Chapter 1

Anatomy and Physiology of the Respiratory and Laryngeal Systems

LEARNING OUTCOMES

1. Identify the structures of the lower respiratory system and describe how muscular forces are involved in inspiration and expiration.
2. List the lung volumes and capacities in reference to resting expiratory level.
3. Compare respiratory patterning for quiet versus speech breathing, and describe nervous system control of respiration.
4. Identify the structures of the laryngeal framework and describe the cover-body model of the vocal folds.
5. List the extrinsic and intrinsic laryngeal muscles and explain the myoelastic aerodynamic theory of vocal fold vibration.
6. Identify the structures involved in nervous system control of phonation; describe the blood supply to the larynx; and discuss laryngeal reflexes.
7. Describe the three components involved in wound healing.
8. Compare modal, falsetto, and pulse registers in terms of their perceptual and acoustic characteristics.

Voice production depends on the integrated coordination of the respiratory, phonatory, and resonatory systems. Voice is also influenced by the digestive and endocrine systems, and voice production is controlled and regulated by the central and peripheral nervous systems. This chapter focuses on the respiratory, laryngeal, and nervous system involvement in voice production.

The chapter begins with a discussion of the structure of the lower respiratory system and the mechanics of breathing, followed by a description of lung volumes and capacities. Differences in the patterning of life and speech breathing are identified, and the nervous system control of respiration is described. Discussion then turns to the laryngeal system with a review of laryngeal structure and function, the expanded myoelastic-aerodynamic theory of phonation, and mechanisms involved in changing pitch and loudness levels. The major functional components of the central and peripheral nervous systems subserving voice production are presented followed by a description of inflammation and wound healing in the vocal folds. The chapter concludes with a discussion of the three primary vocal registers used in speech.

Structures of the Lower Respiratory System and Mechanics of Respiration

The primary purpose of respiration is ventilation. Ventilation is the process of moving air into and out of the airways and lungs in order to exchange oxygen (O_2) entering the lungs and carbon dioxide (CO_2) leaving the lungs. Ventilation depends on generating the pressures required to move the appropriate volumes of air from the atmosphere to the alveoli within the lungs and from the lungs out to the atmosphere (Gildea & McCarthy, 2003). Respiratory and/or laryngeal disorders that obstruct the airway can hinder ventilation and pose a life-threatening risk to the individual.

In addition to ventilation, the respiratory system provides the exhaled airstream that forms the basis of all voice and speech production. Two features of respiration that directly affect voice production are *breath support* and *breath control*. Breath support refers to stabilizing bodily structures to generate adequate air pressures and air flows; breath control refers to how an individual regulates and coordinates airflow for all activities, including speech. Difficulty with generating and/or maintaining breath support and breath control can adversely affect voice production, as can difficulties with inhaling and/or exhaling air or with obtaining an adequate amount of air. For example, if the respiratory system is not able to provide adequate breath support for voice production then the laryngeal system may overcompensate, which can create vocal fatigue, tissue changes in the vocal folds, and changes in voice quality (Tsai, Huang, Che, Huang, Liou, & Kuo, 2016).

CLINICAL NOTE

It is vital for speech-language pathologists (SLPs) to have a thorough understanding of the respiratory system and the interactions between the respiratory and phonatory systems. Because of academic and clinical training, they are in a unique position to provide services focusing on respiratory as well as phonatory parameters. Respiratory techniques that often help to improve vocal output include encouraging individuals to inhale more deeply; showing clients how to breathe more efficiently using abdominal ("belly") breathing instead of thoracic ("chest") breathing; and providing ways to stabilize the person's posture to maximize breath support and breath control.

STRUCTURES OF THE RESPIRATORY SYSTEM

The respiratory system is divided into upper and lower portions (Table 1.1). The larynx is located at the junction of the upper and lower tracts and will be discussed in detail in later sections of the chapter. The following discussion focuses on the lower respiratory tract, the tracheobronchial tree, and the lungs.

Lower respiratory tract The lower respiratory tract is made up of a branching system of air passages called the **tracheobronchial tree**, formed by the trachea, bronchi, bronchioles, and alveolar sacs (Figure 1.1).

