

Anatomy and Physiology of the Larynx

1.1 Anatomy

1.1.1 Laryngeal Cartilages

1.1.1.1 Thyroid

The laryngeal skeleton consists of several cartilaginous structures (Fig. 1.1), the largest of which is the thyroid cartilage. The thyroid cartilage is composed of two rectangular laminae that are fused anteriorly in the midline. The incomplete fusion of the two laminae superiorly forms the thyroid notch. Attached to each lamina posteriorly are the superior and inferior cornua. The superior cornua articulate with the greater horns of the hyoid bone, while the inferior cornua form a synovial joint with the cricoid cartilage (the cricothyroid joint). At the junction of each superior cornu with its respective thyroid ala is a cartilaginous prominence, the superior tubercle. The superior tubercle is of significance because it marks the point 1 cm below which the superior laryngeal artery and nerve cross over the lamina from laterally to pierce the thyrohyoid membrane. The sternothyroid and the thyrohyoid strap muscles attach to

the anterior surface of the thyroid laminae at the oblique line. The inferior pharyngeal constrictor muscles insert on the posterior edge of each thyroid lamina.

The relationship of the internal laryngeal structures to the surface anatomy of the thyroid cartilage is important in surgical planning, particularly in planning the placement of the window for thyroplasty. The level of the vocal fold lies closer to the lower border of the thyroid cartilage lamina than to the upper, and not at its midpoint, as is frequently (and erroneously) stated. Correct placement of the window is necessary to avoid medialization of the false vocal folds or ventricular mucosa.

1.1.1.2 Cricoid

This signet ring-shaped cartilage is the only laryngeal cartilage to encircle completely the airway. The cricoid cartilage articulates with the thyroid cartilage's inferior cornua on the cricothyroid joint facets. It joins the first tracheal ring inferiorly via membranous attachments. The face of the cricoid cartilage has a vertical height of only about 3–4 mm, while the lamina posteriorly stands about 20–30 mm high. There is a steep incline from anterior to posterior of the superior margin of the cricoid cartilage. This incline leaves an anterior window where the cricothyroid membrane lies.

1.1.1.3 Arytenoid

The arytenoid cartilages are paired, pyramidal cartilages that articulate with the posterior lamina of the cricoid cartilage at the cricoarytenoid joint. Each arytenoid has both a vocal process medially and a muscular process laterally. These processes act as the attachment sites for the vocal ligament and the major intrinsic muscles of vocal fold movement respectively.

1.1.1.4 Accessory Cartilages: Cuneiform and Corniculate

The cuneiform cartilages are crico-arytenoid joint paired elastic cartilages that sit on top of, and move with, the corresponding arytenoid. The soft tissue of the aryepiglottic folds covers these cartilages. The corniculates are small, paired, fibroelastic cartilages that sit laterally to each of the arytenoids, and are completely embedded within the aryepiglottic folds. These

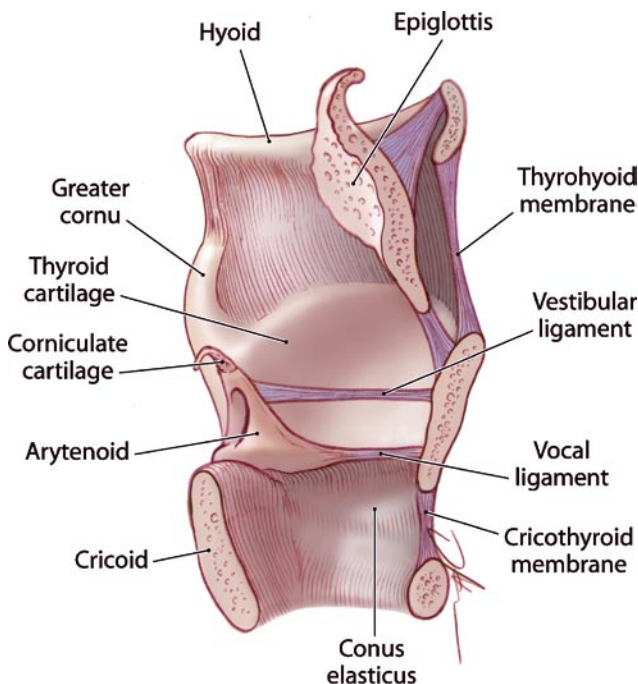


Fig. 1.1 Cartilaginous and fibroelastic structures of the larynx

likely serve to provide additional structural support to the ary-epiglottic folds.

