CHAPTER 15

# Respiratory System

## Chapter Concepts

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*CPR (cardiopulmonary resuscitation) is an artificial means to maintain breathing and keep the blood flowing until a person has recovered the ability to do so.*

*Luckily the police arrived just moments after Tommy was rescued from the pond by his mother. A policeman immediately began CPR, alternately using a resusitator to give him oxygen and then pushing on his chest to have him breathe out. Eventually, Tommy could breathe on his own. All cells of the body require a constant supply of oxygen, and you have to keep breathing in order to bring oxygen into the body. Any cessation of breathing is a cause for concern, and prolonged cessation usually results in death. The heart needs oxygen to pump the blood that carries oxygen to all the cells of the body.*

*Cells use oxygen for cellular respiration, the process that replenishes their limited supply of ATP, without which they have no energy and cannot keep functioning. Carbon dioxide, an end product of cellular respiration, moves in the opposite direction—from the cells to the lungs, where it is expired. In this chapter, the structures and functions of the respiratory system are considered. Also, some of the medical conditions that decrease the functioning of the system will be discussed.*

# 15.1 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 15.1.

The respiratory system also works with the cardiovascular system to accomplish respiration, which consists of:

1. Breathing: entrance and exit of air into and out of lungs.
2. External respiration: exchange of gases (oxygen and carbon dioxide) between air and blood.
3. Internal respiration: exchange of gases between blood and tissue fluid.
4. Cellular respiration: production of ATP in cells.

Cellular respiration uses the oxygen and produces the carbon dioxide that makes gas exchange with the environment necessary. Without a continuous supply of ATP, the cells cease to function. The functioning of the first three portions of respiration allow cellular respiration to continue. In this chapter, we study the first three portions of the respiratory process. Cellular respiration was discussed in chapter 7.

