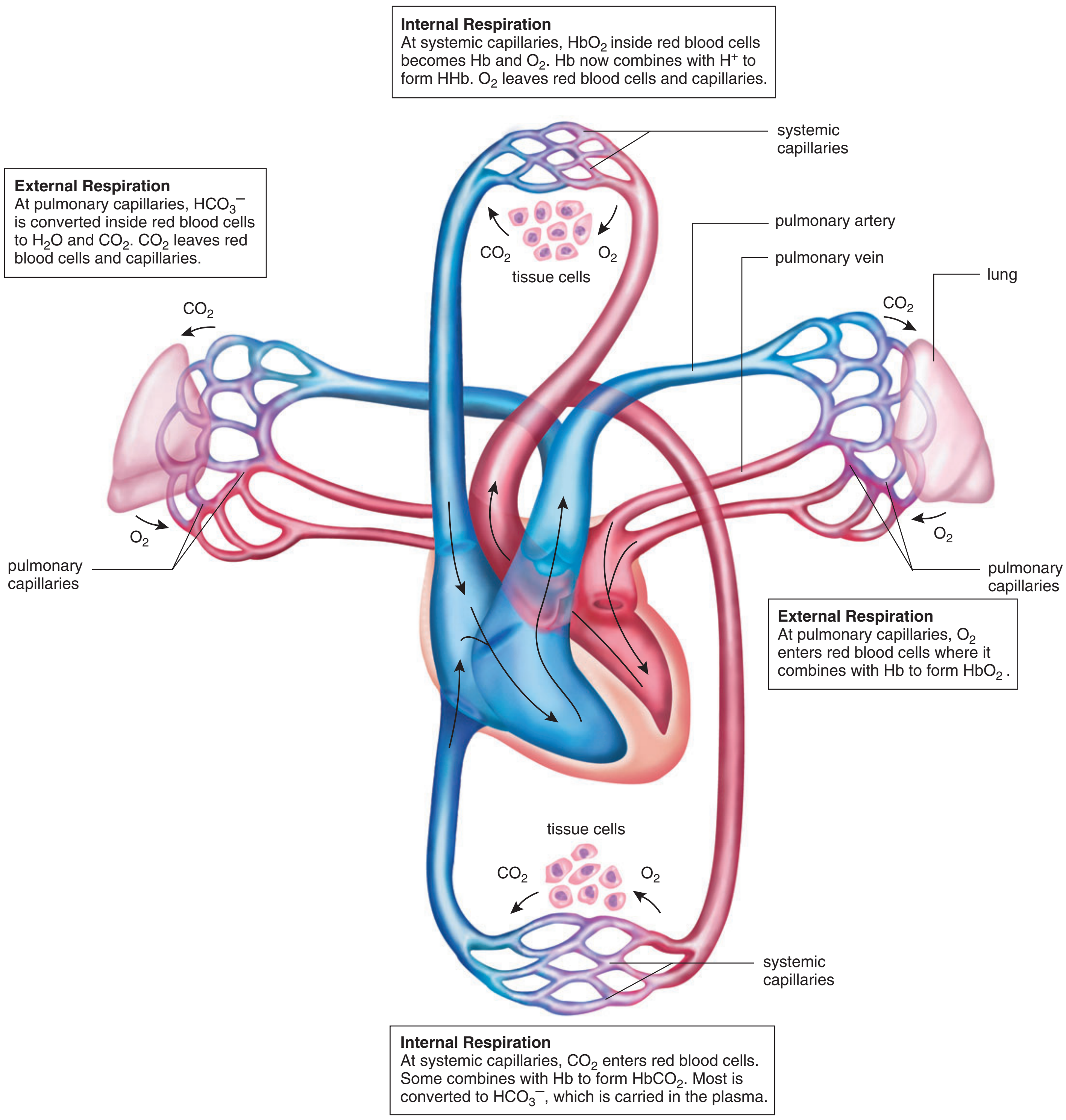


Figure 8.9 **External and internal respiration.**
During external respiration in the lungs, CO_2 leaves the blood and O_2 enters the blood. During internal respiration in the tissues, O_2 leaves the blood and CO_2 enters the blood.

8.4 Respiration and Health

The respiratory tract is constantly exposed to environmental air. The quality of this air and whether it contains infectious pathogens, such as bacteria and viruses, can affect our health.

