CHAPTER

1

The Upper Airways

CHAPTER OUTLINE

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

1. Identify the structures, physiologic processes, and functions of the upper airway.
2. Explain the difference between breathing and respiration.
3. Discuss the filtration, humidification, and warming of inhaled gases.
4. Describe the histology of the upper airway.
5. Provide examples of abnormal physiologic processes of the nose, sinuses, oral cavity, and pharynx.
6. Describe the structure and function of the larynx.
7. Discuss the use of bronchoscopy.
8. Identify different types of artificial airways.

KEY TERMS

airway edema
alar collapse
ankyloglossia
arytenoid cartilages
breathing
bronchoscopy
bronchospasm
cilia
ciliated epithelium
columnar epithelium
corniculate cartilages
cricoid cartilage
croup
cuboidal epithelium
cuneiform cartilages
dysphagia
endotracheal tubes
epiglottis
epiglottitis
epistaxis
extrinsic muscles
hyperactive gag reflex
intrinsic muscles
laryngeal edema
laryngitis
laryngopharynx
laryngoscope
laryngospasm
larynx
nares
nasal cavity
nasal conchae
nasal congestion
nasal flaring
nasal polyps
nasal septum
nasal trumpets
nasal turbinates
nasal valve collapse
nasal vestibules
nasopharyngeal airways
nasopharynx
nose
oral candidiasis
oral cavity
oropharyngeal airways
oropharynx
otitis media
peritonsillar abscess
pharyngeal reflex
pharynx
pseudostratified columnar epithelium
quinsy
respiration
rhinitis
simple squamous epithelium
sinusitis
stratified squamous epithelium
stylet
supraglottic airways
thyroid cartilage
tonsillitis
tracheostomy tubes
upper airway
uvula
vallecula epiglottis
Valsalva maneuver
vibrissae
vocal cord dysfunction (VCD)
Waldeyer's ring

Breathing

The natural act of **breathing** is simply moving air into and out of the body. Once inside the body, a series of physiologic processes warm, filter, and humidify the air; extract oxygen and nutrients; and eliminate carbon dioxide and other by-products. The process of moving air involves a network of nerves, muscles, and tissues that facilitate **respiration**, or gas exchange.

CLINICAL FOCUS: Breathing, Respiration, and Ventilation

Many people use the terms *breathing, respiration*, and *ventilation* interchangeably. However, in clinical practice the terms have distinct meanings. Breathing is the process of moving air into (inhaling) and out of the body (exhaling). Respiration is the process of gas exchange at the cellular level by which oxygen is made available to the cells of the body and carbon dioxide and other by-products are removed. Ventilation is the mechanical movement of air into and out of the body.

As air moves into and out of the body, it passes through the conducting airways to the lungs. The conducting airways include the upper airway and lower airway. The **upper airway** includes the nose, nasal cavity, oral cavity (mouth), and the pharynx, which is divided into the nasopharynx, oropharynx, and laryngopharynx. The larynx, or voice box, is usually considered the demarcation between the upper and lower airways. The lower airway includes the trachea, tracheobronchial tree, bronchioles, and the alveoli. The lower airway provides access to the lungs. The lungs are divided into five lobes, three lobes on the right of the body and two lobes on the left (**Figure 1-1**).

The Nose and Nasal Cavity

The first portion of the anatomy that air encounters as it enters the body is the **nose**. The **nasal cavity** extends from the external opening of the nose to the oral cavity (i.e., the mouth). The opening of the nose through which air enters the body is called the nostrils, or the **nasal vestibules**. The **nasal septum** is the partition that separates the left and right sides of the nose and nasal cavity. It is composed of bones and cartilage. The **nares** are the two openings at the end of the exterior of the nose and are separated from each other by the nasal septum.

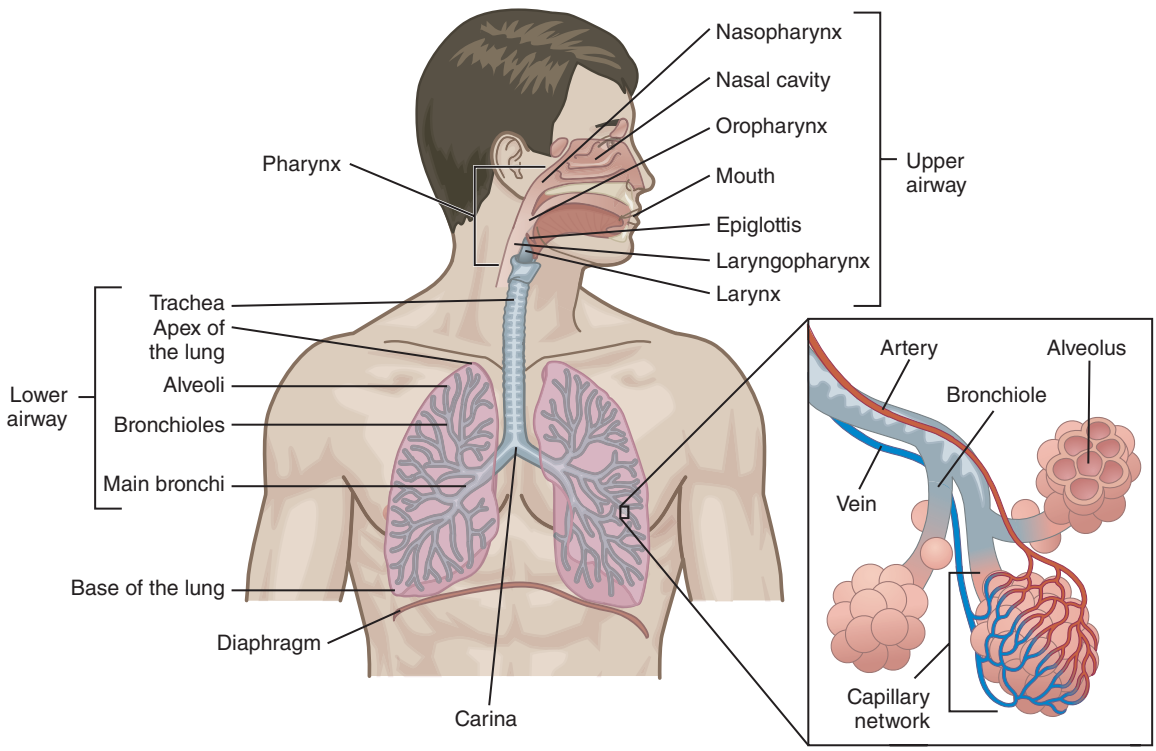


FIGURE 1-1 The respiratory system is divided into the upper and lower airways, which can also be described as the conducting airways and the respiratory zone, or nonconducting airway. The conducting airways include all of the upper airway and the lower airway up until the alveoli. The respiratory zone includes the terminal bronchioles and the alveoli. Gas exchange occurs in the respiratory zone.

In addition to providing sensory receptors for smell and aiding in speech, the nose and nasal cavity warm, humidify, and filter the incoming air. These structures also provide access to the sinuses, a series of hollow passages inside the head. The outer, or external, nose is the part that most people see. It is made up of the nasal bones, the frontal processes of the maxillae, and five cartilages—two lateral nasal cartilages, the greater and lesser alar cartilages, and the septal cartilage. The bones of the nose include the ethmoid bone, palatine bones, maxilla bone, vomer, and nasal conchae. The cribriform plate of the ethmoid bone forms the back interior (i.e., roof) of the nasal cavity. The palatine bone posteriorly and the palatine process of the maxilla bone anteriorly form the floor of the nasal cavity. The vomer serves as the back wall of the cavity.

The **nasal conchae**, which are also called the **nasal turbinates**, are thin bones that extend into the nasal cavity, increasing the surface area inside the nasal cavities. By providing a larger surface area for inhaled air to pass through, the conchae increase the ability of the nose to filter, warm, and humidify the air. There are three sets of conchae bones within the nose, and they include the inferior nasal conchae, the middle nasal conchae, and the superior nasal conchae. The largest of these three sets of bones, the inferior nasal concha, is located horizontally along the lateral wall of the nasal cavity. This structure is responsible for directing the flow of air through the nasal cavity. By channeling the air entering the nasal cavity via the nose through the mucous membrane and cilia, the inferior nasal concha plays a primary role in filtering and humidifying the air as it enters the body. The middle conchae are smaller and sit just above the inferior conchae. They function as a protective structure for the sinuses. The superior nasal conchae, the smallest of the three sets of conchae bones, sit just above the middle conchae. The superior nasal conchae protect a collection of olfactory nerve tissue where much of the information relating to the sense of smell is processed. **Figure 1-2** shows the anatomy of the nose, nasal cavity, and oral cavity.