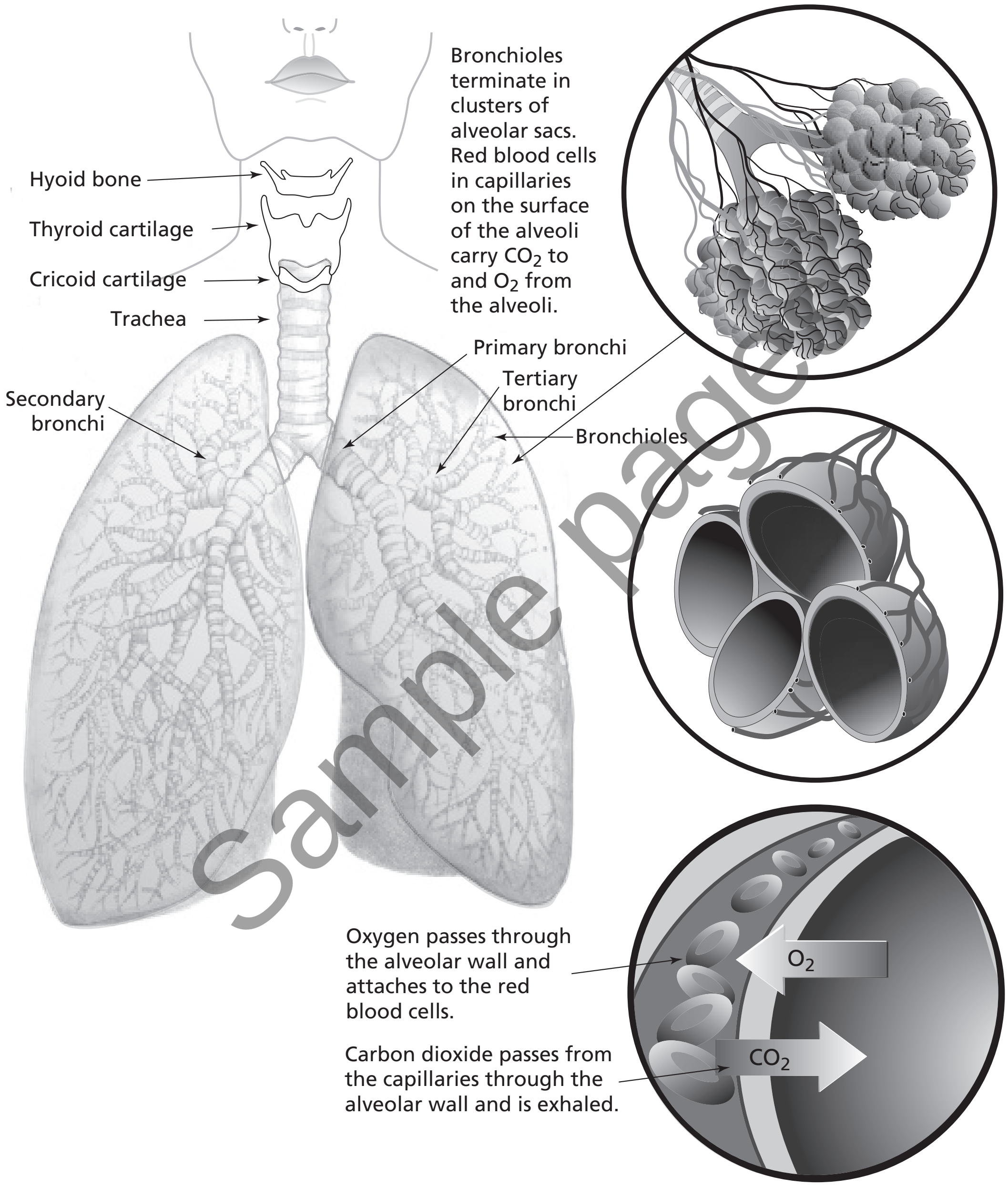
The trachea is a hollow tube formed by sixteen to twenty C-shaped rings of cartilage that are closed anteriorly and open posteriorly (Figure 1.2). The cartilage is covered by layers of smooth muscle and mucous membrane, which serve to close the tube posteriorly, and are also present between the cartilages. The inside of the tube, or lumen, is lined with pseudostratified ciliated columnar epithelium. The epithelium contains goblet cells which secrete mucus. The mucus traps particles of dust and bacteria, and the cilia move in a wavelike fashion to sweep this matter upward and out of the airways. Air traveling to the lungs is thereby cleaned and filtered.

The trachea measures approximately 19 mm in diameter in adult males and approximately 16 mm in diameter in adult females, although there is a great deal of variability between individuals (Breatnach, Abbott, & Fraser, 1984). The trachea divides into a series of bronchi. The two primary (mainstem) bronchi each enter a lung, and then further divide into secondary and tertiary bronchi. The secondary bronchi supply the lobes of the lungs (two lobes in the left lung, three in the right), while the tertiary bronchi supply the segments of the lungs (eight segments in the left lung, ten in the right). Structurally the bronchi are similar to the trachea but smaller in diameter. Each primary bronchus is slightly less than one-half the diameter of the trachea, and the secondary and tertiary bronchi become increasingly smaller and narrower. The tertiary bronchi continue to branch and divide into smaller and smaller tubes, and eventually branch into microscopic bronchioles. Bronchioles are composed solely of smooth muscle and mucous membrane. The bronchioles continue to branch and eventually terminate in respiratory bronchioles. The respiratory bronchioles open into alveolar ducts, which terminate in alveolar sacs. Each alveolar sac is a microscopic, thin-walled, air-filled structure surrounded by a network of microscopic blood capillaries. The alveoli are coated on the