1.1.1.5 Epiglottis

The epiglottis is an oblong, feather-shaped fibroelastic cartilage that is attached, at its inferior end, to the inner surface of the thyroid cartilage laminae just above the anterior commissure. The major function of the epiglottis is to help prevent aspiration during swallowing. The epiglottis is displaced posteriorly by tongue base contraction and laryngeal elevation. This causes the superior free edge of the epiglottis to fall over the laryngeal inlet, which, in conjunction with sphincteric closure of the larynx at the glottic and supraglottic level, closes off the laryngeal vestibule.

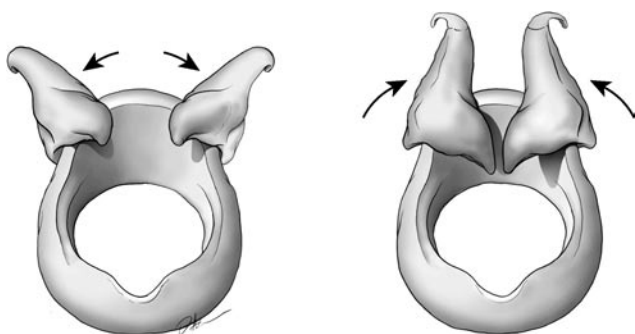


Fig. 1.2 Cricoarytenoid joint action in abduction (*left*) and adduction (*right*). Note the lowering of the vocal process as adduction occurs

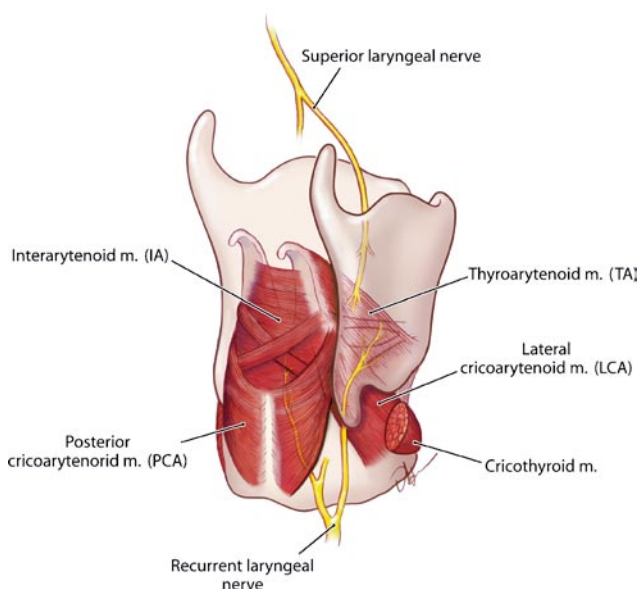


Fig. 1.3 Neuromuscular structures of the larynx

1.1.2 Laryngeal Joints

1.1.2.1 Cricothyroid Joint

The cricothyroid joint is a synovial joint formed from the articulation of the inferior cornua of the thyroid cartilage with facets on the cricoid lamina. The two major actions at this joint are anteroposterior sliding and rotation of the inferior thyroid cornu upon the cricoid cartilage. Cricothyroid muscle contraction pulls the thyroid ala anteriorly with respect to the cricoid cartilage and closes the anterior visor angle between the thyroid and the cricoid cartilage. This motion increases the distance between the anterior commissure and the vocal processes and serves to lengthen and tense the vocal folds. This joint can be manipulated to assist in pitch control in cases of paralytic dysphonia. Cricothyroid joint subluxation, resulting in an exaggerated decrease in the anterior cricothyroid angle, can assist in traditional medialization procedures to provide vocal fold tightening.