Inside the nares, the front of the nose is lined with hair called **vibrissae** that capture large particles and prevent them from moving into the airways. Vibrissae are visible to the naked eye and should not be confused with cilia. **Cilia** are fine hairlike structures that

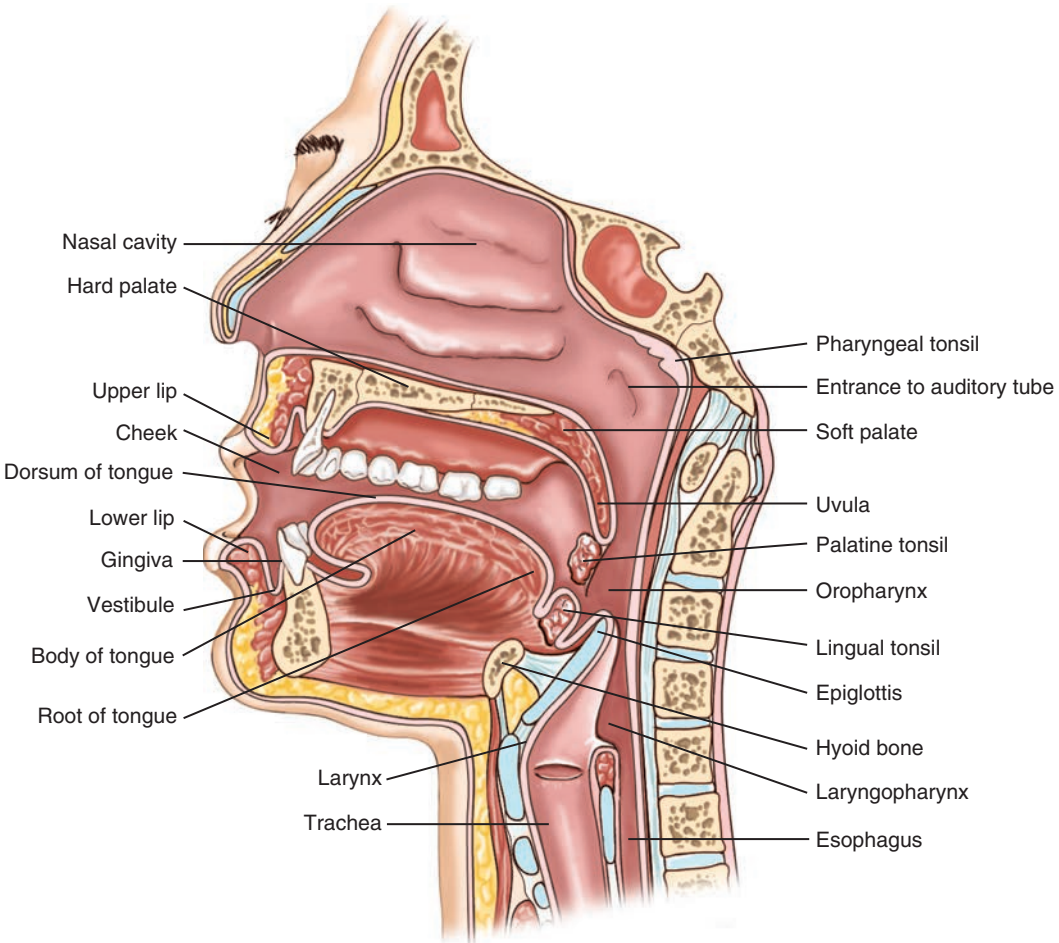


FIGURE 1-2 Anatomy of the nose, nasal cavity, and oral cavity.

occur lower in the respiratory tract. The nasal cavity is also lined with a mucous-producing membrane. This membrane is contiguous throughout the nasal cavity and within the frontal, ethmoidal, sphenoidal, and maxillary sinuses. The membrane in the first third of the nasal cavity is lined by stratified squamous epithelium. These cells are several cell layers thick and lie on top of a layer of proliferative cells that are attached to a basement membrane. The remaining two-thirds of the nasal cavity is lined with pseudostratified columnar ciliated epithelium, which contains mucous-producing cells called goblet cells. This part of the membrane also lies on top of the basement membrane. Beneath the basement membrane is the nasal submucosa. This area contains nerves, capillaries, and mucous-producing cells. The mucus that is secreted by these membranes contains two layers, an upper gel layer and a lower sol layer. The cilia are located in the sol layer and move in a wavelike fashion to push out the mucous and any captured particles or debris that have entered the airway.

Our ability to smell is a primary function of the nose and the olfactory receptor neurons it contains. The olfactory receptor neurons are embedded in the olfactory epithelium located on the roof of the nasal cavity approximately 7 cm inside the nose from the nostrils. Humans have approximately 6 million olfactory receptors in their nose and can distinguish at least 1 trillion different odors. In contrast, a dog has an estimated 300 million olfactory receptors in their nose.

When a person loses his or her ability to smell it is known as anosmia. This may be a transient or permanent condition and can be caused by damage to the olfactory pathways between the nose and the brain, aging, nasal and/or sinus disease, viral upper respiratory tract infections, and/or trauma. Hyposmia is a decreased or reduced ability to smell. This may occur as a result of allergies, nasal polyps, infection, or head trauma. Hyperosmia is an increased ability to smell; it is associated with several medical conditions, including pregnancy, migraines, autoimmune disease, and Lyme disease.

The Sinuses

The word *sinus* refers to a cavity within a bone or other tissue. The body has many sinuses located throughout that serve a variety of functions. The paranasal sinuses are two groups of air-filled spaces located on each side of the face and skull. They drain into the nasal cavity, serving to lighten the weight of the head, acting as a resonance space for speech, and producing mucus that lubricates the nose. Each paranasal sinus is named for the bone upon which it is positioned and include the frontal sinuses, the ethmoid sinuses, the maxillary sinuses, and the sphenoid sinuses (**Figure 1-3**). The paranasal sinuses are lined with pseudostratified ciliated columnar epithelium and drain either directly or indirectly into the nose via the ostiomeatal complex (OMC) or ostiomeatal unit (OMU).

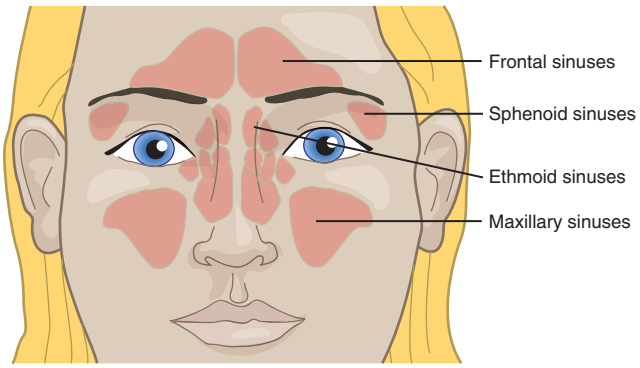


FIGURE 1-3 The paranasal sinuses include the frontal sinuses, sphenoid sinuses, ethmoid sinuses, and maxillary sinuses.

CLINICAL FOCUS : Is It a Sign or a Symptom?

The terms *signs* and *symptoms* often are used together. A sign is an objective indicator of an illness, injury, or disease. It can be seen and measured, as with heart rate or blood pressure. In contrast, symptoms are subjective measures of illness. They are reported by an individual. For example, whether they feel hot or faint.

Conditions of the Nose

The nose plays an important role as the point at which air enters and exits the body. An understanding of the function of the nose with respect to the rest of the body can facilitate keeping the nose healthy and functioning properly.

The mucous membranes of the nose secrete a protective gel-like substance that facilitates the removal of particles and debris that may be carried into the nose during breathing. **Nasal congestion** occurs when the mucous layer inside the nose is overabundant. Nasal congestion may interfere with an individual's sense of smell and taste. Congestion is usually a sign of a larger issue and should be assessed before starting any treatment. Drying of the mucous membranes of the nose can also occur and can be caused by exposure to environmental conditions, such as exposure to hot or cold dry air; diseases, such as Sjögren syndrome; or as a side effect of medications, such as antihistamines and decongestants. A dry nose may be uncomfortable but

is usually self-limiting. Utilization of a nasal moisturizer and/or a humidifier is often recommended for the treatment of dry nose. However, an individual should consult their healthcare provider before starting any therapy.

The nose is highly vascular, and the small blood vessels within the nose can rupture and cause bleeding known as **epistaxis**, or a nosebleed. Nosebleeds can occur at any age, though they are most often seen in children aged 2 to 10 years and adults aged 50 to 80 years. They also are more common in the morning hours and during the winter when the air is dry. Nosebleeds can be classified according to their point of origin. Anterior nosebleeds are the most common type and usually originate from a blood vessel on the nasal septum. Trauma, such as a blow to the nose or picking the nose, is a very common cause of anterior nosebleeds. However, they can also be caused by drying of the nose due to exposure to hot dry air, allergies, nasal and sinus infections, vigorous nose blowing, a foreign body inserted into the nose, a deviated or perforated nasal septum, or nasal surgery. Certain blood-thinning medications such as warfarin, low-molecular-weight heparin (LMWH), unfractionated heparin (UFH), direct oral anticoagulants (DOACs; apixaban, betrixaban, dabigatran, edoxaban, and rivaroxaban), nonsteroidal anti-inflammatory drugs (NSAIDs), aspirin, and illegal drugs such as cocaine may cause anterior nosebleeds. Individuals with liver disease, kidney disease, platelet disorders, and inherited blood-clotting disorders may also experience nosebleeds. Hypertension (high blood pressure) is sometimes cited as a source of nosebleeds. In most cases, hypertension may aggravate the condition, but it is not the initial cause of the nosebleed.