TABLE 1.1 Upper and Lower Respiratory Tracts

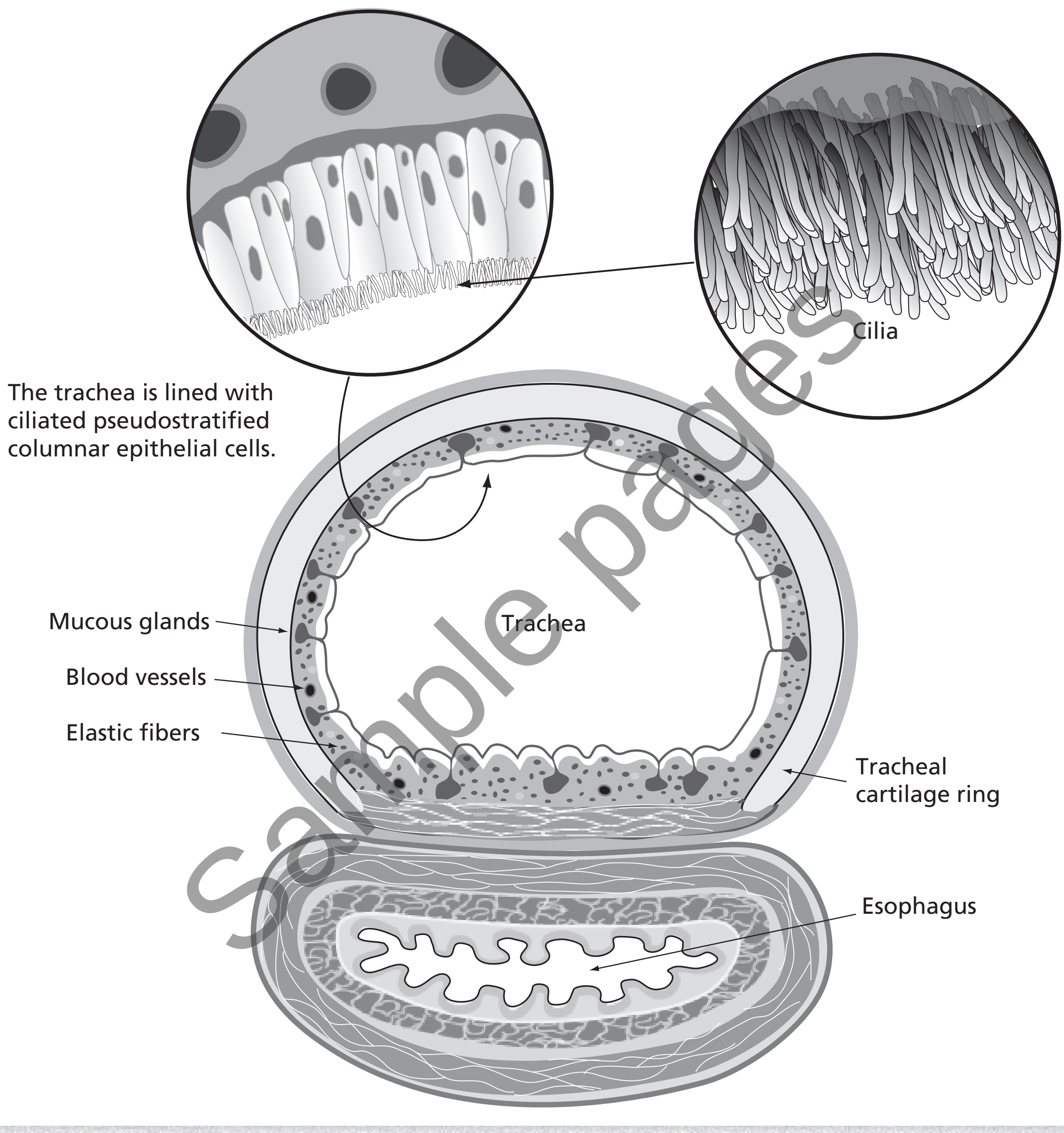
Upper Respiratory Tract	Lower Respiratory Tract
Nasal cavities	Trachea
Oral cavity	Bronchi
Pharynx	Bronchioles
	Alveoli
	Lungs

FIGURE 1.1 **The Tracheobronchial Tree**



inside with a layer of surfactant, which is a substance secreted by the lungs. Surfactant prevents the alveoli from collapsing and helps to keep the bronchioles open during respiration (Griese, 1999). There are an average of 480 million alveoli in the human lung

FIGURE *1.2* **The Trachea**



(Ochs et al., 2004). The alveolar sacs form the location of gas exchange between oxygen and carbon dioxide. Each inhalation of air brings fresh oxygen through the tracheobronchial tree to the alveolar sacs. The oxygen diffuses into the surrounding blood capillaries and is transported to every cell in the body via the circulatory system. The waste product of breathing, carbon dioxide, is brought by the circulatory system back to the capillary network around the alveolar sacs, where it diffuses into the alveoli and is exhaled.

The lungs are located within the thoracic cavity. The thoracic cavity is bounded by the sternum (breastbone) and rib cage on the front and sides, the spinal column and vertebrae at the back, and the diaphragm muscle at the bottom. The rib cage is composed of twelve ribs on either side, which are attached by cartilage to the sternum. The pectoral girdle also forms part of the rib cage. This structure includes the two collar bones (clavicles) in front and two shoulder blades (scapulae) at the back. The diaphragm muscle forms the floor of the thoracic cavity, separating it from the abdominal cavity. The interior of the lungs is composed of the branching bronchi, bronchioles, and alveoli, in addition to blood vessels and nerves. The lungs are cone-shaped structures, and each is slightly different in size and shape. Because it needs to accommodate the heart, the left lung is smaller than the right, with two lobes and eight segments. The larger right lung consists of three lobes and ten segments. The lungs are porous and elastic structures enabling them to be easily and expanded and contracted.

PLEURAL LINKAGE

The lungs contain very little muscle tissue and are unable to spontaneously generate movement. They are, however, highly compliant and can be easily moved by an external source. Each lung is encased in an airtight membrane called the **visceral pleura**. The inside surface of the thoracic cavity is lined by a membrane called the **parietal pleura**. Between these pleurae is a potential space known as the **pleural space**, containing **pleural fluid** (Figure 1.3). The pleural fluid allows the lungs and thorax to move against each other without creating friction. The pleural space has a permanent negative pressure due to the opposing recoil forces of the lung and chest wall. That is, the elastic recoil of the lungs pulls the visceral layer inward, while the elastic tendency of the thorax pulls the parietal layer outward. The space between the pleurae is therefore permanently slightly expanded, which lowers the pleural pressure and keeps the lungs and thorax in close proximity to each other. Because of **pleural linkage** the thorax and lungs act as an integrated unit. Thus, whenever the thoracic cavity is moved by active or passive forces, the lungs are moved as well. This mechanism is vital to inhalation and exhalation.