1.1.2.2 Cricoarytenoid Joint

The cricoarytenoid joint is the primary moving structure of the intrinsic larynx (Fig. 1.2). The arytenoids articulate with the cricoid cartilage forming multiaxial joints. The action of movement at the cricoarytenoid joints changes the distance between the vocal processes of the two arytenoids and between each vocal process and the anterior commissure. The combined action of the intrinsic laryngeal muscles on the arytenoid cartilages alters the position and shape of the vocal folds. Each cricoarytenoid joint sits at a surprisingly steep 45° angle with the horizontal plane on the cricoid cartilage and permits motion in a sliding, rocking, and twisting fashion.

1.1.3 Laryngeal Musculature

1.1.3.1 Intrinsic Laryngeal Muscles

The intrinsic muscles of the larynx are responsible for altering the length, tension, shape, and spatial position of the vocal folds by changing the orientation of the muscular and vocal processes of the arytenoids with the fixed anterior commissure (Fig. 1.3). Traditionally, the muscles are categorized into the following scheme: three major vocal fold adductors, one abductor, and one tensor muscle.

Adductor Muscles

The Lateral Cricoarytenoid Muscle (LCA)

This paired laryngeal muscle is attached to the anterior part of the muscular process medially and to the superior border of the cricoid cartilage laterally. Contraction of this muscle results in movement of the muscular process anterolaterally,

while simultaneously forcing the vocal process downward and medially. The result is adduction and lengthening of the vocal folds. This muscle runs lateral and in large part parallel with the thyroarytenoid muscle.

Thyroarytenoid Muscle (TA)

The thyroarytenoid muscle consists of two main muscle bellies, the internus and the externus. The thyroarytenoid externus inserts anteriorly at the anterior commissure (Broyles' ligament), and posterolaterally on the lateral surface of the arytenoid. During contraction of this portion of the muscle, the vocal process is brought closer to the anterior commissure and the vocal folds are shortened and adducted. The thyroarytenoid internus arises from the anterior commissure and inserts onto the vocal process of the arytenoid cartilage. During contraction, the vocal folds are shortened and thickened. This portion of the thyroarytenoid is also known as the vocalis muscle. In isolation, this action serves to lower the resonant frequency of the vocal folds. In most cases, there is a significant superior extension of the TA muscle into the false vocal folds, often referred to as the ventricularis muscle.

Interarytenoid Muscle (IA)

This nonpaired muscle consists of both transverse fibers and oblique fibers. The transverse fibers insert on the posterior face of each arytenoid and run horizontally, while the oblique fibers attach to each arytenoid apex and run obliquely to attach to the posterior face on the opposite side. Contraction of this muscle leads to arytenoid adduction, closure of the posterior glottis, and narrowing of the laryngeal inlet. Some oblique fibers extend to travel along the quadrangular membrane and are referred to as the aryepiglottic muscle.

Abductor Muscle

Posterior Cricoarytenoid Muscle (PCA)

The posterior cricoarytenoid muscle arises from the posterior face of the cricoid lamina. Its fibers run diagonally to insert on the muscular process of the arytenoid. Contraction displaces the muscular process posteriorly and caudally, while the vocal process moves upward and laterally. The result is vocal fold abduction. The posterior cricoarytenoid is the only abductor of the vocal folds and is principally responsible for control of the glottic airway. The posterior cricoarytenoid muscle affects motion at the cricoarytenoid joint in two planes by its two separate muscle bellies. The medial portion of the posterior cricoarytenoid (horizontal belly) arises from the posterior cricoid lamina and courses obliquely in a superiolateral fashion to insert on the medial aspect of the muscular process. The lateral portion (vertical belly) runs in a more vertical fashion to insert on the lateral side of the muscular process. Because of slightly different positions and orientations, contraction of each muscle belly in isolation causes cricoarytenoid joint motion about a different oblique axis. The horizontal belly has been shown, in cadaver studies, to cause motion in a more vertical axis (true vocal fold abduction), while the vertical belly keeps the aryte-

noids "upright" and has a major role in vocal fold length and tension. The PCA muscle anatomy serves as a key landmark for arytenoid adduction surgery.

