17

Respiratory System

Clinical Case Study

A 37-year-old dock worker was brought to the emergency room after having been stabbed above the left clavicle with an ice pick. The patient's main complaint was pain in the left side of the chest. Initial evaluation revealed a minute puncture wound superior to the left clavicle, just lateral to the sternocleidomastoid muscle. The vital signs were normal except for a moderately high respiratory rate. The chest radiograph showed the left lung to be surrounded by blood and air, a condition known as *hemopneumothorax* (*he''mo-noo''mo-thor'aks*), and collapsed to half its normal size.

Explain how the air got inside the thoracic cavity (assuming it did not enter through the puncture wound). What is the term for the space where the air and blood are located? What membranes define this space?

FIGURE: The thoracic viscera and their associated serous membranes present interesting anatomical, functional, and clinical relationships. Localized trauma frequently causes extensive and predictable problems elsewhere.

INTRODUCTION TO THE RESPIRATORY SYSTEM

The respiratory system can be divided structurally into upper and lower divisions, and functionally into a conducting division and a respiratory division. The principal functions of the respiratory system are gaseous exchange, sound production, and assistance in abdominal compression.

Objective 1 Describe the functions associated with the term *respiration.*

Objective 2 Identify the organs of the respiratory system and describe their locations.

Objective 3 List the functions of the respiratory system.

The term *respiration* refers to three separate but related functions: (1) **ventilation** (breathing); (2) **gas exchange,** which occurs between the air and blood in the lungs and between the blood and other tissues of the body; and (3) **oxygen utilization** by the tissues in the energy-liberating reactions of cell respiration. Ventilation and the exchange of gases (oxygen and carbon dioxide) between the air and blood are collectively called *external respiration*. Gas exchange between the blood and other tissues are collectively known as *internal respiration*.

A relaxed adult breathes an average of 15 times a minute, ventilating approximately 6 liters of air during this period. This amounts to over 8,000 liters in a 24-hour period. Strenuous exercise increases the demand for oxygen and increases the respiratory rate fifteenfold to twentyfold, so that about 100 liters of air are breathed each minute. If breathing stops, a person will lose consciousness after 4 or 5 minutes. Brain damage may occur after 7 to 8 minutes, and the person will die after 10 minutes. Knowledge of the structure and function of the respiratory system is therefore of the utmost importance in a clinical setting.

Physical Requirements of the Respiratory System

The respiratory system includes those organs and structures that function together to bring gases in contact with the blood of the circulatory system. In order to be effective, the respiratory system must comply with certain physical requirements.

- The surface for gas exchange must be located deep within the body so that incoming air will be sufficiently warmed, moistened, and cleansed of airborne particles before coming in contact with it.
- The membrane must be thin-walled and selectively permeable so that diffusion can occur easily.
- The membrane must be kept moist so that oxygen and carbon dioxide can be dissolved in water to facilitate diffusion.
- The system must have an extensive capillary network.
- The system must include an effective ventilation mechanism to constantly replenish the air.
- The system must function autonomically through effective monitoring and feedback mechanisms. However, it must also be able to function voluntarily for desired increased or decreased rates.

The respiratory system adequately meets all of these requirements, thus ensuring that all of the trillions of cells of the body will be able to carry on the metabolic processes necessary to maintain life.

Functions of the Respiratory System

The four basic functions of the respiratory system, not all of which are associated with breathing, are as follows:

- It provides oxygen to the bloodstream and removes carbon dioxide.
- It enables sound production or vocalization as expired air passes over the vocal folds.
- It assists in abdominal compression during micturition (urination), defecation (passing of feces), and parturition (childbirth). The abdominal muscles become more effective during a deep breath when the air is held in the lungs by closing the glottis and fixing the diaphragm. This same technique is used when lifting a heavy object, in which case the diaphragm indirectly assists the back muscles.
- It enables protective and reflexive nonbreathing air movements, as in coughing and sneezing, to keep the air passageways clean.

Basic Structure of the Respiratory System

The major passages and structures of the respiratory system are the *nasal cavity, pharynx, larynx* and *trachea,* and the *bronchi, bronchioles*, and *pulmonary alveoli* within the *lungs* (fig. 17.1).

The structures of the **upper respiratory system** include the nose, pharynx, and associated structures; the **lower respiratory system** includes the larynx, trachea, bronchial tree, pulmonary alveoli, and lungs.

On the basis of general function, the respiratory system is frequently divided into a conducting division and a respiratory division. The **conducting division** includes all of the cavities and structures that transport gases to and from the pulmonary alveoli. The **respiratory division** consists of the pulmonary alveoli, which are the functional units of the respiratory system where gas exchange between the air and the blood occur.

Early Greek and Roman scientists placed great emphasis on the invisible material that was breathed in. They knew nothing about oxygen or the role of the blood in transporting this vital substance to cells. For that matter, they knew nothing about microscopic structures like cells because the microscope had not yet been invented. They did know, however, that respiration was essential for life. Early Greeks referred to air as an intangible, divine spirit called *pneuma.* In Latin, the term for breath, *spiritus,* meant lifeforce.

respiration: L. *re,* back; *spirare,* to breathe

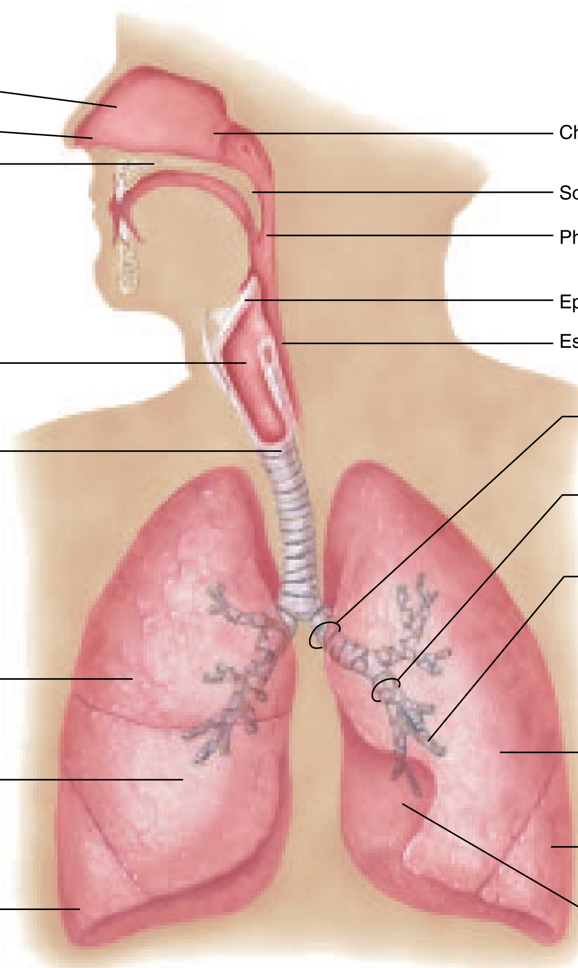


FIGURE 17.1 The basic anatomy of the respiratory system.

Knowledge Check

1. Define the terms *external respiration* and *internal respiration*.
2. What are the physical requirements of the respiratory system? What are its basic functions?
3. List in order the major passages and structures through which inspired air would pass from the nostrils to the pulmonary alveoli of the lungs.

CONDUCTING PASSAGES

Air is conducted through the oral and nasal cavities to the pharynx, and then through the larynx to the trachea and bronchial tree. These structures deliver warmed and humidified air to the respiratory division within the lungs.

Objective 4 List the types of epithelial tissue that characterize each region of the respiratory tract and comment on the significance of the special attributes of each type.

Objective 5 Identify the boundaries of the nasal cavity and discuss the relationship of the paranasal sinuses to the rest of the respiratory system.

Objective 6 Describe the three regions of the pharynx and identify the structures located in each.

Objective 7 Discuss the role of the laryngeal region in digestion and respiration.

Objective 8 Identify the anatomical features of the larynx associated with sound production and respiration.

The conducting passages serve to transport air to the respiratory structures of the lungs. The passageways are lined with various

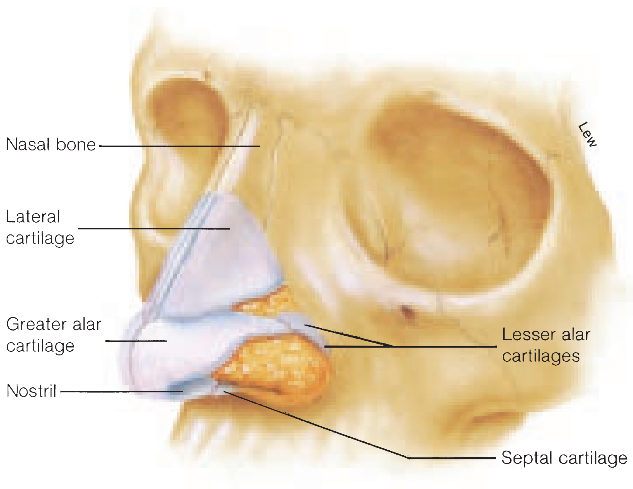


FIGURE 17.2 The supporting framework of the nose.

types of epithelia that cleanse, warm, and humidify the air. The majority of the conducting passages are held permanently open by muscle or a bony or cartilaginous framework.

Nose

The **nose** includes an external portion that protrudes from the face and an internal **nasal cavity** for the passage of air. The external portion of the nose is covered with skin and supported by paired **nasal bones,** which form the bridge, and pliable cartilage, which forms the distal portions (fig. 17.2). The **septal cartilage** forms the anterior portion of the **nasal septum,** and the paired **lateral cartilages** and **alar cartilages** form the framework around the **nostrils.**

The **vomer** and the perpendicular plate of the **ethmoid bone** (see fig. 6.17), together with the septal cartilage, constitute the supporting framework of the nasal septum, which divides the nasal cavity into two lateral halves. Each half is referred to as a **nasal fossa.** The **nasal vestibule** is the anterior expanded portion of the nasal fossa (fig. 17.3).

nose: O.E. *nosu,* nose
nostril: O.E. *nosu,* nose; *thyrel,* hole

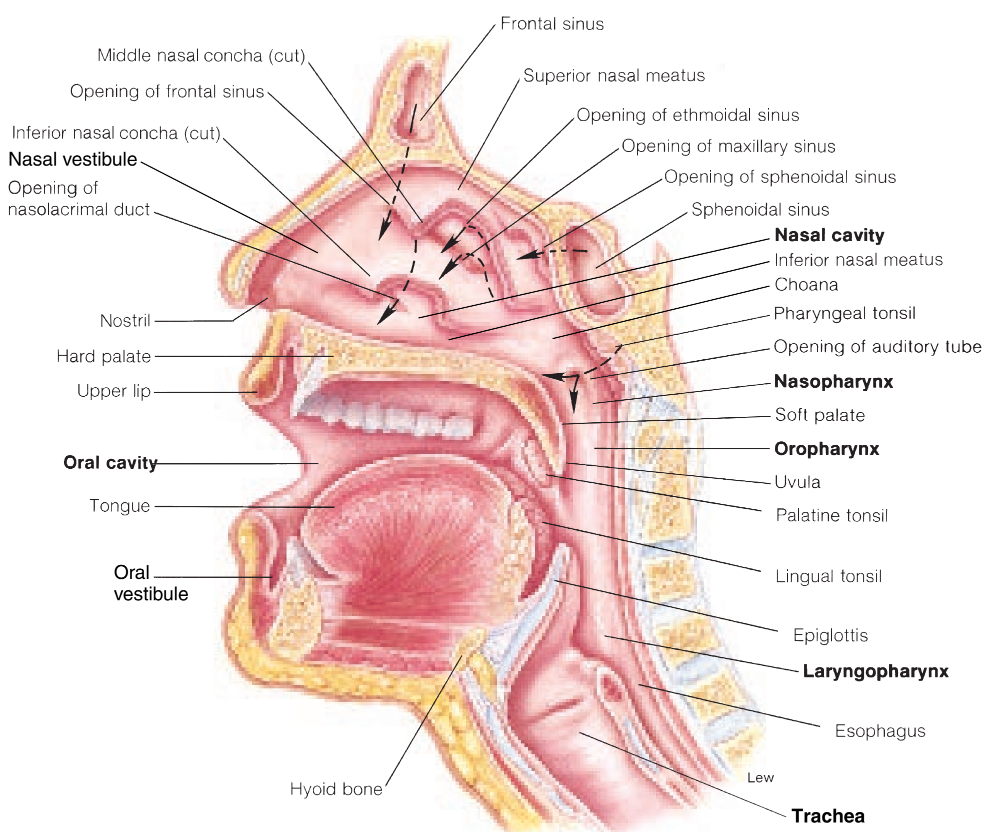


FIGURE 17.3 A sagittal section of the head showing the structures of the upper respiratory tract. There are several openings into the nasal cavity, including the openings of the various paranasal sinuses, those of the nasolacrimal ducts that drain from the eyes, and those of the auditory tubes that drain from the tympanic cavities. (The drainage pathways are indicated with arrows.)

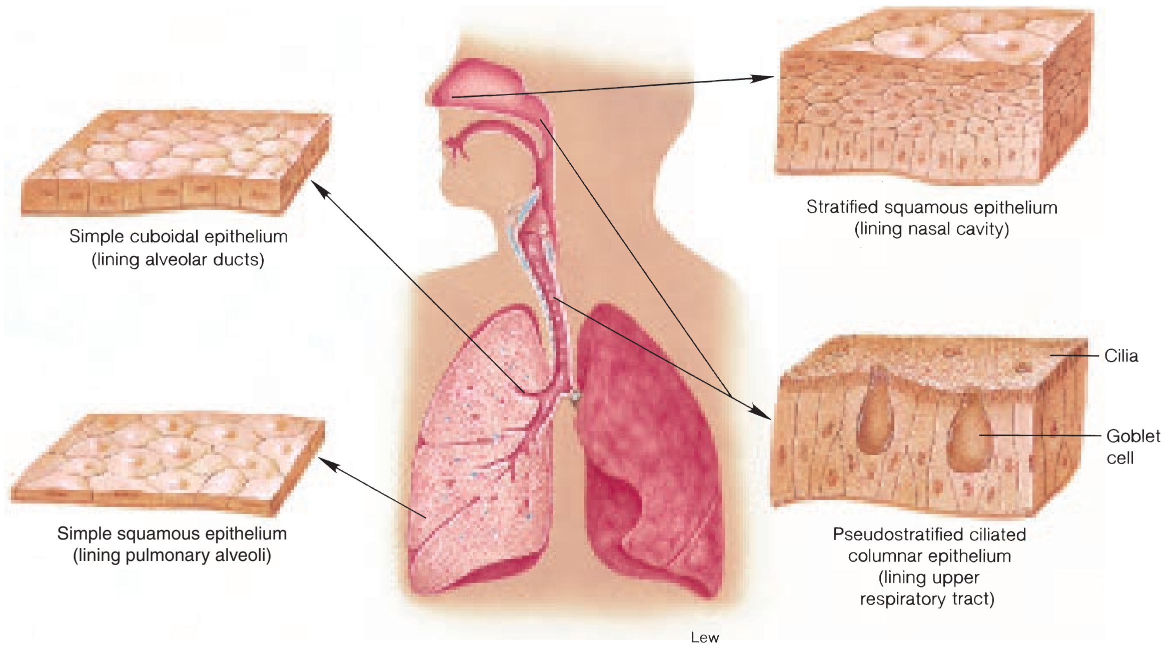


FIGURE 17.4 The various types of epithelial tissue found throughout the respiratory system.

Each nasal fossa opens anteriorly through the **nostril** (*naris; exteral nares*), and communicates posteriorly with the **nasopharynx** through the **choana** (*ko-a'nă*), (*internal nares*). The roof of the nasal cavity is formed anteriorly by the frontal bone and paired nasal bones, medially by the cribriform plate of the ethmoid bone, and posteriorly by the sphenoid bone (see figs. 6.17 and 6.20). The palatine and maxillary bones form the floor of the cavity. On the lateral walls of the nasal cavity are three bony projections, the **superior, middle,** and **inferior nasal conchae** (*kong'ke*), or **turbinates** (see fig. 6.26). Air passages between the conchae are referred to as **nasal meatuses** (*me-a'tuses*) (fig. 17.3). The anterior openings of the nasal cavity are lined with stratified squamous epithelium, whereas the conchae are lined with pseudostratified ciliated columnar epithelium (figs. 17.4 and 17.5). Mucus-secreting goblet cells are present in great abundance throughout both regions.

