CHAPTER

2

The Lower Airways

CHAPTER OUTLINE

The Lower Airway
The Trachea
Conditions of the Trachea
Main Stem Bronchi
Lobar, Segmental, and Subsegmental Bronchi
The Bronchioles
The Terminal Bronchioles
The Respiratory Bronchioles, the Acinus, the Alveolar Ducts, and the Alveoli
Conditions of the Lower Airway and Alveolus
The Cranial Nerves

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

1. Identify the structures of the lower airway.
2. Describe the histology of the lower respiratory airways.
3. Identify the cartilaginous and noncartilaginous airways.
4. Explain the rationale behind endotracheal intubation to facilitate ventilation and the clearance of secretions.
5. Identify the markings on an endotracheal tube.
6. List the structures through which air travels from the nose to the alveoli.
7. Provide examples of abnormal physiologic processes of the lower airway.
8. Identify the cranial nerves that affect ventilation.

KEY TERMS

acute respiratory distress syndrome (ARDS)
alveolar sac
alveoli
asthma
bronchiectasis
bronchioles
bronchiolitis
bronchoalveolar lavage (BAL)
canals of Lambert
cartilaginous airways
chronic bronchitis
club cells
cranial nerves
dyspnea
emphysema
endotracheal intubation
fibroblast cells
isothermic saturation boundary
lobar bronchi
lower airway
main stem bronchi
noncartilaginous airways
pneumonia
pores of Kohn
pulmonary edema
pulmonary interstitium
pulmonary parenchyma
segmental bronchi
sputum
subsegmental bronchi
surfactant
terminal bronchioles
trachea
tracheal agenesis
tracheal stenosis
tracheobronchial tree
tracheoesophageal fistula (TEF)
tracheomalacia

The Lower Airway

The **lower airway** includes those airways that are below the larynx. These airways bifurcate, or split, branching in an inverted treelike fashion as they move deeper into the airway toward the alveoli. Because of this inverted treelike structure, the lower airway is often referred to as the **tracheobronchial tree**. Like the upper airway, a portion of the lower airway is classified as the conducting airway. The conducting airway, or conducting zone, of the lower airway begins at the larynx and extends to the end of the terminal bronchioles. This portion of the lower airway is lined with epithelium, mucous-producing cells, and cilia that help to remove particles and debris from the airway. Gas exchange does not occur in this portion of the airway. Gas exchange occurs in the small grapelike clusters at the end of the airway known as **alveoli**. Some gas exchange also occurs in the terminal bronchioles. For this reason, the alveoli and the terminal bronchioles are called the respiratory zone (**Figure 2-1**).

The lower airway is divided into generations. The main generations of the airway and some of their characteristics are provided in **Figure 2-2**.

The Trachea

The large airway descending immediately below the larynx and beginning approximately at the level of the sixth cervical vertebra is the **trachea**. The trachea contains 16 to 20 C-shaped hyaline cartilage rings, with the open portion of the rings facing the back, or posterior, of the neck. The tracheal rings are completed by a membrane that contains a smooth muscle called the trachealis. This muscle constricts the trachea, allowing air to be expelled with more force, for example, when an individual coughs. Directly posterior to this membrane is the esophagus. The trachea is lined with pseudostratified ciliated columnar epithelium and goblet cells (**Figure 2-3**). Along with the submucosal glands, the goblet cells secrete high-molecular-weight

CLINICAL FOCUS: Cartilaginous and Noncartilaginous Airways

At the top of the tracheobronchial tree, the outermost layer of the airway is made up of cartilage. This layer of cartilage decreases in thickness moving down the airway until it completely disappears at the level of the bronchioles. The **cartilaginous airways** are the trachea, main stem bronchi, lobar bronchi, segmental bronchi, and the subsegmental bronchi. The **noncartilaginous airways** are the bronchioles and alveolar ducts.

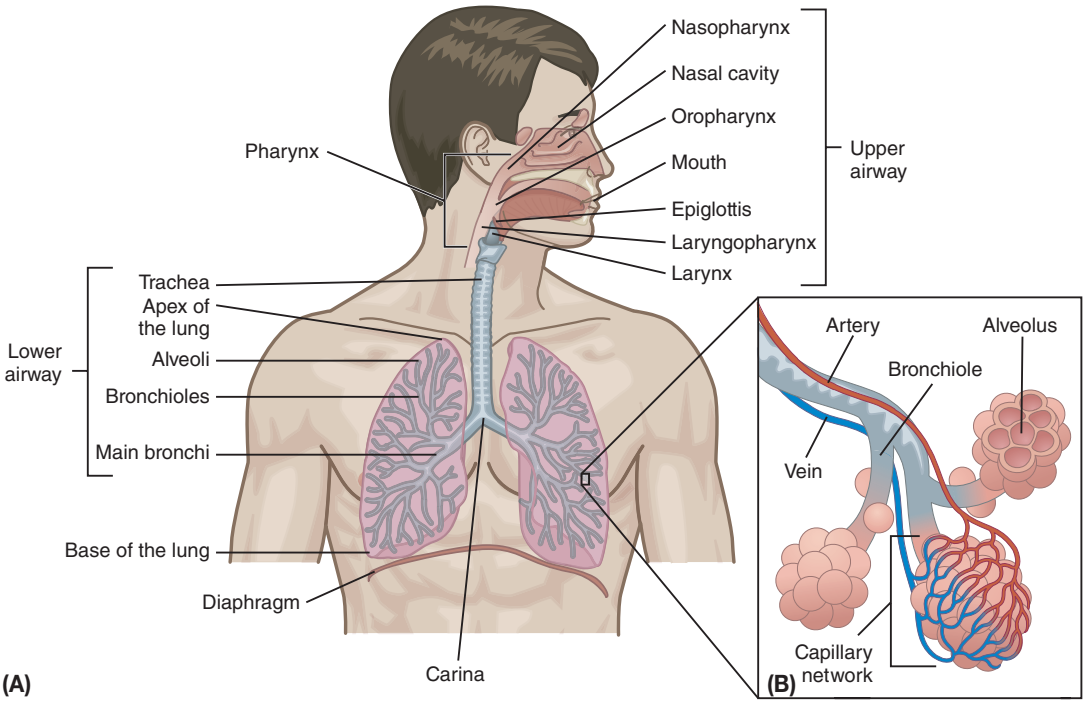
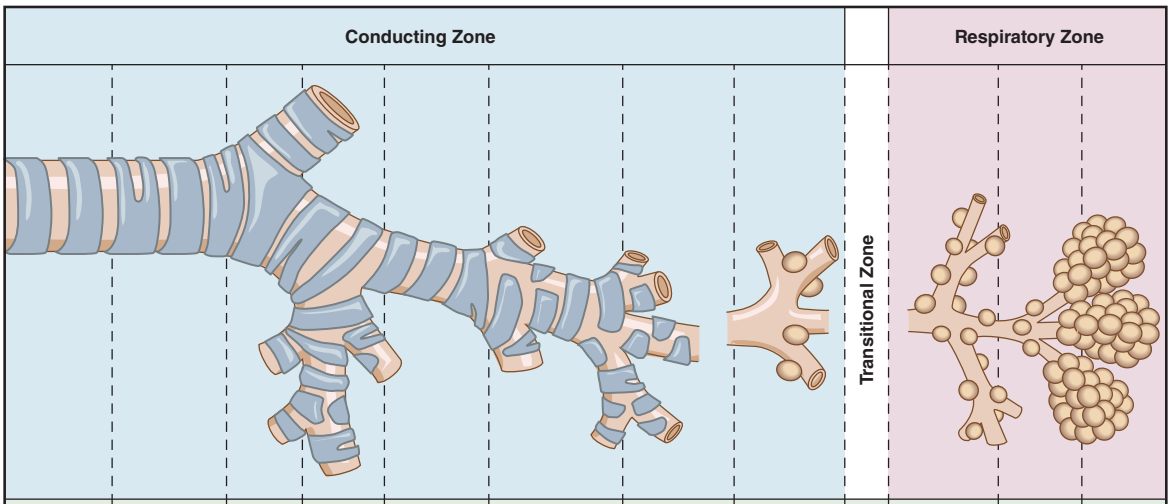