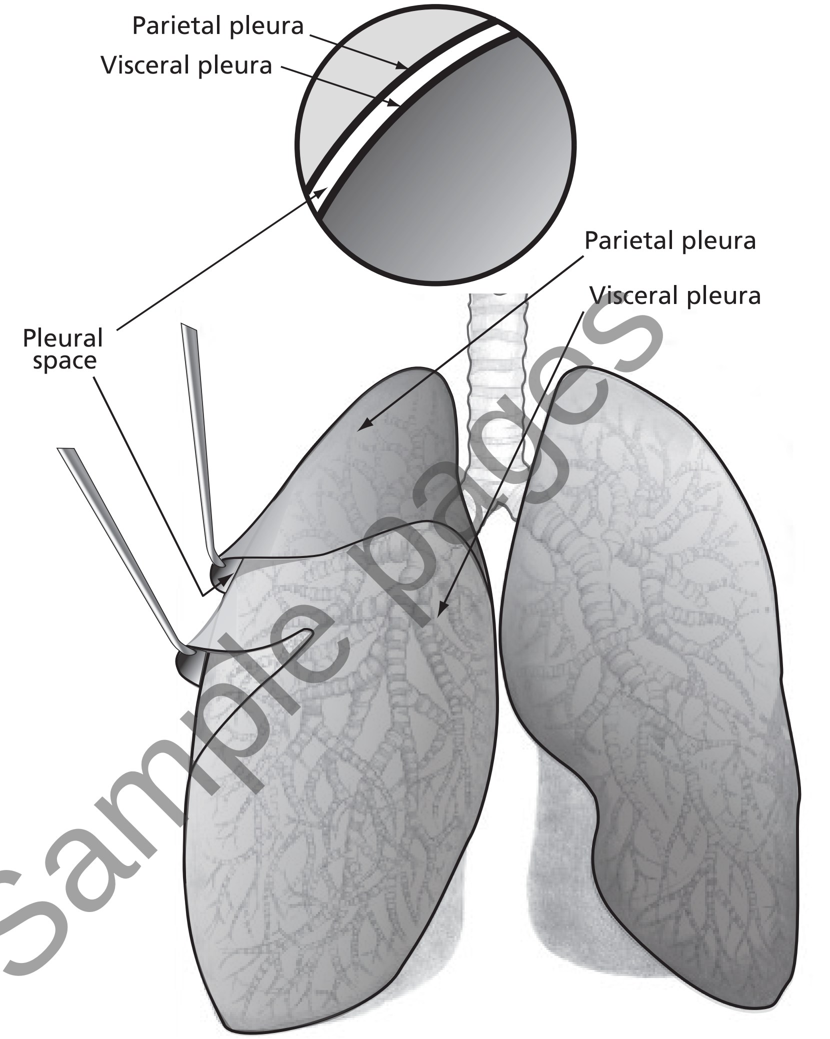
CLINICAL NOTE

A collapsed lung (called a *pneumothorax*) can result when air leaks into the pleural space and pushes on the lung. Pneumothorax can result from injury to the chest, damage from lung disease, or for no apparent reason. Smoking increases the risk of pneumothorax. Symptoms usually include sudden chest pain and shortness of breath. A small pneumothorax may heal without any treatment. If treatment is necessary, it usually involves inserting a flexible tube or needle between the ribs to remove the excess air.

MUSCLES OF RESPIRATION

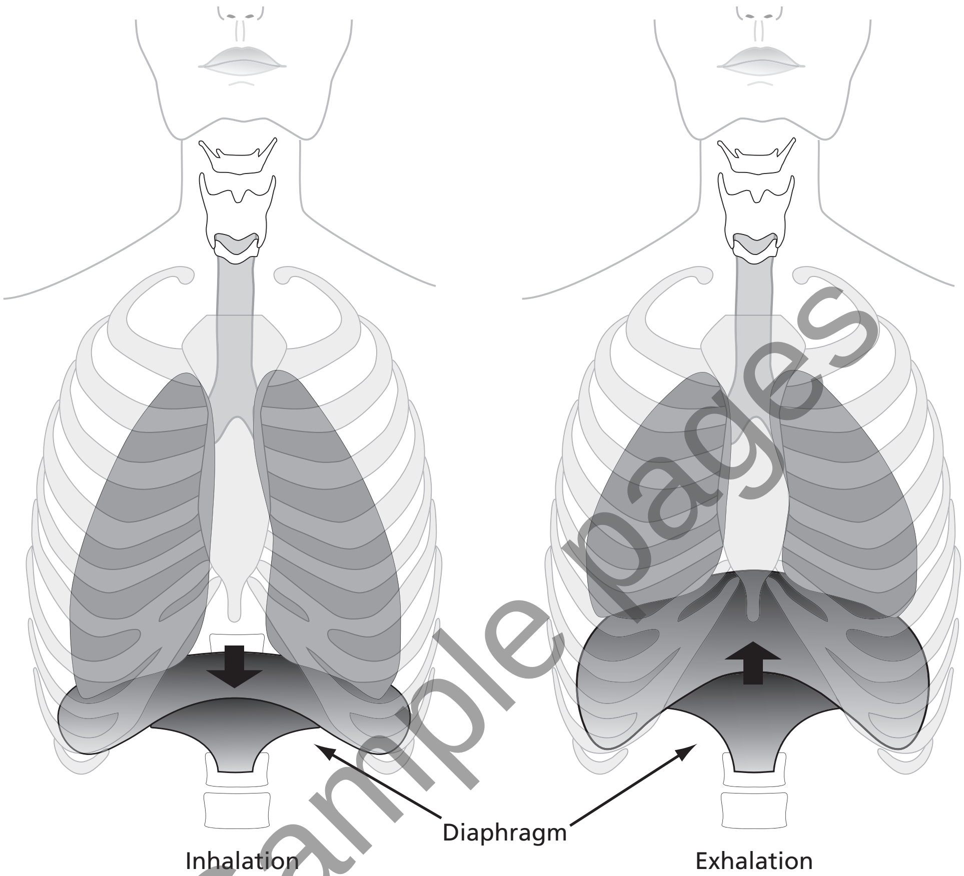
The primary muscles of respiration are the diaphragm and the intercostals. The diaphragm attaches to the bottom six ribs on either side of the rib cage (Figure 1.4). At rest the diaphragm is shaped like an inverted bowl. Upon contraction, the diaphragm