Tensor Muscle

Cricothyroid Muscle

The cricothyroid muscle is a laryngeal tensor, composed of two separate muscle bellies, located on the external surface of the laryngeal cartilages. The pars recta, the more vertical component, arises laterally from the superior rim of the cricoid cartilage and inserts on the inferior rim of the thyroid cartilage, while the pars obliqua, runs obliquely from the superior arch of the cricoid to insert on the inferior cornu. Contraction of the cricothyroid muscle bellies affects motion at the cricothyroid joint. During contraction, the cricothyroid space is narrowed anteriorly, while the posterior cricoid lamina and cricoarytenoid joints are forced caudally, resulting in lengthening, tightening and thinning of the vocal folds and as well as increasing their resonant frequency. This action also results in vocal fold adduction.

1.1.3.2 Extrinsic Laryngeal Muscles

The infrahyoid strap muscles (the sternothyroid, the sternohyoid, and the thyrohyoid), the mylohyoid, digastric, geniohyoid, and stylopharyngeus muscles all act in concert to provide laryngeal stabilization, and indirectly may affect vocal fold position.

1.1.4 Fibroelastic Tissue of the Larynx

1.1.4.1 Quadrangular Membrane

The quadrangular membrane is an accessory elastic support structure of the supraglottic larynx. It attaches anteriorly to the lateral edges of the epiglottis, and wraps around posteriorly to attach to the arytenoids. The superior free edge of the quadrangular membrane is the mucosa-covered aryepiglottic fold. As the quadrangular membrane extends inferiorly, it becomes the medial wall of the piriform sinus. At its inferior extent, it is continuous with the vestibular ligament.

1.1.4.2 Conus Elasticus

The thick fibroelastic support structure of the glottis and subglottis originates inferiorly along the superior border of the cricoid cartilage. It extends superiorly to attach to the anterior commissure and vocal processes. The conus elasticus rolls medially within the substance of the vocal fold; its medial extent is the vocal ligament. Anteriorly, the conus elasticus is continuous with the cricothyroid membrane.

1.1.5 Microanatomy of the Vocal Fold

The complex microanatomy of the true vocal fold allows the loose and pliable superficial mucosal layers to vibrate freely over the stiffer structural underlayers (Fig. 1.4). The true vocal fold can be divided into three major layers: the mucosa, the vocal ligament, and the underlying muscle. The mucosa of the vocal fold is highly specialized for its vibratory function; it can also be divided into layers. The most superficial layer is the squamous epithelium. Deep to the epithelium are three layers of lamina propria, each of increasing rigidity. The most superficial layer (superficial layer of the lamina propria, or SLP) is mostly acellular and composed of extracellular matrix proteins, water, and loosely arranged fibers of collagen and elastin. The SLP is gelatinous in nature. The potential space between the SLP and the intermediate layer of lamina propria is Reinke's space. The intermediate and deep layers of the lamina propria (ILP and DLP) are composed mostly of elastin and collagen; the deepest and most dense layer (DLP) is composed of tightly arranged collagen fibers. The ILP and DLP together form the vocal ligament. The gelatinous superficial layer of the lamina propria, together with the squamous epithelium, moves freely over the underlying vocal ligament and muscle to form the vibrations that produce sound.