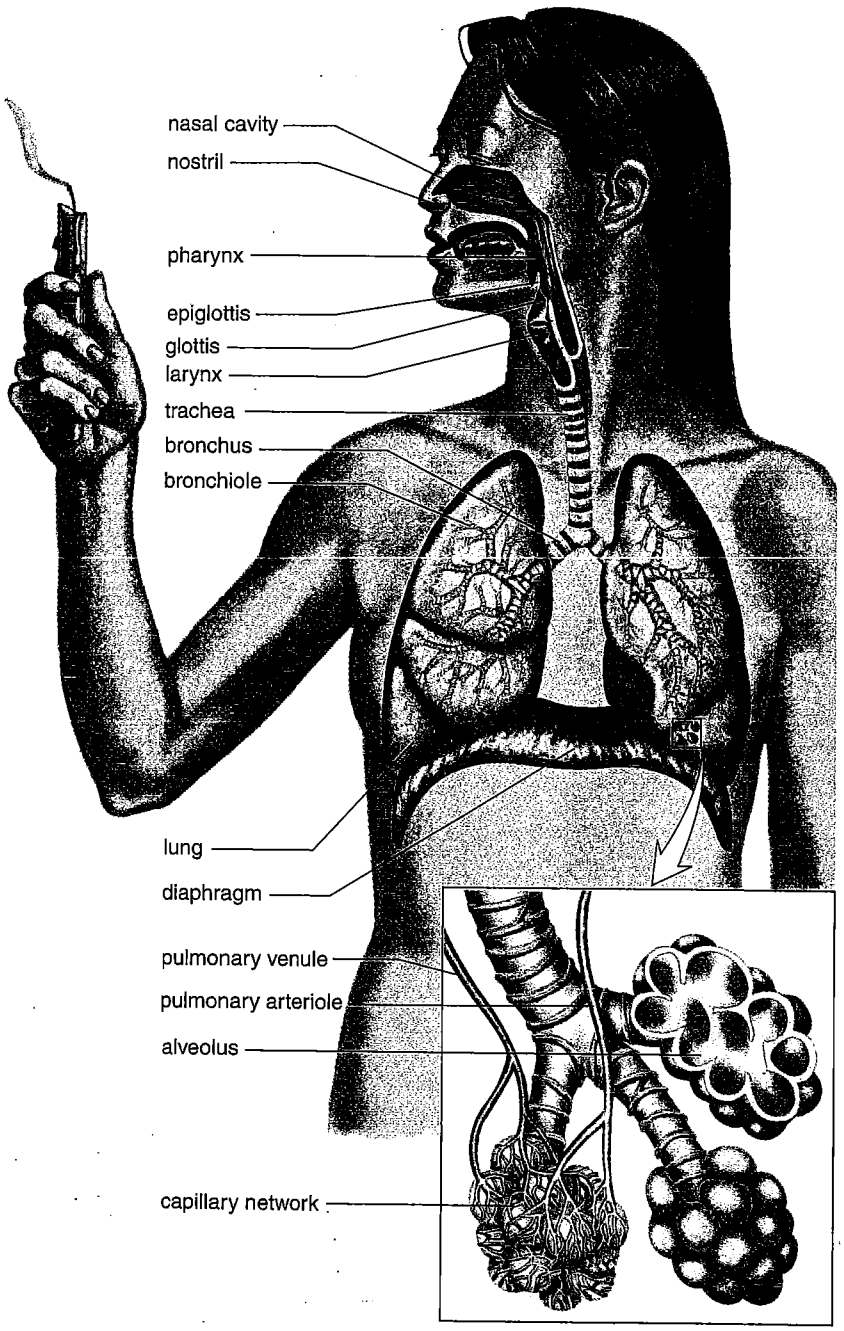



**Figure 15.1 The respiratory tract.**
The respiratory tract extends from the nose to the lungs, which are composed of air sacs called alveoli. Gas exchange occurs between air in the alveoli and blood within a capillary network that surrounds the alveoli. Notice that the pulmonary arteriole is colored 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 alveoli toward the heart.

## The Respiratory Tract

Table 15.1 traces the path of air from the nose to the lungs. As air moves in 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 alone 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 surface of 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 windpipe 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.

### *The Nose*

The nose contains two **nasal cavities,** which are narrow canals separated from one another by a septum composed of bone and cartilage (Fig. 15.2).

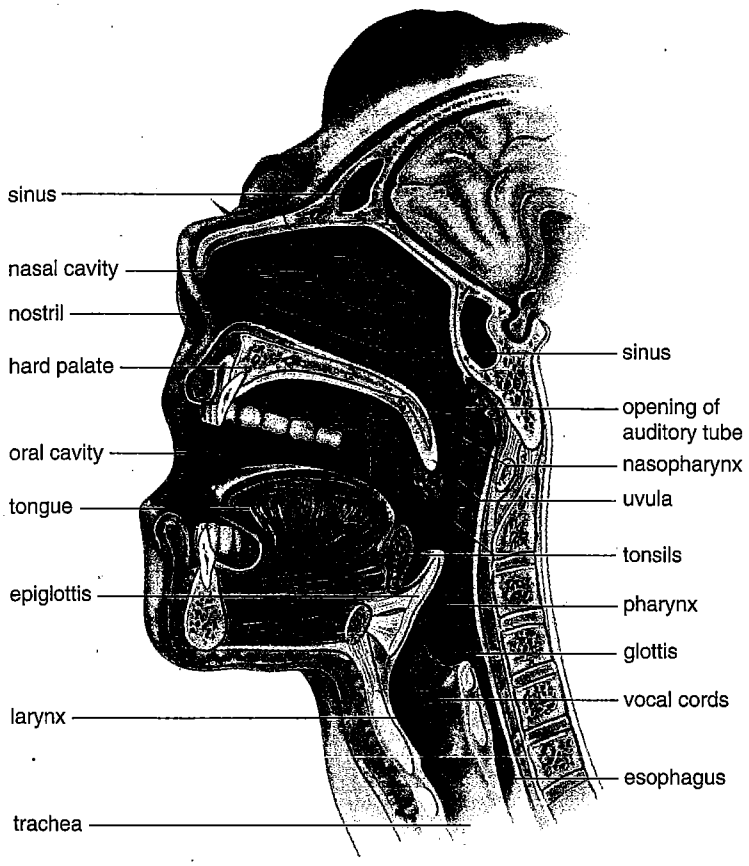



**Figure 15.2 The path of air.**
This drawing shows the path of air from the nasal cavities to the trachea, which is a part of the lower respiratory tract. The other organs are in the upper respiratory tract.

**Table 15.1 Path of Air**

| Structure | Description | Function |
|---|---|---|
| ***The Upper Respiratory Tract*** | | |
| Nasal cavities | Hollow spaces in nose | Filter, warm, and moisten air |
| Pharynx | Chamber behind oral cavity and between nasal cavity and larynx | Connection to surrounding regions |
| Glottis | Opening into larynx | Passage of air into larynx |
| Larynx | Cartilaginous organ that contains vocal cords; voice box | Sound production |
| ***The Lower Respiratory Tract*** | | |
| Trachea | Flexible tube that connects larynx with bronchi; windpipe | Passage of air to bronchi |
| Bronchi | Divisions of the trachea that enter lungs | Passage of air to lungs |
| Bronchioles | Branched tubes that lead from bronchi to alveoli | Passage of air to each alveolus |
| Lungs | Soft, cone-shaped organs that occupy a large portion of the thoracic cavity | Gas exchange |

Special ciliated cells in the narrow upper recesses of the nasal cavities act as 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, mucus 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 lymphoid 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 the passage of air, but the esophagus is normally closed and opens only when swallowing occurs.