The three functions of the nasal cavity and its contents are as follows:

- The nasal epithelium covering the conchae serves to warm, moisten, and cleanse the inspired air. The nasal epithelium is highly vascular and covers an extensive surface area. This is important for warming the air but unfortunately also makes humans susceptible to nosebleeds because the nasal mucosa may dry and crack. Nasal hairs called **vibrissae** (*vi-bris'e*), which often extend from the nostrils, filter macroparticles that might otherwise be inhaled. Dust, pollen, smoke, and other fine particles are trapped along the moist mucous membrane lining the nasal cavity.
- The olfactory epithelium in the upper medial portion of the nasal cavity is concerned with the sense of smell.
- The nasal cavity affects the voice by functioning as a resonating chamber.

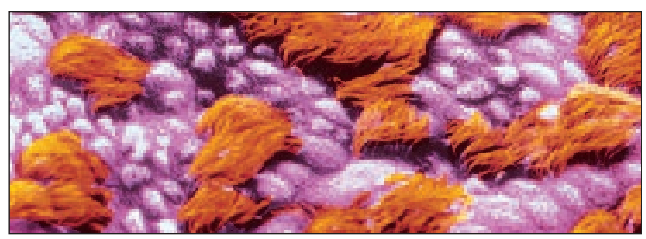


FIGURE 17.5 A color-enhanced scanning electron micrograph of a bronchial wall showing cilia. In the trachea and bronchi, there are about 300 cilia per cell. The cilia move mucus-dust particles toward the pharynx, where they can either be swallowed or expectorated.

choana: Gk. *choane*, funnel
concha: L. *choncha*, mussel shell
vibrissa: L. *vibrare*, to vibrate

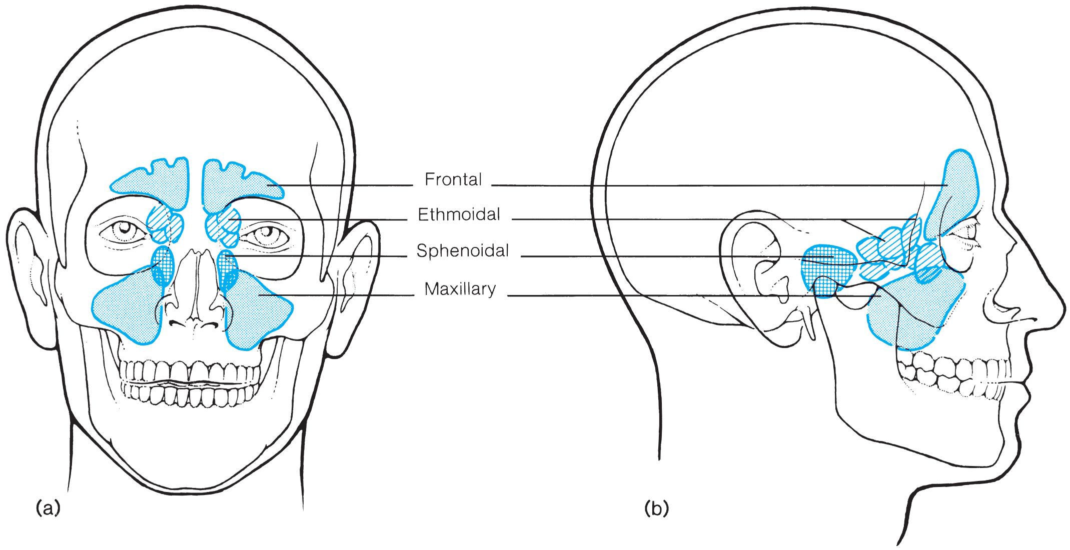


FIGURE 17.6 The paranasal sinuses.

There are several drainage openings into the nasal cavity (see fig. 17.3). The paranasal ducts (discussed below) drain mucus from the paranasal sinuses, and the nasolacrimal ducts drain tears from the eyes (see fig. 15.11). An excessive secretion of tears causes the nose to run as the tears drain into the nasal cavity. The auditory tube from the tympanic cavity enters the upper respiratory tract posterior to the nasal cavity in the nasopharynx. With all these accessory connections, it is no wonder that infections can spread so easily from one chamber to another throughout the facial area. To avoid causing damage or spreading infections to other areas, one must be careful not to blow the nose too forcefully.

Paranasal Sinuses

Paired air spaces in certain bones of the skull are called **paranasal sinuses.** These sinuses are named according to the bones in which they are found; thus, there are the **maxillary, frontal, sphenoidal,** and **ethmoidal sinuses** (fig. 17.6). Each sinus communicates via drainage ducts within the nasal cavity on its own side (see figs. 6.17, 6.20, and 17.3). Paranasal sinuses may help warm and moisten the inspired air. These sinuses are responsible for some sound resonance, but most important, they function to decrease the weight of the skull while providing structural strength.

You can observe your own paranasal sinuses. Face a mirror in a darkened room and shine a small flashlight into your face. The frontal sinuses will be illuminated by directing the light just below the eyebrow. The maxillary sinuses are illuminated by shining the light into the oral cavity and closing your mouth around the flashlight.

sinus: L. *sinus*, bend or curve

Pharynx

The **pharynx** (*far′ingks*) is a funnel-shaped organ, approximately 13 cm (5 in.) long, that connects the nasal and oral cavities to the larynx of the respiratory system and the esophagus of the digestive system. The supporting walls of the pharynx are composed of skeletal muscle, and the lumen is lined with a mucous membrane. Within the pharynx are several paired lymphoid organs called **tonsils.** Commonly referred to as the "throat" or "gullet," the pharynx has both respiratory and digestive functions. It also provides a resonating chamber for certain speech sounds. The pharynx is divided on the basis of location and function into three regions (see fig. 17.3).

- The **nasopharynx** serves only as a passageway for air, because it is located above the point of food entry into the body (the mouth). It is the uppermost portion of the pharynx, positioned directly behind the nasal cavity and above the soft palate. A pendulous **uvula** (*yoo′vyŭ-lă*) hangs from the middle lower portion of the soft palate. The paired **auditory** (eustachian) **tubes** connect the nasopharynx with the tympanic cavities. The **pharyngeal tonsils,** or **adenoids,** are situated in the posterior wall of the nasal cavity.

  During the act of swallowing, the soft palate and uvula are elevated to block the nasal cavity and prevent food from entering. Occasionally a person may suddenly exhale air (as

pharynx: L. *pharynx*, throat
tonsil: L. *toles*, goiter or swelling
uvula: L. *uvula*, small grape
adenoid: Gk. *adenoeides*, glandlike

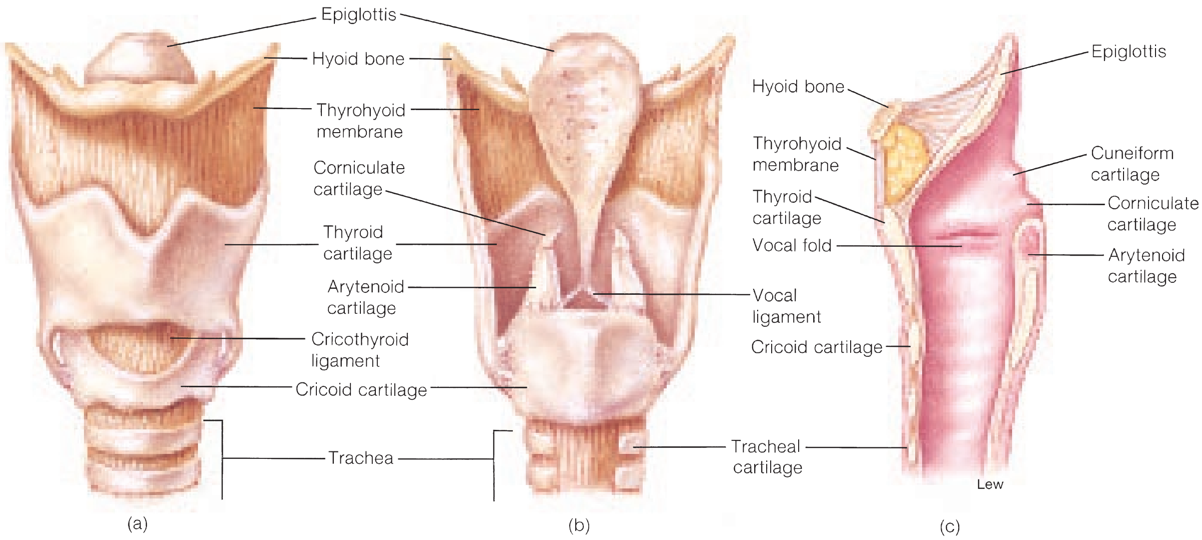


FIGURE 17.7 The structure of the larynx. (*a*) An anterior view, (*b*) a posterior view, and (*c*) a sagittal view.

with a laugh) while in the process of swallowing fluid. If this occurs before the uvula effectively blocks the nasopharynx, fluid will be discharged through the nasal cavity.

- The **oropharynx** is the middle portion of the pharynx between the soft palate and the level of the hyoid bone. Both swallowed food and fluid and inhaled air pass through it. The base of the tongue forms the anterior wall of the oropharynx. Paired **palatine tonsils** are located on the posterior lateral wall, and the **lingual tonsils** are found on the base of the tongue.
- The **laryngopharynx** (*lă-ring''go-far'ingks*) is the lowermost portion of the pharynx. It extends inferiorly from the level of the hyoid bone to the larynx and opens into the esophagus and larynx. It is at the lower laryngopharynx that the respiratory and digestive systems become distinct. Swallowed food and fluid are directed into the esophagus, whereas inhaled air is directed anteriorly into the larynx.

During a routine physical examination, the physician will commonly depress the patient's tongue and examine the condition of the palatine tonsils. Tonsils are lymphoid organs and tend to become swollen and inflamed after persistent infections. If after periods of infection, the tonsils become so large as to obstruct breathing, they may have to be surgically removed. The removal of the palatine tonsils is called a *tonsillectomy,* whereas the removal of the pharyngeal tonsils is called an *adenoidectomy* (*ad''ĕ-noid-ek'tŏ-me*).

Larynx

The **larynx** (*lar'ingks*), or "voice box," is a continuation of the conducting division that connects the laryngopharynx with the trachea. It is positioned in the anterior midline of the neck at the level of the fourth through sixth cervical vertebrae. The larynx has two functions. Its primary function is to prevent food or fluid from entering the trachea and lungs during swallowing and to permit passage of air while breathing. A secondary role is to produce sound.

Laryngitis is the inflammation of the mucosal epithelium of the larynx and vocal folds, which causes a hoarseness of a person's voice or an inability to speak above a whisper. Laryngitis may result from overuse of the voice, inhalation of an irritating chemical, or a bacterial or viral infection. Mild cases are temporary and seldom of major concern.

The larynx is shaped like a triangular box (fig. 17.7). It is composed of a framework involving nine cartilages: three are large unpaired structures, and six are smaller and paired. The largest of the unpaired cartilages is the anterior **thyroid cartilage.** The **laryngeal prominence** of the thyroid cartilage is commonly called the "Adam's apple." It is an anterior vertical ridge along the larynx that can be palpated on the midline of the neck. The thyroid cartilage is typically larger and more prominent in males than in females because of the effect of male sex hormones on the development of the larynx during puberty.

The spoon-shaped **epiglottis** (*ep''ĭ-glot'is*) has a framework of hyaline cartilage, referred to as the *epiglottic cartilage*. The epiglottis is located behind the root of the tongue where it aids in closing the **glottis,** or laryngeal opening, during swallowing.

The entire larynx elevates during swallowing to close the glottis against the epiglottis. This movement can be noted by cupping the fingers lightly over the larynx and then swallowing. If the glottis is not closed as it should be during swallowing, food may become lodged within the glottis. In this case, the *abdominal thrust* (Heimlich) *maneuver* can be used to prevent suffocation. (See "Clinical Considerations" for how to perform this maneuver.)

larynx: Gk. *larynx*, upper windpipe

thyroid: Gk. *thyreos*, shieldlike

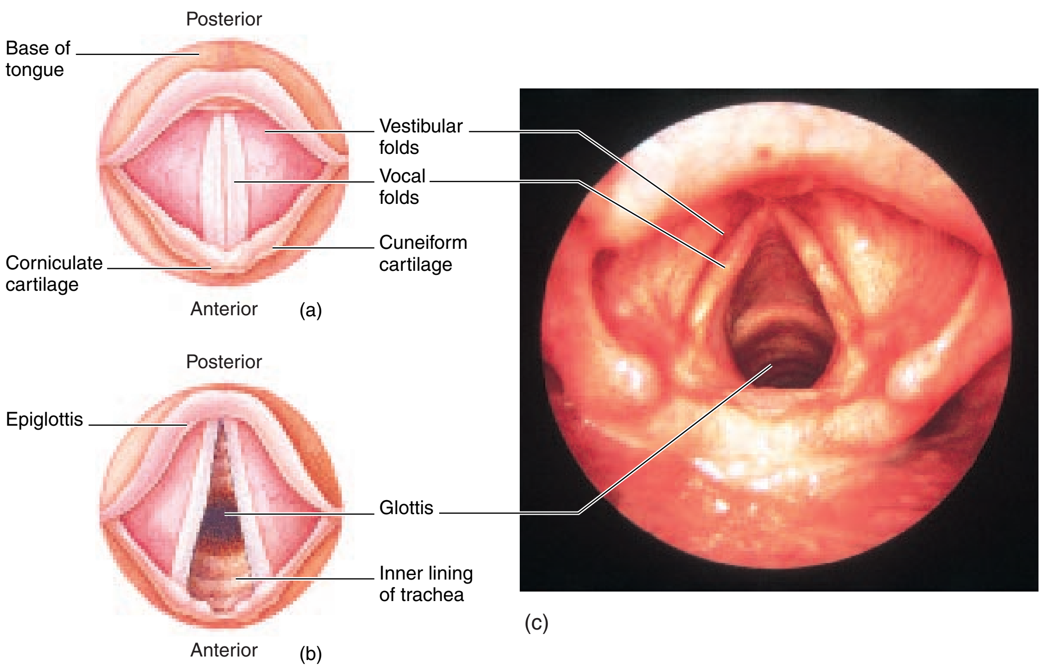


FIGURE 17.8 A superior view of the vocal folds (vocal cords). In (*a*) the vocal folds are taut; in (*b*) they are relaxed and the glottis is opened. (*c*) A photograph through a laryngoscope showing the glottis, the vestibular folds, and the vocal folds.

The lower end of the larynx is formed by the ring-shaped **cricoid** (*kri'koid*) **cartilage.** This third unpaired cartilage connects the thyroid cartilage above and the trachea below. The paired **arytenoid** (*ar''ĭ-te'noid*) **cartilages,** located above the cricoid and behind the thyroid, are the posterior attachments of the *vocal folds*. The other paired **cuneiform cartilages** and **corniculate** (*kor-nik'yŭ-lāt*) **cartilages** are small accessory cartilages that are closely associated with the arytenoid cartilages (fig. 17.8).

Two pairs of strong connective tissue bands are stretched across the upper opening of the larynx from the thyroid cartilage anteriorly to the paired arytenoid cartilages posteriorly. These are the **vocal folds** (*true vocal cords*) and the **vestibular folds** (*false vocal cords*) (fig. 17.8). The vestibular folds support the vocal folds and produce mucus from its epithelial lining, which keep the vestibular folds from drying out. The vestibular folds are not used in sound production, but rather the vocal folds vibrate to produce sound. Stratified squamous epithelium lines the vocal folds, whereas the rest of the larynx is lined with pseudostratified ciliated columnar epithelium. This is an important anatomical modification considering the tremendous vibratory action of the vocal folds in the production of sound.

cricoid: Gk. *krikos*, ring; *eidos*, form
arytenoid: Gk. *arytaina*, ladle- or cup-shaped
cuneiform: L. *cuneus*, wedge-shaped
corniculate: L. *corniculum*, diminutive of *cornu*, horn

The **laryngeal muscles** are extremely important in closing the glottis during swallowing and in speech. There are two groups of laryngeal muscles: **extrinsic muscles,** responsible for elevating the larynx during swallowing, and **intrinsic muscles** that, when contracted, change the length, position, and tension of the vocal folds. Various pitches are produced as air passes over the altered vocal folds. If the vocal folds are taut, vibration is more rapid and causes a higher pitch. Less tension on the vocal folds produces lower sounds. Mature males generally have thicker and longer vocal folds than females; therefore, the vocal folds of males vibrate more slowly and produce lower pitches. The loudness of vocal sound is determined by the force of the air passed over the vocal folds and the amount of vibration. The vocal folds do not vibrate when a person whispers.