FIGURE *1.3* **Pleural Linkage**



flattens out, thus increasing the vertical dimension of the thoracic cavity. The eleven pairs of **external intercostal muscles** run between the ribs on either side (Figure 1.5). Their contraction pulls the rib cage in an upward and outward direction, expanding the thoracic cavity. The **internal intercostal muscles** also run between the ribs, deep to and in the opposite direction of the external intercostals. Their action depresses the rib cage and contracts the thoracic cavity. Additional muscles may be recruited for inspiration and expiration when the individual needs to take in a larger amount of air (see Table 1.2).

FIGURE *1.4* **The Diaphragm**



RESPIRATORY CYCLE

One cycle of respiration includes an inhalation and an exhalation phase.

Inhalation To inhale, the thoracic cavity and lungs must expand through active muscular contraction of the diaphragm and external intercostals. Air pressure and air volume have an inverse relationship—that is, the greater the volume the lower the pressure, and the smaller the volume the higher the pressure. Therefore, increasing the volume of the lungs results in a drop of *alveolar pressure* (pressure within the lungs). Air always flows from an area of higher pressure to an area of lower pressure. Consequently, air from the atmosphere is forced to flow into the respiratory system via the nose or mouth. The oxygen-rich air travels through the tracheobronchial tree to the alveoli, where gas exchange takes place.

FIGURE 1.5 **Muscles of Respiration**

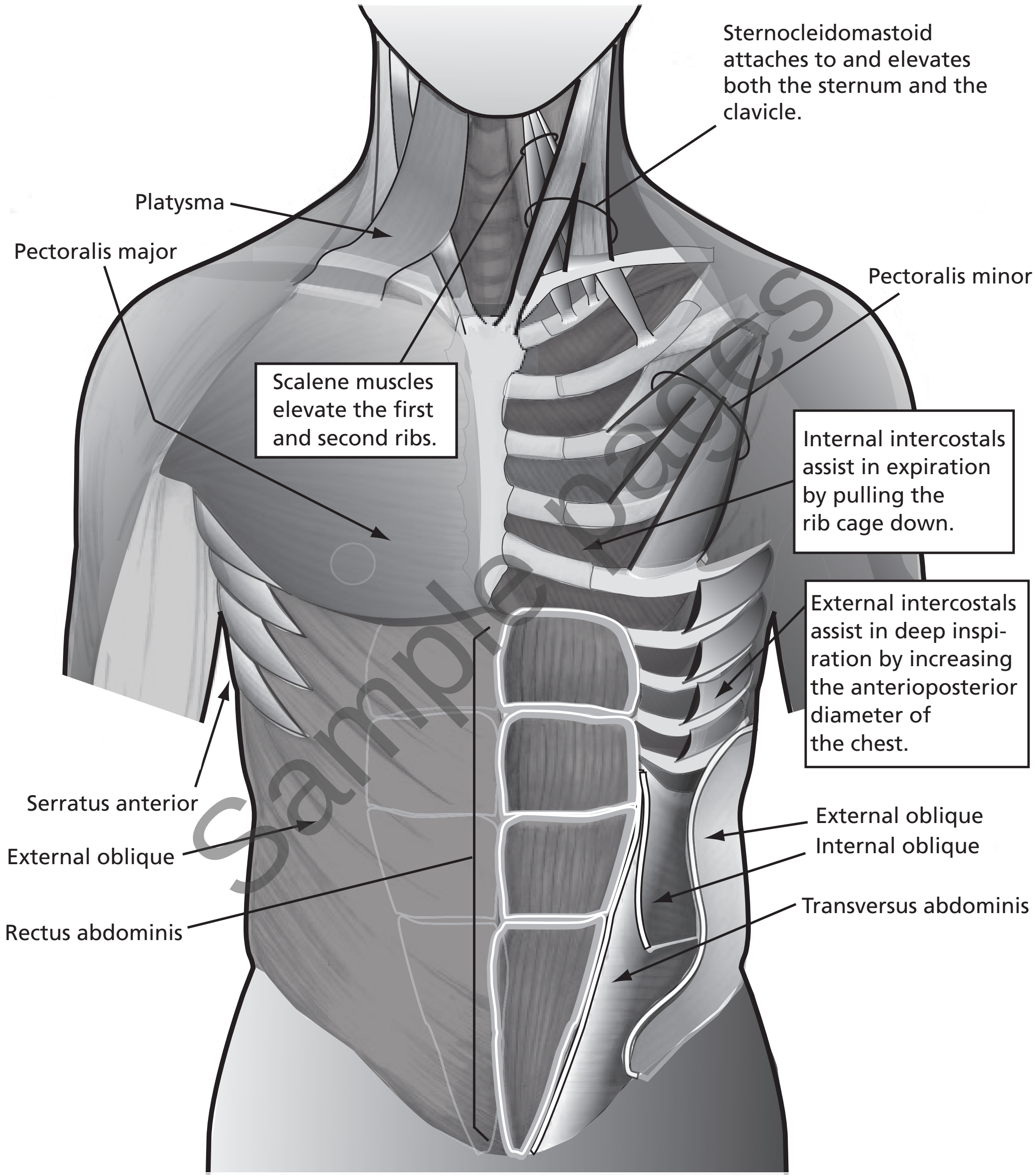


TABLE 1.2 **Accessory Muscles of Respiration**

Inspiration (Muscles of the Rib Cage Wall)	Expiration (Abdominal Muscles)
Sternocleidomastoid	Rectus abdominis
Scalene (anterior, medial, posterior)	External oblique
Serratus anterior	Internal oblique
Pectoralis (major and minor)	Transverses abdominis
Upper trapezius	
Latissimus dorsi	
Iliocostalis lumborum	
Quadratus lumborum	
Serratus (posterior, superior, inferior)	
Levatores costarum	
Transverses thoracis	
Subclavius	