Upper Respiratory Tract Infections

The upper respiratory tract consists of the nasal cavities, the pharynx, and the larynx. Upper respiratory infections (URI) can spread from the nasal cavities to the sinuses, middle ears, and larynx. Viral infections sometimes lead to secondary bacterial infections. What we call "strep throat" is a primary bacterial infection caused by *Streptococcus pyogenes* that can lead to a generalized upper respiratory infection and even a systemic (affecting the body as a whole) infection. Although antibiotics have no effect on viral infections, they are successfully used to treat most bacterial infections, including strep throat. The symptoms of strep throat are severe sore throat, high fever, and white patches on a dark red throat.

Sinusitis

Sinusitis is an infection of the cranial sinuses, the cavities within the facial skeleton that drain into the nasal cavities. Only about 1–3% of URIs are accompanied by sinusitis. Sinusitis develops when nasal congestion blocks the tiny openings leading to the sinuses. Symptoms include postnasal discharge, as well as facial pain that worsens when the patient bends forward. Pain and tenderness usually occur over the lower forehead or over the cheeks. If the latter, toothache is also a complaint. Successful treatment depends on restoring proper drainage of the sinuses. Even a hot shower and sleeping upright can be helpful. Otherwise, spray decongestants are preferred over oral antihistamines, which thicken rather than liquefy the material trapped in the sinuses.

Otitis Media

Otitis media is an infection of the middle ear. The middle ear is not a part of the respiratory tract, but this infection is considered here because it is a complication often seen in children who have a nasal infection. Infection can spread by way of the **auditory (Eustachian) tube** that leads from the nasopharynx to the middle ear. Pain is the primary symptom of a middle ear infection. A sense of fullness, hearing loss, vertigo (dizziness), and fever may also be present. Antibiotics are prescribed if necessary, but physicians are aware today that overuse of antibiotics can lead to resistance of bacteria to antibiotics. Tubes (called tympanostomy tubes) are sometimes placed in the eardrums of children with multiple recurrences to help prevent the buildup of pressure in the middle ear and the possibility of hearing loss. Normally, the tubes fall out with time.

Tonsillitis

Tonsillitis occurs when the **tonsils,** masses of lymphatic tissue in the pharynx, become inflamed and enlarged. The tonsils in the posterior wall of the nasopharynx are often called adenoids. If tonsillitis occurs frequently and enlargement makes breathing difficult, the tonsils can be removed surgically in a **tonsillectomy.** Fewer tonsillectomies are performed today than in the past because we now know that the tonsils remove many of the pathogens that enter the pharynx; therefore, they are a first line of defense against invasion of the body.

Laryngitis

Laryngitis is an infection of the larynx with accompanying hoarseness leading to the inability to talk in an audible voice. Usually, laryngitis disappears with treatment of the URI. Persistent hoarseness without the presence of an URI is one of the warning signs of cancer, and therefore should be looked into by a physician.

Lower Respiratory Tract Disorders

Lower respiratory tract disorders include infections, restrictive pulmonary disorders, obstructive pulmonary disorders, and lung cancer.

Lower Respiratory Infections

Acute bronchitis, pneumonia, and tuberculosis are infections of the lower respiratory tract. **Acute bronchitis** is an infection of the primary and secondary bronchi. Usually, it is preceded by a viral URI that has led to a secondary bacterial infection. Most likely, a nonproductive cough has become a deep cough that expectorates mucus and perhaps pus.

Pneumonia is a viral or bacterial infection of the lungs in which the bronchi and alveoli fill with thick fluid (Fig. 8.10). Most often, it is preceded by influenza. High fever and chills, with headache and chest pain, are symptoms of pneumonia. Rather than being a generalized lung infection, pneumonia may be localized in specific lobules of the lungs; obviously, the more lobules involved, the more serious is the infection. Pneumonia can be caused by a bacterium that is usually held in check but has gained the upper hand due to stress and/or reduced immunity. AIDS patients are subject to a particularly rare form of pneumonia caused by the protozoan *Pneumocystis jiroveci* (formerly *Pneumocystis carinii*). Pneumonia of this type is almost never seen in individuals with a healthy immune system.