Sounds originate in the larynx, but other structures are necessary to convert sound into recognizable speech. Vowel sounds, for example, are produced by constriction of the walls of the pharynx. The pharynx, paranasal sinuses, and oral and nasal cavities act as resonating chambers. The final enunciation of words is accomplished through movements of the tongue and lips.

Trachea

The **trachea** (*tra'ke-ă*) commonly called the "windpipe," is a semirigid, tubular organ, approximately 12 cm (4 in.) long and 2.5 cm (1 in.) in diameter, connecting the larynx to the

trachea: L. *trachia*, rough air vessel

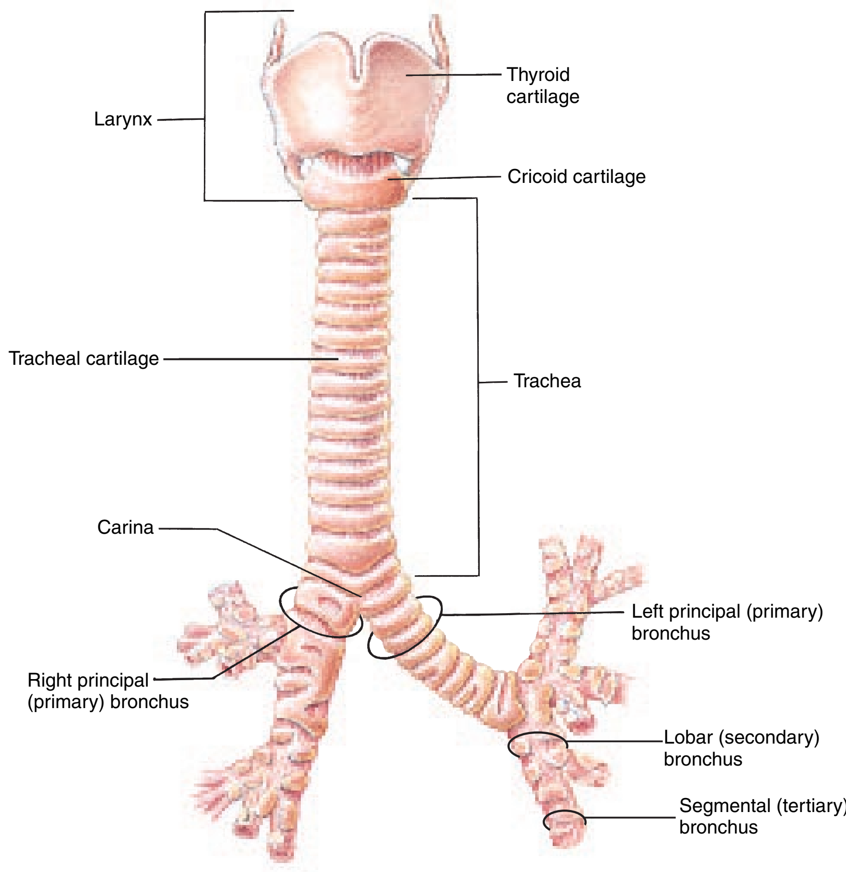


FIGURE 17.9 An anterior view of the larynx, trachea, and bronchi.

principal (primary) bronchi (fig. 17.9). It is positioned anterior to the esophagus as it extends into the thoracic cavity. A series of 16 to 20 C-shaped hyaline cartilages form the supporting walls of the trachea (fig. 17.10). These tracheal cartilages ensure that the airway will always remain open. The open part of each of these cartilages faces the esophagus and permits the esophagus to expand slightly into the trachea during swallowing. The mucosa (surface lining the lumen) consists of pseudostratified ciliated columnar epithelium containing numerous mucus-secreting **goblet cells** (see figs. 17.4 and 17.5). It provides the same protection against dust and other particles as the membrane lining the nasal cavity and larynx. Medial to the lungs, the trachea splits to form the right and left principal bronchi. This junction is reinforced by the **carina** (*kă-ri′nă*), a keel-like cartilage plate (see fig. 17.9).

If the trachea becomes occluded through inflammation, excessive secretion, trauma, or aspiration of a foreign object, it may be necessary to create an emergency opening into this tube so that ventilation can still occur. A *tracheotomy* is the procedure of surgically opening the trachea, and a *tracheostomy* involves inserting a tube into the trachea to permit breathing and to keep the passageway open (fig. 17.11). A tracheotomy should be performed only by a competent physician as there is a great risk of cutting a recurrent laryngeal nerve or the common carotid artery.

Bronchial Tree

The **bronchial tree** is so named because it is composed of a series of respiratory tubes that branch into progressively narrower tubes as they extend into the lung (fig. 17.12). The trachea bifurcates into **right** and **left principal** (primary) **bronchi** at the level of the sternal angle behind the manubrium. Each principal bronchus has hyaline cartilage rings within its wall surrounding the lumen to keep it open as it extends into the lung. Because of the more vertical position of the right principal bronchus, foreign particles are more likely to lodge here than in the left principal bronchus.

The principal bronchus divides deeper in the lungs to form **lobar** (secondary) **bronchi** and **segmental** (tertiary) **bronchi** (see figs. 17.1 and 17.9). The bronchial tree continues to branch into

carina: L. *carina*, keel

bronchus: L. *bronchus*, windpipe

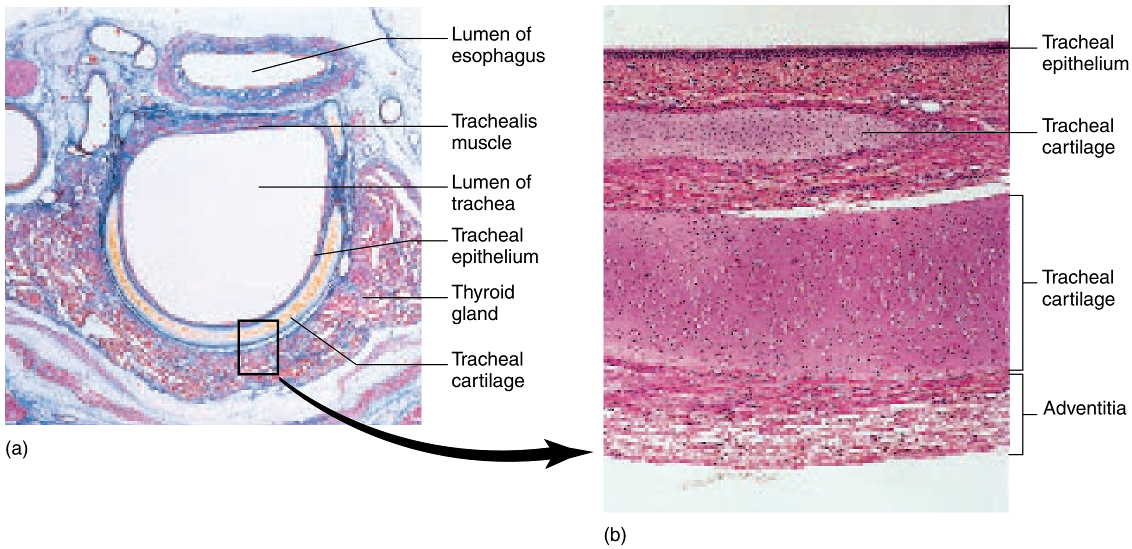


FIGURE 17.10 The histology of the trachea. (*a*) A photomicrograph showing the relationship of the trachea to the esophagus (3×) and (*b*) a photomicrograph of tracheal cartilage (63×).

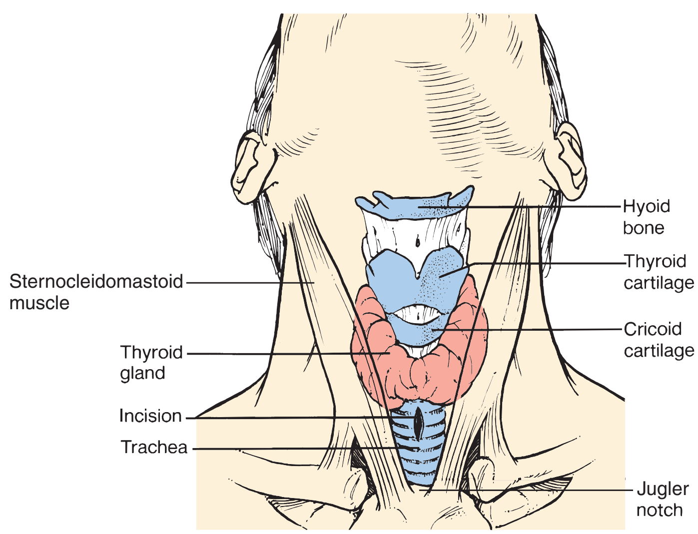


FIGURE 17.11 The site for a tracheostomy.

even smaller tubules called **bronchioles** (*brong'ke-ōlz*). There is little cartilage in the bronchioles. The thick smooth muscle that encircles their lumina can constrict or dilate these airways. Bronchioles provide the greatest resistance to air flow in the conducting passages—a function analogous to that of arterioles in the circulatory system. A simple cuboidal epithelium lines the bronchioles rather than the pseudostratified columnar epithelium that lines the bronchi (see fig. 17.4). Numerous **terminal bronchioles** connect to **respiratory bronchioles** that lead into **alveolar ducts,** and then into **alveolar sacs** (see fig. 17.14). The conduction portion of the respiratory system ends at the terminal bronchioles, and the respiratory portion begins at the respiratory bronchioles.

Asthma is an infectious or allergenic condition that involves the bronchi. During an asthma attack, there is a spasm of the smooth muscles in the respiratory bronchioles. Because of an absence of cartilage at this level, the air passageways constrict.

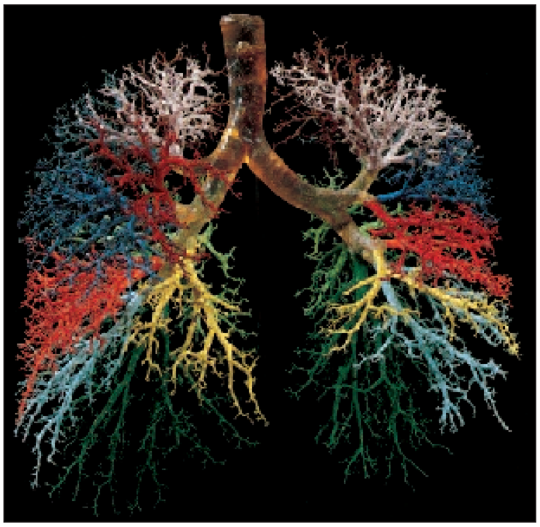


FIGURE 17.12 A photograph of a plastic cast of the conducting airways from the trachea to the terminal bronchioles.

A fluoroscopic examination of the bronchi using a radiopaque medium for contrast is called *bronchography*. This technique enables the physician to visualize the bronchial tree on a bronchogram (fig. 17.13).

Knowledge Check

4. List in order the types of epithelia through which inspired air would pass in traveling through the nasal cavity to the alveolar sacs of the lungs. What is the function of each of these epithelia?
5. What are the functions of the nasal cavity?
6. Identify the structures that make up the nasal septum.
7. Describe the location of the nasopharynx and list the structures within this organ.
8. List the paired and unpaired cartilages of the larynx and describe the functions of the larynx.
9. Describe the structure of the conducting airways from the trachea to the terminal bronchioles.

PULMONARY ALVEOLI, LUNGS, AND PLEURAE

Pulmonary alveoli are the functional units of the lungs, where gas exchange occurs. Right and left lungs are separately contained in pleural membranes.

Objective 9 Describe the structure and function of the pulmonary alveoli.

Objective 10 Describe the surface anatomy of the lungs in relation to the thorax.

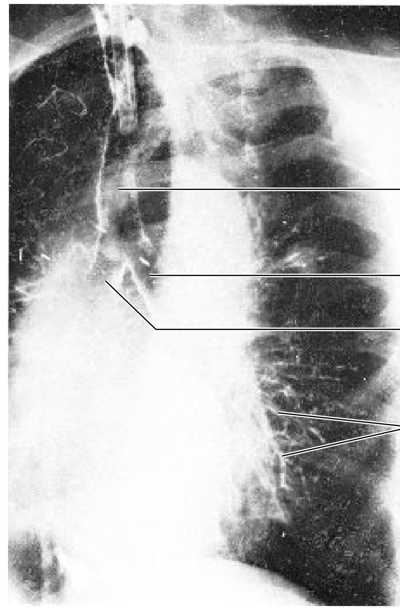


FIGURE 17.13 An anteroposterior bronchogram.

Objective 11 Discuss the structural arrangement of the thoracic serous membranes and explain the functions of these membranes.

Pulmonary Alveoli

The alveolar ducts open into **pulmonary alveoli** (*al-ve'ŏ-li*) as outpouchings along their length. Alveolar sacs are clusters of pulmonary alveoli (fig. 17.14). The alveolar ducts, pulmonary alveoli, and alveolar sacs make up the *respiratory division* of the lungs. Gas exchange occurs across the walls of the tiny pulmonary alveoli; hence, these minute expansions (0.25–0.50 mm in diameter) are the functional units of the respiratory system. The vast number of these structures (about 350 million per lung) provides a very large surface area (60–80 square meters, or 760 square feet) for the diffusion of gases. The diffusion rate is further increased by the fact that the wall of each pulmonary alveolus is only one cell layer thick, so that the total air-blood barrier is only one pulmonary alveolar cell with its basement membrane and one blood capillary cell across, or about 2 micrometers. This is an average distance because type II alveolar cells are thicker than type I alveolar cells (fig. 17.15). Type I alveolar cells permit diffusion, and type II alveolar cells (septal cells) secrete a substance called *surfactant* that reduces the tendency for pulmonary alveoli to collapse.

Pulmonary alveoli are polyhedral in shape and are usually clustered together, like the units of a honeycomb, in the alveolar sacs at the ends of the alveolar ducts (fig. 17.16). Although the

alveolus: L. diminutive of *alveus*, cavity

CHAPTER 17

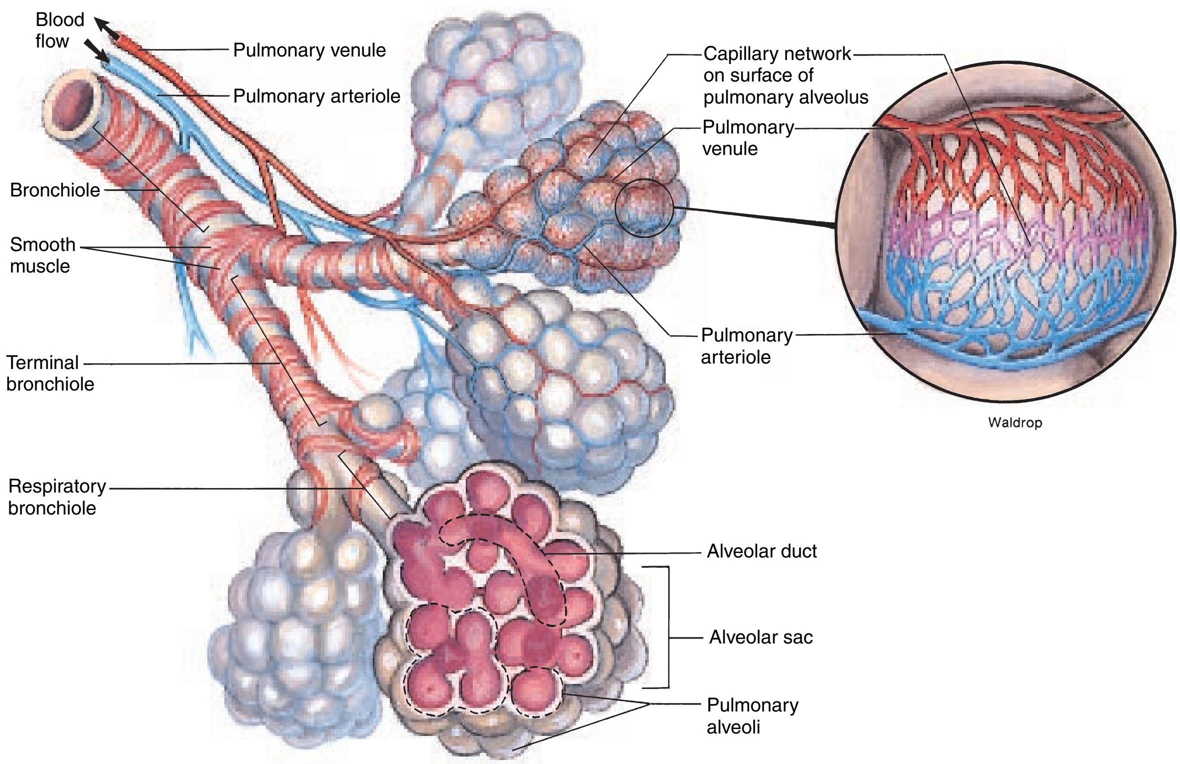


FIGURE 17.14 The respiratory division of the respiratory system. The respiratory tubes end in pulmonary alveoli, each of which is surrounded by an extensive pulmonary capillary network.