The vocal fold mucosa and vocal ligament cover the vocalis muscle and extend from the anterior commissure to the vocal processes of the arytenoids. The mucosa and vocal ligament extend posteriorly to cover the entirety of the vocal process. The posterior third of the endoscopically visualized true vocal fold, then, is the aphonatory (respiratory), or cartilaginous portion, while the anterior two thirds of the endoscopically visualized vocal fold is the phonatory, or membranous portion.

1.1.6 Vasculature

The arterial supply to the larynx comes from the superior and inferior laryngeal arteries; the venous supply mirrors the arterial supply. The superior laryngeal artery is a branch of the superior thyroid artery, which arises directly from the external carotid. The superior laryngeal artery branches from the superior thyroid artery at the level of the hyoid bone. This artery then courses medially with the internal branch of the superior laryngeal nerve and enters the thyrohyoid membrane 1 cm anterior and superior to the superior tubercle. The cricothyroid artery, one of the major branches of the superior laryngeal artery, runs along the inferior surface of the thyroid cartilage to supply its similarly named muscle and joint. Branches of this artery pierce the cricothyroid membrane and ascend on the internal surface of the thyroid cartilage, making them possible targets during the creation of a thyroplasty window. The second major arterial supply to the larynx comes from the inferior laryngeal artery, a branch of the inferior thyroid artery. This artery enters the larynx between fibers of the inferior constrictor muscle and anastomoses with branches of the superior laryngeal artery.

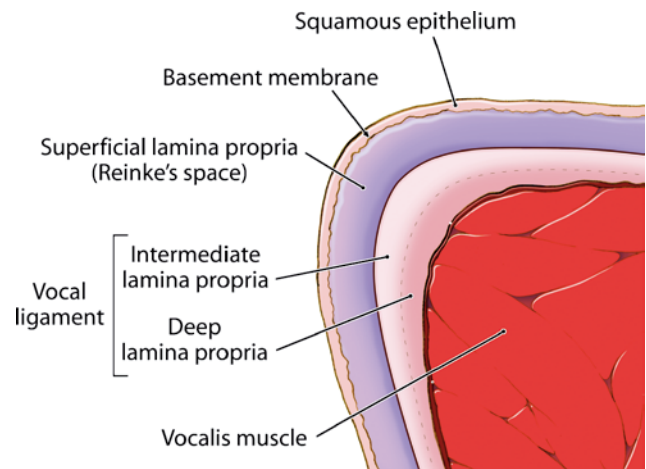


Fig. 1.4 Coronal section through the free edge of the vocal fold, demonstrating the layered microanatomical structures that allow vibration

1.1.7 Innervation

Corticobulbar fibers from the cerebral cortex descend through the internal capsule and synapse on the motor neurons in the nucleus ambiguus. The nucleus ambiguus is the area within the brainstem (medulla) from which the fibers that will contribute to the vagus nerve arise. Lower motor neurons leave the nucleus ambiguus and travel laterally, exiting the medulla between the olive and the pyramid as a series of eight to ten rootlets. These rootlets coalesce into a single nerve root, known as the vagus nerve, which then exits the skull base via the jugular foramen. The vagus nerve descends in the carotid sheath, giving off three major branches: the pharyngeal branch, the superior laryngeal nerve (SLN), and the recurrent laryngeal nerve (RLN). The SLN supplies sensation to the glottic and supraglottic larynx, as well as motor input to the cricothyroid muscle, which controls vocal fold lengthening and pitch. There are some recent anatomic studies that suggest that the superior aspect of the TA muscle (the ventricularis muscle in the false vocal fold) may have SLN innervation, which could explain the presence of false vocal fold muscular contraction in cases of RLN transection. The RLN arises from the vagus nerve in the upper chest and loops under the aortic arch (left) or subclavian artery (right), and ascends back into the neck, traveling in the tracheoesophageal groove. The nerve enters the larynx posteriorly, adjacent to the cricothyroid joint (Fig. 1.3). The RLN innervates the ipsilateral posterior cricoarytenoid (PCA), the interarytenoid (IA) (an unpaired muscle), and the lateral cricoarytenoid (LCA), and terminates in the thyroarytenoid (TA). Thus, the RLN supplies all of the intrinsic laryngeal muscles with the exception of the cricothyroid muscle (and possibly the ventricularis muscle, as indicated above). Ipsilateral RLN transection typically results in vocal fold immobility (the ipsilateral CT does not contribute to vocal fold adduction or abduction). It is important to remember, however, that the interarytenoid muscle is unpaired,

and contralateral RLN input to the IA may lead to some adduction of the vocal fold on the paralyzed side.