Posterior nosebleeds occur in the larger vessels in the back of the nasopharynx. They are more likely to occur in the elderly but may also affect children. Posterior nosebleeds are most often related to bleeding disorders, medication usage, and nasal or sinus surgery.

Ascertaining the difference between an anterior nosebleed and a posterior one can be challenging and may require a physical exam to identify the origin of the bleeding. Home treatment of anterior nosebleeds includes having the individual sit upright and lean forward to prevent the blood from going down the back of the throat. The nostrils may be pinched together using the thumb and index finger for 5 to 10 minutes. Effort should be made to ensure that the individual is breathing through his or her mouth and in no distress. This process can be repeated. If the bleeding does not stop or is excessive after 10 minutes, the person should seek medical attention. This technique should not be used in cases of posterior nosebleeds. In cases of a posterior nosebleed, pinching the nose will cause the blood to run down the back of the nasopharynx into the oropharynx. Individuals with known or suspected posterior nosebleeds should seek medical attention.

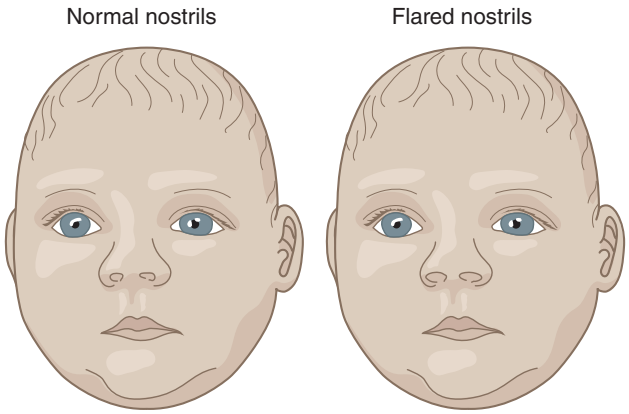


FIGURE 1-4 Nasal flaring is most commonly seen in children and infants, though it can occur at any age. It is characterized by the nostrils widening while breathing and may be a sign of respiratory distress.

Nasal flaring occurs when the nostrils widen during breathing. Although it can occur at any age, nasal flaring is most often used as an assessment in newborns. It may occur as a result of asthma, nasal obstruction, respiratory distress of the newborn, or pneumonia (**Figure 1-4**).

Nasal polyps are noncancerous bead-shaped growths within the nasal cavity or sinuses. The etiology of nasal polyps is unclear; however, they may be related to chronic inflammation, asthma, and allergies. Some diseases, such as cystic fibrosis and Churg-Strauss syndrome, may also be risk factors for the development of nasal polyps. Nasal polyps may be asymptomatic or they may be associated with a runny nose, congestion, postnasal drip, decreased or absent sense of smell and/or taste, pain in the upper teeth, snoring, and facial pressure or pain. If a large number of polyps are present they may obstruct the nasal passages and sinuses and should be evaluated by a medical professional.

Alar collapse is the visible closing of the nostrils during breathing. **Nasal valve collapse** occurs deeper in the nose as a result of narrowness and/or weakness at the nasal valve, the narrowest part of the nasal airway. These conditions may be associated with snoring and sleep apnea. Treatment may include the utilization of continuous positive airway pressure (CPAP) or a number of surgical approaches. Proper identification of the anatomic cause and location of the collapse is necessary to determine the correct treatment.

Rhinitis is an inflammation of the mucous membranes of the nasal cavity. It can be allergic, nonallergic, or related to an infection. Complications may include ear infections, nasal polyps, or sinusitis.

Symptoms include runny nose; nasal congestion; watery, itchy, red eyes; sneezing; and cough. Optimal treatment should address the underlying cause of the rhinitis and/or avoiding the allergen if it is allergic rhinitis.

Sinusitis is an inflammation of one or more of the sinus cavities. The inflammation may be caused by a bacterial, fungal, or viral infection. Sinusitis can be either acute or chronic. An acute sinus infection lasts from 10 days up to 8 weeks. Symptoms include nasal obstruction or congestion; discolored nasal discharge; postnasal drip; headaches; pain, tenderness, swelling, and pressure around the eyes, cheeks, nose, or forehead that worsens when bending over; pain in the jaw or teeth; fatigue; and may or may not be accompanied by fever. Treatment should be directed toward the underlying cause of the infection and may also include medications for symptom relief.

The Oral Cavity

The **oral cavity**, or mouth, includes the vestibule, teeth, tongue, hard palate, soft palate, palatoglossal arch, palatine tonsil, palatopharyngeal arch, uvula, and tongue. The vestibule is the space between the lips, cheeks, gums, and teeth.

The teeth define the separation between the vestibule and the main oral cavity. Children have 20 deciduous teeth that are replaced by permanent teeth as they grow older. The deciduous teeth include four incisors, two canines, and four molars in the upper and lower jaws, respectively. The adult teeth are the 32 permanent teeth. These include four incisors, two canines, four premolars, and six molars in the upper and lower jaws, respectively.

The alveolar ridges are the bony portions of the jaw behind the teeth that hold the tooth sockets. The ridges can be felt in the roof of the mouth and in the front of the mouth behind the lower teeth. The tooth sockets are called alveoli. This same word, alveoli, is also used to refer to the air sacs in the lower portion of the lungs where gas exchange occurs.

The tongue is the largest organ in the mouth and plays a role in taste, speech, moving food, and adding saliva during chewing. The tongue has extrinsic and intrinsic muscles. The extrinsic muscles include the genioglossus muscle, the hyoglossus muscle, the styloglossus muscle, and the palatoglossus muscle. These muscles allow the tongue to move in and out and from side to side. The four paired intrinsic muscles of the tongue are the superior longitudinal muscles, the inferior longitudinal muscles, the transverse muscles, and vertical muscles. These muscles allow the tongue to change shape and therefore play a role in speech, chewing, and swallowing. The tongue is connected to the floor of the mouth by the lingual frenulum.

The sense of taste primarily derives from the taste buds located in the papillae or bumps under the mucous membrane of the tongue. Although most of the taste buds are located on the tongue, sensory cells that detect taste may also be found in the nasal cavity, in the back of the throat, on the epiglottis, and in the upper part of the esophagus. Adults have between 2000 and 4000 taste buds. Each taste bud, in turn, has between 10 and 50 sensory cells. These sensory

CLINICAL FOCUS: Histology of the Respiratory System

Epithelium is the cellular lining or covering of a cavity. Epithelium is classified based on the number of layers and the shape of the cells:

- **Ciliated epithelium**: Epithelium that has hairlike projections.
- **Cuboidal epithelium**: Epithelium with cells that are square in appearance (like little cubes).
- **Columnar epithelium**: Epithelium that has cells that are taller than they are wide (looks like it has rows of columns).
- **Pseudostratified columnar epithelium**: Epithelium that has one layer of cells but because of the positioning of the cell nuclei looks uneven, giving the illusion that it has more than one layer of cells. It can be ciliated or nonciliated.
- **Simple squamous epithelium**: Epithelium with flattened platelike cells.
- **Stratified squamous epithelium**: Epithelium with square cells arranged in layers. Can be keratinized or nonkeratinized:
  - *Keratinized epithelium*: Epithelium that has layers of dead squamous cells and large amounts of the protein keratin. This type of epithelium acts as a dry covering capable of withstanding severe abrasive stresses. Also referred to as cornified epithelium.

- *Nonkeratinized stratified squamous epithelium*: This type of epithelium does not have large amounts of keratin and serves as a wet lining capable of withstanding relatively moderate abrasive stresses.

The epithelial lining changes from the upper to the lower airways to meet the body's physiologic needs. **Figure 1-5** shows the different types of epithelial tissues associated with different parts of the respiratory tract.