The path of air starts with the nasal cavities and ends with the lungs. Air from either the nose or the mouth enters the pharynx, as does food. The passage of air continues in the larynx and then in the trachea.

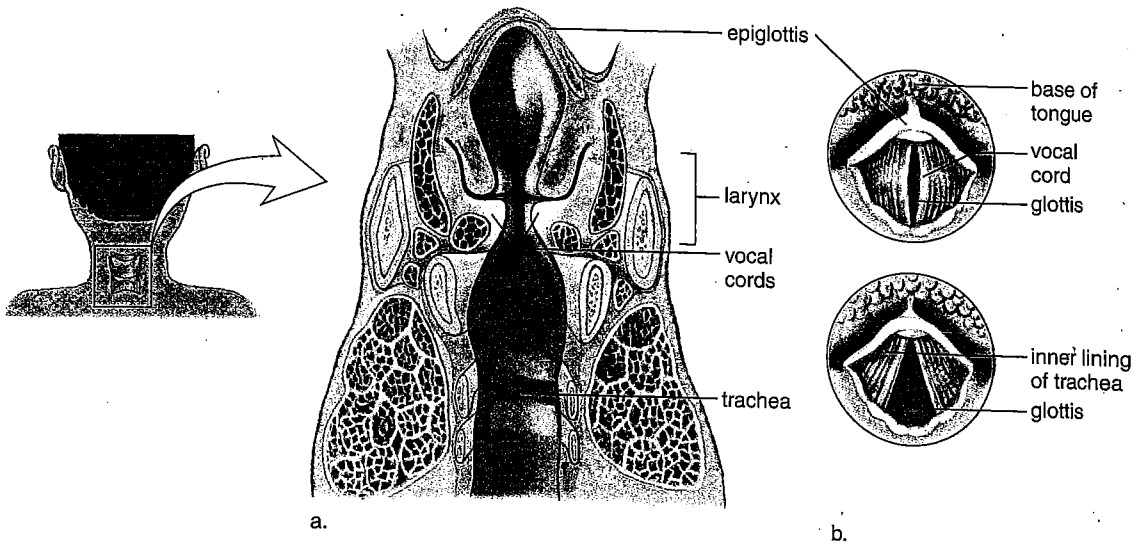



**Figure 15.3 Placement of the vocal cords.**
**a.** Frontal section of the larynx shows the location of the vocal cords. **b.** Viewed from above, it can be seen that the vocal cords are stretched across the glottis. When air passes through the glottis, the vocal cords vibrate, producing sound. The glottis is narrow when we produce a high-pitched sound *(top)*, and it widens as the pitch deepens *(bottom)*.

## The Larynx

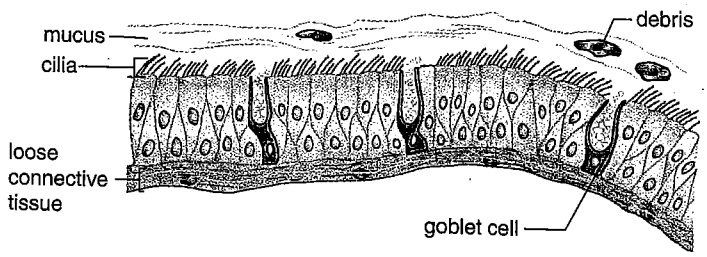
The **larynx** is a cartilaginous boxlike structure that serves as a passageway for air between the pharynx and the trachea. The larynx can be pictured as a triangular box whose apex, the Adam's apple, is located at the front of the neck. At the top of the larynx is a variable-sized opening called the **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. 15.3). 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 more narrow, the higher the pitch. When the glottis is wider, the pitch is lower (Fig. 15.3*b*). 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

The **trachea,** commonly called the windpipe, is a tube connecting the larynx to the primary bronchi. The trachea lies ventral to the esophagus and is held open by C-shaped cartilaginous rings. The open part of the C-shaped rings faces the esophagus, and this allows the esophagus to expand when swallowing. The mucosa that lines the trachea has a 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:




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 297.