Exhalation For exhalation, the external intercostal muscles and the diaphragm recoil back to their resting positions, causing the volume of the thoracic cavity and lungs to decrease. Alveolar pressure therefore increases and becomes higher than atmospheric pressure. Thus, air from the lungs is forced to exit the system through the nose or mouth.

CLINICAL NOTE

Respiratory dysfunction can impact vocal production by reducing vocal loudness and decreasing the length of time a person can sustain phonation. For example, in people with quadriplegia the intercostal and abdominal muscles are paralyzed. This means that to inhale, they are forced to rely on the diaphragm and accessory muscles of respiration (sternocleidomastoid and trapezius) to elevate the rib cage. To generate enough airflow for speech, these individuals must use the pectoralis major to decrease the volume of the thoracic cavity and lungs and thereby increase the duration and volume of an utterance (Tamplin et al., 2011).

Lung Volumes and Capacities

Respiration deals with volumes and pressures of air and airflows, and it is useful to have a way of describing the different volumes to compare how they change during different activities (e.g., quiet breathing, exertion, speaking, singing, etc.) and between various groups (e.g., older versus younger, men versus women, etc.). Lung volumes and capacities provide a way of categorizing volumes of air inhaled and exhaled through the respiratory system. Volumes and capacities are measured with a spirometer in units of milliliters (mL) or liters (L). Spirometers record either volume (the amount of air exhaled or inhaled within a certain time) or flow (how fast the air flows in or out of the individual's respiratory system). Lung volumes include single, nonoverlapping quantities, while lung capacities comprise two or more volumes (Wanger et al., 2005). There are four lung volumes and four capacities measured in relation to resting expiratory level.

RESTING EXPIRATORY LEVEL

Resting expiratory level (REL) refers to a state of equilibrium in the respiratory system in which alveolar pressure and atmospheric pressure are equalized, so air is neither entering nor exiting the system. This occurs at the end of every inspiration and expiration. The endpoint of a quiet expiration is also called the **end-expiratory level (EEL).**

PERCENTAGE OF VITAL CAPACITY

Lung volumes include tidal volume (TV), inspiratory reserve volume (IRV), expiratory reserve volume (ERV), and residual volume (RV). Lung capacities include vital capacity (VC), inspiratory capacity (IC), functional residual capacity (FRC), and total lung capacity (TLC). Table 1.3 defines the lung volumes and capacities.

TABLE *1.3* **Lung Volumes and Capacities**

Lung Volumes	
Tidal volume (TV)	Volume of air inhaled and exhaled during a cycle of respiration; approximately 500 mL depending on age, gender, and level of physical exertion
Inspiratory reserve volume (IRV)	Volume of air that can be inhaled above TV
Expiratory reserve volume (ERV)	Volume of air that can be exhaled below TV
Residual volume (RV)	Volume of air remaining in the lungs after a maximum exhalation and that cannot be voluntarily expired
Lung Capacities	
Vital capacity (VC)	Volume of air that can be exhaled following a maximum inhalation (TV + IRV + ERV); approximately 5,000 mL depending on age and gender
Inspiratory capacity (IC)	Volume of air that can be inhaled from end-expiratory level (TV + IRV)
Functional residual capacity (FRC)	Volume of air remaining in the lungs and airways at the end-expiratory level (ERV + RV)
Total lung capacity (TLC)	Total amount of air that can be held in the lungs (TV + IRV + ERV + RV)

Source: Information from Wanger et al., 2005.

Volumes and capacities are often described in terms of the percentage of **vital capacity (VC)** expended. VC is the maximum amount of air one can voluntarily breathe out. REL occurs around 35 to 40 percent of VC. At that point, one can inhale 60 to 65 percent more air to fill the lungs to their maximum capacity and can continue to exhale below REL to 0 percent VC.

CLINICAL NOTE

Airway and lung diseases such as asthma, chronic bronchitis, and emphysema result in changes in lung volumes and capacities that may affect voice and speech production.

Respiratory Patterning for Speech

While the same basic maneuvers are involved in breathing for life (also called *tidal breathing, quiet breathing,* or *vegetative breathing*) and breathing for speech, there are several crucial differences in the specific patterns of inspiration and expiration. The differences arise because in addition to fulfilling basic ventilation needs, breathing for speech requires integration of linguistic factors into the physiologic function. Linguistic considerations include an adequate breath supply for the planned utterance, prosodic variations, changes in the rate and loudness of speech, and inhaling at linguistically and conversationally appropriate junctures. Five major changes occur in the patterning of inspiration and expiration when switching from life to speech breathing. These include location of air intake, ratio of time for inhalation versus exhalation, volume of air inspired, muscle activity for exhalation, and abdominal displacement (Table 1.4).