Location	Type of Epithelium
First one-third of the nose	Stratified squamous epithelium
Second two-thirds of the nose, including the trachea and bronchi	Pseudostratified columnar epithelium with goblet cells
Bronchioles	Cuboidal epithelium
Alveoli	Simple squamous epithelium

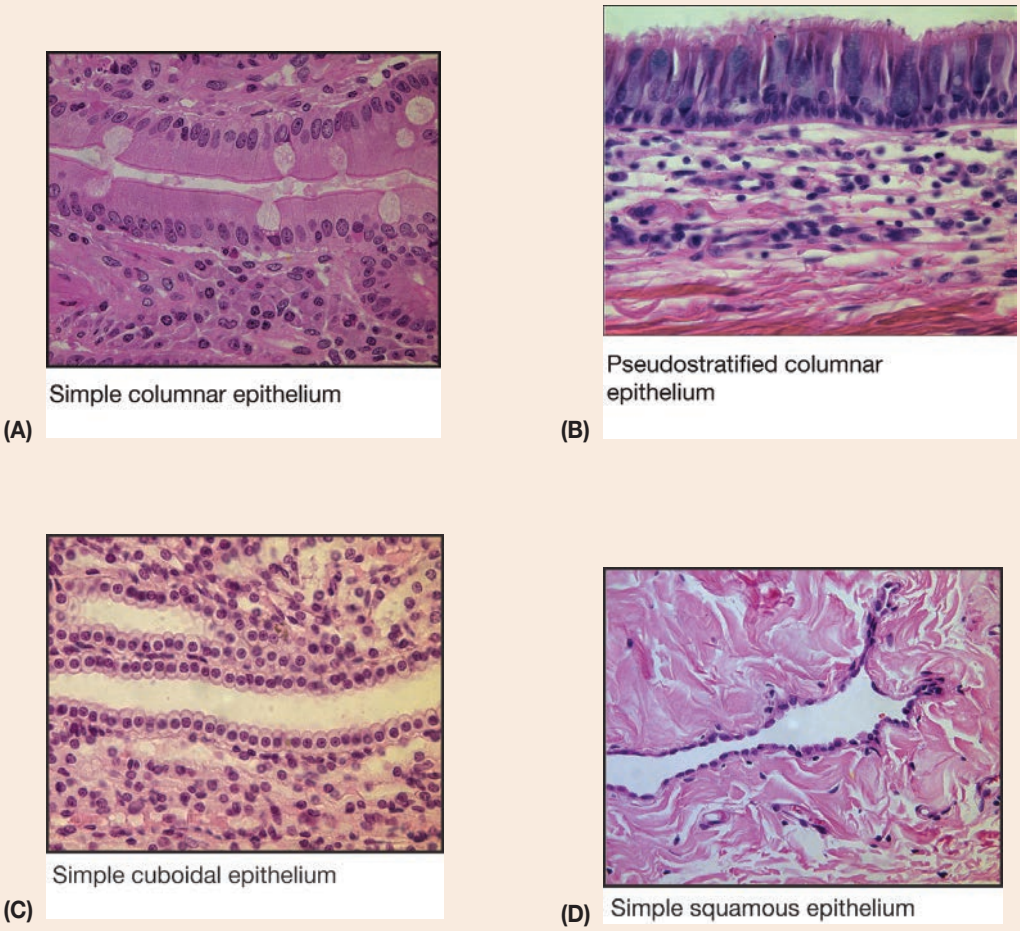


FIGURE 1-5 The respiratory epithelium.

cells have a pore in the top that opens into a chamber lined with very fine taste hairs that detect the five basic tastes. The five taste sensations are sweet, sour, salty, bitter, and umami (savory). The sensations of "spicy" and "peppery" are often called a taste, but they are not. The peppery effect caused by capsaicin is not detected in the taste sensory cells, but rather is produced via the pain pathway.

The main cavity of the mouth is located behind the teeth. The hard palate forms the roof of the mouth and is enclosed by the alveolar arches and gums. Another name for the gums is the gingiva. Behind the hard

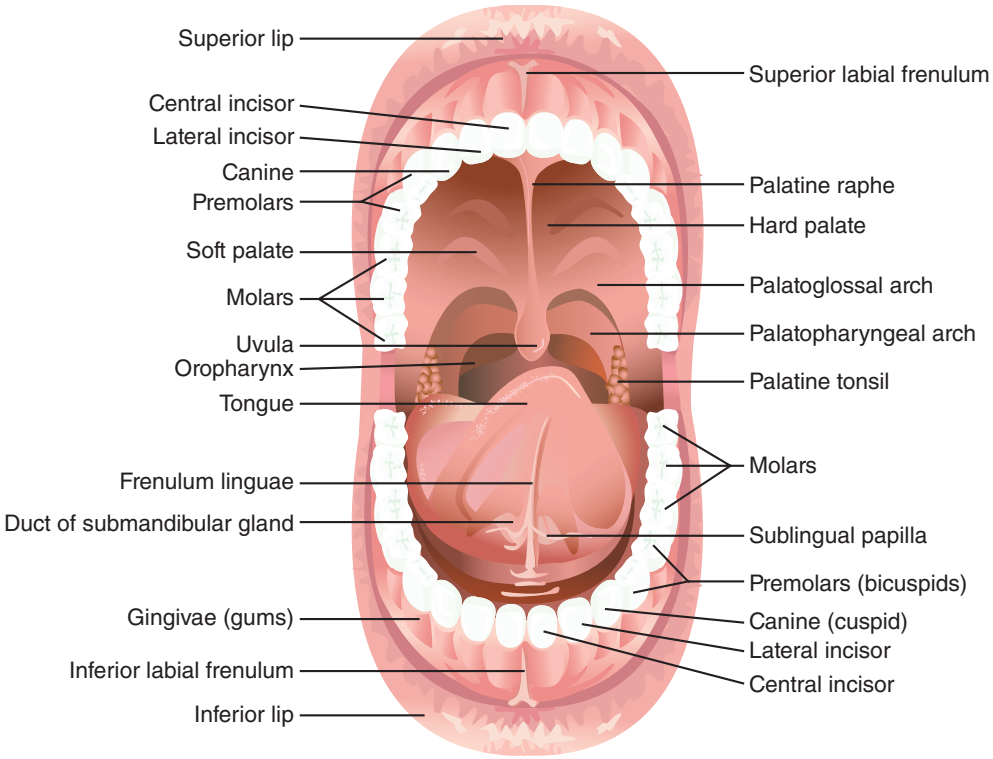


FIGURE 1-6 Anatomy of the mouth.

CLINICAL FOCUS: Types of Muscles

Muscles are fibrous tissue that allow our bodies to move. The human body has three types of muscles:

- *Skeletal muscles* are striated muscles that are attached to the bones and other structures, such as the eyes, and allow for movement. In most instances, the movement associated with these muscles is voluntary because they are under conscious control.
- *Cardiac muscles* are involuntary striated *muscles that are said to have autorhythmicity, or the ability* to set their own contraction rate, and cause the heart to beat.
- *Smooth muscles* are involuntary nonstriated muscles that line the walls of the blood vessels and organs such as the stomach, intestine, and bladder.

In addition, muscles can be classified as either **extrinsic muscles** because they are located superficially, or on top, of a structure, or as **intrinsic muscles**, which are located deep within or inside of a structure.

palate is the soft palate, which forms a partial septum between the mouth and pharynx. The **uvula** is a fleshy, conelike structure that extends from the center of the soft palate (**Figure 1-6**). During swallowing, the soft palate and the uvula move upward and backward, closing off the nasal cavity and preventing food and liquids from entering the nasopharynx. Coordinated movement of these structures also occurs during sucking, blowing, and when enunciating consonants in certain languages. Five paired muscles play a role in the movement of the soft palate: the tensor veli palatine, levator veli palatine, palatopharyngeus, palatoglossus, and the muscles of the uvula.

The palatine arches are folds of soft tissue covered by a mucous membrane that passes from the soft palate to the side of the tongue and forms the anterior margin of the tonsillar fossa. The innermost arch is the palatopharyngeal arch. This arch covers the palatopharyngeal muscle. The outer arch is the palatoglossal arch, and it encloses the palatoglossal muscle. Located between these two arches and on either side of the oropharynx are the palatine tonsils. The two palatine tonsils form part of **Waldeyer's ring**. Although there are several different tonsillar structures in Waldeyer's ring, the palatine tonsils are the structures most often referred to as the tonsils. When inflamed they can obstruct the rear of the oral cavity. The palatine tonsils may be seen in

Did You Know?

Uvular and Alveolar Sounds and Speech

Several languages use uvular sounds that are classified as uvular stops, fricatives, nasals, trills, or approximants. The sounds are articulated with the back of the tongue and throat moving against or near the uvula. Uvular consonants are extremely rare in English; they are more common in French, Catalan, German, Hebrew, Japanese, and Arabic. Examples of a uvular trill are the pronunciation of the letter *r* in the German word *rot* ("red") and the French word *rue* ("street").

Linguists also refer to alveolar sounds that are produced by placing the tongue on the alveolar ridge close to the back of the upper teeth. These sounds occur in English. An example of an alveolar consonant is the pronunciation of the *zs* in the word *pizza*.

Did You Know?

Waldeyer's Ring

Waldeyer's ring, also known as nasal-associated lymphoid tissue (NALT), was first described in 1884 by Heinrich Wilhelm Gottfried von Waldeyer-Hartz. A German anatomist, Waldeyer-Hartz also coined the terms *neuron* for a nerve cell and *chromosome* for the smallest molecule of genetic material.

Waldeyer's ring is a circle of lymphoid tissue found in the nasopharynx and oropharynx. Waldeyer's ring includes the pharyngeal tonsils (adenoids) in the center rear of the nasopharynx, the two tubal tonsils near the opening of the eustachian tubes on either side, the two palatine tonsils on either side of the oropharynx, and the lingual tonsils on the posterior third of the tongue.

the back of the throat between the two arches. They are lined by stratified nonkeratinized squamous epithelium. The pharyngeal tonsils, also known as the adenoids, are located in the rear of the nasopharynx. When enlarged, they may cause nasal airway obstruction. The pharyngeal tonsils are lined with pseudostratified ciliated columnar epithelium.