Pulmonary tuberculosis is caused by the tubercle bacillus, a type of bacterium. When tubercle bacilli invade the lung tissue, the cells build a protective capsule around the foreigners, isolating them from the rest of the body. This tiny capsule is called a tubercle. If the resistance of the body is high, the imprisoned organisms die, but if the resistance is low, the organisms eventually can be liberated. If a chest X ray detects active tubercles, the individual is put on appropriate drug therapy to ensure the localization of the disease and the eventual destruction of any live bacteria. It is possible to tell if a person has ever been exposed to tuberculosis with a test in which a highly diluted extract of the bacillus is injected into the skin of the patient. A person who has never been in contact with the tubercle bacillus shows no reaction, but one who has had or is fighting an infection shows an area of inflammation that peaks in about 48 hours.

Restrictive Pulmonary Disorders

In restrictive pulmonary disorders, vital capacity is reduced because the lungs have lost their elasticity. Inhaling particles such as silica (sand), coal dust, asbestos, and, now it seems, fiberglass can lead to **pulmonary fibrosis,** a condition in which fibrous connective tissue builds up in the lungs. The lungs cannot inflate properly and are always tending toward deflation. Breathing asbestos is also associated with the development of cancer. Because asbestos was formerly used widely as a fireproofing and insulating agent, unwarranted exposure has occurred. It has been projected that 2 million deaths caused by asbestos exposure—mostly in the workplace—will occur in the United States between 1990 and 2020.