FIGURE 2-1 The lower airway includes the conducting zone and the respiratory zone. (**A**) The conducting zone of the lower airway extends from the larynx to the end of the terminal bronchioles. The change between the terminal bronchioles and respiratory bronchioles is sometimes referred to as the transitional zone of the lungs. (**B**) The respiratory zone is made up of the respiratory bronchioles, the alveolar ducts, and alveoli. Gas exchange occurs in the respiratory zone.



Structure	Larynx	Trachea	Main Stem Bronchi	Lobar Bronchi	Segmental Bronchi	Subsegmental Bronchi	Bronchioles	Terminal Bronchioles		Respiratory Bronchioles	Alveolar Ducts	Alveolar Sacs
Generation	Tracheo-bronchial tree begins beneath the larynx	0	1	2	3	4–9	10–15	16–19		20–23	24–27	28
Anatomic Note/ Diameter		6th Cervical vertebrae Approx. 18 mm in diameter	T5 12 mm	Division of the main stem bronchi into left and right sides at the carina 8–5 mm	4 mm	Ten segmental bronchi on the right and eight on the left. The pulmonary parenchyma begins below this level. 3–1 mm	1 mm	0.5 mm		0.4 mm	0.3 mm	0.2 mm
Cartilaginous	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Disappears at this level	No	No	No	No
Gas Exchange	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes

FIGURE 2-2 The main generations of the lower airway and their characteristics.

mucus glycoproteins (mucins) into the lining of the airway. These mucins, along with water, comprise the airway mucus. The mucins provide the gel-forming properties of mucus and also promote viscosity. Goblet cells are found inside the trachea, bronchi, and larger bronchioles in the respiratory tract and also in the small intestines, the large intestine, and conjunctiva in the upper eyelid.

The trachea extends downward into the chest until it splits into the two main stem bronchi at the carina, which is at the level of the fifth thoracic vertebra (T5), the second costal cartilage, and externally at the angle of Louis (**Figure 2-4**). An adult trachea is approximately 11 to 13 cm in length and 1.5 to 2.5 cm in diameter. An infant's trachea is approximately 6 to 8 cm in length and is approximately 0.5 cm in diameter. Note that in newborns the larynx is positioned slightly higher in the neck than in adults. The carina in a newborn is located between the third and fifth thoracic vertebrae (T3–T5), usually around the fourth thoracic vertebra (T4).

Conditions of the Trachea

Several conditions can cause obstruction of the trachea. **Tracheal agenesis** is a congenital condition in which an infant is born without a trachea (agenesis) or with a significantly underdeveloped trachea (atresia). The condition may be corrected by surgery, though the prognosis is usually poor.

A **tracheoesophageal fistula (TEF)** is an opening between the trachea and the esophagus or another portion of the digestive tract. TEF may occur concurrently with esophageal atresia (EA), a condition in which the upper part of the esophagus does not connect with the lower esophagus and/or stomach. TEF may be corrected by surgery in some cases. Both TEF and EA are part of a family of disorders that are said to have a

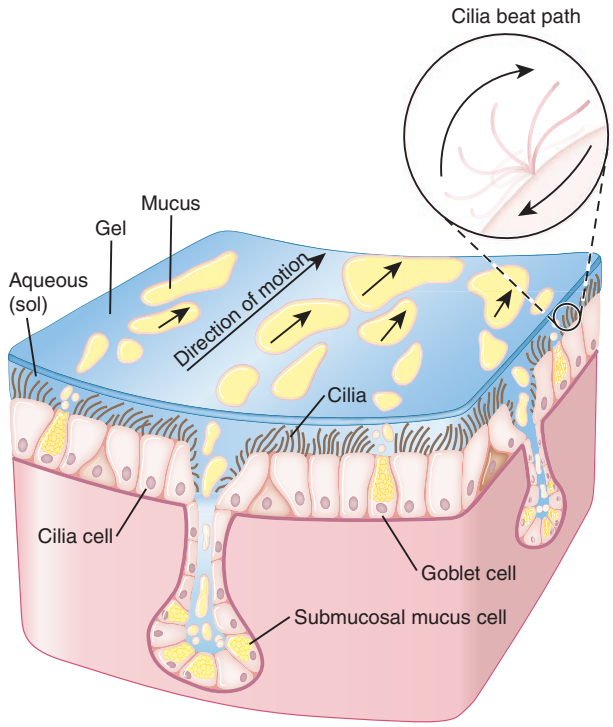


FIGURE 2-3 The airways are coated with a protective layer of an extracellular mucous that is primarily made up of water and mucins (heavily glycosylated proteins). Under normal conditions, airway mucus has two layers: an aqueous or watery sol layer and the thicker gel-like layer. The submucosal glands and the goblet cells secrete the mucins that make up the mucous layer.

Just beneath this gel-like mucous coating and located in the sol layer is a layer of fine hairlike structures called cilia. The cilia beat in a wavelike pattern and move the mucus up and out of the lungs. The mucus layer protects the airway by trapping toxins and debris, which are then transported out of the lungs by means of ciliary beating and when the individual coughs. The process of moving the toxins and debris out of the lungs is called the mucociliary escalator or mucociliary clearance.

Williams R, et al. Relationship between humidity and temperature of inspired gas and the function of the airway mucosa. *Crit Care Med* 1996;24:1920–1929.

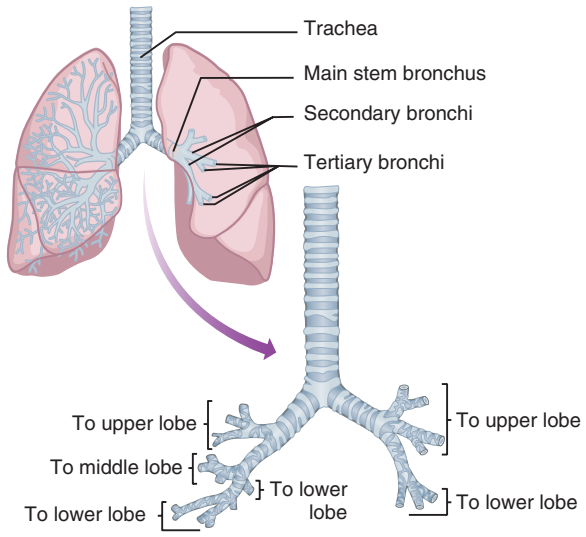


FIGURE 2-4 The trachea and bronchial tree.