Swallowing and Deglutition Apnea

During the complex act of swallowing, breathing briefly stops as the mechanisms to protect the airway and prevent aspiration are initiated. This brief cessation of breathing is known as deglutition apnea. To better understand this occurrence, the process of swallowing can be broken down into four phases: the oral preparatory phase, the oral transit phase, the pharyngeal phase, and the esophageal phase (**Figure 1-7**).

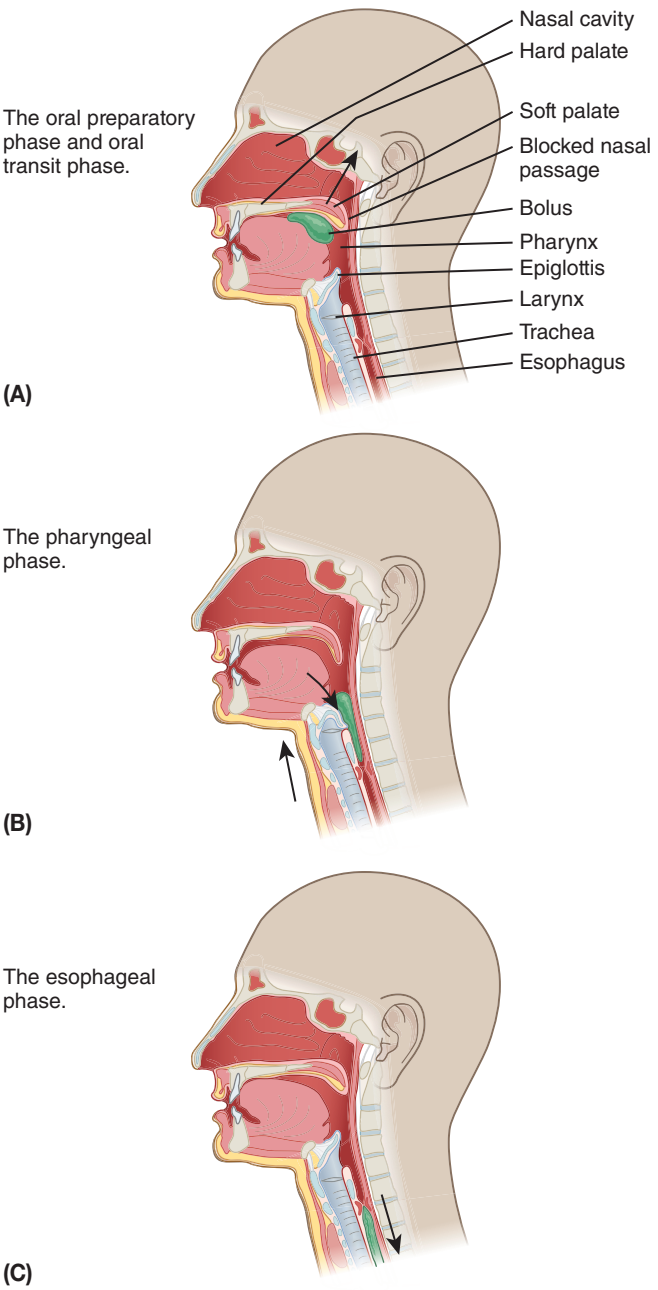


FIGURE 1-7 Swallowing and deglutition apnea. (**A**) The oral preparatory phase and oral transit phase. (**B**) The pharyngeal phase. (**C**) The esophageal phase.

Phase 1: Oral Preparatory Phase

1. Food is taken into the mouth.
2. The tongue positions the food on the teeth for mastication and repositions the food, as necessary.
3. The tongue mixes food with saliva during mastication.
4. This process continues until a bolus or ball of food is formed.
5. Breathing continues through the nose, and the pharynx and larynx are at rest.

Phase 2: Oral Transit Phase

1. As the tongue moves the bolus of food toward the back of the mouth, the soft palate raises to prevent nasal regurgitation.
2. Sensory receptors in the oropharynx and tongue stimulate the pharynx and swallowing is initiated.

Phase 3: Pharyngeal Phase

1. The soft palate is tensed by the tensor palatini muscles and then elevated by the levator palatini muscles to close the nasopharynx and prevent food from entering the nasal cavity. This action also opens the eustachian tubes to equalize the pressure between the nasopharynx and the middle ear.
2. The hyoid bone and larynx are elevated and lifted anteriorly to protect the airway.
3. The palatoglossus, intrinsic muscles of the tongue, and the styloglossus close the oropharynx.
4. The stylopharyngeus, salpingopharyngeus, and palatopharyngeus muscles lift the pharynx and pull it forward to receive the bolus.
5. In the larynx, the lateral cricoarytenoids and the oblique and transverse arytenoids close the vocal cords. It is at this stage that breathing stops briefly and deglutition apnea occurs.
6. The bolus is moved toward the esophagus by a series of sequential contractions called pharyngeal peristalsis.

Phase 4: Esophageal Phase

1. The food bolus enters the esophagus and moves downward toward the stomach at a rate of 3 to 5 cm per second.
2. Breathing resumes when this is completed.

Conditions of the Oral Cavity

A variety of conditions may affect the oral cavity. **Ankyloglossia** (tongue-tied) is a condition in which the lingual frenulum is unusually short or thick. It is most often diagnosed and treated in infants. When left untreated, ankyloglossia can result in difficulties in breastfeeding, speaking, and swallowing. Treatment is usually a surgical procedure called a frenulectomy to release the tongue.

Cold-stimulus headaches ("ice cream" headaches) are characterized by a sharp, stabbing pain in the forehead following exposure to sudden extreme cold or by having something cold move across the roof of the mouth. The physiologic cause of these headaches is unknown. Treatment is to allow the body to stabilize and adapt to the temperature change.

Oral candidiasis, commonly known as *thrush*, is an infection caused by the fungus *Candida albicans*. Symptoms include white lesions inside the mouth. Risk factors for the development of oral candidiasis include a weakened immune system, diabetes, and the use of certain medications, such as prednisone, inhaled corticosteroids, or antibiotics. Treatment focuses on improved oral hygiene and antifungal medications.

The Pharynx

The **pharynx**, more commonly known as the throat, extends from the back of the nasal cavity down to the larynx. Anatomically, the pharynx begins at the base of the skull and extends to the cricoid cartilage. It can be divided into three sections: the nasopharynx, the oropharynx, and the laryngopharynx.

The pharynx has two types of muscles: circular and longitudinal. The circular muscles form partial or incomplete ringlike structures that contract to move food from the oral cavity into the esophagus. They include the superior pharyngeal constrictor in the oropharynx; the middle pharyngeal constrictor in the laryngopharynx; and the inferior pharyngeal constrictor, also in the laryngopharynx. These muscles are innervated by the vagus nerve (CN X).

The longitudinal muscles lift the larynx and widen the pharynx during swallowing. These muscles include the stylopharyngeus, which is innervated by the glossopharyngeal nerve (CN IX), and the palatopharyngeus and salpingopharyngeus muscles, which are innervated by the vagus nerve (CN X). The salpingopharyngeus muscle also opens and closes the eustachian tubes to equalize the pressure in the middle ear with atmospheric pressure.

The Nasopharynx

The **nasopharynx** provides a passage from the back of the nasal cavity to the soft palate. The pharyngeal tonsils, commonly known as the adenoids, are located in the upper-rear portion of the nasopharynx. When enlarged, they may cause nasal airway obstruction. The nasopharynx and the pharyngeal tonsils are lined with pseudostratified ciliated columnar epithelium. While not technically a portion of the nasopharynx, the

eustachian tubes (also called pharyngotympanic tubes) are canals that link the nasopharynx to the middle ear. These tubes may be divided into two sections: a bony portion arising from the anterior wall of the tympanic cavity and a fibrocartilaginous portion closer to the entry point of the nasopharynx. In an infant, the eustachian tubes are approximately 18 mm in length, whereas in an adult they are approximately 36 mm in length. In addition to equalizing pressure between the atmosphere and the inner ear, the eustachian tubes also protect the middle ear from nasopharyngeal secretions and drain middle ear secretions into the nasopharynx. At its opening in the nasopharynx, the eustachian tube is lined by pseudostratified columnar epithelium with goblet cells. The pseudostratified columnar epithelium lining transitions to a type of lining called the middle ear mucosa as the tubes progress toward the bony portion nearest the tympanic cavity.

The Oropharynx

The **oropharynx** is the portion of the pharynx that proceeds from the soft palate to the superior border of the epiglottis. This section of the pharynx can be easily seen via the oral cavity. The two palatine tonsils and the lingual tonsils are technically located in the oropharynx. When inflamed, the palatine tonsils can obstruct the rear of the oral cavity. The oropharynx is lined by nonciliated stratified squamous epithelium.

In the back of the oral cavity, posterior to the root of the tongue between the median and lateral glossoepiglottic folds, is a small groove or indentation called the **vallecula epiglottis**. The word *vallecula* is derived from the Latin *valles* meaning "valley." The vallecula epiglottis groove is an important reference landmark that is used when placing a breathing tube into the trachea. The procedure for placing a breathing tube through the oropharynx is called *intubation*. It can be done manually with a laryngoscope or with the assistance of a fiberoptic scope.