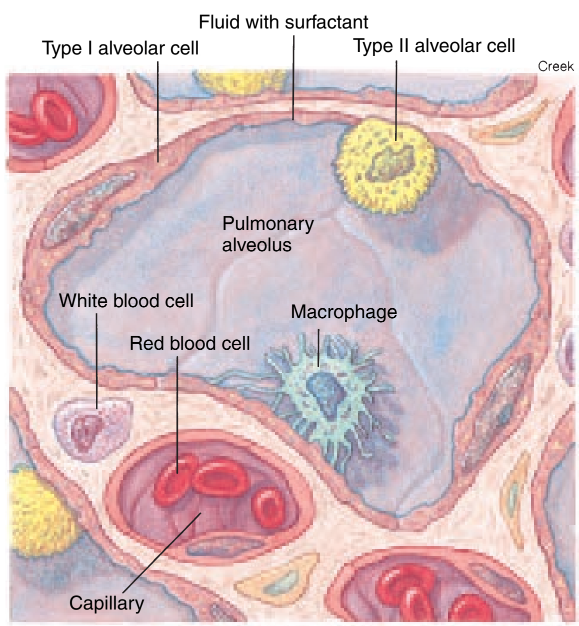


FIGURE 17.15 The relationship between a pulmonary alveolus and a pulmonary capillary.

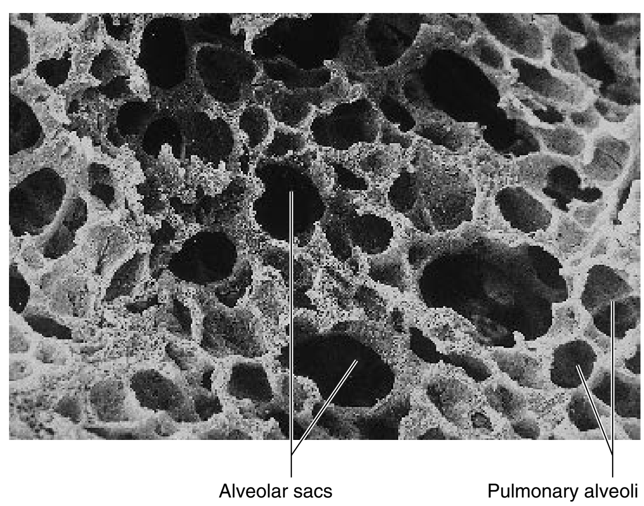


FIGURE 17.16 A scanning electron micrograph of lung tissue showing alveolar sacs and pulmonary alveoli.

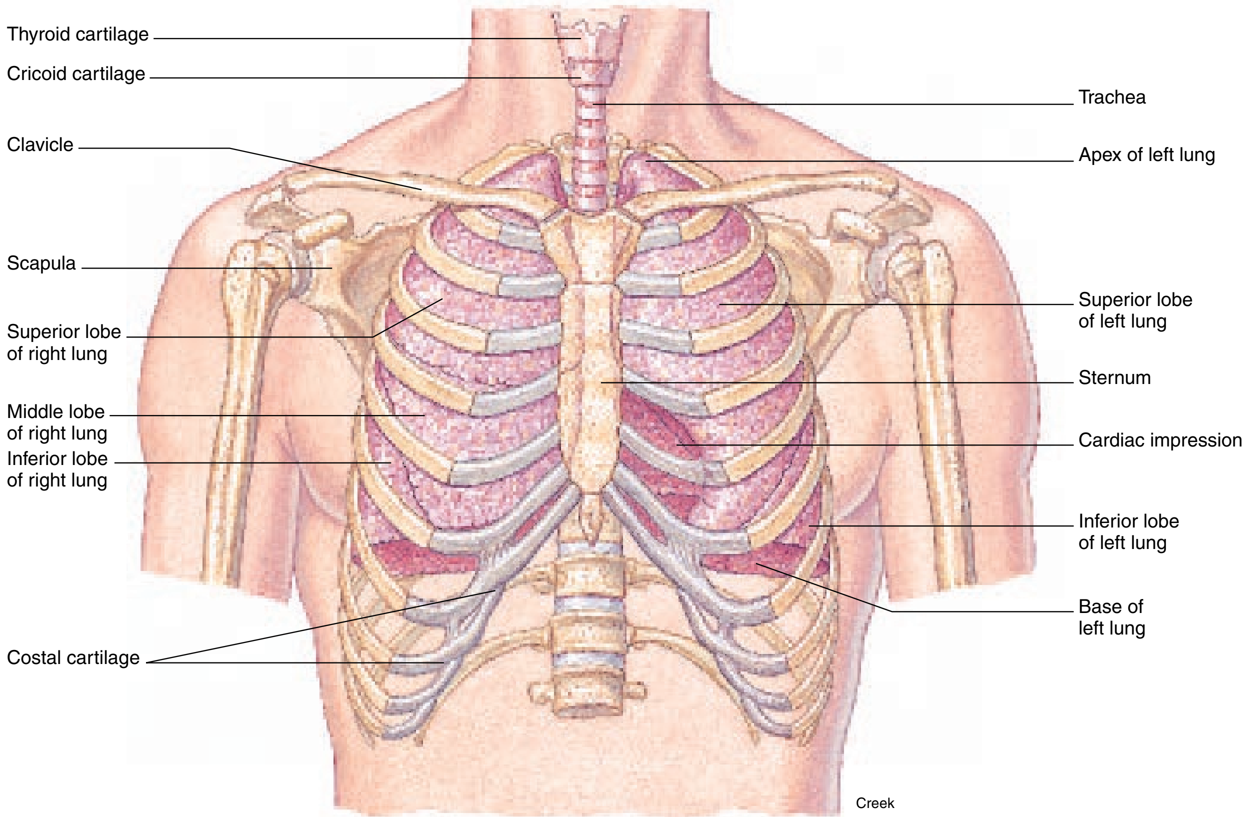


FIGURE 17.17 The position of the lungs within the rib cage.

distance between each alveolar duct and its terminal pulmonary alveoli is only about 0.5 mm, these units together compose most of the mass of the lungs.

Lungs

The large, spongy **lungs** are paired organs within the thoracic cavity (fig. 17.17). Each lung extends from the diaphragm to a point just above the clavicle, and its surfaces are bordered by the ribs to the front and back. The lungs are separated from one another by the heart and other structures of the **mediastinum** (*me''de-ă-sti'num*) which is the area between the lungs. All structures of the respiratory system beyond the principal bronchi, including the bronchial tree and the pulmonary alveoli, are contained within the lungs.

Each lung has four surfaces that match the contour of the thoracic cavity. The **mediastinal** (medial) **surface** of the lung is slightly concave and contains a vertical slit, the **hilum** through which pulmonary vessels, nerves, and bronchi pass (fig. 17.18). The inferior surface of the lung, called the **base of the lung,** is concave as it fits over the convex dome of the diaphragm. The superior surface, called the **apex** (cupola) **of the lung,** extends above the level of the clavicle. Finally, the broad, rounded surface in contact with the membranes covering the ribs is called the **costal surface of the lung.**

Although the right and left lungs are basically similar, they are not identical. The left lung is somewhat smaller than the right and has a **cardiac impression** on its medial surface to accommodate the heart. The left lung is subdivided into a **superior lobe** and an **inferior lobe** by a single fissure. The right lung is subdivided by two fissures into three lobes: **superior, middle,** and **inferior lobes** (see figs. 17.1, 17.17, and 17.18). Each lobe of the lung is divided into many small lobules, which in turn contain the pulmonary alveoli. Lobular divisions of the lungs make up specific **bronchial segments.** Each bronchial segment has its own

mediastinum: L. *mediastinus*, intermediate
hilum: L. *hilum*, a trifle (little significance)
cupola: L. *cupula*, diminutive of *cupa*, dome or tub

FIGURE 17.18 Lungs from a cadaver. (*a*) A medial view of the right lung and (*b*) a medial view of the left lung.

blood supply and if diseased it can be surgically isolated. The right lung contains 10 bronchial segments and the left lung contains 8 (fig. 17.19).

The lungs of a newborn are pink but may become discolored in an adult as a result of smoking or air pollution. Smoking not only discolors the lungs, it may also cause deterioration of the pulmonary alveoli. *Emphysema* (*em''fĭ-se'ma*) and *lung cancer* (see figs. 17.32 and 17.33) are diseases that are linked to smoking. If a person moves to a less polluted environment or gives up smoking, the lungs will get pinker and function more efficiently, unless they have been permanently damaged by disease.

Pleurae

Pleurae (*ploor'e*) are serous membranes surrounding the lungs and lining the thoracic cavity (figs. 17.20 and 17.21). The **visceral pleura** adheres to the outer surface of the lung and extends into each of the interlobar fissures. The **parietal pleura** lines the thoracic walls and the thoracic surface of the diaphragm. A continuation of the parietal pleura and between the lungs forms the boundary of the mediastinum. Between the visceral and parietal pleurae is the slitlike **pleural cavity.** It contains a lubricating fluid that allows the membranes to slide past each other easily during respiration. An inferiorly extending reflection of the pleural layers around the roots of each lung is called the **pulmonary ligament.** The pulmonary ligaments help support the lungs.

The moistened serous membranes of the visceral and parietal pleurae are normally flush against each other like two wet pieces of glass, and therefore the lungs are stuck to the thoracic wall. The pleural cavity (intrapleural space) between the two moistened membranes contains only a thin layer of fluid secreted by the serous membranes. The pleural cavity in a healthy, living person is thus potential rather than real; it can become real only in abnormal situations when air enters the intrapleural space. Because the lungs normally remain in contact with the thoracic wall, they get larger and smaller along with the thoracic cavity during respiratory movements.

The thoracic cavity has four distinct compartments: a pleural cavity surrounds each lung; the pericardial cavity surrounds the heart; and the mediastinum contains the esophagus, thoracic duct, major vessels, various nerves, and portions of the respiratory tract. This *compartmentalization* has protective value in that infections are usually confined to one compartment. Also, damage to one organ usually will not involve another. For example, *pleurisy*, an inflamed pleura, is generally confined to one side; and a penetrating injury to the thoracic cavity, such as a knife wound, may cause one lung to collapse but not the other.

A summary of the major structures of the respiratory system is presented in table 17.1.

Knowledge Check

10. Describe the structure of the respiratory division of the lungs and explain how this structure aids in gas exchange.
11. Compare the structure of the right and left lungs.
12. Describe the location of the mediastinum and list the organs it contains.
13. Describe the arrangement of the visceral pleura, parietal pleura, and pleural cavity. Comment on the functional significance of the compartmentalization of the thoracic cavity.

pleura: Gk. *pleura*, side or rib
pulmonary: Gk. *pleumon*, lung

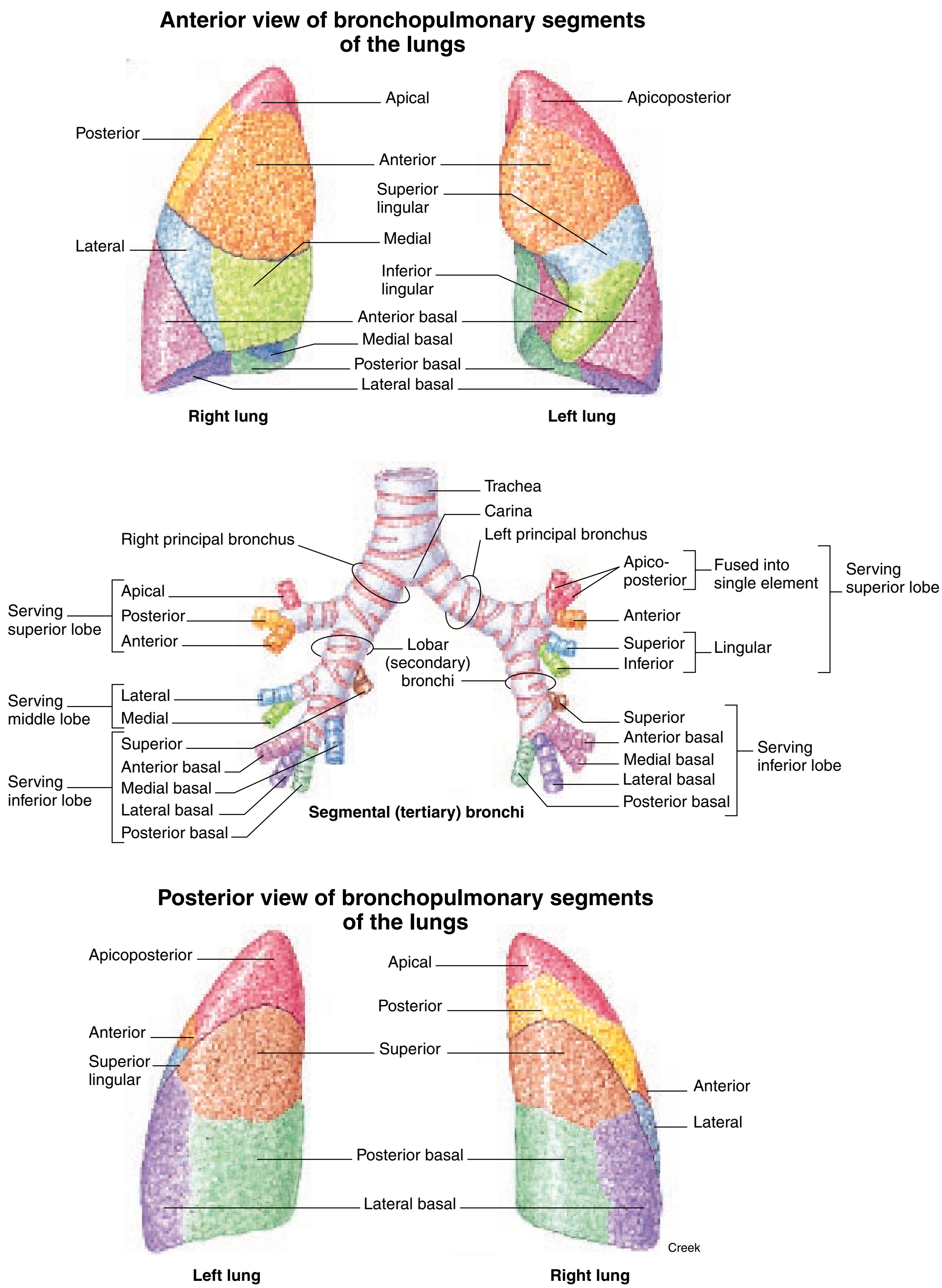


FIGURE 17.19 Lobes, lobules, and bronchopulmonary segments of the lungs.