VACTERL association. VACTERL is an acronym of six congenital birth defects: vertebral defects, anal atresia, cardiac defects, tracheoesophageal fistula, renal anomalies, and limb abnormalities. Individuals diagnosed with VACTERL association will usually have at least three of these defects. Currently, specific diagnostic criteria for VACTERL are unavailable, and the cause is unknown. Treatment of VACTERL focuses on the correction/management of the specific symptoms that are apparent in each individual. Infants with VACTERL can grow to lead normal healthy lives with treatment of the underlying disorders.

Tracheomalacia is weakness and limpness of the walls of the trachea. It may be either congenital or acquired. Congenital tracheomalacia occurs when the cartilage of the trachea is not fully developed at birth. This condition usually resolves by age 18 to 24 months. Acquired tracheomalacia may occur when pressure is placed on the airway by other structures, such as large blood vessels; as a complication after surgery to repair the trachea or esophagus; or as a result of the long-term placement of an endotracheal or tracheostomy tube. Acquired tracheomalacia may improve over time, or continuous positive airway pressure (CPAP) may be used as a treatment option. If surgery is needed, a tube, called a tracheobronchial stent, may be placed inside the airway to provide support. Another procedure, tracheobronchoplasty, involves surgical placement of a mesh to the outside of the trachea to provide support.

Tracheal stenosis is a narrowing of the airway that may be either congenital or acquired. The cause of

Did You Know?

Mucous Membranes

Mucous membranes are found throughout the body in any cavity that has some type of contact with the outside environment. This includes the upper and lower respiratory airways, digestive tract, reproductive tract, and urinary tract. These mucous membranes are called mucosae. Their role is to protect the various tracts of the body from debris and toxins. The structures of these membranes are basically the same throughout the body. They include some type of epithelial tissue with or without goblet cells, a basement membrane, and a thin layer of loose areolar connective tissue called the lamina propria. This layer of connective tissue contains blood vessels; nerves; and, in some areas of the body, glands. In the lungs, the lamina propria directly connects to the pulmonary parenchyma.

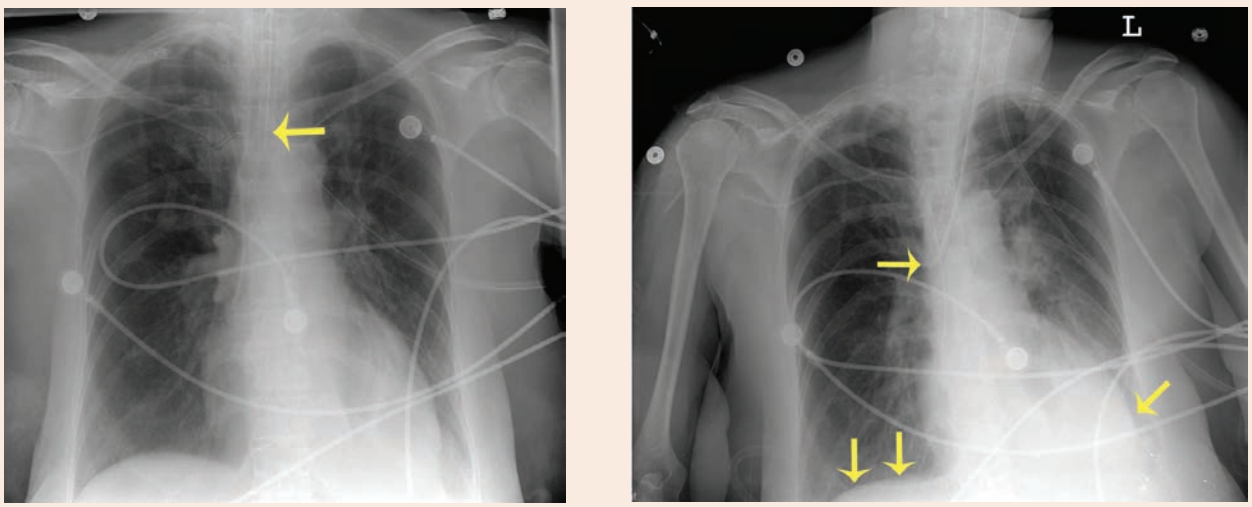
congenital tracheal stenosis is unknown. Acquired tracheal stenosis is usually related to the development of scar tissue in the airway after long-term placement of an endotracheal or a tracheostomy tube. Treatment may include surgical resection and reconstruction of the trachea; bronchoscopic tracheal dilation, which is a procedure that widens the trachea, either with a balloon or surgical instruments; laser bronchoscopy to remove the scar tissue; or the placement of a tracheobronchial stent.

Main Stem Bronchi

The trachea divides into the left and right **main stem bronchi** at a point called the carina. Anatomically, this bifurcation is approximately at the level of the fifth thoracic vertebra (T5). The right main stem bronchus is wider and shorter than the left main stem bronchus. This is because the right main stem bronchi will further branch into the three lobes of the right lung, whereas the left bronchi will only divide into airways that support the two lobes of the left lung. The left main stem bronchus is therefore smaller in diameter and longer than the right main stem bronchus. In addition, the left main stem bronchus makes a 45° to 55° angle as it branches into the left side of the chest. In contrast, the right main stem bronchus only makes a 20° to 30° angle as it branches into the right side of the chest. The wider diameter and less sharp angle of the right main stem bronchus predispose the right lung to increased risk of aspiration and also pose a greater risk of endotracheal tube displacement into the right lung.

CLINICAL FOCUS: Endotracheal Intubation

The placement of an endotracheal tube into the airway to facilitate ventilation and the clearance of secretions is known as **endotracheal intubation**. Whether inserted through the nose or the mouth, the tip of the endotracheal tube should be positioned approximately 4 to 6 cm above the carina (**Figure 2.5A**). An endotracheal tube that is positioned too low is likely to slip into the right main stem bronchus, which can result in underventilation of the left lung and atelectasis (i.e., collapse) of the alveolus on the left side (**Figure 2.5B**). Overinflation and injury to the right lung may also occur. Verification of endotracheal tube placement requires a chest x-ray (radiograph). An endotracheal tube that is inadvertently placed in the esophagus can be life-threatening, because it prevents adequate ventilation of the lungs. In this instance, attempts at ventilation will push air into the stomach. Once distended with air, the patient may vomit, increasing their risk of aspiration, and the stomach may push upward on the diaphragm, limiting its ability to function correctly.



(A) (B)

FIGURE 2-5 The tip of the endotracheal tube should be positioned approximately 4 to 6 cm above the carina. (**A**) In this chest radiograph, the endotracheal tube can be seen by the radiopaque. The tip of this tube is properly positioned above the carina (the single yellow arrow). (**B**) In this chest radiograph, the endotracheal tube is too low. The tube has advanced into the right main stem bronchus, resulting in hyperinflation of the right lung and atelectasis of the left lung.

Hess D, MacIntyre N, Adams A, Galvin W. Respiratory care: principles and practice. Burlington, MA. Jones & Bartlett Learning; 2015.

Both the right and left main stem bronchi are supported by C-shaped cartilaginous rings similar to those found in the trachea.