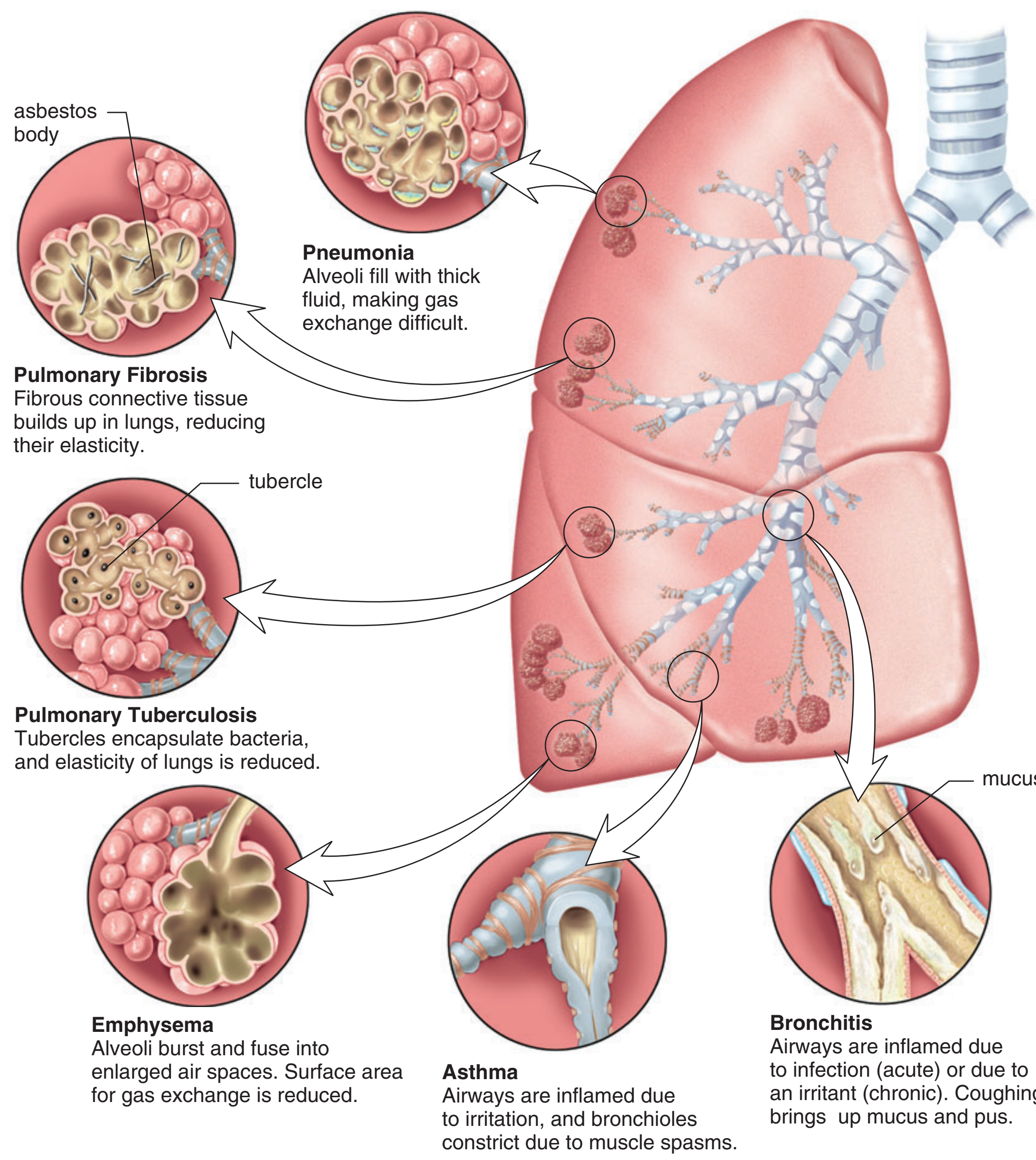


Figure 8.10 **Common bronchial and pulmonary diseases.**
Exposure to infectious pathogens and/or polluted air, including tobacco smoke, causes the diseases and disorders shown here.

Obstructive Pulmonary Disorders

In obstructive pulmonary disorders, air does not flow freely in the airways, and the time it takes to inhale or exhale maximally is greatly increased. Several disorders, including chronic bronchitis, emphysema, and asthma, are collectively referred to as chronic obstructive pulmonary disease (COPD) because they tend to recur.

In **chronic bronchitis,** the airways are inflamed and filled with mucus. A cough that brings up mucus is common. The bronchi have undergone degenerative changes, including the loss of cilia and their normal cleansing action. Under these conditions, an infection is more likely to occur. Smoking is the most frequent cause of chronic bronchitis. Exposure to other pollutants can also cause chronic bronchitis.

Emphysema is a chronic and incurable disorder in which the alveoli are distended and their walls damaged so that the surface area available for gas exchange is reduced. Emphysema is often preceded by chronic bronchitis. Air trapped in the lungs leads to alveolar damage and a noticeable ballooning of the chest. The elastic recoil of the lungs is reduced, so not only are the airways narrowed, but the driving force behind expiration is also reduced. The victim is breathless and may have a cough. Because the surface area for gas exchange is reduced, less oxygen reaches the heart and the brain. Even so, the heart works furiously to force more blood through the lungs, and an increased workload on the heart can result. Lack of oxygen to the brain can make the person feel depressed, sluggish, and irritable. Exercise, drug therapy, supplemental oxygen, and giving up smoking may relieve the symptoms and possibly slow the progression of emphysema.

Asthma is a disease of the bronchi and bronchioles that is marked by wheezing, breathlessness, and sometimes a cough and expectoration of mucus. The airways are unusually sensitive to specific irritants, which can include a wide range of allergens such as pollen, animal dander, dust, tobacco smoke, and industrial fumes. Even cold air can be an irritant. When exposed to the irritant, the smooth muscle in the bronchioles undergoes spasms. It now appears that chemical mediators given off by immune cells in the bronchioles cause the spasms. Most asthma patients have some degree of bronchial inflammation that reduces the diameter of the airways and contributes to the seriousness of an attack. Asthma is not curable, but it is treatable. Special inhalers can control the inflammation and hopefully prevent an attack, while other types of inhalers can stop the muscle spasms should an attack occur.

Lung Cancer

Lung cancer is more prevalent in men than in women, but recently lung cancer has surpassed breast cancer as a cause of death in women. The recent increase in the incidence of lung cancer in women is directly correlated to increased numbers of women who smoke. Autopsies on smokers have revealed the progressive steps by which the most common form of lung cancer develops. The first event appears to be thickening and callusing of the cells lining the bronchi. (Callusing occurs whenever cells are exposed to irritants.) Then cilia are lost, making it impossible to prevent dust and dirt from settling in the lungs. Following this, cells with atypical nuclei appear in the callused lining. A tumor consisting of disordered cells with atypical nuclei is considered cancer in situ (at one location). A normal lung versus a lung with cancerous tumors is shown in Figure 8.11. A final step occurs when some of these cells break loose and penetrate other tissues, a process called metastasis. Now the cancer has spread. The original tumor may grow until a bronchus is blocked, cutting off the supply of air to that lung. The entire lung then collapses, the secretions trapped in the lung spaces become infected, and pneumonia or a lung abscess (localized area of pus) results. The only treatment that offers a possibility of cure is to remove a lobe or the whole lung before metastasis has had time to occur. This operation is called **pneumonectomy.** If the cancer has spread, chemotherapy and radiation are also required.