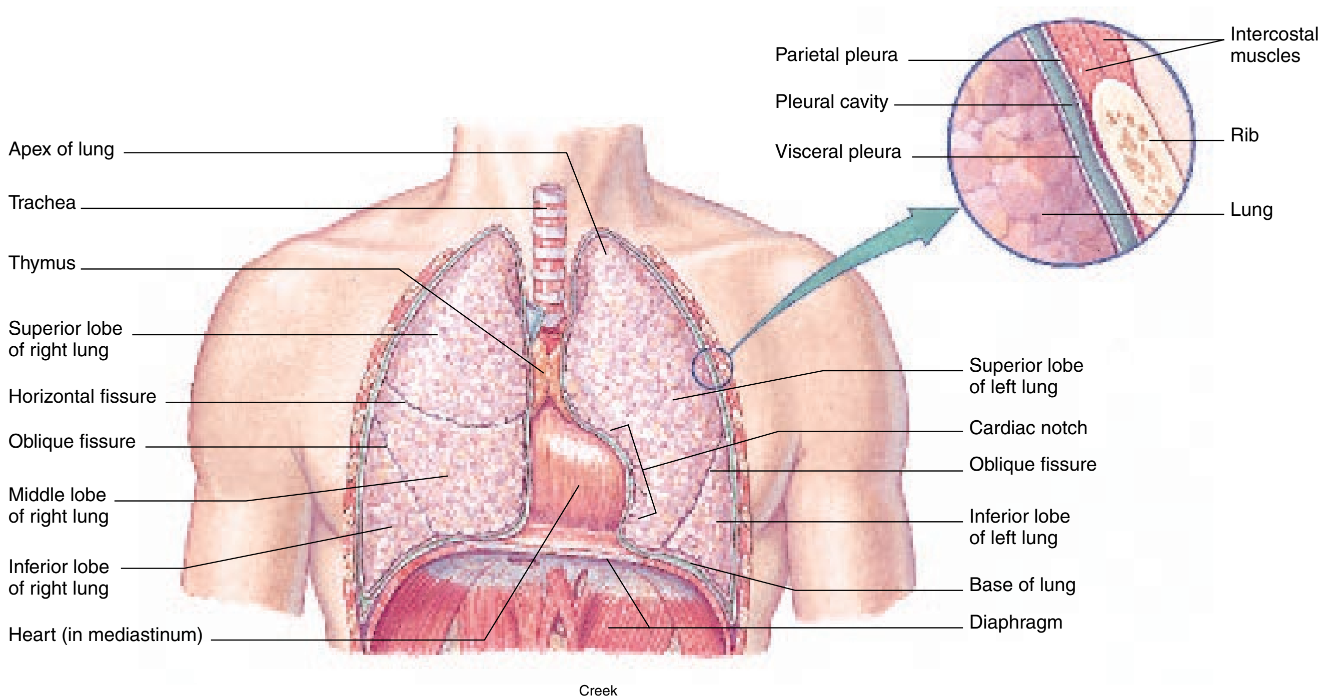


FIGURE 17.20 The position of the lungs and associated pleurae.

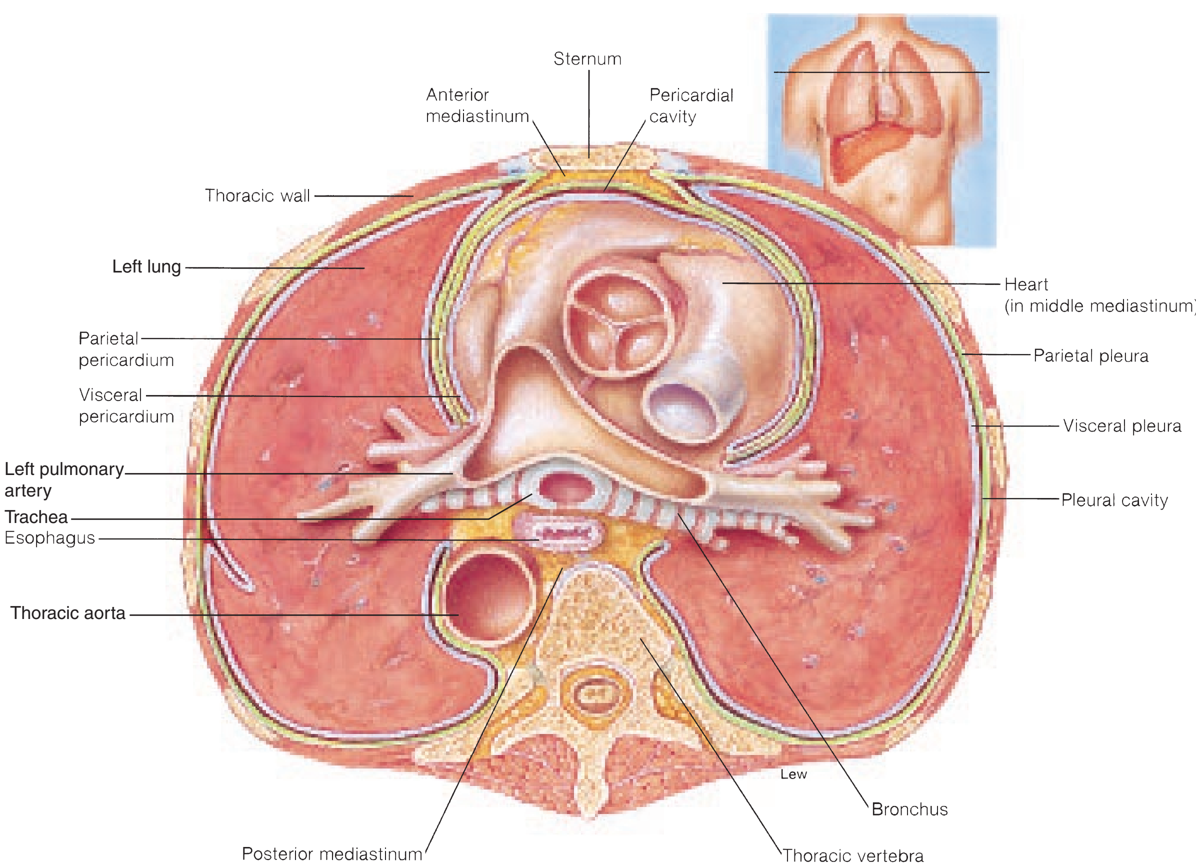


FIGURE 17.21 A cross section of the thoracic cavity showing the mediastinum and pleural membranes.

TABLE 17.1 Major Structures of the Respiratory System

Structure	Description	Function
Nose	Primary passageway for air entering the respiratory system; consists of jutting external portion and internal nasal cavity	Warms, moistens, and filters inhaled air as it is conducted to the pharynx
Paranasal sinuses	Air spaces in the maxillary, frontal, sphenoid, and ethmoid bones	Produce mucus; provide sound resonance; lighten the skull
Pharynx	Tubular organ connecting oral and nasal cavities to the larynx	Serves as passageway for air entering the larynx and for food entering the esophagus
Larynx	Voice box; short passageway that connects the pharynx to the trachea	Serves as passageway for air; produces sound; prevents foreign materials from entering the trachea
Trachea	Flexible tubular connection between the larynx and bronchial tree	Serves as passageway for air; pseudostratified ciliated columnar epithelium cleanses the air
Bronchial tree	Bronchi and branching bronchioles in the lung; tubular connection between the trachea and pulmonary alveoli	Serves as passageway for air; continued cleansing of inhaled air
Pulmonary alveoli	Microscopic membranous air sacs within the lungs	Functional units of respiration; site of gaseous exchange between the respiratory and circulatory systems
Lungs	Major organs of the respiratory system; located in the thoracic cavity and surrounded by pleural cavities	Contain bronchial trees, pulmonary alveoli, and associated pulmonary vessels
Pleurae	Serous membranes covering the lungs and lining the thoracic cavity	Compartmentalize, protect, and lubricate the lungs

MECHANICS OF BREATHING

Normal quiet inspiration is achieved by muscle contraction, and quiet expiration results from muscle relaxation and elastic recoil. A deeper inspiration and expiration can be forced by contractions of the accessory respiratory muscles. The amount of air inspired and expired can be measured to test pulmonary function.

Objective 12 Identify and describe the actions of the muscles involved in both quiet and forced inspiration.

Objective 13 Describe how quiet expiration occurs and identify and describe the actions of the muscles involved in forced expiration.

Objective 14 List the various lung volumes and capacities and describe how pulmonary function tests help in the diagnosis of lung disorders.

Breathing, or **pulmonary ventilation,** requires that the thorax be flexible in order to function as a bellows during the ventilation cycle. Breathing consists of two phases, *inspiration* and *expiration*. Inspiration (inhaling) and expiration (exhaling) are accomplished by alternately increasing and decreasing the volume of the thoracic cavity (fig. 17.22). Breathing in takes place when the air pressure within the lungs is lower than the atmospheric pressure; breathing out takes place when the air pressure within the lungs is greater than the atmospheric pressure.

Pressure gradients change as the size of the thoracic cavity changes. Not only must the thorax be flexible, it also must be sufficiently rigid to protect the vital organs it contains. In addition, it must provide extensive attachment surfaces for many short, powerful muscles. These requirements are met through the structure and composition of the rib cage. The rib cage is pliable because the ribs are separated from one another and because most ribs (upper 10 of the 12 pairs) are attached to the sternum by resilient costal cartilage. The vertebral attachment likewise allows for considerable mobility. The structure of the rib cage and associated cartilage provides continuous elastic tension so that an expanded thorax will return passively to its resting position when relaxed.

Inspiration

The overall size of the thoracic cavity increases with inspiration (fig. 17.23). During relaxed inspiration, the muscles of importance are the *diaphragm*, the *external intercostal muscles*, and the interchondral portion of the *internal intercostal muscles* (fig. 17.24). Contraction of the dome-shaped diaphragm causes it to flatten, lowering its dome. This increases the vertical dimen-

diaphragm: Gk. *dia*, across; *phragma*, fence

CHAPTER 17

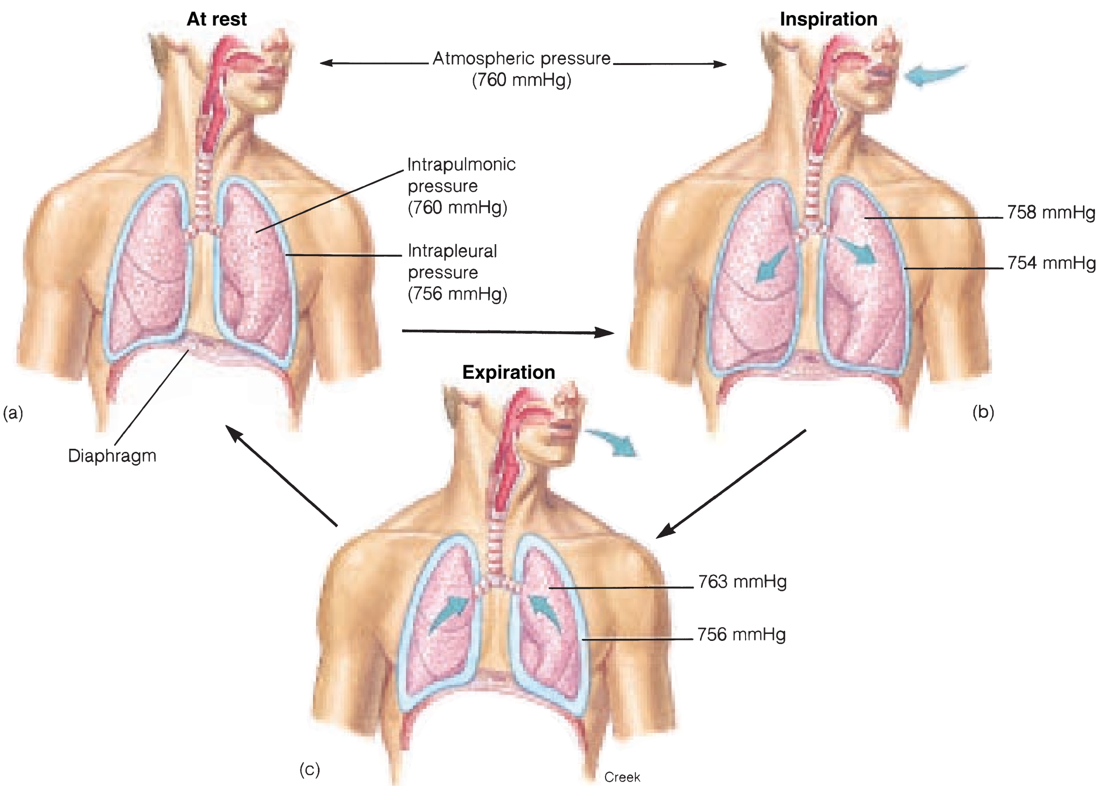


FIGURE 17.22 The mechanics of pulmonary ventilation. At rest (*a*), the atmospheric pressure at sea level and within the plural cavities is 760 mmHg. During inspiration (*b*), the diaphragm contracts, causing a decrease in intrapleural pressure and consequent inflation of the lungs. During expiration (*c*), the diaphragm recoils, causing an increase in intrapleural pressure and consequent deflation of the lungs.

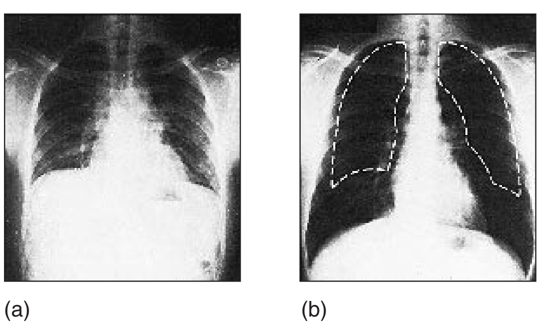


FIGURE 17.23 A change in lung volume, as shown by radiographs, during expiration (*a*) and inspiration (*b*). The increase in lung volume during full inspiration is shown by comparison with the lung volume in full expiration (dashed lines).

sion of the thoracic cavity. A simultaneous contraction of the external intercostal muscles and interchondral portion of the internal intercostal muscles increases the diameter of the thorax.

The *scalenes* and *sternocleidomastoid muscles* are involved in deep inspiration or forced breathing. When these muscles are contracted, the ribs are elevated. At the same time, the upper rib cage is stabilized so that the external intercostal muscles become more effective.

The expanded thoracic cavity decreases the air pressure within the pleural cavities to below that of the atmosphere. It is this pressure difference that causes the lungs to become inflated.

Expiration

For the most part, expiration is a passive process that occurs as the muscles of inspiration are relaxed and the rib cage returns to its original position. The lungs recoil during expiration as elastic fibers within the lung tissue shorten and the pulmonary alveoli draw together. Lowering of the surface tension in the pulmonary alveoli,

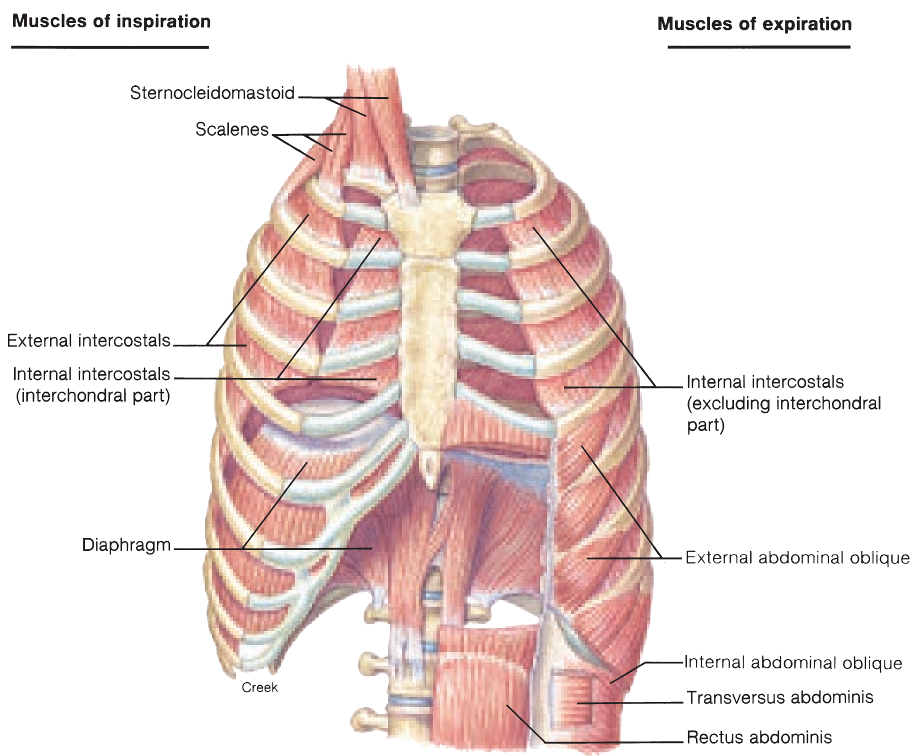


FIGURE 17.24 The muscles of respiration. The principal muscles of inspiration are shown on the right side of the trunk and the principal muscles of forced expiration are shown on the left side. For the most part, expiration is passive.

which brings on recoiling, is due to a lipoprotein substance called *surfactant* produced by type II alveolar cells. Surfactant is extremely important in reducing the surface tension in the pulmonary alveoli by becoming interspersed between water molecules, thereby reducing the attracting forces of hydrogen bonds. A deficiency in surfactant in premature infants can cause *respiratory distress syndrome (RDS)* or, as it is commonly called, *hyaline membrane disease*.