TABLE 1.4 **Respiratory Patterning for Life Versus Speech Breathing**

	Life	Speech
1. Location of air intake	Nose	Mouth
2. Ratio of time for inhalation versus exhalation	Inhale: 40% Exhale: 60%	Inhale: 10% Exhale: 90%
3. Volume of air	500 mL 10% VC	Variable, depending on length and loudness of utterance; 20–25% VC
4. Muscle activity for exhalation	Passive; external intercostals and diaphragm relax	Active; thoracic and abdominal muscles contract to control recoil of rib cage and diaphragm
5. Chest wall position	Abdomen displaced outward relative to rib cage	Abdomen displaced inward relative to rib cage

LOCATION OF AIR INTAKE

During life breathing, air is inhaled and exhaled via the nasal passageway, which effectively warms the air to body temperature, humidifies the incoming air, and filters the air by removing dust, bacteria, and pollutants (Lester & Hoit, 2014). Breathing for speech occurs primarily via the oral passageway, allowing for a quicker inhalation and extended exhalation for production of oral sounds. Healthy individuals, however, reportedly show simultaneous oral and nasal inspiration for speech tasks (Lester & Hoit, 2014). Lester and Hoit suggested that keeping both the oral and nasal pathways open during speech breathing is healthy because it makes it easier for air to enter the respiratory system, and the air that passes through the nasal cavities is filtered, humidified, and warmed.

CLINICAL NOTE

Most mouth breathing is caused by some type of nasal obstruction, such as polyps or enlarged adenoids. Prolonged mouth breathing has been reported to result in chronic hyperventilation, reduced blood circulation, buildup of toxins, sleep disorders, and other adverse effects on a person's health. Mouth breathing also dehydrates the surface of the vocal folds, which increases the amount of effort needed to produce voice and can result in vocal fatigue (Sivasankar & Erickson-Levendoski, 2012).

RATIO OF TIME FOR INHALATION VERSUS EXHALATION

The ratio of time for inhalation and exhalation in each respiratory cycle changes from nearly equal in life breathing (40 percent inhalation, 60 percent exhalation) to a considerably shorter and quicker inhalation and prolonged exhalation for speech (10 percent inhalation, 90 percent exhalation). This allows for a sufficient number of syllables per exhalation with quick replenishment of air that facilitates the uninterrupted flow of connected speech.

FUN FACT

The reason humans can manipulate the length of the exhalation for speech is because of our fine control of the intercostal muscles. This control developed because our species walks upright so we don't need to use our rib cages to support our weight, freeing up the muscles.

VOLUME OF AIR INHALED AND EXHALED

The volume of air inhaled and exhaled differs during life and speech breathing. During quiet breathing, approximately 500 mL are inspired, depending on the age and gender of the individual. This amount is 10 percent of VC, which is approximately 5,000 mm. Inhalation for life breathing begins at REL (35–40 percent of VC) and goes up to a lung volume that is 50 percent of VC. The individual then exhales back down to REL. The volume inhaled for speech is variable, depending on the length and loudness of the upcoming utterance. Volumes for normal conversation typically occur in the mid-range of VC (35–60 percent) and are around twice as much as those involved in life breathing. At 60 percent of VC the corresponding alveolar pressure is 10 centimeters of water (cm H_2O), which is sufficient for most normal conversational utterances. The mid-volume range of VC is highly efficient because it requires very little respiratory muscle activity (Huber, 2008). For longer and louder utterances speakers inhale to higher lung volumes and continue the exhalation into lower volumes (Huber, 2008).

MUSCLE ACTIVITY FOR EXHALATION

Switching from life to speech breathing changes the muscle activity required for exhalation. For both life and speech breathing, inhalation is an active process that requires contraction of the diaphragm and external intercostals to increase the volume of the thoracic cavity and lungs. For quiet breathing exhalation occurs passively (i.e., without any muscular contraction), as the respiratory tissues recoil back to their rest positions due to gravity, muscle relaxation, and elasticity of the lung tissue. For speech purposes the rate of recoil must be controlled to prolong the exhalation. Exhalation for speech typically begins around 60 percent VC. As the person begins to exhale, the muscles of inspiration continue to contract to provide a counteracting checking force that prevents the thoracic cavity and lungs from deflating too quickly. In general, exhalations for speech fall between around 60 percent VC and REL. Sometimes however, an individual may wish to continue speaking below REL. In this case the individual needs to access the expiratory reserve volume. The abdominal muscles and internal intercostal muscles are recruited to assist with this. Contraction of the abdominal muscles forces the abdominal wall to press inward on the abdominal contents (stomach, intestines, etc.). This, in turn, pushes the contents headward against the diaphragm, which further decreases the volume of the thorax and lungs so air continues to be exhaled. Contraction of the internal intercostals depresses the rib cage which also decreases the thoracic and lung volume and forces air out of the system. Speaking at lung volumes below REL thus requires considerable muscular effort to continue decreasing the lung volume for exhalation and to prevent the rib cage from recoiling outward in an inspiratory direction.

CLINICAL NOTE

Speaking at lung volumes below REL affects phonation and can be a cause of, or result from, laryngeal disorders such as nodules. Individuals with nodules have been reported to initiate and end speech tasks at lower than normal lung volumes (below REL), spend a higher percentage of their vital capacity per second in all tasks, inhale more frequently but to a lesser lung volume and demonstrate fewer syllables per breath group (Iwarsson & Sundberg, 1999; Schaeffer, Cavallo, Wall, & Diakow, 2002). The increased strain on the respiratory muscles that occurs when speaking at low lung volumes can further affect phonation by stiffening the vocal folds which therefore requires greater effort to initiate vibration.