The RLN also supplies the glottic and subglottic mucosa and the myotatic receptors of the laryngeal musculature.

1.2 Physiology

1.2.1 Major Laryngeal Functions: Lower Airway Protection, Respiration, and Phonation

The most primitive of the laryngeal functions is protection of the airway. In humans, the larynx has evolved into a highly complex and specialized organ not only for airway protection and control of respiration, but also for sound and speech production. Precise control of all of these mechanisms, as well as exact anatomic structure, is required for normal laryngeal functioning. The larynx has evolved several important reflexes for the purpose of airway protection against external stimuli and foreign bodies. These reflex mechanisms are relayed by the mucosal (sensory afferent), myotatic, and articular receptors of the larynx via both the superior and recurrent laryngeal nerves (Fig. 1.3).

The strongest of the laryngeal reflexes is that of laryngospasm—a response to mechanical stimulation. The larynx has also evolved reflexes that produce cough, apnea, bradycardia, and hypotension.

1.2.1.1 Phonation

The most complex and highly specialized of the laryngeal functions is sound production. The ability to couple phonation with articulation and resonance allows for human speech. Phonation and precisely how it relates to laryngeal vibration has undergone many evolving theories over the years. Sound production requires that several mechanical properties be met. There must be adequate breath support to produce sufficient subglottic pressure. There also must be adequate control of the laryngeal musculature to produce not only glottic closure, but also the proper length and tension of the vocal folds. Finally, there must be favorable pliability and vibratory capacity of the tissues of the vocal folds. Once these conditions are met, sound is generated from vocal fold vibration.

The detailed contribution, timing, and recruitment of each of the above-described laryngeal muscles in the production of sound have been studied. In a fine-wire electromyographic study of human larynges, it was found that the intrinsic laryngeal muscles are not only highly specialized for their particular vector of action, but they are also controlled for the timing of onset of contraction, and the degree of recruitment and fade during phonation. The thyroarytenoid and the lateral cricoarytenoid muscles have been shown to exhibit burst-like activity at the onset of phonation (as well as pre-phonatory), with a measurable degree of fade during sustained phonation. The

interarytenoid muscle, on the other hand, has been shown to have increased latency of contraction, but regular sustained tonicity during prolonged sound production. The cricothyroid seems to have the greatest measurable action with increases in pitch and volume, while the posterior cricoarytenoid shows its greatest degree of activation with voluntary deep inhalation and sniff functions.

Actual phonation is a complex and specialized process that involves not only brainstem reflexes and the muscular actions described above, but high-level cortical control as well. Accessory effects such as lung capacity, chest wall compliance, pha-