The Health Focus on page 155 lists the various illnesses, including cancer, that are apt to occur when a person smokes. Current research indicates that passive smoking (secondhand smoke)—exposure to smoke related by others who are smoking—can also cause lung cancer and other illnesses associated with smoking. If a person stops voluntary smoking and avoids passive smoking and if the body tissues are not already cancerous, the lungs may return to normal over time.

a.

b.

Figure 8.11 **Normal lung versus cancerous lung.**
a. Normal lung with heart in place. Note the healthy red color. **b.** Lungs of a heavy smoker. Notice how black the lungs are except where cancerous tumors have formed.

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EQA

Health Focus

The Most Often Asked Questions About Tobacco and Health

Is there a safe way to smoke?

No. All forms of tobacco can cause damage, and smoking even a small amount is dangerous. Tobacco is perhaps the only legal product whose advertised and intended use—that is, smoking it—will hurt the body.

Does smoking cause cancer?

Yes, and not only lung cancer. Besides lung cancer, smoking a pipe, cigarettes, or cigars is also a major cause of cancers of the mouth, larynx (voice box), and esophagus. In addition, smoking increases the risk of cancer of the bladder, kidney, pancreas, stomach, and uterine cervix.

What are the chances of being cured of lung cancer?

Very low; the five-year survival rate is only 13%. Fortunately, lung cancer is a largely preventable disease. In other words, by not smoking, you can probably prevent it.

Does smoking cause other lung diseases?

Yes. It leads to chronic bronchitis, a disease in which the airways produce excess mucus, forcing the smoker to cough frequently. Smoking is also the major cause of emphysema, a disease that slowly destroys a person's ability to breathe. Chances of chronic bronchitis and pulmonary emphysema are higher in smokers than in nonsmokers.

Why do smokers have "smoker's cough"?

Normally, cilia (tiny hair-like formations that line the airways) beat outwards and "sweep" harmful material out of the lungs. Smoke, however, decreases this sweeping action, so some of the poisons in the smoke remain in the lungs.

If you smoke but don't inhale, is there any danger?

Yes. Wherever smoke touches living cells, it does harm. So, even if smokers of pipes, cigarettes, and cigars don't inhale, they are at an increased risk for lip, mouth, and tongue cancer.

Does smoking affect the heart?

Yes. Smoking increases the risk of heart disease, which is the United States' number-one killer. Smoking, high blood pressure, high cholesterol, and lack of exercise are all risk factors for heart disease. Smoking alone doubles the risk of heart disease.

Is there any risk for pregnant women and their babies?

Pregnant women who smoke endanger the health and lives of their unborn babies. When a pregnant woman smokes, she really is smoking for two because the nicotine, carbon monoxide, and other dangerous chemicals in smoke enter her bloodstream and then pass into the baby's body. Smoking mothers have more stillbirths and babies of low birth weight than nonsmoking mothers.

Does smoking cause any special health problems for women?

Yes. Women who smoke and use the birth control pill have an increased risk of stroke and blood clots in the legs. In addition, women who smoke increase their chances of getting cancer of the uterine cervix.

What are some of the short-term effects of smoking cigarettes?

Almost immediately, smoking can make it hard to breathe. Within a short time, it can also worsen asthma and allergies. Only seven seconds after a smoker takes a puff, nicotine reaches the brain, where it produces a morphine-like effect.

Are there any other risks to the smoker?

Yes, there are many more risks. Smoking contributes to the likelihood of stroke, which is the third leading cause of death in the United States. Smokers are more likely to have and die from stomach ulcers than nonsmokers. Smokers have a higher incidence of cancer in general. If a person smokes and is exposed to radon or asbestos, the risk for lung cancer increases dramatically.

What are the dangers of passive smoking?

Passive smoking causes lung cancer in healthy nonsmokers. Children whose parents smoke are more likely to suffer from pneumonia or bronchitis in the first two years of life than children who come from smoke-free households. Passive smokers have a 30% greater risk of developing lung cancer than do nonsmokers who live in a smoke-free house.

Are chewing tobacco and snuff safe alternatives to cigarette smoking?