Even under normal conditions, the first breath of life is a difficult one because the newborn must overcome large surface tension forces in order to inflate its partially collapsed pulmonary alveoli. The transpulmonary pressure required for the first breath is 15 to 20 times that required for subsequent breaths, and an infant with *respiratory distress syndrome* must duplicate this effort with every breath. Fortunately, many babies with this condition can be saved by mechanical ventilators that keep them alive long enough for their lungs to mature and manufacture sufficient surfactant.

During forced expiration, such as coughing or sneezing, contraction of the interosseous portion of the internal intercostal muscles causes the rib cage to be depressed. The *abdominal muscles* may also aid expiration because, when contracted, they force abdominal organs up against the diaphragm and further decrease the volume of the thorax. Thus, intrapulmonary pressure can rise to 20 or 30 mmHg above the atmospheric pressure.

The events that occur during inspiration and expiration are summarized in table 17.2.

Respiratory Volumes and Capacities

The respiratory system is somewhat inefficient because the air enters and exits at the same place, through either the nose or the mouth. Consequently, there is an incomplete exchange of gas during each ventilatory cycle, and approximately five-sixths of the air present in the lungs still remains when the next inspiration begins.

The amount of air breathed in a given time and the degree of difficulty in breathing are important indicators of a person's respiratory status. The amount of air exchanged during pulmonary ventilation varies from person to person according to age, gender, activity level, general health, and individual differences. Respiratory volumes are measured with a *spirometer* (fig. 17.25). Any ventilatory abnormalities can then be compared to what is accepted as normal. The normal adult respiratory volumes and capacities are presented in table 17.3 and figure 17.26.

TABLE 17.2 Pulmonary Ventilation: Events of Inspiration and Expiration*

Nerve Stimulus	Event
Inspiration	
Phrenic nerves	The diaphragm contracts, moving inferiorly, which measures the volume of the thorax. The diaphragm is the principal muscle involved in quiet inspiration.
Intercostal nerves	Contraction of the external intercostal muscles and the interchondral portion of the internal intercostal muscles elevates the ribs, thus increasing the capacity of the thoracic cavity.
Accessory, cervical, and thoracic nerves	Forced inspiration is accomplished through contraction of the scalenes and sternocleidomastoid muscles, which increases the dimension of the thoracic cavity anteroposteriorly. Pulmonary ventilation during forced inspiration usually occurs through the mouth rather than through the nose.
	As the dimension of the thoracic cavity increases, the pressure within the pleural cavities decreases; the lungs inflate because the atmospheric pressure is greater than the intraplural pressure.
Expiration	
	Nerve stimuli to the inspiratory muscles cease and the muscles relax.
	The rib cage and lungs recoil as air is forced out of the lungs because of the increased pressure.
Intercostal and lower spinal nerves	Forced expiration occurs when the interosseus portion of the internal intercostal and abdominal muscles are contracted.

*Some of the events during inspiration and expiration may occur simultaneously.

People with pulmonary disorders frequently complain of *dyspnea* (*disp'ne-ā*), a subjective feeling of shortness of breath. Dyspnea may occur even when ventilation is normal, however, and may not occur even during exercise, when the total volume of air movement is very high. Some of the terms used to describe ventilation are defined in table 17.4.

Nonrespiratory Air Movements

Air movements through the respiratory system that are not associated with pulmonary ventilation are termed *nonrespiratory movements*. Such movements accompany emotional displays such as laughing, sighing, crying, or yawning, or they may function to expel foreign matter from the respiratory tract, as in coughing and sneezing. Nonrespiratory movements are generally reflexive. Some of them, however, can be voluntarily initiated. These types of air movements and the reflexive mechanisms involved are summarized in table 17.5.

dyspnea: Gk. *dys*, bad; *pnoe*, breathing

FIGURE 17.25 A spirometer. With the exception of the residual volume, which is measured using special techniques, this instrument can determine respiratory air volumes.

TABLE 17.3 Respiratory Volumes and Capacities of Healthy Adult Males

Volume	Quanity of Air	Description
Tidal volume (TV)	500 cc	Volume moved in or out of the lungs during quiet breathing
Inspiratory reserve volume (IRV)	3,000 cc	Volume that can be inhaled during forced breathing in addition to tidal volume
Expiratory reserve volume (ERV)	1,000 cc	Volume that can be exhaled during forced breathing in addition to tidal volume
Vital capacity (VC)	4,500 cc	Maximum amount of air that can be exhaled after taking the deepest breath possible: VC = TV + IRV + ERV
Residual volume (RV)	1,500 cc	Volume that cannot be exhaled
Total lung capacity (TLC)	6,000 cc	Total volume of air that the lungs can hold: TLC = VC + RV

Knowledge Check

14. Describe the actions of the diaphragm and intercostal muscles during relaxed inspiration.
15. Describe how forced inspiration and forced expiration are produced.
16. Define the terms *tidal volume* and *vital capacity*.
17. Indicate the respiratory volumes being used during a sneeze, a deep inspiration prior to jumping into a swimming pool, maximum ventilation while running, and quiet breathing while sleeping.

CHAPTER 17

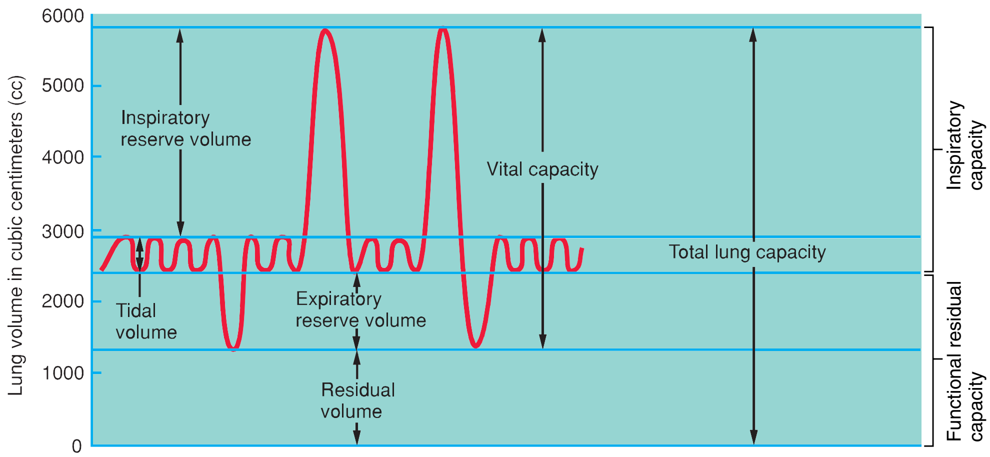


FIGURE 17.26 Respiratory volumes and capacities.

TABLE 17.4 Ventilation Terminology

Term	Definition
Air spaces	Alveolar ducts, alveolar sacs, and pulmonary alveoli
Airways	Structures that conduct air from the mouth and nose to the respiratory bronchioles
Alveolar ventilation	Removal and replacement of gas in pulmonary alveoli; equal to the tidal volume minus the volume of dead space times the breathing rate
Anatomical dead space	Volume of the conducting airways to the zone where gas exchange occurs
Apnea	Cessation of breathing
Dyspnea	Unpleasant subjective feeling of difficult or labored breathing
Eupnea	Normal, comfortable breathing at rest
Hyperventilation	Abnormally rapid, deep breathing; results in abnormally low alveolar CO_2
Hypoventilation	Abnormally slow, shallow breathing; results in abnormally high alveolar CO_2
Orthopnea	Inability to breathe comfortably while lying down
Physiological dead space	Combination of anatomical dead space and underventilated pulmonary alveoli that do not contribute normally to blood-gas exchange
Pneumothorax	Presence of gas in the pleural cavity (the space between the visceral and parietal pleural membranes) that may cause lung collapse

TABLE 17.5 Nonrespiratory Air Movements

Air Movement	Mechanism	Comments
Coughing	Deep inspiration followed by a closure of the glottis. The forceful expiration that results abruptly opens the glottis, sending a blast of air through the upper respiratory tract.	Reflexive or voluntary. Stimulus may be foreign material irritating the larynx or trachea.
Sneezing	Similar to a cough, except that the forceful expired air is directed primarily through the nasal cavity. The eyelids close reflexively during a sneeze.	Reflexive response to irritating stimulus of the nasal mucosa. Sneezing clears the upper respiratory passages.
Sighing	Deep, prolonged inspiration followed by a rapid, forceful expiration.	Reflexive or voluntary, usually in response to boredom or sadness.
Yawning	Deep inspiration through a widely opened mouth. The inspired air is usually held for a short period before sudden expiration.	Usually reflexive in response to drowsiness, fatigue, or boredom, but exact stimulus-receptor cause is unknown.
Laughing	Deep inspiration followed by a rapid convulsive expiration. Air movements are accompanied by expressive facial distortions.	Reflexive; may be voluntary to express emotions.
Crying	Similar to laughing, but the glottis remains open during entire expiration and different facial muscles are involved.	Somewhat reflexive but under voluntary control.
Hiccuping	Spasmodic contraction of the diaphragm while the glottis is closed, producing a sharp inspiratory sound.	Reflexive; serves no known function.

REGULATION OF BREATHING

The rhythm of breathing is controlled by centers in the brain stem. These centers are influenced by higher brain function and regulated by sensory input that makes breathing responsive to the changing respiratory needs of the body.

Objective 15 Describe the functions of the pneumotaxic, apneustic, and rhythmicity centers in the brain stem.

Objective 16 Identify the chemoreceptors and describe their pathway of innervation.

Pulmonary ventilation is primarily an involuntary, rhythmic action so effective that it continues to function even when a person is unconscious. In order for the neural control center of respiration to function effectively, it must possess monitoring, stimulating, and inhibiting properties so that the body can respond appropriately to increased or decreased metabolic needs. In addition, the center must be connected to the cerebrum to receive the voluntary impulses from a person who wants to change the rate of respiration.

The three **respiratory centers** of the brain are the rhythmicity, apneustic, and pneumotaxic areas (see fig. 11.28). The **rhythmicity area,** located in the medulla oblongata, contains two aggregations of nerve cell bodies that form the **inspiratory** and **expiratory portions.** Nerve impulses from the inspiratory portion travel through the phrenic and intercostal nerves and stimulate the diaphragm and intercostal muscles. Impulses from the expiratory portion stimulate the muscles of expiration. These two portions act reciprocally; that is, when one is stimulated, the other is inhibited. Stretch receptors in the visceral pleura of the lungs provide feedback through the vagus nerves to stimulate the expiratory portion.

The **apneustic** (*ap-noo'stik*) and **pneumotaxic** (*noo''mŏ-tak'sik*) **areas** are located in the pons. These areas influence the activity of the rhythmicity area. The apneustic center promotes inspiration and the pneumotaxic center inhibits the activity of inspiratory neurons.

The brain stem respiratory centers produce rhythmic breathing even in the absence of other neural input. This intrinsic respiratory pattern, however, is modified by input from higher brain centers and by input from receptors sensitive to the chemical composition of the blood. The influence of higher brain centers is evidenced by the fact that you can voluntarily hypoventilate (as in breath holding) or hyperventilate. The inability to hold your breath for more than a short period is due to reflex breathing in response to input from the chemoreceptors.

Two groups of chemoreceptors respond to changes in blood chemistry. These are the *central chemoreceptors* in the medulla oblongata and the *peripheral chemoreceptors*. The peripheral chemoreceptors include the **aortic bodies,** located in the aortic arch, and the **carotid bodies,** located at the junctions of the internal and external carotid arteries (fig. 17.27). These peripheral chemoreceptors control breathing indirectly via sensory neurons to the medulla oblongata. The aortic bodies send sensory information to the medulla oblongata in the vagus nerves; the carotid bodies stimulate sensory fibers in the glossopharyngeal nerve.

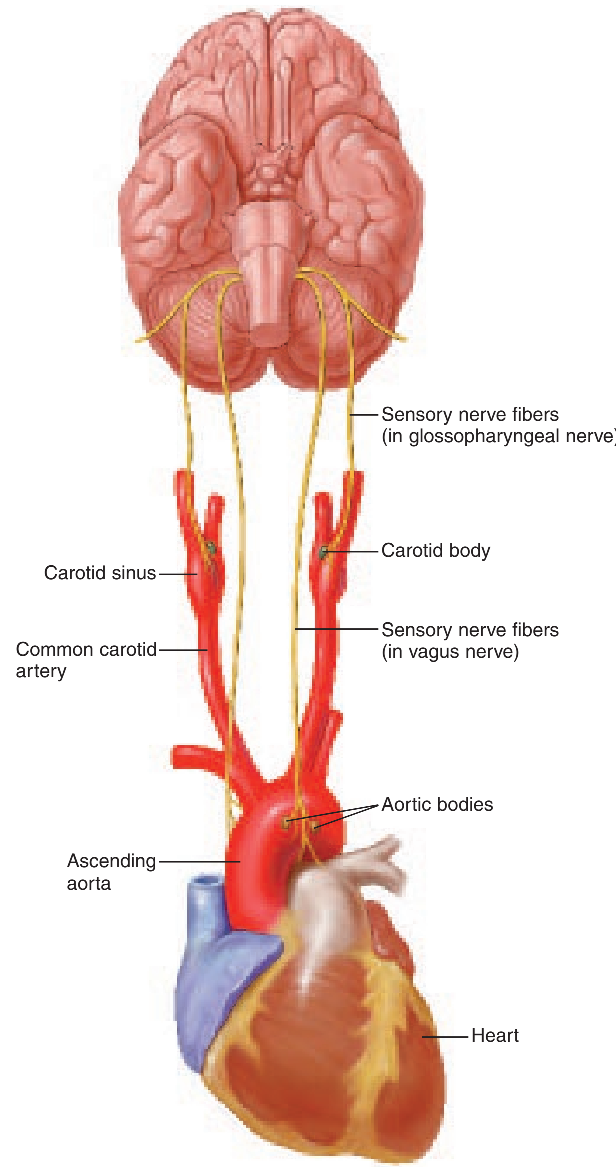


FIGURE 17.27 The peripheral chemoreceptors (aortic and carotid bodies) regulate the brain stem respiratory centers by means of sensory nerve stimulation.

Knowledge Check

18. State where in the brain the three respiratory areas are located. Which of these three areas is responsible for autonomic rhythmic breathing?
19. Describe the locations of the peripheral chemoreceptors and identify the two paired cranial nerves that carry sensory impulses from these sites to the respiratory centers within the brain stem.

Developmental Exposition

The Respiratory System

EXPLANATION

The development of the respiratory system is initiated early in embryonic development and involves both ectoderm and endoderm. Although all of the structures of the respiratory system develop simultaneously, we will consider the upper and lower systems separately because of the different germ layers involved.

Development of the Upper Respiratory System

Cephalization (*sef″ă-lĭ-za′shun*) is the evolutionary tendency toward structural and functional differentiation of the cephalic, or head, end of an organism from the rest of the body. In humans, cephalization is apparent early in development. One of the initial events is the formation of the nasal cavity at 3 1/2 to 4 weeks of embryonic life. A region of thickened ectoderm called the **olfactory** (nasal) **placode** (*plak′ōd*) appears on the front inferior part of the head (exhibit I). The placode invaginates to form the **olfactory pit,** which extends posteriorly to connect with the **foregut.** The foregut, derived of endoderm, later develops into the pharynx.

The mouth, or oral cavity, develops at the same time as the nasal cavity, and for a short time there is a thin **oronasal membrane** separating the two cavities. This membrane ruptures during the seventh week, and a single large **oronasal cavity** forms. Shortly thereafter, tissue plates of mesoderm begin to grow horizontally across the cavity. At approximately the same time, a vertical plate develops inferiorly from the roof of the nasal cavity. These plates have completed their formation by 3 months of development. The vertical plate forms the nasal septum, and the horizontal plates form the hard palate.

A *cleft palate* forms when the horizontal plates fail to meet in the midline. This condition can be corrected surgically (see fig. 17.28). The more immediate and serious problem facing an infant with a cleft palate is that it may be unable to create enough suction to nurse properly.

Development of the Lower Respiratory System

The lower respiratory system begins as a diverticulum, or outpouching, from the ventral surface of endoderm along the lower pharyngeal region (exhibit II). This diverticulum, which forms during the fourth week of development, is referred to as the **laryngotracheal** (*lā-ring″go-tra′ke-al*) **bud.** As the bud grows, the proximal portion forms the trachea and the distal portion bifurcates (splits) into a right and left principal bronchus.