This branching of the trachea at the carina into the left and right main stem bronchus is the first generation of the tracheobronchial tree. As the airways continue to divide and become smaller, they are called successive generations and are given numbers. Two to three generations, or subdivisions, below the carina the inspired air becomes warmed to body temperature (37° C) and fully saturated with water vapor. This is called the **isothermic saturation boundary**. Below this boundary, gas temperature and humidity remain constant. However, the boundary may shift downward if an individual breathes through his or her mouth or inspires cold air.

CLINICAL FOCUS: Endotracheal Tube Markings and Sizes

Older endotracheal tubes were made of rubber or metal. These tubes were often rigid and hard, thereby increasing the risk of airway trauma. Today, endotracheal tubes are usually made of a more flexible polyvinyl chloride with an embedded radiopaque blue line to help gauge the position on the chest radiograph. These tubes have a slight curve to mimic the curvature of the upper airway. They also have a left-facing beveled edge and a hole in the back side of the tube at the base. The left-facing bevel tip helps improve visualization of the vocal cords during intubation. The hole is called a Murphy's eye and functions as a vent that prevents complete obstruction of the patient's airway should the primary opening of the tube become occluded. It was named after Francis J. Murphy (1900–1972), who in 1941 defined the characteristics of the optimal endotracheal tube.

Adult endotracheal tubes may or may not have a balloon in the distal end of the tube. This balloon is known as the "cuff" and when inflated provides a seal within the airway thereby preventing the passage of air or fluids around the endotracheal tube. When properly inflated, air may only move through the endotracheal tube to the airways below. Leakage of fluid around the cuff into the airway below is considered a form of microaspiration. These fluids or secretions may contain bacteria and increase the patient's risk of infections and pneumonia if allowed to leak around the cuff. The passage of air around the cuff allows air to escape during mechanical ventilation and alters the effectiveness of the process. The endotracheal cuff may be self-inflating but is usually inflated manually via a pilot balloon, located at the opposite end of the endotracheal tube. Traditionally, uncuffed endotracheal tubes are used in pediatrics. It is believed that due to the narrowness of the pediatric airway, particularly around the cricoid cartilage, cuffs are unnecessary and may cause tracheal stenosis in infants and children. However, cuffed tubes are available for pediatrics and may be used under certain conditions.

Most tubes, both adult and pediatric, have another hole above the cuff that allows for suctioning and is called the subglottic suction port.

Connectors on the end of the endotracheal tubes have been standardized across manufacturers to prevent a potentially dangerous situation. An endotracheal tube with a nonstandard adapter that does not connect to the ventilator or resuscitation bag could be potentially fatal. Therefore, adult tubes usually have a 15-mm connector. Although pediatric tubes may have a smaller connector, many also have a 15-mm connector.

Several markings are placed on the side of the endotracheal tube (**Figure 2-6**). These include the manufacturer's name; length marks in centimeters to assist in determining the proper placement and depth of the tube; and tube-size markings that label the internal and external diameter of the tube in millimeters. The letters IT indicate that the tube has been implant tested in living tissue, has not generated toxic side effects, and is safe for use in humans. The marking Z79 on an endotracheal tube indicates that the tube was manufactured in accordance with the American Material Standards Institute Z79 Committee, which establishes the requirements for these tubes.

Endotracheal tubes come in various sizes. The term "size" usually refers to the internal diameter of the tube. Therefore a "size 8" endotracheal tube, has as internal diameter of 8 mm. The age-recommended endotracheal tube sizes are as follows:

Premature infant: 2.5 to 3.0 uncuffed
Full-term infant: 3.0 to 3.5 uncuffed
6 months to 1 year: 3.0 to 4.5 uncuffed
1 to 6 years: 4.5 to 5.5 uncuffed
6 to 10 years: 5.5 to 6.5 uncuffed or cuffed
10 years to adolescents: 6.5 to 8.0 cuffed
Adolescents and adults: 7.0 to 9.0 cuffed

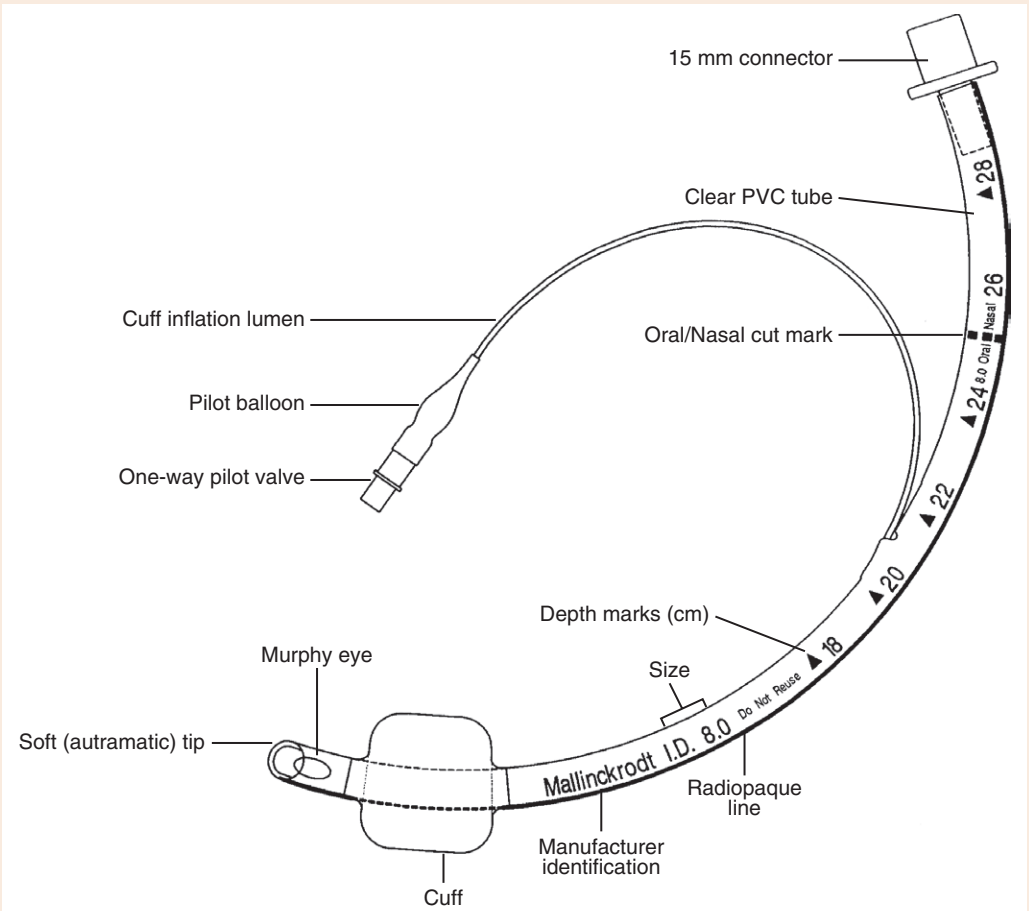


FIGURE 2-6 Identifying marks on an endotracheal tube.

Lobar, Segmental, and Subsegmental Bronchi

The second generation of the tracheobronchial tree begins where the main stem bronchi divide into the **lobar bronchi**. In these airways, the cartilaginous rings transition into more platelike structures. The right side of the tracheobronchial tree has three lobar bronchi known as the upper, middle, and lower lobar bronchi. The divisions of the left main stem bronchi are the upper and lower lobar bronchi.