The Laryngopharynx

The **laryngopharynx** is the passage that extends from the superior border of the epiglottis to the inferior border of the cricoid cartilage, where it becomes continuous with the esophagus. This portion of the pharynx is also known as the hypopharynx. The laryngopharynx plays a crucial role in preventing aspiration; that is, stopping food and liquid particles from entering the airway. In the lower portion of the laryngopharynx is the piriform recess. Also called the piriform sinus, this area is located on either side of the opening to the larynx. It is bounded medially by the aryepiglottic fold, and laterally by the thyroid cartilage and the thyrohyoid membrane. This recess is an important anatomic marker when discussing cancer staging and treatment. The laryngopharynx is lined with nonciliated stratified squamous epithelium.

The Larynx

The **larynx**, or voice box, provides protection for the airways during swallowing, assists in airway patency, and supports vocalization. Considered the transition point from the upper airways to the lower airways, the larynx is positioned in the anterior portion of the neck, beneath the hyoid bone, and between the third and sixth cervical (C3 and C6) vertebrae. The inlet of the larynx is called the aditus and is bordered anteriorly by the epiglottis, on each side by the aryepiglottic folds, and inferiorly and posteriorly by an interarytenoid fold. Primarily cartilaginous, the larynx is made up of three single cartilages—the thyroid, cricoid, and epiglottic cartilages—and three paired cartilages—the arytenoid, corniculate, and cuneiform cartilages. The cartilages are controlled by both intrinsic and extrinsic ligaments and muscles. The intrinsic ligaments and muscles of the thyroid cartilage are the cricothyroid ligament and the cricothyroid muscle, thyroarytenoid muscle, posterior cricoarytenoid muscles, lateral cricoarytenoid muscles, and the transverse and oblique arytenoid muscles. The extrinsic ligaments of the thyroid cartilage are the median thyrohyoid ligament, lateral thyrohyoid ligament, hyoepiglottic ligament, cricotracheal ligament, and the median cricothyroid ligament. The extrinsic muscles of the thyroid cartilage are the suprahyoid group and the infrahyoid group (**Figure 1-8**).

The inside cavity of the larynx can be divided into three sections: the supraglottis; the glottis, which contains the vocal folds (vocal cords); and the subglottis (**Figure 1-9**). The glottis has two pairs of vocal folds. The upper pair is known as the false vocal cords because they do not play a role in speech. The lower pair is known as the true vocal cords. The opening between the vocal cords is called the rima glottides. The interior cavity of the larynx is lined by ciliated columnar epithelium.

Cartilages of the Larynx

The larynx has multiple cartilages. The **thyroid cartilage**, more commonly known as the Adam's apple, is the largest cartilage in the larynx. It is composed of two rectangular laminae that are fused in the midline and anteriorly. The position of these internal laryngeal structures to the thyroid cartilage is an important landmark in surgical planning.

The **cricoid cartilage** is located below the thyroid cartilage. The cricoid cartilage is the only laryngeal cartilage to completely encircle the airway. Shaped like a signet ring, this cartilage joins the first tracheal ring inferiorly via membranous attachments.

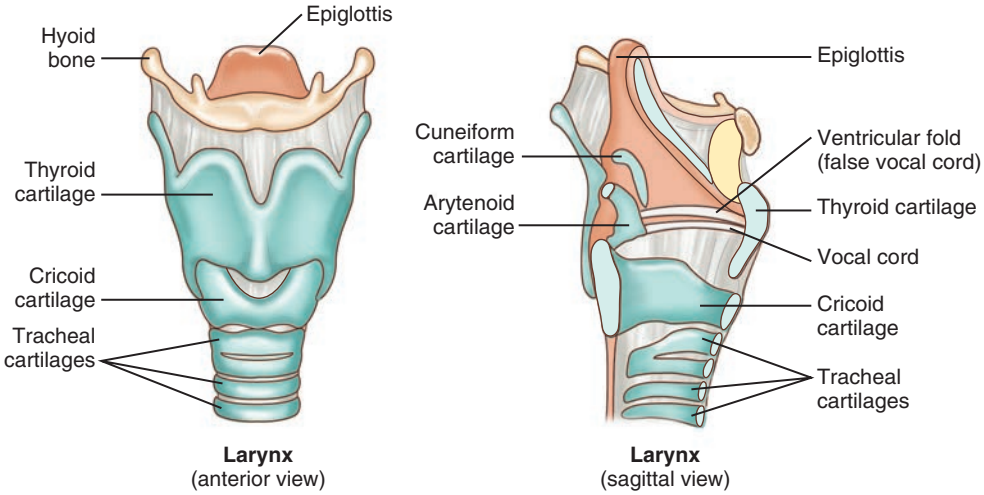


FIGURE 1-8 The larynx.

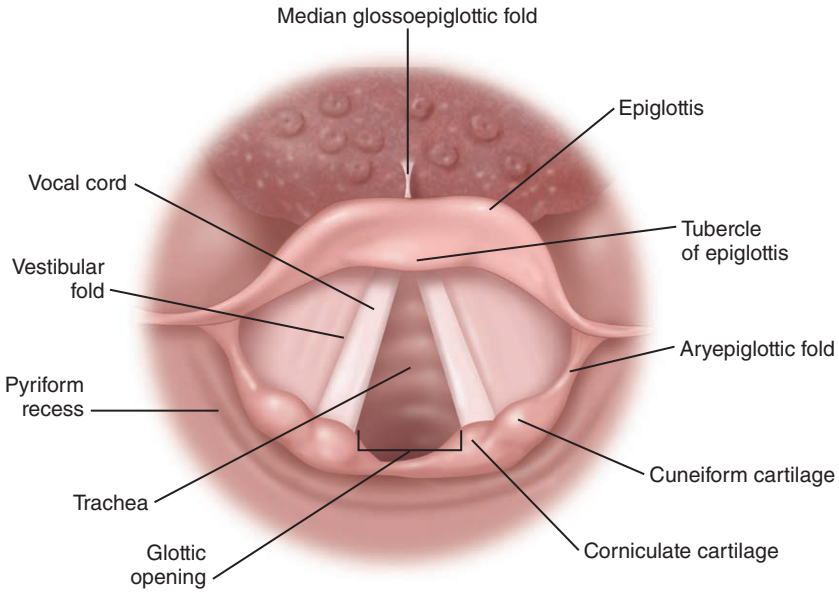


FIGURE 1-9 The vocal cords as seen with an open glottis.

A cricothyrotomy is a procedure that places a tube through an incision via the cricothyroid membrane to establish an airway for oxygenation and ventilation.

The **epiglottis** is a piece of cartilage positioned behind the root of the tongue and the hyoid bone and just above the aditus of the larynx. The purpose of the epiglottis is to prevent aspiration during swallowing.

The **arytenoid cartilages** are two pyramid-shaped cartilages that have an apex, a base, three sides, a vocal process medially, and a muscular process laterally. Vocal ligaments and intrinsic muscles that coordinate the movements of the vocal folds attach to these processes.

The **corniculate cartilages** are two small conical cartilages that are also known as the cartilages of Santorini. They are positioned above each of the arytenoid cartilages and are embedded within the aryepiglottic folds. The corniculate cartilages are accessory cartilages that aid in the opening and closing of the glottis and sound production.

The **cuneiform cartilages** are two rod-shaped nodules that are positioned at the edge of the aryepiglottic folds, above and anterior to the corniculate cartilages. They are classified as accessory cartilages that provide support to the vocal folds and the lateral aspects of the epiglottis.

Muscles of the Larynx

A number of intrinsic and extrinsic muscles support the functions of the larynx. The intrinsic muscles include the cricothyroid muscle, thyroarytenoid muscle, posterior cricoarytenoid muscles, lateral cricoarytenoid

muscle, oblique arytenoid muscles, and the transverse arytenoid muscle. The cricothyroid muscle originates in the anterolateral aspect of the cricoid cartilage and attaches to the inferior margin and inferior horn of the thyroid cartilage. This muscle tightens and thins the vocal folds and increases their resonant frequency in speech.

The thyroarytenoid muscle originates in the inferoposterior angle of the thyroid cartilage and attaches to the arytenoid cartilage. Its primary action is to relax the vocal ligaments.

The posterior cricoarytenoid muscles originate in the posterior surface of the cricoid cartilage and attach to the arytenoid cartilage. These muscles rotate the arytenoid cartilages laterally, thereby abducting the vocal folds and opening the rima glottidis. These muscles are used as a landmark for arytenoid adduction surgery, which is a procedure to treat vocal cord paralysis.

The lateral cricoarytenoid muscles originate in the arch of the cricoid cartilage and attach to the arytenoid cartilage. These muscles rotate the arytenoid cartilages medially, thereby adducting the vocal folds and closing the rima glottides.

The oblique arytenoid muscles originate on the posterior surface and muscular process of the arytenoid cartilage and attach to the arytenoid cartilage on the opposite side inside the aryepiglottic fold. They move the vocal folds either closer together or farther apart.