The buds continue to elongate and split until the entire tubular network within the lower respiratory tract is formed (exhibit II). As the terminal portion forms air sacs, called **pulmonary alveoli,** at about 8 weeks of development, the supporting lung tissue begins to form. The complete structure of the lungs, however, is not fully developed until about 26 weeks of fetal development. Premature infants born prior to this time therefore require special artificial respiratory equipment to live.

cephalization: Gk. *kephale,* head

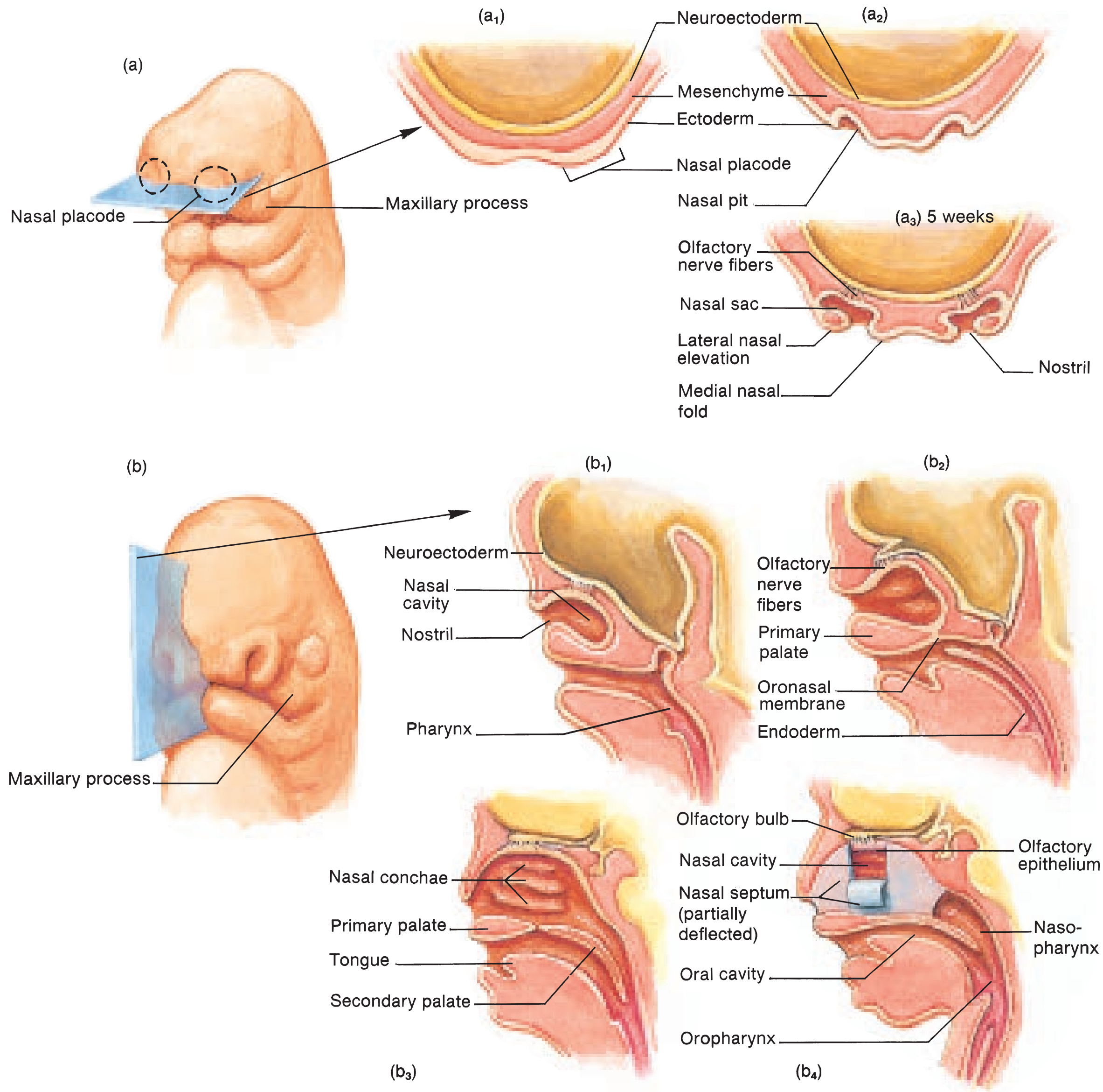


EXHIBIT I The development of the upper respiratory system. (*a*) An anterior view of the developing head of an embryo at 4 weeks showing the position of a transverse cut depicted in (a_1), (a_2), and (a_3). (a_2) Development at 5 weeks and (a_3) at 5 1/2 weeks. (*b*) An anterior view of the developing head of an embryo at 6 weeks showing the position of a sagittal cut depicted in (b_1), (b_2), (b_3), and (b_4) at 14 weeks.

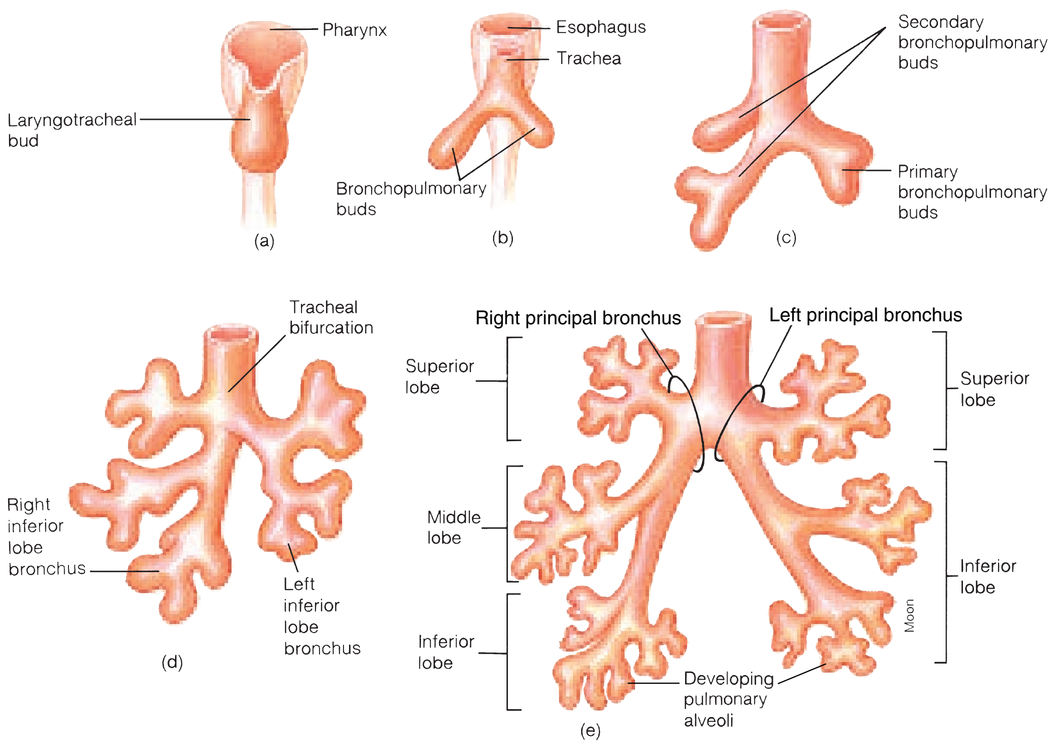


EXHIBIT II The development of the lower respiratory tract. Developments in (*a*) and (*b*) occur during the first month. Those in (*c*), (*d*), and (*e*) occur during the second month.

CLINICAL CONSIDERATIONS

The respiratory system is particularly vulnerable to infectious diseases simply because many pathogens are airborne; humans are highly social, and the warm, moistened environment along the respiratory tract allows pathogens to thrive. Injury and trauma are also frequent problems. Protruding noses are subject to fractures; the large, spongy lungs are easily penetrated by broken ribs; and portions of the respiratory tract may become occluded because they also have a digestive function.

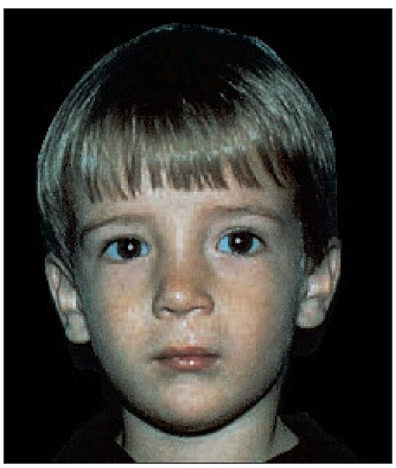
Developmental Problems of the Respiratory System

Birth defects, inherited disorders, and premature births commonly cause problems in the respiratory system of infants. A **cleft palate** is a developmental deformity of the hard palate of the mouth. An opening persists between the oral and nasal cavities that makes it difficult, if not impossible, for the infant to nurse. A cleft palate may be hereditary or a complication of some disease (e.g., German measles) contracted by the mother during pregnancy. A **cleft lip** is a genetically based developmental disorder in which the two sides of the upper lip fail to fuse. Cleft palates and cleft lips can be treated very effectively with cosmetic surgery (fig. 17.28).

As mentioned earlier, **hyaline membrane disease** is a fairly common respiratory disorder that accounts for about one-third of neonatal deaths. This condition results from the deficient production of surfactant. **Cystic fibrosis** is a genetic disorder that affects the respiratory system, as well as other systems of the body, and accounts for approximately 1 childhood death in 20. The effect of this disease on the respiratory system is usually a persistent inflammation and infection of the respiratory tract.

Pulmonary alveoli are not developed sufficiently to sustain life until after week 20 of gestation. Thus, extrauterine life prior to that time is extremely difficult even with life-supporting devices.

(a)



(b)

FIGURE 17.28 (*a*) An infant with a unilateral cleft lip and palate. (*b*) The same child following corrective surgery.

Trauma or Injury

Humans are especially susceptible to **epistaxes** *(ep''ĭ-stak'sēz)* (nosebleeds) because the prominent nose can be easily bumped and because the nasal mucosa has extensive vascularity for warming the inspired air. Epistaxes may also be caused by high blood pressure or diseases such as leukemia.

When air enters the pleural cavity surrounding either lung, the condition is referred to as a **pneumothorax** (fig. 17.29). A pneumothorax can result from an external injury, such as a stabbing, bullet wound, or penetrating fractured rib, or it can be the result of internal conditions. A severely diseased lung, as in emphysema, can create a pneumothorax as the wall of the lung deteriorates along with the visceral pleura and permits air to enter the pleural cavity.

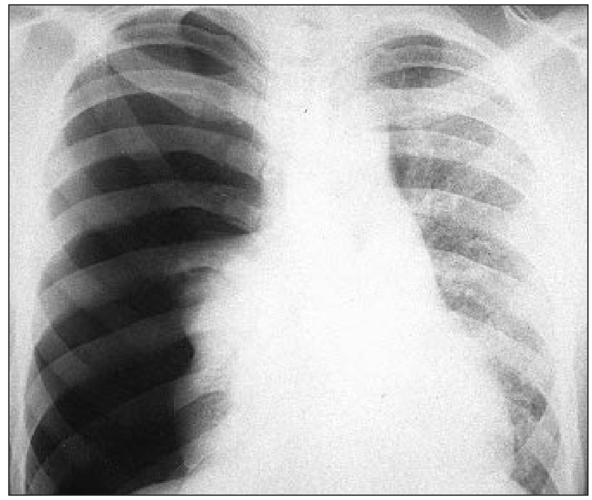


FIGURE 17.29 A pneumothorax of the right lung. The right side of the thorax appears uniformly dark because it is filled with air; the spaces between the ribs are also greater than those on the left, because the ribs are released from the elastic tension of the lungs. The left lung appears denser (less dark) because of shunting of blood from the right to the left lung.

Choking on a foreign object is a common serious trauma to the respiratory system. More than eight Americans choke to death each day on food lodged in their trachea. A simple procedure termed the **abdominal thrust** (Heimlich) **maneuver** can save the life of a person who is choking (fig. 17.30). The abdominal thrust maneuver is performed as follows:

A. If the victim is standing or sitting:
   1. Stand behind the victim or the victim's chair and wrap your arms around his or her waist.
   2. Grasp your fist with your other hand and place the fist against the victim's abdomen, slightly above the navel and below the rib cage.
   3. Press your fist into the victim's abdomen with a quick upward thrust.
   4. Repeat several times if necessary.

B. If the victim is lying down:
   1. Position the victim on his or her back.
   2. Face the victim, and kneel on his or her hips.
   3. With one of your hands on top of the other, place the heel of your bottom hand on the abdomen, slightly above the navel and below the rib cage.
   4. Press into the victim's abdomen with a quick upward thrust.
   5. Repeat several times if necessary.

If you are alone and choking, use whatever is available to apply force just below your diaphragm. Press into a table or a sink, or use your own fist.

FIGURE 17.30 The abdominal thrust (Heimlich) maneuver.

People saved from drowning and victims of shock frequently experience apnea (cessation of breathing) and will soon die if not revived by artificial respiration. The accepted treatment for reviving a person who has stopped breathing is illustrated in figure 17.31.

Common Respiratory Disorders

A cough is the most common symptom of respiratory disorders. Acute problems may be accompanied by dyspnea or wheezing. Respiratory or circulatory problems may cause **cyanosis** (*si'ă-no'-sis*), a blue discoloration of the skin resulting from blood with a low oxygen content.

Although the **common cold** is the most widespread of all respiratory diseases, there is still no cure for this ailment—only medications that offer symptomatic relief. Colds occur repeatedly because acquired immunity for one virus does not protect against other viruses. Cold viruses generally incite acute inflammation in the respiratory mucosa, causing flow of mucus, sometimes accompanied by fever and/or headache.

Nearly all of the structures and regions of the respiratory passageways can become infected and inflamed. **Influenza** is a viral disease that causes an inflammatory condition of the upper respiratory tract. Influenza can be epidemic, but fortunately vaccines are available. **Sinusitis** is an inflammation of the paranasal sinuses. Sinusitis can be quite painful if the drainage ducts from the sinuses into the nasal cavity become blocked. **Tonsillitis** may involve any or all of the tonsils and frequently follows other lingering diseases of the oral or pharyngeal regions. Chronic tonsillitis sometimes requires a tonsillectomy. **Laryngitis** is inflammation of the larynx, which often produces a hoarse voice and limits the ability to talk. **Tracheobronchitis** and **bronchitis** are infections of the regions for which they are named. Severe inflammation in these areas can cause smaller respiratory tubules to collapse, blocking the passage of air.

Diseases of the lungs are likewise common and usually serious. **Pneumonia** is an acute infection and inflammation of lung tissue accompanied by exudation (accumulation of fluid). It is usually caused by bacteria, most commonly by the pneumococcus bacterium. Viral pneumonia is caused by a number of different viruses. **Tuberculosis** is an inflammatory disease of the lungs contracted by inhaling air sneezed or coughed by someone who is carrying active tuberculosis bacteria. Tuberculosis softens lung tissue, which eventually becomes ulcerated. **Asthma** is a disease that affects people who are allergic to certain inhaled antigens. It causes a swelling and blocking of lower respiratory tubes, often accompanied by the formation of mucus plugs. **Pleurisy** (*ploor'ĭ-se*) is an inflammation of the pleura and is usually secondary to some other respiratory disease. Inspiration may become painful, and fluid may collect within the pleural cavity. **Emphysema** (*em''fĭ-se'mă*) is a disease that causes the breakdown of the pulmonary alveoli, thus increasing the size of air spaces and decreasing the surface area (fig. 17.32). It is a frequent cause of death among heavy cigarette smokers.

Cancer in the respiratory system is known to be caused by the repeated inhalation of irritating substances, such as cigarette smoke. Cancers of the lip, larynx, and lungs (fig. 17.33) are especially common in smokers over the age of 50.