As the airway continues to divide, the next generation is called the **segmental bronchi**. The right side of the tracheobronchial tree at this level has 10 segmental bronchi; the left side has 8 segmental bronchi. Below this level, the airways are said to enter the **pulmonary parenchyma**. By definition, parenchyma is the functional tissue of an organ. In the lungs, this would be the tissue containing the alveoli where gas exchange occurs. However, the term *pulmonary parenchyma* is often used to describe the lung tissue as a whole.

Beneath the segmental bronchi are the **subsegmental bronchi**. These airways are approximately 1 to 4 mm in diameter. At this level, the cartilaginous tissue supporting the airway has disappeared. The subsegmental bronchi mark the end of the cartilaginous airways.

Did You Know?

Gray's Anatomy

When we hear the phrase "Gray's anatomy," we usually think of the hit television show *Grey's Anatomy*. However, the original "Gray's anatomy" was a textbook written by Henry Gray and illustrated by Henry Vandyke Carter that was first published in 1858. They wanted to publish an affordable anatomy reference for medical and surgical students. The diagrams and descriptions in the book are based on their work dissecting bodies from London's workhouse and hospital mortuaries. Still in print today, the book was considered the definitive text on anatomy for many years.

The Bronchioles

Occurring at the 10th through the 15th generations, the **bronchioles** are the next level of the airway. They are less than 1 mm in diameter and do not contain supporting cartilage. These airways are surrounded by spiral smooth muscles. The lack of supporting cartilage

CLINICAL FOCUS: Sputum

The mucous produced by the submucosal glands and goblet cells of the lungs is called **sputum**. A sputum culture is a laboratory test to assess the presence of an infection in the lungs that may be caused by bacteria or fungi. Sputum cytology is another laboratory test that may be done to detect some types of cancer or other lung conditions.

Sputum samples may be collected for testing by asking the individual to cough, by providing an aerosol treatment with a solution such as hypertonic saline to stimulate a cough, or by tracheal aspiration. Samples may also be collected during a bronchoscopy. This procedure involves inserting a bronchoscope, which has a light and a small camera, through the nasal or oral cavity through the larynx and into the tracheobronchial tree. This allows the healthcare provider to see inside the airway and complete both diagnostic and therapeutic procedures. Biopsy samples may be collected as part of a bronchoscopy. Another sample collection method, **bronchoalveolar lavage (BAL)**, involves squirting a small amount of fluid into a portion of the lungs, usually via the bronchoscope, and then collecting the fluid for examination.

Bronchoscopes are either flexible or rigid. Flexible bronchoscopes are more commonly used. General anesthesia is usually not required for procedures that use flexible bronchoscopes.

means that these airways are subject to the activity of the smooth muscles to remain patent. Contraction of the smooth muscles may collapse or constrict these airways. Relaxation of the smooth muscles opens these airways and results in bronchial dilation. The bronchioles are also dependent upon changes in intrapleural pressure (also called intrathoracic pressure). As pressures rise in the chest cavity, these airways may be squeezed, causing them to collapse or be constricted.

The Terminal Bronchioles

The **terminal bronchioles** occur at the 16th to the 19th generations of the tracheobronchial tree. They mark the end of the conducting zone of the airway and the beginning of the respiratory zone of the lungs, where gas exchange occurs (**Figure 2-7**). The diameter of the terminal bronchioles is approximately 0.5 mm.

Several structural changes occur at this level. The cilia and mucous-producing cells that have lined the airways above disappear, and the epithelium transitions to a more cuboidal shape. Two new structures, club cells and canals of Lambert, appear in the terminal bronchioles. Embedded in the bronchial epithelium, **club cells** are also known as Clara cells and nonciliated nonmucous secretory cells of the bronchiolar epithelium. Club cells are cuboidal in shape and have a large number of mitochondria. Each club cell contains approximately six dense membrane-coated granularities that are approximately 0.3 μm in size. They secrete several proteins and are believed to play a role in the regulation of pulmonary homeostasis in both acute and chronic inflammatory conditions. **Canals of Lambert** provide alternate pathways between some bronchioles and their adjacent alveoli. These channels provide collateral ventilation and may help to prevent atelectasis. Canals of Lambert are absent/unformed in newborns, and usually develop during childhood.

Did You Know?

Clara Cells

Many textbooks and articles refer to Clara cells. These cells were discovered by Max Clara, a German anatomist and Chair of Anatomy at Leipzig University in Germany in 1935. He discovered the cells while examining lung samples acquired from prisoners killed in the concentration camps near Dresden. An active member of the National Socialist German Workers' Party (Nazi Party), Clara was arrested by the U.S. Army in October 1945. He underwent a "denazification process" and went on to hold a professorship for histology at the University of Istanbul, Turkey, from 1950 to 1961. He died in Munich in 1966.

Because of the associations with the Nazi Party, the term *club cell*, rather than Clara cell, was used in German and English publications in the 1950s and 1960s, and the term has been recommended as an alternative to *Clara cells*.

The Respiratory Bronchioles, the Acinus, the Alveolar Ducts, and the Alveoli

The lower end of the terminal bronchioles is considered the end of the tracheobronchial tree. Beneath this level are the respiratory bronchioles, generations 20 through 23; the alveolar ducts, generations 24 through 27; and the alveolar sacs, generation 28. The change between the terminal bronchioles and respiratory bronchioles is sometimes referred to as the transitional zone of the lungs or as a single structure, the acinus. The beginning of the respiratory zone occurs at the level of the acinus.