No, they are not. Many people who use chewing tobacco or snuff believe it can't harm them because there is no smoke. Wrong. Smokeless tobacco contains nicotine, the same addicting drug found in cigarettes and cigars. While not inhaled through the lungs, the juice from smokeless tobacco is absorbed through the lining of the mouth. There it can cause sores and white patches, which often lead to cancer of the mouth. Snuff dippers actually take in an average of over ten times more cancer-causing substances than cigarette smokers.

Bioethical Focus

Bans on Smoking

In 1964, the surgeon general of the United States made it known to the general public that smoking was hazardous to our health and thereafter, a health warning was placed on packs of cigarettes. At that time, 40.4% of adults smoked, but by 1990, only about 26% of adults smoked. In the meantime, however, the public became aware that passive smoking—that is, just being in the vicinity of someone who is smoking—can also lead to cancer and other health problems. By now, many state and local governments have passed legislation that bans smoking in public places such as restaurants, elevators, public meeting rooms, and in the workplace.

Is legislation that restricts the freedom to smoke ethical? Or is such legislation akin to racism and creating a population of second-class citizens who are segregated from the majority on the basis of a habit? Are the desires of nonsmokers being allowed to infringe on the rights of smokers? Or is this legislation one way to help smokers become nonsmokers? One study showed that workplace bans on smoking reduce the daily consumption of cigarettes among smokers by 10%.

Is legislation that disallows smoking in family-style restaurants fair, especially if bars and restaurants associated with casinos are not included in the ban on smoking? The selling of tobacco and even the increased need for health care it generates helps the economy. One smoker writes, "Smoking causes people to drink more, eat more, and leave larger tips. Smoking also powers the economy of Wall Street." Is this a reason to allow smoking to continue? Or should we simply require all places of business to put in improved air filtration systems? Would that do away with the dangers of passive smoking?

Does legislation that bans smoking in certain areas represent government invasion of our privacy? If yes, is reducing the chance of cancer a good enough reason to allow the government to invade our privacy? Some people are prone to cancer more than others. Should we all be regulated by the same legislation? Are we our brother's keeper, meaning that we have to look out for one another?

Decide Your Opinion

1. Is legislation that bans smoking in public places creating a group of second-class citizens whose rights are being denied?
2. Should we be concerned about passing and following legislation that possibly puts a damper on the economy, even if it does improve the health of people?
3. Are bans on smoking an invasion of our privacy? If so, is prevention of cancer in certain persons a good enough reason to risk a possible invasion of our privacy?

Summarizing the Concepts

8.1 The Respiratory System

The respiratory tract consists of the nose (nasal cavities), the nasopharynx, the pharynx, the larynx (which contains the vocal cords), the trachea, the bronchi, the bronchioles, and the lungs. The bronchi, along with the pulmonary arteries and veins, enter the lungs, which consist of the alveoli, air sacs surrounded by a capillary network.

8.2 Mechanism of Breathing

Inspiration begins when the respiratory center in the medulla oblongata sends excitatory nerve impulses to the diaphragm and the muscles of the rib cage. As they contract, the diaphragm lowers, and the rib cage moves upward and outward; the lungs expand, creating a partial vacuum, which causes air to rush in (inspiration). The respiratory center now stops sending impulses to the diaphragm and muscles of the rib cage. As the diaphragm relaxes, it resumes its dome shape, and as the rib cage retracts, air is pushed out of the lungs (expiration).

8.3 Gas Exchanges in the Body

External respiration occurs in the lungs when CO_2 leaves blood via the alveoli and O_2 enters blood from the alveoli. Diffusion accounts for the passage of molecules in different directions: There is more carbon dioxide in pulmonary blood when it enters the lungs than in alveoli, and there is more oxygen in alveoli than in pulmonary blood when it enters the lungs. Because carbon dioxide is present in blood as the bicarbonate ion (HCO_3^-), carbonic acid first forms and is broken down to carbon dioxide and water. Then, carbon dioxide diffuses out of the blood. Oxygen is transported to the tissues in combination with hemoglobin as oxyhemoglobin (HbO_2).

Internal respiration occurs in the tissues when O_2 leaves blood and CO_2 enters blood. When carbon dioxide enters blood, carbonic acid forms and is broken down to the bicarbonate ion (HCO_3^-) and hydrogen ions. Carbon dioxide is mainly carried to the lungs within the plasma as the bicarbonate ion. Hemoglobin combines with hydrogen ions and becomes reduced (HHb).