The transverse arytenoid muscle originates from the arytenoid cartilage on one side and inserts in the arytenoid cartilage on the opposite side. It pulls the arytenoid cartilages and the vocal folds together, closing the rima glottides.

The extrinsic muscles of the larynx include the suprahyoid group and the infrahyoid group of muscles. The suprahyoid group of muscles are four sets of muscles that work together with the longitudinal muscles of the pharynx, specifically the stylopharyngeus, to lift the hyoid bone and widen the esophagus during swallowing. The infrahyoid group of muscles are four sets of muscles that depress the hyoid bone and larynx during swallowing and speech.

Conditions of the Pharynx or Larynx

Several conditions that may affect the pharynx or larynx can have a negative impact on ventilation. For example, edema, by definition, is an abnormal accumulation of fluid in the tissues or cavities of the body. It most often manifests as swelling. In the airways, edema may become life-threatening if it obstructs airflow and makes breathing difficult. **Airway edema** has a variety of etiologies, including allergic response, trauma, infection, inhalation of toxic or noxious gases, or hereditary conditions, such as hereditary angioedema (HAE). Upper airway edema should be regarded as a potentially life-threatening condition.

Croup, also known as inspiratory stridor, is an infection of the vocal cords, trachea, and/or bronchial tubes. The infection can be either viral or bacterial in origin, but is most often caused by human parainfluenza viruses (HPIVs). Children between 6 months and 3 years of age are at highest risk for developing croup due to the small diameter of their airways. The infection may begin with coldlike symptoms and progress to a barking cough. Symptoms usually last for 3 to 5 days. Parents and caregivers should seek immediate medical attention if a child develops stridor (high-pitched breathing sounds), has excessive drooling, has difficulty swallowing, is anxious and agitated or fatigued and listless, shows an increased respiratory rate or difficulty breathing, or develops cyanosis.

Dysphagia, or difficulty swallowing, can also cause problems with airway functioning. Dysphagia may be related to a physical obstruction of the pharynx or esophagus, diseases of the muscles of the pharynx or esophagus, or other diseases/conditions that alter the swallowing process such as a stroke or degenerative diseases of the brain.

Epiglottitis is an inflammation of the epiglottis. This is a potentially life-threatening condition because the swelling may obstruct the airway. The condition may occur at any age and can be caused by a variety of triggers, including trauma or infection. Common causes of epiglottitis in adults include infections with *Streptococcus pneumoniae* and groups A, B, and C *streptococcus*. The most common cause of epiglottitis in children is infection with *Haemophilus influenzae* type b (Hib). Immunization with the Hib vaccine is recommended for children beginning at 2 months of age.

Laryngitis is an inflammation of the larynx. Acute laryngitis may be caused by either viral or bacterial infection or by vocal strain. Chronic laryngitis, lasting longer than 3 weeks, may be caused by inhalation of irritants, allergens, or smoke; conditions such as gastroesophageal reflux disease (GERD) or sinusitis; smoking; or excessive overuse of the voice.

Laryngeal edema, the abnormal accumulation of fluid in the larynx, is a common cause of airway obstruction after the removal of an endotracheal tube. The condition may result from trauma to the larynx by the endotracheal tube. Postextubation stridor (PES), defined as a high-pitched sound produced by airflow through a narrowed airway, is a clinical indicator of laryngeal edema following extubation. Treatment of the condition varies based on the severity of the edema.

Laryngospasm is a spasm or contraction of the vocal cords. It may be triggered by trauma, gastroesophageal reflux disease (GERD), anxiety, or stress. Laryngospasm should not be confused with **bronchospasm**, which is contractions of the muscles in the walls of the bronchioles.

The **pharyngeal reflex**, also known as the gag reflex, is a contraction of the back of the laryngopharynx triggered by an object or particle touching the back of the hard or soft palate or an area of the oropharynx. This reflex is intended to protect the individual from choking or aspirating food. A **hyperactive gag reflex** is a heightened pharyngeal reflex that may or may not be a learned response.

Otitis media is an infection of the middle ear. Symptoms may include pain, fever, bulging or erythema of the tympanic membrane, and middle ear effusion (fluid behind the eardrum). Treatment may include antibiotic therapy and symptom relief for the pain.

A **peritonsillar abscess** is caused by an infection of the palatine tonsils that spreads and forms an abscess in the surrounding tissue. Infection of the palatine tonsils can also cause deviation of the uvula, which is called **quinsy**. A diagnosis of quinsy is usually considered a medical emergency, because the deviation may obstruct the airway or alter swallowing, resulting in aspiration of particles into the lungs and infections. Treatment is usually intravenous antibiotics and incision and drainage of the abscess.

Tonsillitis is an infection of the palatine tonsils caused by either a bacteria or virus. The condition can be acute or chronic. Concurrent infection of the adenoids may also occur. Treatment includes antibiotics or surgical removal with a tonsillectomy and/or an adenoidectomy.

The **Valsalva maneuver** involves forcibly exhaling air against a closed airway to normalize middle-ear pressure. It is usually done by pinching the nose, closing the mouth, and exhaling. The maneuver can be used when ambient pressure changes, as in diving or air travel, cause discomfort in the inner ear. However, the maneuver also has cardiac ramifications. Intrathoracic pressure changes that occur during the Valsalva maneuver may initiate changes in heart rate and/or blood pressure.

Vocal cord dysfunction (VCD) is characterized by paroxysmal adduction of the vocal cords, resulting in airway restriction, and is often misdiagnosed as asthma. Correct diagnosis is usually confirmed by direct visualization of vocal cord movement. The treatment of choice is usually speech therapy.

Bronchoscopy

A **bronchoscopy** is a procedure where a fiberoptic scope with a camera and light are used to visualize the upper airways and lungs. The procedure is performed using either a flexible bronchoscope or a rigid bronchoscope that is passed through the nose or mouth into the trachea, bronchi, and bronchioles of the lungs. Flexible bronchoscopy is performed more often than rigid bronchoscopy and usually does not require general anesthesia. In addition to providing visualization of the airways, tissue samples and bronchial lavage samples can be taken during this procedure. Bronchoscopes may also be used to facilitate endotracheal intubation in some instances.

Artificial Airways

Sometimes it becomes necessary to bypass the upper airways in order to prevent or relieve obstruction of the airway, to allow access for suctioning or removal of mucous, to prevent aspiration, or to provide a route for mechanical ventilatory support. Several devices, known as artificial airways, are available to safely and effectively bypass the upper airways.

Nasopharyngeal airways, also called **nasal trumpets**, are flexible, soft tubelike devices that have a flared end (**Figure 1-10**). They are usually lubricated and inserted via the nares. Although nasopharyngeal airways may be used to relieve upper airway obstruction, they are most often used to prevent damage to the nasal passages when frequent suctioning is needed to keep the airway clear. They are available in a variety of sizes, from pediatric to adult.

Oropharyngeal airways are curved plastic devices with a flange that rests against the teeth when inserted. They are inserted into the mouth and used to maintain a patent airway in an unconscious patient who is at risk of his or her tongue obstructing their airway. These airways may also be used to facilitate suctioning via the oral cavity in an unconscious or semiconscious patient and/or prevent him or her from biting his or her tongue.

The two most common oropharyngeal airways are the Berman airway and the Guedel airway. The Berman airway has two open channels, one along each side of the airway, and the Guedel airway has a single closed channel down the center (**Figure 1-11**). Other types of oropharyngeal airways include the Williams airway intubator, Ovassapian airway, and the Berman intubating airway. These airways are most often used during bronchoscopy and intubation.

Oropharyngeal airways come in a variety of sizes. With an appropriately sized oropharyngeal airway, the flange should be approximately at the level of the teeth when the airway is placed against the patient's

FIGURE 1-10 Nasopharyngeal airways.

FIGURE 1-11 Several types of oropharyngeal airways are available. (**A**) The Berman airway has two lateral air channels or grooves that open to the oral cavity and promote air passage. (**B**) The Guedel airway has one internal tubelike passage that allows for air movement. (**C**) The Williams airway intubator has an enclosed upper channel and an open lower channel and is often used as an aid in fiberoptic intubations. (**D**) The Ovassapian airway has a closed upper portion and a curved open portion and is used during intubation and bronchoscopy. The bronchoscope or endotracheal tube can fit inside the open central portion, allowing for some air passage around the airway. (**E**) The Berman intubating airway has a large central channel that permits air passage. It is primarily used during fiberoptic intubation and bronchoscopy.

(**A**) © deepspacedave/Shutterstock; (**B**) Courtesy of Intersurgical Ltd/Wikimedia Commons; (**C**) Courtesy of SunMed; (**D**) Courtesy of Teleflex; (**E**) Reproduced with permission from CareFusion.

cheek and the opposite end should extend to the angle of the jaw. Improperly sized oropharyngeal airways can obstruct the airway. Oropharyngeal airways are usually not well tolerated in conscious patients, as they tend to stimulate the gag reflex at the back of the oropharynx.