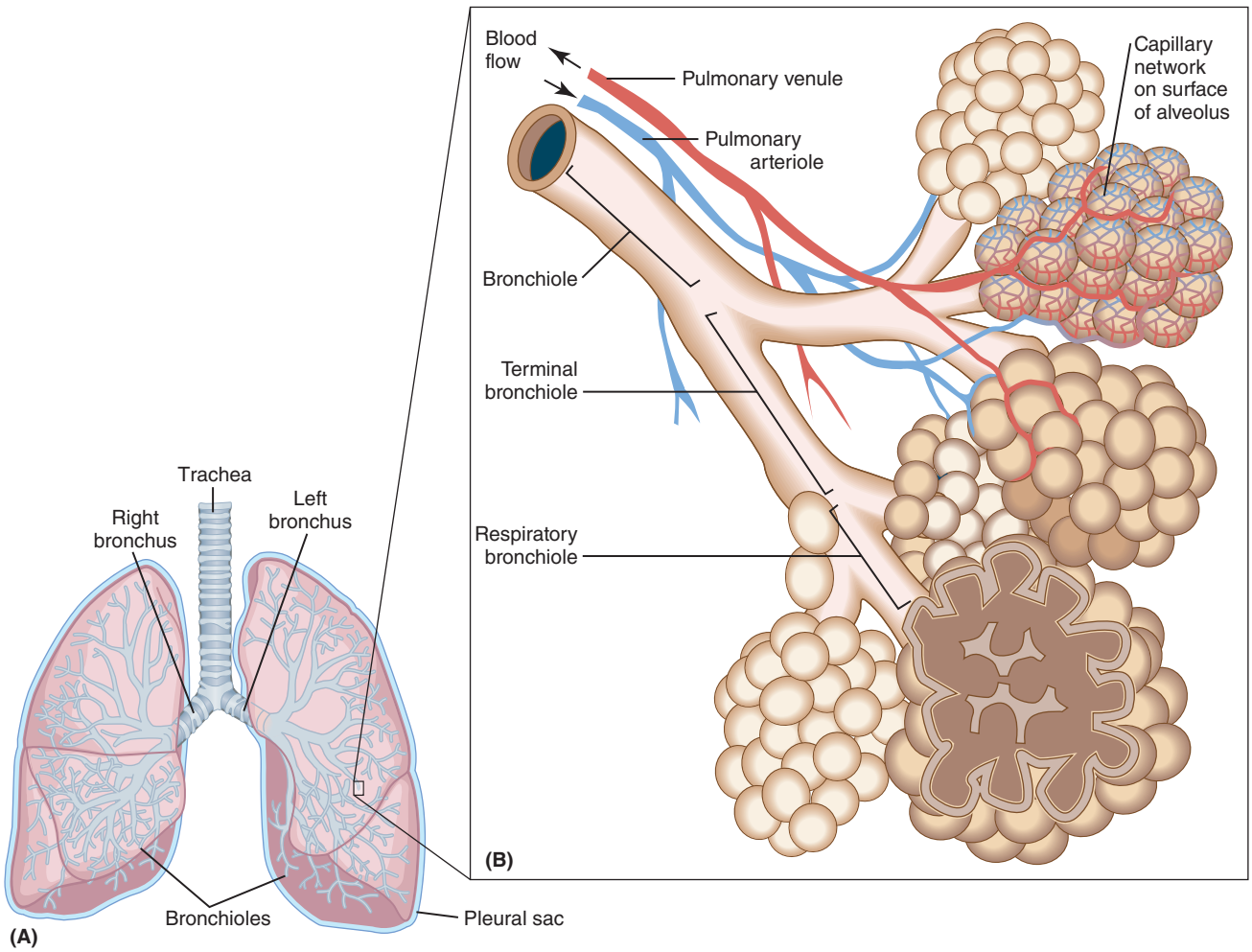


FIGURE 2-7 The terminal bronchioles are the smallest of the airways and are the end of the conducting zone of the airway. Beneath the terminal bronchioles is the respiratory zone. In the respiratory zone, the alveoli are surrounded by a network of capillaries.

Other names used for the acinus are the primary lobule, functional units of the lung, and the terminal respiratory unit. A closer look reveals that the acinus is made up of approximately three generations of respiratory bronchioles, three generations of alveolar ducts, and 15 to 20 grapelike clusters of **alveolar sacs**. The estimated mean size of a single alveolus is $4.2 \times 10^6 \mu m^3$. It has also been suggested that it is approximately 0.2 mm in diameter. In adults, the estimated mean number of alveoli is 480 million (range: 274 to 790 million). Between the alveoli are openings that provide alternate circulation (**Figure 2-8**). These are known as the **pores of Kohn**.

The alveolar epithelium has several different types of cells. Type I cells, also called squamous pneumocytes, cover approximately 95% of the alveolar surface. These cells are the primary site of gas exchange. They are unable to replicate, and when they die, they are replaced by type II cells, which are also known as granular pneumocytes. The type II cells that take the place of type I cells soon convert to type I cells. Type II cells comprise the remaining 5% of the alveolar surface. They provide little structural support. They contain lamellated bodies that transform into surfactant.

Surfactant is a mixture of phospholipids and proteins that prevents alveolar collapse at low lung volumes and preserves airway patency during normal ventilation. The principal phospholipid in surfactant is dipalmitoylphosphatidylcholine (DPPC), also known as lecithin. The remaining components in surfactant are surfactant proteins (SP-A, SP-B, SP-C, and SP-D) and neutral lipids, primarily cholesterol. One of the most significant phospholipids in surfactant is phosphatidylglycerol (PG). The concentration of PG in amniotic fluid is a predictor, or biomarker, of neonatal lung maturity.

A third type of cell, type III cells, also known as brush cells, have been identified in the alveolus. Their function is unknown. However, unmyelinated nerve cells have been associated with these cells, which suggests that type III cells may have a chemoreceptor function.

Alveolar macrophages are scavenger mononuclear phagocyte cells that remove foreign particles and bacteria from the alveolus. These cells phagocytose (i.e.,

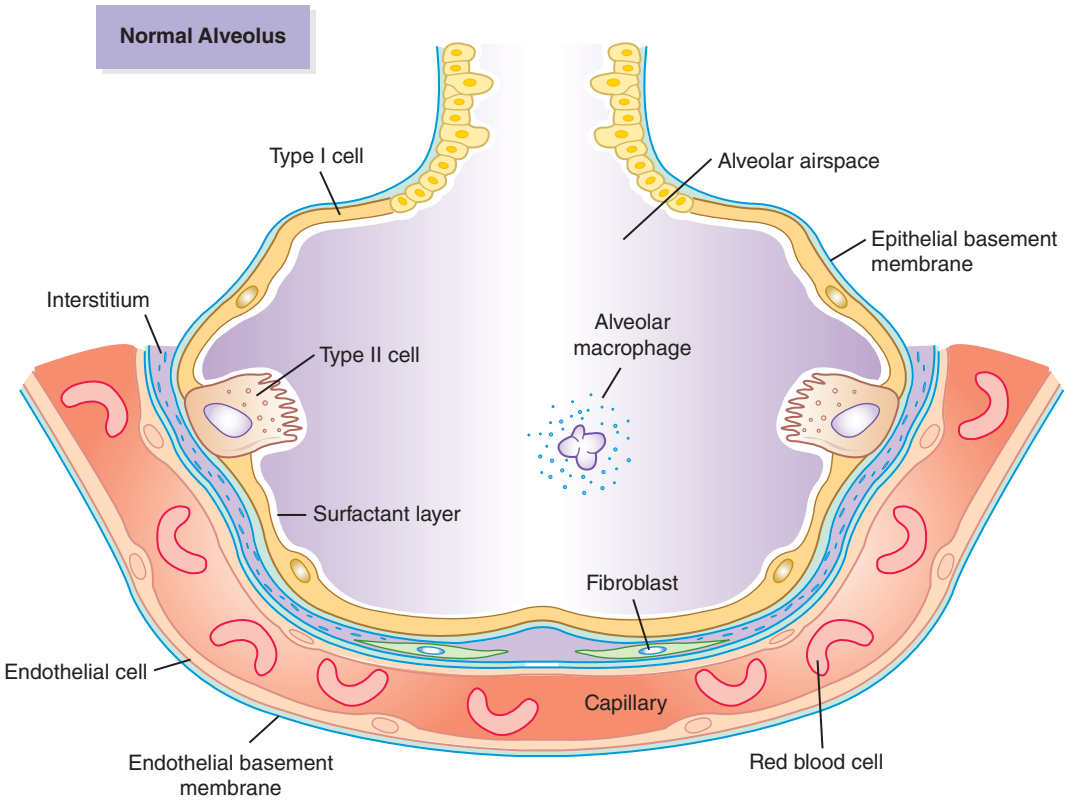


FIGURE 2-8 Structure of the alveolus.
Reproduced from Ware LB, Matthay MA. The acute respiratory distress syndrome. N Engl J Med 2000;342:18:1334–1348.

ingest) the bacteria and kill it. If there are too many bacteria or the macrophage is unable to kill it, the macrophage works with the inflammatory response. **Fibroblast cells** play a role in the lung repair/fibrosis process.