8.4 Respiration and Health

A number of illnesses are associated with the respiratory tract. These disorders can be divided into those that affect the upper respiratory tract and those that affect the lower respiratory tract. Infections of the nasal cavities, sinuses, throat, tonsils, and larynx are all well known. In addition, infections can spread from the nasopharynx to the ears.

The lower respiratory tract is subject to infections such as acute bronchitis, pneumonia, and pulmonary tuberculosis. In restrictive pulmonary disorders, exemplified by pulmonary fibrosis, the lungs lose their elasticity. In obstructive pulmonary disorders, exemplified by chronic bronchitis, emphysema, and asthma, the bronchi (and bronchioles) do not effectively conduct air to and from the lungs. Smoking, which is associated with chronic bronchitis and emphysema, can eventually lead to lung cancer.

Studying the Concepts

1. Name and explain the four phases of respiration. 142
2. What is the path of air from the nose to the lungs? What are the special functions of the nasal cavity, the larynx, and the alveoli? 143–45
3. What is the difference between tidal volume and vital capacity? Of the air we inhale, some is not used for gas exchange. Why not? 146
4. What are the steps in inspiration and expiration? How is breathing controlled? 148–49
5. Discuss the events of external respiration, and include two pertinent equations in your discussion. 150
6. What two equations pertain to the exchange of gases during internal respiration? 150
7. Name and describe several upper and several lower respiratory tract disorders (other than cancer). If appropriate, explain why breathing is difficult with these conditions. 152–54
8. List the steps by which lung cancer develops. 154

Thinking Critically About the Concepts

Refer to the opening vignette on page 141, and then answer these questions.

1. Why are distance-running performances not as good when the weather is cold?
2. Why are distance-running performances not as good when it is hot?

Testing Your Knowledge of the Concepts

Choose the best answer for each question.

1. Which of these is anatomically incorrect?
   a. The nose has two nasal cavities.
   b. The pharynx connects the nasal and oral cavities to the larynx.
   c. The larynx contains the vocal cords.
   d. The trachea enters the lungs.
   e. The lungs contain many alveoli.
2. How is inhaled air modified before it reaches the lungs?
   a. It must be humidified.
   b. It must be warmed.
   c. It must be filtered.
   d. All of these are correct.
3. What is the name of the structure that prevents food from entering the trachea?
   a. glottis
   b. septum
   c. epiglottis
   d. Adam's apple
4. The maximum volume of air that can be moved in and out during a single breath is called the
   a. expiratory and inspiratory reserve volume.
   b. residual volume.
   c. tidal volume.
   d. vital capacity.
   e. functional residual capacity.
5. Internal respiration refers to
   a. the exchange of gases between alveolar air and the blood in the lungs.
   b. the movement of air into the lungs.
   c. the exchange of gases between the blood and tissue fluid.
   d. cellular respiration, resulting in the production of ATP.
6. The chemical reaction that converts carbon dioxide to a bicarbonate ion takes place in
   a. the blood plasma.
   b. red blood cells.
   c. the alveolus.
   d. the hemoglobin molecule.
7. If air enters the intrapleural space (the space between the pleura),
   a. a lobe of the lung can collapse.
   b. the lungs could swell and burst.
   c. the diaphragm will contract.
   d. nothing will happen because air is needed in the intrapleural space.
8. The enzyme carbonic anhydrase
   a. causes the blood to be more basic in the tissues.
   b. speeds up the conversion of carbonic acid to carbon dioxide and water and the reverse.
   c. actively transports carbon dioxide out of capillaries.
   d. is active only at high altitudes.
   e. All of these are correct.
9. Which of these statements is true?
   a. The P_{O_2}, temperature, and pH are higher in the lungs.
   b. The P_{O_2}, temperature, and pH are lower in the lungs.
   c. The P_{O_2} and temperature are higher and the pH is lower in the lungs.
   d. The P_{O_2} and temperature are lower and the pH is higher in the lungs.
   e. The P_{O_2} and pH are higher, but the temperature is lower in the lungs.
10. Air enters the human lungs because
    a. atmospheric pressure is lower than the pressure inside the lungs.
    b. atmospheric pressure is greater than the pressure inside the lungs.
    c. although the pressures are the same inside and outside, the partial pressure of oxygen is lower within the lungs.
    d. the residual air in the lungs causes the partial pressure of oxygen to be lower than it is outside.
11. In humans, the respiratory center
    a. is stimulated by carbon dioxide.
    b. is located in the medulla oblongata.
    c. controls the rate of breathing.
    d. All of these are correct.