CHEST-WALL SHAPE

The chest wall includes the rib cage, diaphragm, abdominal wall, and abdominal contents. For speech breathing the abdomen is displaced further inward relative to the rib cage (Bailey & Hoit, 2002; Kalliakosta, Mandros, & Tzelepis, 2007). This positioning lifts the diaphragm (because of the upward pressure on the abdominal contents) and expands the lower rib cage. The muscle fibers of the diaphragm are thereby placed in an optimal position for generating quick strong contractions (Kalliakosta et al., 2007; Solomon & Charron, 1998). In addition, keeping the abdomen inward relative to the rib cage provides a platform against which the rib cage can move to control the varying lung volumes and air pressures necessary in connected speech (Bailey & Hoit, 2002). Movement of the rib cage is more efficient in changing lung volumes than movement of the abdomen because of the greater surface area of the lung (about three-quarters) that is adjacent to the rib cage (Connaghan, Moore, & Higashakawa, 2004; Kalliakosta et al., 2007). Therefore, the rib cage wall needs to move only one-quarter of the distance that the abdominal wall does to achieve the same change in alveolar pressure (Kalliakosta et al., 2007).

Nervous System Control of Respiration

Respiration is controlled primarily by the medulla and pons in the brain stem. The rate and depth of breathing are dependent on the levels of O_2 and CO_2 in the bloodstream. O_2 and CO_2 receptors are located peripherally and in the central nervous system (CNS) (Zhang & Davenport, 2005). When O_2 levels decrease or when CO_2 levels increase, the receptors signal the CNS to increase respiratory drive with resulting increased inflow of O_2 (Zhang & Davenport, 2005). Other respiratory receptors that are involved in generating the respiratory rhythm produced in the brain stem (respiratory motor output) include **pulmonary stretch receptors (PSRs)** and **rapidly adapting receptors (RARs)** in the smooth muscles of the tracheobronchial tree (Zhang & Davenport, 2005). The PSRs sense the airway smooth muscle tone and project to the medullary respiratory neural network via the vagus nerve. The PSRs signal the transition from inspiration to expiration by inhibiting respiratory neuronal activity (Zhang & Davenport, 2005). RARs are sensitive to both mechanical and chemical changes and are stimulated by airway irritants.

While respiration is an autonomic process, higher brain centers can come into play, for example, in voluntary breath holding, or deliberately slowing down one's breathing rhythm. Many yoga techniques (called *pranayama*) focus on controlling respiratory rhythm through conscious regulation of breathing cycles. These techniques can have a lasting and beneficial effect, such as increasing the depth of tidal breathing (e.g., Beutler, Beltrami, Boutellier, & Spengler, 2016).

Control of breathing for vocalization and speech has been associated with the primary motor and sensory cortex, supplementary motor area, cerebellum, thalamus, and

CLINICAL NOTE

Airway irritants include tussive triggers such smoke, fumes, cigarettes, aspiration; and non-tussive triggers such as talking, cold air, perfume, and exercise (Vertigan & Gibson, 2016). Both tussive and non-tussive triggers can cause coughing which is normally a protective airway reflex, but which can become chronic. Individuals with chronic cough are abnormally sensitive to triggers. Treatment of chronic cough is ideally a combination of medical and speech-language pathology intervention (Vertigan, Kapela, Ryan, Birring, McElduff, & Gibson, 2016).

FUN FACT

Yoga breathing techniques have become so popular that one can find many mobile apps for breathing training (e.g., Chittaro & Sioni, 2014). The apps provide visualization of rate of the inspiratory and expiratory cycles and cue the user to regulate their inhalations and/or exhalations. Some of the apps display a circle that expands and contracts, and some also change the color of the circle for different phases of the respiratory cycle. Other apps use a tone whose pitch increases and decreases to alert the user to inhale or exhale. Most apps allow the user to adjust the rate of breathing to a level that is comfortable, and some apps provide a comparison based on age and gender.

limbic system (Murphy et al., 1997; Wheeler & Sapienza, 2005). These structures are also involved in the conscious awareness of respiration, sensation of breathlessness, and subsequent enhanced breathing efforts (Wheeler & Sapienza, 2005). However, input from the medullary respiratory center can override the cognitive control. Thus, it is only possible for an individual to voluntarily hold his or her breath until CO_2 increases and O_2 decreases to a certain point, beyond which autonomic brain stem control takes over (Zhang & Davenport, 2005).

Laryngeal Functions and Structures

The **larynx** is a complex structure formed by interlinked cartilages, membranes and ligaments, muscles, and soft tissues. Because the larynx is continuous with both the trachea and the pharynx, it is involved in respiration, in swallowing, in airway protection, and in phonation (Figure 1.6).

FUNCTIONS OF THE LARYNX

The larynx houses three pairs of folds that function as valves to open and close the airway, including the aryepiglottic folds, false (ventricular) vocal folds, and true vocal folds (these will be discussed in more depth later in the chapter). For respiration, the laryngeal valves are open, allowing air to flow freely into and out of the respiratory system. When greater amounts of air are needed, for example, during increased exertion, the glottis (space between the vocal folds) opens more widely to allow an increased flow of air through the system.

An important function of the larynx is airway protection during swallowing. For swallowing the entire larynx is raised by muscles in the neck and all three sets of folds close the larynx as the bolus of food enters the pharynx. The closure prevents food or liquid from entering the airway.

The larynx also protects the airway by means of coughing. Coughing is a reflex designed to expel any foreign objects from the airway and can be triggered by stimulation of the mucous lining in the trachea, glottis, and supraglottic region (Ludlow, 2005). During a cough the vocal folds adduct with tremendous force to build up a strong stream of air beneath them. As the vocal folds abduct the air is released under high pressure, thereby expelling the foreign object.