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.**

## The Bronchial Tree

The trachea divides into right and left primary bronchi (sing., **bronchus**), which lead into the right and left lungs (see Fig. 15.1). 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 terminates in an elongated space enclosed by a multitude of air pockets, or sacs, called alveoli (sing., **alveolus**). The alveoli make up the lungs.

## The Lungs

The **lungs** are paired, cone-shaped organs that lie on either side of the heart within the thoracic cavity. The right lung has three lobes, and the left lung has two lobes, allowing room for the heart, which is on the left side of the body. A lobe is further divided into lobules, and each lobule has a bronchiole serving many alveoli. The base of each lung is broad and concave so that it fits the convex surface of the diaphragm. The other surfaces of the lungs follow the contours of the ribs and the diaphragm in the thoracic cavity.

### *The Alveoli*

Each alveolar sac is made up of simple squamous epithelium surrounded by blood capillaries. Gas exchange occurs between air in the alveoli and blood in the capillaries (Fig. 15.4). 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.

There are altogether about 300 million alveoli, with a total cross-sectional area of 50–70 $m^2$. This is the surface area of a typical classroom and at least 40 times the surface area of the skin. Because of their many air spaces, the lungs are very light; normally, a piece of lung tissue dropped in a glass of water floats.

The trachea divides into the primary bronchi, which divide repeatedly to give rise to the bronchioles. The bronchioles have many branches and terminate at the alveoli, which make up the lungs.

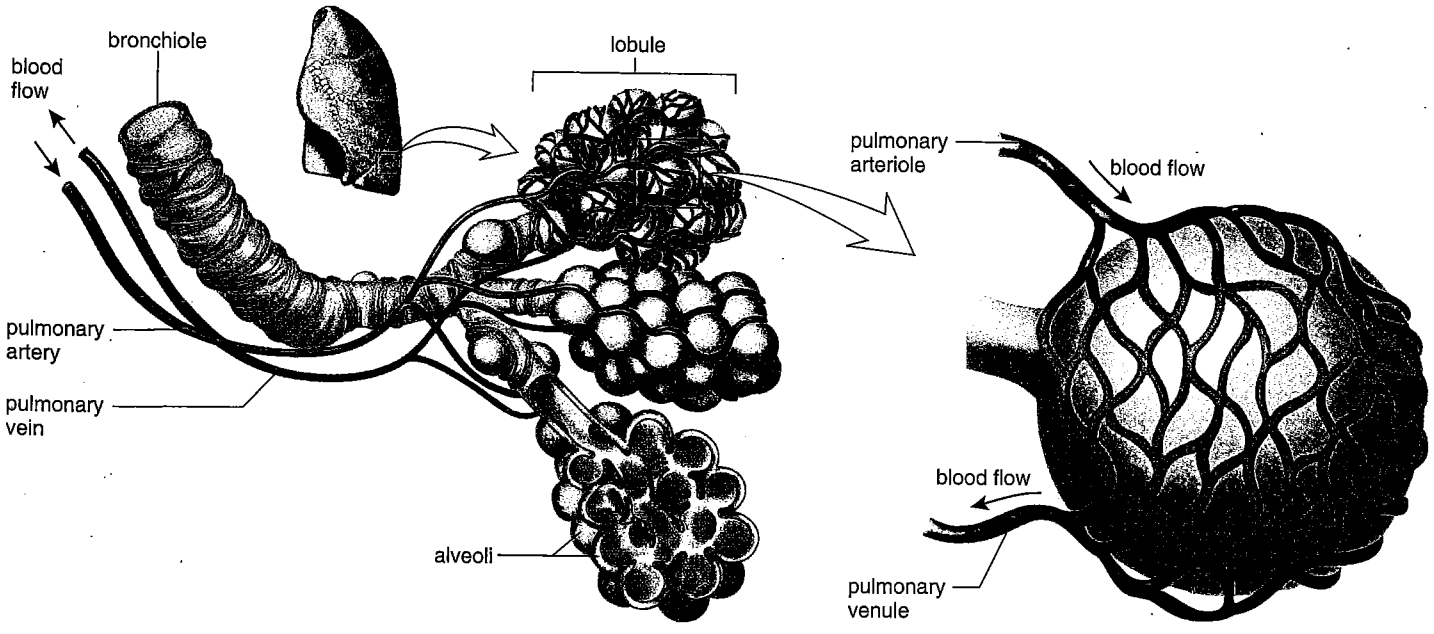



**Figure 15.4 Gas exchange in the lungs.**
The lungs consist of alveoli surrounded by an extensive capillary network. Notice that the pulmonary arteriole carries $O_2$-poor blood (colored blue), and the pulmonary venule carries $O_2$-rich blood (colored red).