The **pulmonary interstitium** is a collective term for the support tissues that surround the lungs. These tissues include the alveolar epithelium, pulmonary capillary endothelium, basement membrane, and perivascular and perilymphatic tissues.

Conditions of the Lower Airway and Alveolus

Several diseases and conditions can affect the lower airways. **Acute respiratory distress syndrome (ARDS)** is a progressive inflammatory condition of the lungs that can be the result of direct injury to the lungs, such as pneumonia, or indirect injury that affects the lungs, such as sepsis or severe bleeding. ARDS usually leads to low blood oxygen levels known as hypoxemia and requires mechanical ventilation.

Asthma is a heterogeneous disease characterized by chronic airway inflammation; variable expiratory airflow limitation; intermittent symptoms of wheezing; shortness of breath, or **dyspnea**; tightness in the chest; and coughing. The wheezing and tightness in the chest that is associated with asthma is caused by tightening of the smooth muscles that surround and constrict the lower airways and is known as bronchoconstriction.

Bronchiolitis is an infection that affects the bronchioles. The condition is common in children and often caused by respiratory syncytial virus (RSV). Because their lungs and immune systems are not yet fully developed, young infants are at greatest risk of developing bronchiolitis. No vaccine is available for RSV, and treatment is supportive. Bronchiolitis usually lasts for 2 to 3 weeks.

Bronchiectasis is a chronic condition that occurs when the walls of the bronchi become thickened due to inflammation and infection. Adults are most likely to develop this condition secondary to lung infections or conditions that damage the airways, such as cystic fibrosis.

Chronic obstructive pulmonary disease (COPD) is a preventable disease that is characterized by airflow limitation related to airway and/or alveolar abnormalities that are usually caused by exposure to noxious particles or gases and accompanied by persistent symptoms of dyspnea, cough, and/or sputum production. The chronic airflow limitation that is characteristic of COPD is caused by a mixture of small airways diseases, such as bronchiolitis, and parenchymal damage, such as emphysema. **Chronic bronchitis** is a type of COPD

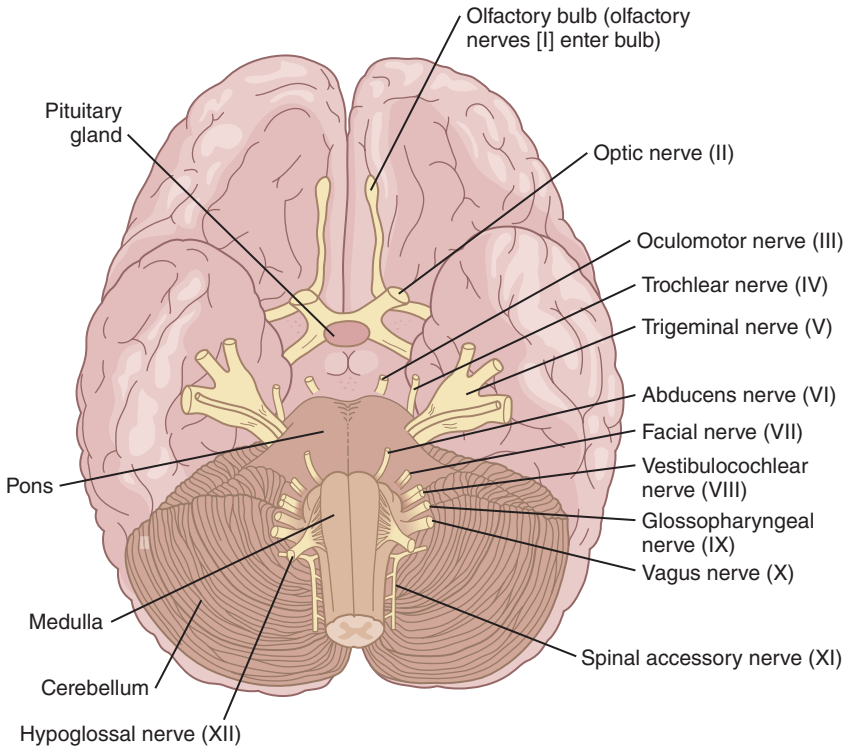


FIGURE 2-9 The cranial nerves.

characterized by chronic cough and sputum production for 3 or more months. **Emphysema** is a type of COPD that is characterized by alveolar wall destruction without fibrosis and a loss of elastic recoil. When the alveolar walls are worn away to the point that the alveous is greater than 1 cm in diameter, it is called pulmonary bullae or bleb.

Pneumonia is an inflammatory condition that is usually related to an infectious process and accompanied by congestion. The infection can be cause by bacteria, viruses, or fungi and may occur in one or both lungs. Symptoms may include fatigue, shortness of breath, coughing that may or may not be associated with mucus, fever, sweating or chills, and chest pain.

Pulmonary edema is a condition characterized by fluid in the airways that restricts ventilation and obstructs respiration. This condition may be caused by heart failure, kidney failure, high-altitude exposure, or injury to the lungs. Symptoms may include shortness of breath, difficulty speaking, coughing and frothy or blood-tinged mucous.

The Cranial Nerves

Many of the physiologic functions that occur in the airways and throughout the body are controlled by the **cranial nerves**. The 12 cranial nerves originate in the pons and medulla of the brain (**Figure 2-9**). The pons is part of the brain stem that is located between the medulla oblongata and the midbrain and anterior to the cerebellum. The nerves originate from these portions of the brain stem and run in pairs down either side of the body. The nerves are assigned the Roman numerals I through XII. They are also referred to by the functions they support; for example, sensory, motor, or mixed/both (**Table 2-1**).

Three of the cranial nerves are primarily associated with sensory function: cranial nerve I, the olfactory nerve; cranial nerve II, the optic nerve; and cranial nerve VIII, the acoustovestibular nerve. Four cranial nerves support motor function: cranial nerve IV, the trochlear nerve; cranial nerve VI, the abducens; cranial nerve XI, the spinal accessory nerve; and cranial nerve XII, the hypoglossal nerve. Five cranial nerves have mixed sensory, motor, and parasympathetic function and will be discussed in detail here due to their role in the respiration: cranial nerve III, the oculomotor nerve; cranial nerve V, the trigeminal nerve; cranial nerve VII, the facial nerve; cranial nerve IX, the glossopharyngeal nerve; and cranial nerve X, the vagus nerve. A mnemonic for remembering the cranial nerves is: On old Olympus's towering top a Finn and German viewed some hops. This sentence uses the first letter of each of the 12 nerves in order.

Afferent neurons, also called sensory neurons, carry stimulus from the body to the central nervous system and brain. Efferent neurons, also called motor neurons, carry impulses away from the central nervous system and brain to initiate an action or movement in the body. The afferent and efferent neurons do not directly connect to one another. Association neurons, also called interneurons, act as the middleman, or bridge, between afferent and efferent neurons.