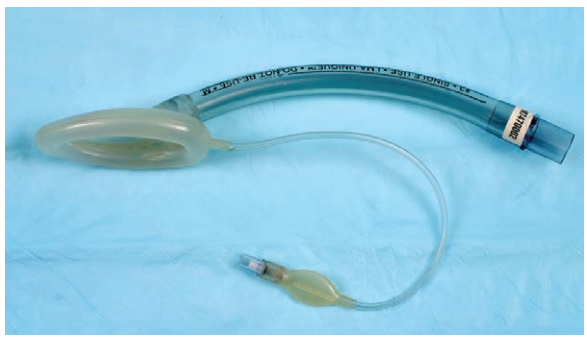
Supraglottic airways are used to deliver manual ventilation using a resuscitation bag. They may be used in place of intubation with an endotracheal tube, when intubation attempts have failed, or when bag-valve-mask ventilation has failed. Supraglottic devices include the laryngeal tube, the Cobra perilaryngeal airway (PLA), the Elisha airway, the supraglottic airway laryngopharyngeal tube (SALT), and the streamlined liner of the pharynx airway (SLIPA) (**Figure 1-12**). A similar device is the laryngeal mask airway (LMA). The designs and utilization of each of these devices differ, and training is required before safely and effectively using them.

Endotracheal tubes are firm, yet flexible curved tubes that are inserted via the nose or mouth, passed through the vocal cords, and extended into the trachea (**Figure 1-13**). The placement of an endotracheal tube, also known as intubation, is indicated to maintain airway patency, facilitate mechanical ventilation, and/or prevent aspiration. Several varieties of endotracheal tubes are available. The tubes most often used in adults have an inflatable pilot balloon, or cuff, at the distal end of the tube. When inflated this cuff cushions the airway and provides a seal to prevent gas from escaping during mechanical ventilation. A double-lumen tube, called a Carlen's tube, has two pilot balloons, and is used to perform independent ventilation of the right and left lung. Endotracheal tubes used in infants and children are usually uncuffed. Most endotracheal tubes have a slight curvature that follows the natural curvature of the upper airways. However, preformed tubes are available that have a sharp U-shaped curve. These tubes are most often used in the operating room. Endotracheal tubes come in several sizes to suit infants through adults.

A **stylet** is a thin, flexible rod that may be inserted inside an endotracheal tube during intubations to provide stability to the tube. The stylet should not extend beyond the end of the tube and is removed immediately after the intubation. Similar to a stylet, a gum-elastic bougie or "introducer" is a flexible rod that is used as a guide for intubation of a difficult airway. This device is passed into the airway and an endotracheal tube threaded over it, and then the introducer is removed.

A **laryngoscope** is used to visualize the larynx and insert the endotracheal tube via the mouth (**Figure 1-14**). The laryngoscope has three parts: a light source, a handle, and a blade. The most common blades are a curved blade known as a Macintosh blade and a

(A)



(B)

FIGURE 1-12 (**A**) Supraglottic airway laryngopharyngeal tube (SALT) and (**B**) a laryngeal mask airway (LMA).
(**A**) Courtesy of Ecolab; (**B**) © Jones & Bartlett Learning. Courtesy of MIEMSS.

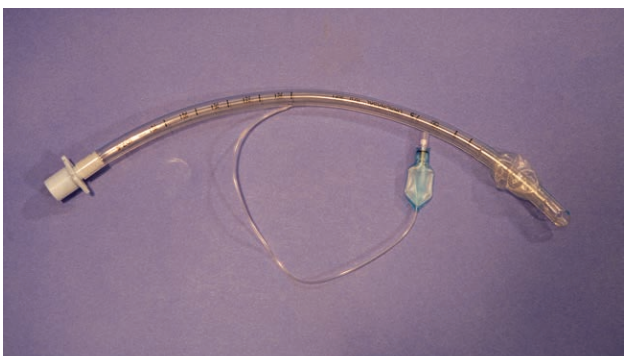


FIGURE 1-13 Endotracheal tubes.
© Jones & Bartlett Learning. Courtesy of MIEMSS.

FIGURE 1-14 Laryngoscopes come in a variety of styles and sizes.
© Jones & Bartlett Learning. Courtesy of MIEMSS.

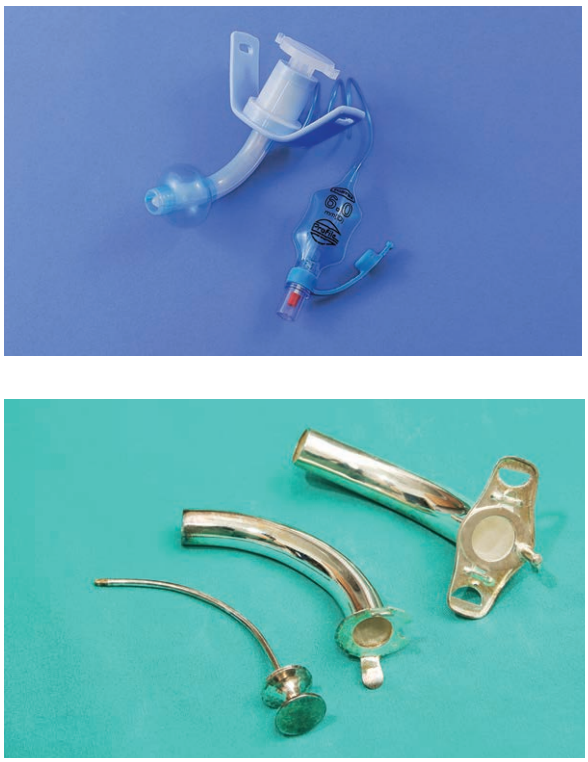


FIGURE 1-15 Tracheostomy tubes. (**A**) A cuffed tracheostomy tube. (**B**) An uncuffed tracheostomy tube.
(**B**) © praisaeng/iStockPhoto.

straight blade known as a Miller blade. When utilizing a Macintosh blade, the tip of the blade is placed in the vallecula, shifting the tongue forward and lifting the epiglottis, thereby permitting visualization of the vocal cords. When using a Miller blade, the tip of the blade is inserted beneath the epiglottis, depressing the tongue and permitting visualization of the vocal cords. Miller and Macintosh laryngoscope blades are available in infant through adult sizes. Fiberoptic or video laryngoscopes also are available, though they are less common. These laryngoscopes permit indirect visualization of the larynx and the feeding of the endotracheal tube via a video monitor. Regardless of the type of laryngoscope selected, all intubation procedures carry the risk of airway or dental trauma and should not be attempted without proper training.

Tracheostomy tubes are inserted through a surgical incision into the trachea to facilitate ventilation or to clear secretions (**Figure 1-15**). The opening in the trachea that is visible on the individual's neck is known as the stoma. The tracheostomy tube can be plastic or metal and is shorter than an endotracheal tube. They come in several sizes to suit infants through adults. Like an endotracheal tube, tracheostomy tubes can be either cuffed or uncuffed. When the tracheostomy tube is no longer needed, it may be capped, or it may be replaced with a speaking valve.

Summary

The upper airway is the first place where atmospheric air comes into contact with the interior of the human body. Air moves into and out of the body via the conducting airways to the lungs. The conducting airways include the upper airway and lower airway. The upper airway includes the nose, nasal cavity, oral cavity or mouth, and the pharynx, which is divided into the nasopharynx, oropharynx, and laryngopharynx. The larynx or voice box is usually considered the demarcation between the upper and lower airways. Through a complex interaction of nerves, muscles, cartilage, and bones, the sense of smell, hearing, and taste, as well as chewing and swallowing and speech, all take place in the same physiologic space that comprises the upper airways. Understanding the physiology of this compact and highly active portion of the body is the first step in understanding the respiratory system.

Case Study

A 9-year-old male presents to his primary care provider with fever, a sore throat, chills, and congestion. His mother states that the symptoms began approximately 4 days ago and have gotten progressively worse. He also complains of intermittent pain in his right ear. Upon examination, the provider suspects tonsillitis.

1. **Which tonsils is the provider most likely referring with regards to suspicion of tonsillitis? Where are these tonsils located?**
2. **During the examination, the provider notes a slight deviation of the uvula. What is this condition called?**
3. **How should this condition be treated?**

Review Questions

1. The conducting airways include:
   a. the upper airways.
   b. the lower airways.
   c. both the upper and lower airways.
   d. the nasal cavity and the oropharynx.
2. The mucus secreted by the mucous membranes of the nose contains two layers. The lower layer is known as the:
   a. bronchial mucosa.
   b. olfactory mucosa.
   c. gel layer.
   d. sol layer.

3. During swallowing, the soft palate is tensed by the tensor palatini and then elevated by the levator palatini to close the:
   a. nasopharynx.
   b. oropharynx.
   c. laryngopharynx.
   d. larynx.
4. Forcibly exhaling against a closed airway to normalize middle-ear pressures is also known as:
   a. the Valsalva maneuver.
   b. vocal cord dysfunction.
   c. the pharyngeal reflex.
   d. laryngospasm.
5. The tongue is connected to the floor of the mouth by the:
   a. alveoli.
   b. columnar epithelium.
   c. keratin.
   d. lingual frenulum.

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