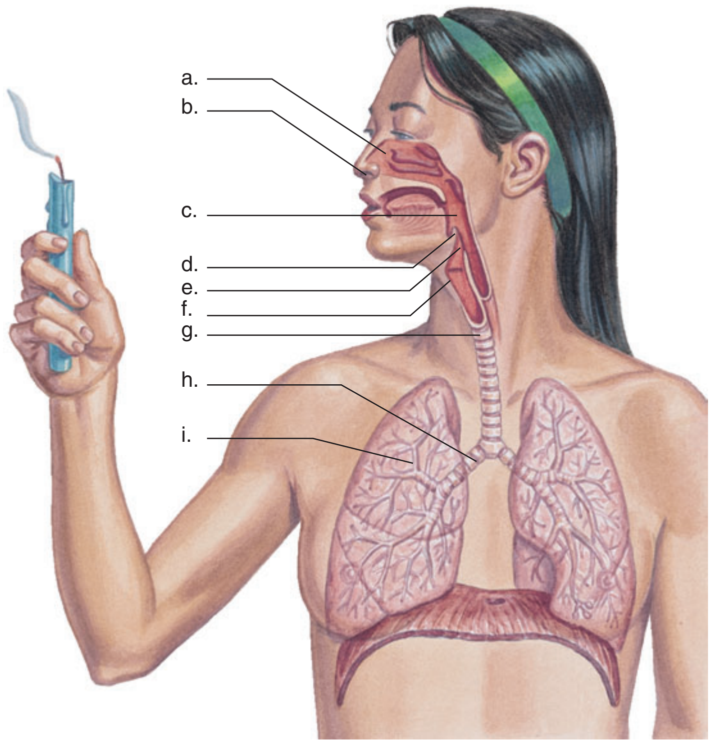
In questions 12–16, match each description with a structure in the key.

Key:

a. pharynx
b. glottis
c. larynx
d. trachea
e. bronchi
f. bronchioles

12. Branched tubes that lead from bronchi to the alveoli
13. Reinforced tube that connects larynx with bronchi

14. Chamber behind oral cavity and between nasal cavity and larynx
15. Opening into larynx
16. Divisions of the trachea that enter lungs
17. Which of these is incorrect concerning inspiration?
    a. Rib cage moves up and out.
    b. Diaphragm contracts and moves down.
    c. Pressure in lungs decreases, and air comes rushing in.
    d. The lungs expand because air comes rushing in.
18. Label this diagram of the human respiratory tract.



Understanding Key Terms

acute bronchitis 152
alveolus 145
aortic body 149
asthma 154
auditory (Eustachian) tube 152
bicarbonate ion 150
bronchiole 145
bronchus 145
carbaminohemoglobin 150
carbonic anhydrase 150
carotid body 149
chronic bronchitis 153
dead air space 146
emphysema 153
epiglottis 144
expiration 142
expiratory reserve volume 146
external respiration 150
glottis 144
infant respiratory distress syndrome 145
inspiration 142
inspiratory reserve volume 146
internal respiration 150
laryngitis 152
larynx 144
lung cancer 154
lungs 145
nasal cavity 143
otitis media 152
oxyhemoglobin 150
pharynx 143
pneumonectomy 154
pneumonia 152
pulmonary fibrosis 153
pulmonary tuberculosis 152
reduced hemoglobin 150
residual volume 146
respiratory center 149
sinusitis 152
surfactant 145
tidal volume 146
tonsillectomy 152
tonsillitis 152
tonsils 152
trachea 144
tracheostomy 144
ventilation 142
vital capacity 146
vocal cord 144

Match the key terms to these definitions.

a. ________ Common passageway for both food intake and air movement, located between the mouth and the esophagus.

b. ________ Sensory receptor in the aortic arch sensitive to the O_2 content of the blood.

c. ________ Fold of tissue across the glottis within the larynx; creates vocal sounds when it vibrates.

d. ________ Form in which most of the carbon dioxide is transported in the bloodstream.

e. ________ Stage during breathing when air is pushed out of the lungs.

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