TABLE 2-1
Cranial Nerve Function and Location

Cranial Nerve		Function		Location
I	Olfactory nerve	Sensory	Afferent neurons that carry impulses for the sense of smell.	Originates in the left and right olfactory bulbs. Exits the skull through the cribriform plate and passes along the roof of the nasal cavity.
II	Optic nerve	Sensory	Afferent neurons that carry impulses for vision/sight.	Originates from the bipolar cells of the retina and connects to the specialized rod and cone receptors in the retina. Exits the skull through the optic canal.
III	Oculomotor nerve	Both/mixed	Contains both afferent sensory and efferent sensory neurons that control the muscles of the eye, including the ciliary, pupillary sphincter, and extrinsic eye muscles. It does not control the superior oblique and lateral rectus muscles. It also carries parasympathetic input to the ciliary ganglion that constrict the pupils.	Originates in the motor neurons in the oculomotor and Edinger-Westphal nuclei in the brain stem. Exits the skull through the superior orbital fissure and ends in the eyes.
IV	Trochlear nerve	Motor	Efferent neurons that control eye movements, specifically abduction, depression, and internal rotation of the eye.	Originates in the trochlear nucleus, which is located in the midbrain. Exits the skull through the superior orbital fissure and ends in the superior oblique eye muscles.
V	Trigeminal nerve	Both/mixed	Contains both afferent sensory and motor neurons and efferent sensory and motor neurons that control the muscles of the head and face and support the act of chewing. This nerve has three branches: the ophthalmic, maxillary, and mandibular nerves.	Originates in the lateral superior margin of the left and right side of the pons. This nerve branches into three smaller nerves that exit the skull at the superior orbital fissure, the foramen rotundum, and the foramen ovale.
VI	Abducens nerve	Motor	Efferent neurons that control the internal retraction of the eyes.	Originates in the neuronal cell bodies located in the ventral pons. Exits the skull via the superior orbital fissure.
VII	Facial nerve	Both/mixed	Contains afferent sensory neurons and efferent motor and parasympathetic neurons that control the movement of the face, allowing for expressions, and supports taste. This nerve also controls the lacrimal, submandibular, sublingual glands and mucous glands of mouth and nose.	Originates in the facial nerve nucleus in the pons. Exits the skull through the internal acoustic meatus.
VIII	Auditory (or vestibulocochlear) nerve	Sensory	Afferent neurons that support hearing and balance.	Originates between the pons and the medulla oblongata. Exits the skull via the internal acoustic meatus.
IX	Glossopharyngeal nerve	Both/mixed	Contains afferent sensory neurons and efferent motor and parasympathetic neurons that support taste, movement of the tongue, swallowing, secretion of saliva, reflex control of blood pressure and respiration.	Originates in the medulla oblongata. Exits the skull via the jugular foramen.

Cranial Nerve		Function		Location
X	Vagus nerve	Both	Contains afferent sensory neurons and efferent motor neurons that support the heart, lungs, pharynx, larynx, trachea, bronchi, and gastrointestinal tract. The longest of the cranial nerves, the vagus nerve derives its name from the Latin *vagary*, which means "wandering." It is sometimes referred to as the "wandering nerve" due to its many branches and interactions with the systems of the body.	Originates in the medulla of the brain stem. Exits the skull via the jugular foramen. Travels through the neck via the carotid sheath, traveling inferiorly with the internal jugular vein and common carotid artery.
XI	Spinal accessory nerve	Motor	Efferent neurons that support the movement of the shoulders by controlling the sternocleidomastoid muscles and trapezius muscles.	Originates from neuronal cell bodies located in the cervical spinal cord and caudal medulla. Exits the skull via the jugular foramen. This is the only cranial nerve to both enter and exit the skull.
XII	Hypoglossal nerve	Motor	Efferent neurons that control the movement of the intrinsic and extrinsic tongue muscles except for the palatoglossus and enables swallowing.	Originates in the dorsal medulla of the brain stem in the hypoglossal nucleus. This nerve exits the skull via the hypoglossal canal.

CLINICAL FOCUS: The Phrenic Nerve

The phrenic nerve is both a sensory and a motor nerve that controls the diaphragm and supports breathing. This nerve originates in the spinal column from the ventral rami of the cervical 3, 4, and 5 nerve roots, which are part of the cervical plexus. The left phrenic nerve descends to the left subclavian artery, the arch of the aorta, the left auricle, and the left ventricle, and then moves downward toward the left half of the diaphragm. The right phrenic nerve descends to the superior vena cava, right atrium, right ventricle, and inferior vena cava before passing through the vena caval foramen to the right half of the diaphragm.

CLINICAL FOCUS: A Review of Ventilation

Air moving into the body travels through the nose or mouth, the nasal cavity or oral cavity, oral pharynx, pharynx, larynx, trachea, main stem bronchi, lobar bronchi, segmental bronchi, subsegmental bronchi, bronchioles, terminal bronchioles, alveolar ducts, alveolar sacs, and alveoli.

Summary

The lower airway is often referred to as the tracheobronchial tree. The airway bifurcates in a branching inverted treelike fashion moving downward toward the alveoli. At the top of the tracheobronchial tree the outermost layer of the airway is made up of cartilage. The layer of cartilage decreases down the airway until it completely disappears at the level of the bronchioles. Respiration (i.e., gas exchange) occurs in the acinus and primarily in the small grapelike clusters at the end of the airway known as alveoli. Many of the functions of the respiratory system are controlled by the cranial nerves, and the phrenic nerve controls the diaphragm and supports breathing. Understanding the activity of these nerves is critical when performing an assessment of a respiratory patient.

Case Study

A 62-year-old female is admitted to the intensive care unit from her long-term care facility after 1 week of progressive shortness of breath, fatigue, and a cough. She has a history of diabetes and hypertension. A physical examination shows that the patient has a temperature of 38.3° C, a heart rate

of 84 beats/min, a respiratory rate of 18 breaths/min, and a blood pressure of 138/102 mm Hg. She may have been exposed to multidrug-resistant organisms at the long-term care facility. Chest radiograph and laboratory testing confirm that she has pneumonia. The chest radiograph reveals a left lower-lobe opacity. The laboratory results showed a positive pneumococcal urine antigen test, and she was started on a 7-day course of antibiotics. On day 2 her shortness of breath is getting worse and she has begun to have copious amounts of sputum in her lungs.

1. **What is the medical term for shortness of breath?**
2. **The patient's condition continues to deteriorate, and the decision is made to intubate this patient and initiate mechanical ventilation. An endotracheal tube is placed. Where should the tip of the endotracheal tube be placed for optimal ventilation?**
3. **Identify the anatomic structures the endotracheal tube passed through as part of the oral intubation process.**

Review Questions

1. What is the medical term for an opening between the trachea and the esophagus or digestive tract?
   a. Tracheoesophageal fistula (TEF)
   b. Esophageal atresia (EA)
   c. VACTERL
   d. Tracheomalacia
2. The point at which the gas temperature and humidity remain constant in the tracheobronchial tree is called the:
   a. humidification gradient.
   b. heated humidification point.
   c. isothermic saturation boundary.
   d. airway humidification boundary.
3. Which of the following conditions is characterized by fluid or mucous in the airways that restricts ventilation and obstructs respiration?
   a. Pulmonary homeostasis
   b. Bronchiectasis
   c. Airway limitation
   d. Pulmonary edema
4. Which structures provide alternate pathways between some bronchioles and their adjacent alveoli?
   a. Clara cells
   b. Pores of Kohn
   c. Canals of Lambert
   d. Alveolar ducts
5. Which of the following is *not* a cartilaginous airway?
   a. Trachea
   b. Main stem bronchi
   c. Subsegmental bronchi
   d. Alveolar duct

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