Disorders of Respiratory Control

A variety of disease processes can result in cessation of breathing during sleep, or *sleep apnea*. **Sudden infant death syndrome (SIDS)** is an especially tragic form of sleep apnea that claims the lives of about 10,000 babies annually in the United States. Victims of this condition are apparently healthy 2-to-5-month-old babies who die in their sleep without apparent reason—hence, the layperson's term, "crib death." These deaths seem to be caused by failure of the respiratory control mechanisms in the brain stem and/or by failure of the carotid bodies to be stimulated by reduced arterial oxygen.

cyanosis: Gk. *kyanosis*, dark-blue color
influenza: L. *influentia*, a flowing in
tuberculosis: L. *tuberculum*, diminutive of *tuber*, swelling
asthma: Gk. *asthma*, panting
emphysema: Gk. *emphysan*, blow up, inflate

Mouth-to-Mouth Method

1. **Check for unresponsiveness.** Gently shake the victim and shout, "Are you okay?" If no response, get the attention of someone who can phone for help. Make sure that the victim is on his or her back.

2. **Open the airway.** Tilt the victim's head back by pushing on his or her forehead with your hand and lifting the chin with your fingers under his or her jaw. This will open the airway by moving the tongue away from the back of the victim's throat.

3. **Check for breathing.** Put your ear close to the victim's face to listen and feel for any return of air. At the same time, look to see if there is chest movement. Check for breathing for about 5 seconds.

4. **If no breathing, give two full breaths.** While maintaining the victim in the head-tilt position, pinch his or her nose to close off the nasal passageway. Take a deep breath, then seal your mouth around the victim's mouth and give two full breaths. (After the first breath, raise your head slightly to inhale quickly and then give the second breath.)

5. **Check for pulse.** While maintaining head tilt, feel for a carotid pulse for 5 to 10 seconds on the side of the victim's neck.

6. **Continue rescue breathing.** With the victim in the head-tilt position and his or her nostrils pinched, give one breath every 5 seconds. Observe for signs of breathing between breaths. For an infant, give one gentle puff every 3 seconds.

7. **Recheck for pulse.** Feel for a carotid pulse at 1-minute intervals. If the victim has a pulse but is not breathing, continue rescue breathing.

Mouth-to-Nose Method

1. **Open the airway.** Place the victim in the head-tilt position as described above.

2. **Blow into the victim's nose.** Using the same sequence described above, blow into the victim's nose while holding his or her mouth closed.

3. **Feel and observe for breathing.** With the victim's mouth held open, detect for breathing between giving forced breaths.

FIGURE 17.31 Artificial respiration.

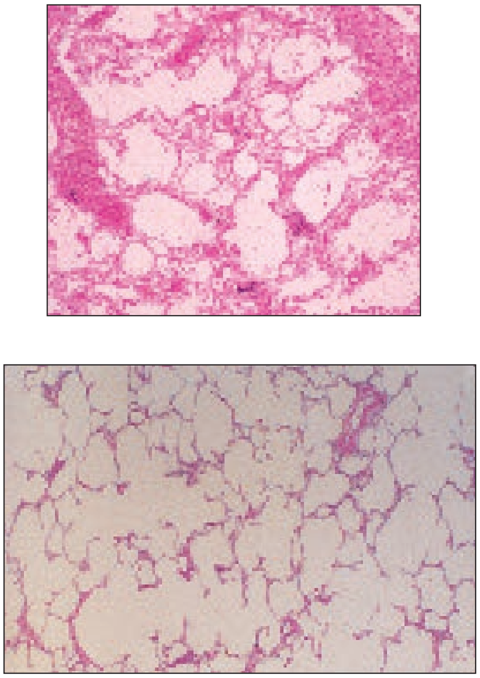


FIGURE 17.32 Photomicrographs of tissue (*a*) from a normal lung and (*b*) from the lung of a person with emphysema. In emphysema, lung tissue is destroyed, resulting in fewer and larger pulmonary alveoli.

Abnormal breathing patterns often appear prior to death from brain damage or heart disease. The most common of these abnormal patterns is **Cheyne–Stokes** (*chān'stōks'*) **breathing,** which the depth of breathing progressively increases and then progressively decreases. These cycles of increasing and decreasing tidal volumes may be followed by periods of apnea of varying durations. Cheyne–Stokes breathing may be caused by neurological damage or by insufficient oxygen delivery to the brain. The latter may result from heart disease or from a brain tumor that diverts a large part of the vascular supply from the respiratory centers.

Cheyne–Stokes breathing: from John Cheyne, British physician, 1777–1836; and William Stokes, Irish physician, 1804–78.

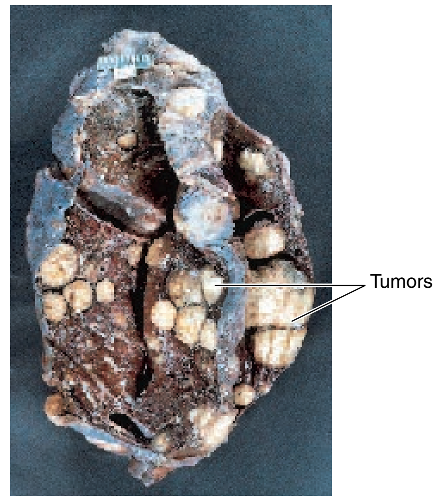


FIGURE 17.33 A cancerous lung. For people who regularly smoke a pack of cigarettes a day, the risk of developing lung cancer is 20 times greater than for people who have never smoked.

Clinical Case Study Answer

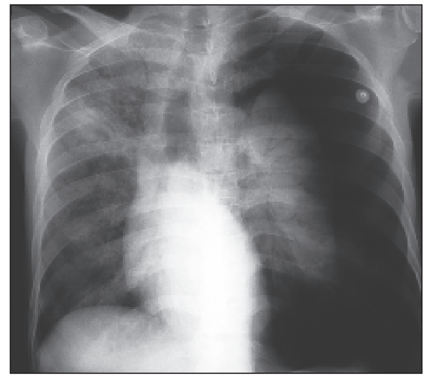
The ice pick traversed the parietal pleura, the visceral pleura, and then entered the airway, at least at the alveolar–terminal bronchiole level, but possibly at larger airways. This allowed inspired air to escape from the airway into the pleural cavity. The air would have taken the following route: pharynx → larynx → trachea → left principal bronchus → lobar bronchus (of left upper lobe) → apical segmental (tertiary) bronchus → bronchioles through laceration into pleural space. This condition is treated by inserting a tube (tube thoracostomy) into the pleural cavity to allow suction evacuation of air and blood, which results in reexpansion of the lung. The laceration usually seals over within a day or two. Persistent bleeding may necessitate thoracotomy (incision of the chest wall) for repair.

CLINICAL PRACTICUM 17.1

You admitted a 45-year-old male with AIDS to the hospital two days ago with shortness of breath and fevers. His chest radiograph showed diffuse opacities throughout both lungs, and a diagnosis of *Pneumocytsis carnii* pneumonia was made from sputum samples. The patient was receiving appropriate treatment and seemed to be doing well. The nurse calls you to report that the patient has become acutely short of breath and is having left-sided chest pain. When you examine the patient, you note him to have greatly decreased breath sounds on the left side of his chest. You order a new chest radiograph.

QUESTIONS

1. Why does this patient have worsening shortness of breath and left-sided chest pain?
2. How does this affect the other lung and the heart?
3. What is the proper treatment?

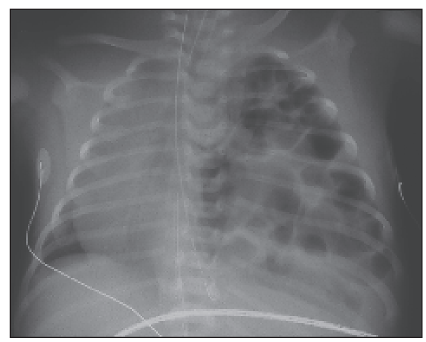


CLINICAL PRACTICUM 17.2

You are working in the newborn nursery of the hospital when you are called by the obstetrician to evaluate a newborn in respiratory distress. On exam, you note that the patient has no breath sounds on the left side of her chest and has very labored breathing. You order a chest radiograph.

QUESTIONS

1. What do you see in the left hemithorax?
2. What congenital anomaly resulted in this condition?
3. Once the anomaly is repaired, will the patient's breathing be normal?



Chapter Summary

CHAPTER 17

Introduction to the Respiratory System (pp. 603–604)

1. Respiration refers not only to ventilation (breathing), but also to the exchange of gases between the atmosphere, the blood, and individual cells. Within cells, the metabolic reactions that release energy are called cellular respiration.
2. In order for the respiratory system to function, the respiratory membranes must be moist, thin-walled, highly vascular, and differentially permeable.
3. The functions of the respiratory system include gaseous exchange, sound production, assistance in abdominal compression, and reflexive coughing and sneezing, and immune response.

Conducting Passages (pp. 604–612)

1. The nose is supported by nasal bones and cartilages.
2. The nasal epithelium warms, moistens, and cleanses the inspired air.
3. Olfactory epithelium is associated with the sense of smell, and the nasal cavity acts as a resonating chamber for the voice.
4. The paranasal sinuses are found in the maxillary, frontal, sphenoid, and ethmoid bones.
   (a) These sinuses lighten the skull and are lined with mucus-secreting goblet cells.
   (b) Sinusitis is an inflammation of one or more of the paranasal sinuses.
5. The pharynx is a funnel-shaped organ. It contains a passageway that connects the oral and nasal cavities with the esophagus and larynx.
   (a) The nasopharynx, connected by the auditory tubes to the tympanic cavities, contains the pharyngeal tonsils, or adenoids.
   (b) The oropharynx is the middle portion, extending from the soft palate to the level of the hyoid bone; it contains the palatine and lingual tonsils.
   (c) The laryngopharynx extends from the hyoid bone to the larynx and esophagus.

6. The larynx contains a number of cartilages that keep the passageway to the trachea open during breathing and closes the respiratory passageway during swallowing.
   (a) The epiglottis is a spoon-shaped structure that aids in closing the laryngeal opening, or glottis, during swallowing.
   (b) The vocal folds in the larynx are controlled by intrinsic muscles and are used in sound production.
7. The trachea is a semirigid tubular organ supported by incomplete rings of hyaline cartilage, that leads from the larynx to the bronchial tree.
8. The bronchial tree includes a principal bronchus, which divides to produce lobar bronchi, segmental bronchi, and bronchioles; the conducting division ends with the respiratory bronchioles, which connect to the pulmonary alveoli.

Pulmonary Alveoli, Lungs, and Pleurae (pp. 612–618)

1. Pulmonary alveoli are the functional units of the lungs, where gas exchange occurs; they are small, moistened, thin-walled air sacs.
2. The right and left lungs are separated by the mediastinum. Each lung is divided into lobes and lobules.
   (a) The right lung is subdivided by two fissures into superior, middle, and inferior lobes.
   (b) The left lung is subdivided into a superior lobe and an inferior lobe by a single fissure.
3. The lungs are covered by visceral pleura, and the thoracic cavity is lined by a parietal pleura.
   (a) The potential space between these two pleural membranes is called the pleural cavity.
   (b) The pleural membranes compartmentalize each lung and exclude the structures located in the mediastinum.

Mechanics of Breathing (pp. 618–622)

1. Quiet (unforced) inspiration is due to contraction of the diaphragm and certain intercostal muscles. Forced inspiration is aided by the scalenes and the pectoralis minor and sternocleidomastoid muscles.
2. Quiet expiration is produced by relaxation of the respiratory muscles and elastic recoil of the lungs and thorax. Forced expiration is aided by certain intercostal muscles and the abdominal muscles.
3. Among the air volumes exchanged in ventilation are tidal, inspiratory reserve, and expiratory reserve volumes.
4. Nonrespiratory air movements are associated with coughing, sneezing, sighing, yawning, laughing, crying, and hiccuping.

Regulation of Breathing (p. 623)

1. Ventilation is directly controlled by the rhythmicity center in the medulla oblongata, which in turn is influenced by the pneumotaxic and apneustic centers in the pons.
2. These brain stem areas are affected by higher brain function and by sensory input from chemoreceptors.
3. Central chemoreceptors are located in the medulla oblongata; peripheral chemoreceptors are located in the aortic and carotid bodies.

Review Activities

Objective Questions

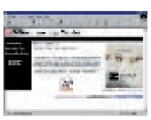
1. Which of the following is a *false* statement?
   (a) The term *respiration* can be used in reference to ventilation (breathing) or oxygen utilization by body cells.
   (b) The incoming (inhaled) air that contacts the pulmonary alveoli is unchanged from that which surrounds the body.
   (c) As a resonating chamber, the nasal cavity is important in sound production.
   (d) It is only through the walls of the pulmonary alveoli that gaseous exchange occurs.
2. Which is *not* a component of the nasal septum?
   (a) the palatine bone
   (b) the vomer
   (c) the ethmoid bone
   (d) septal cartilage
3. An adenoidectomy is the removal of
   (a) the uvula.
   (b) the pharyngeal tonsils.
   (c) the palatine tonsils.
   (d) the lingual tonsils.
4. Which is *not* a paranasal sinus?
   (a) the palatine sinus
   (b) the ethmoidal sinus
   (c) the sphenoidal sinus
   (d) the frontal sinus
   (e) the maxillary sinus
5. Which of the following is *not* characteristic of the left lung?
   (a) a cardiac impression
   (b) a superior lobe
   (c) a single fissure
   (d) an inferior lobe
   (e) a middle lobe
6. The epithelial lining of the wall of the thoracic cavity is called
   (a) the parietal pleura.
   (b) the pleural peritoneum.
   (c) the mediastinal pleura.
   (d) the visceral pleura.
   (e) the costal pleura.
7. Which muscle group combination permits inspiration?
   (a) diaphragm, abdominal complex
   (b) internal intercostals, diaphragm
   (c) external intercostals, internal intercostals
   (d) external intercostals, diaphragm, internal intercostals (interchondral part)
8. The vocal folds (cords) are attached to
   (a) the cricoid and thyroid cartilages.
   (b) the cuneiform and cricoid cartilages.
   (c) the corniculate and thyroid cartilages.
   (d) the arytenoid and thyroid cartilages.
9. The maximum amount of air that can be expired after a maximum inspiration is
   (a) the tidal volume.
   (b) the forced expiratory volume.
   (c) the vital capacity.
   (d) the maximum expiratory flow rate.
   (e) the residual volume.
10. The rhythmic control of breathing is produced by the activity of inspiratory and expiratory neurons in
    (a) the medulla oblongata.
    (b) the apneustic center of the pons.
    (c) the pneumotaxic center of the pons.
    (d) the cerebral cortex.
    (e) the hypothalamus.

Essay Questions

1. Why is warming, moistening, and filtering the air so important for a healthy, functioning respiratory system?
2. Explain the structural and functional differences between the three regions of the pharynx.
3. What is a bronchial tree? Why are pulmonary alveoli rather than bronchial trees considered the functional units of the respiratory system?
4. Define each of the following terms relating to the structure of the lung: *base*, *hilum*, *apex*, *costal surface*, *fissure*, *lobe*, *lobule*, *pulmonary ligament*, and *bronchial segment*.
5. Diagram the location of the lungs in the thoracic cavity with respect to the heart. Identify the various thoracic serous membranes.
6. List the kinds of epithelial tissues found within the respiratory system and describe the location of each.
7. What protective devices of the respiratory system guard against pollutants, the spread of infections, and dual collapse of the lungs?
8. What are the functions of the larynx? List some of the clinical conditions that could involve this organ.
9. What are the advantages of compartmentalization of the thoracic organs?
10. Explain the sequence of pulmonary ventilation. Discuss the mechanisms of inspiration and expiration. How are air pressures related to ventilation?
11. Distinguish between tidal volume, vital capacity, and total lung capacity.
12. What is meant by a rhythmicity respiratory area? How are the apneustic and pneumotaxic areas related to the rhythmicity area?

Critical-Thinking Questions

1. Identify two places in the respiratory system where large surface areas of capillary networks are found. What is the function of each of these areas and why are the capillary networks important in the treatment of certain clinical conditions?
2. On what principal is the abdominal thrust maneuver based? When would mouth-to-mouth resuscitation rather than the abdominal thrust maneuver be used to revive a person?
3. The nature of the sounds produced by percussing (tapping) a patient's chest can tell a physician a great deal about the condition of the organs within the thoracic cavity. Healthy, air-filled lungs resonate, or sound hollow. How do you think the lungs of a person with emphysema would sound in comparison to healthy lungs? What kind of sound would be produced by a collapsed lung, or one that was partially filled with fluid?
4. Why do premature infants often require respiratory assistance (a mechanical ventilator) to keep their lungs inflated?
5. Nicotine from cigarette smoke causes mucus to build up and paralyzes the cilia that line the respiratory tract. How do these changes affect the lungs?



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