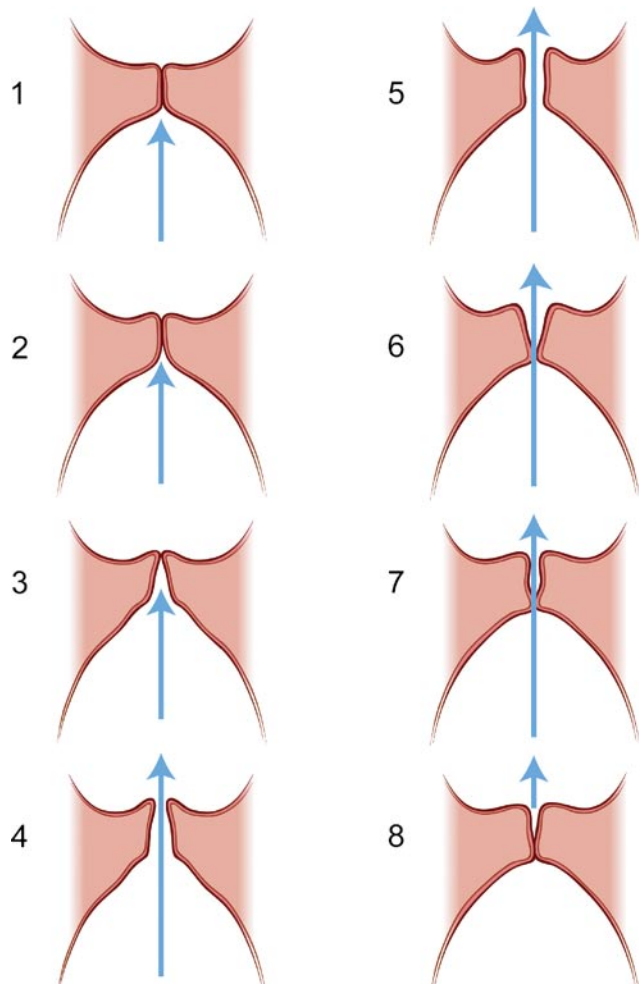


Fig. 1.5 Schematic coronal section through the vocal folds, demonstrating mucosal wave propagation. 1 Vocal folds are completely closed as subglottic pressure (arrow) builds up. 2 Lower lips separate due to rising subglottic pressure. 3 Only the upper lips are in contact. 4 A puff of air is released as the vocal folds separate completely. 5, 6 As airflow continues, the elastic recoil of the vocal folds, as well as Bernoulli's forces, result in the lower lips of the vocal folds drawing inward. At the same time, the mucosal wave is propagated superiolaterally. 7 Airflow is reduced, and the lower lips are completely approximated. 8 In a zipper-like closure, the free edge of the vocal folds come into contact from inferiorly to superiorly

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ryngeal, nasal, and oral anatomy, and subsequent mental status also play a role. The process begins with inhalation and subsequent glottal closure. An increase in subglottic pressure follows until the pressure overcomes the glottal closure force and air is allowed to escape between the vocal folds. Once air passes between the vocal folds, the body-cover concept of phonation takes effect. The body-cover theory describes the wave-like motion of the loose mucosa of the vocal folds over the stiffer, more densely organized vocal ligament and vocalis muscle. This motion is known as the mucosal wave. The wave begins infraglottically and is propagated upward to the free edge of the vocal fold and then laterally over the superior surface (Fig. 1.5). Eventually, the inferior edges become reapproximated due both to a drop in pressure at the open glottis, and to the elastic recoil of the tissues themselves. The closure phase is also propagated rostrally. With the vocal folds fully approximated, subglottic pressure may again build and the cycle is repeated (Fig. 1.5).

Key Points

1. The relationship of the surface anatomy of the thyroid and arytenoid cartilages to the internal laryngeal structures are critical to surgical planning for laryngeal framework surgery and in-office procedures (i. e., percutaneous laryngeal injections).
2. The primary adductor muscles of the larynx consist of:
 - Lateral cricoarytenoid (LCA)
 - Thyroarytenoid (TA)
 - Interarytenoid (IA)
3. The main abductor muscle of the larynx is the posterior cricoarytenoid (PCA).
4. The cricothyroid and the TA/LCA muscles control vocal fold length, tension, and vocal frequency.
5. The microanatomy of the vocal folds is complex and consists of the following layers, from superficial to deep:
 - Epithelium
 - Superficial lamina propria
 - Intermediate lamina propria
 - Deep lamina propria
 - Vocalis muscle
6. Reinke's space is a potential space between the superficial and intermediate layer of the lamina propria. The intermediate and deep layers of the lamina propria together are referred to as the vocal ligament.

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