Anatomy and Physiology of Phonation

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Abstract

This chapter focuses on a detailed anatomy of the larynx and the laryngeal structures required for phonation. It also goes on further to discuss the physiology of phonation and how we convert air into words. It describes the necessary requirements to produce voice.

Keywords: Airway, Dysphonia, Head & neck anatomy, Laryngeal anatomy, Larynx, Larynx anatomy, Phonation, Recurrent laryngeal Nerve, Speaking, Swallowing, Vocal cord, Voice, Voice quality.

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Embryology

Development

The structures of the larynx develop during the 4th week of gestation. They are derived from both the endoderm (the internal lining) and the mesoderm (cartilage and muscles). An outgrowth of the foregut starts to appear at the 4th week and is first known as the tracheobronchial groove. The tracheobronchial groove eventually deepens which will form the tracheoesophageal septum and separate the esophagus from the respiratory tract. With continued deepening of the laryngotracheal groove, a laryngotracheal diverticulum appears which will eventually give rise to the larynx, trachea, and lungs. Of note, in development of the larynx, it is initially obliterated with epithelium but will recanalize between 7 and 10 weeks of gestation.

Pharyngeal Arches

The pharyngeal arches give rise to the laryngeal muscles, cartilages, and nerves.

- Third branchial arch
  - Nerve: CN IX
  - Cartilage:
    - Greater horn of hyoid bone
    - Epiglottic cartilage.
- Fourth branchial arch
  - Nerve: CN X–Superior laryngeal nerve
  - Cartilage:
    - Thyroid
    - Cuneiform cartilage
    - Epiglottic cartilage.
  - Muscles:
    - Cricopharyngeus muscle
    - Cricothyroid muscle.
- Sixth branchial arch
- Nerve: CN X–Recurrent laryngeal nerve
  - Cartilage:
    - Cricoid cartilage
    - Arytenoid cartilage
    - Corniculate cartilage.
  - Muscles
    - All intrinsic muscles of larynx except cricothyroid muscle.

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Anatomy

Cartilaginous Framework

The cartilaginous framework of the larynx consists of:

- Three large unpaired cartilages
  - Cricoid
  - Thyroid
  - Epiglottis.
- Three pairs of smaller cartilages
  - Arytenoid
  - Corniculate
  - Cuneiform.

These are suspended from the hyoid bone at the superior aspect and connected to each other *via* fibroelastic membranes and ligaments. The inferior border is defined by the cricoid, with the intervening thyroid cartilage attached to these elements by the thyrohyoid and cricothyroid membranes. As a result of these attachments, the larynx moves together as a unit, allowing for the elevation necessary for swallowing and phonation.

Thyroid Cartilage

The largest cartilage in the laryngeal framework, the thyroid cartilage consists of two lamina that converge anteriorly to form a triangular shape as viewed from above. The angle between the lamina varies from 90º in men to 120º in women, thus accounting for the more pronounced laryngeal prominence, or Adam's apple, in men. The posterior aspect of each lamina extends superiorly to form a superior horn and inferiorly to form an inferior horn:

- The superior horn is attached to the hyoid *via* the lateral thyrohyoid ligament.
- The medial surface of the inferior horn is defined by a facet for articulation with the lateral surface of the cricoid, thus forming the cricothyroid joint.

Cricoid Cartilage

The only complete cartilaginous ring in the airway, the cricoid is shaped like a signet ring, with a broad posterior lamina and a narrower anterior arch. The lamina's posterior surface has depressions for attachment of the cricoarytenoid muscles, while the superior and lateral surfaces have facets for arytenoid and thyroid cartilage articulation, respectively.

Epiglottic Cartilage

The epiglottis is an elastic cartilage which looks like a leaf. It is attached to the larynx *via* the thyroepiglottic and hyoepiglottic ligaments and serves to protect the laryngeal introitus during swallowing. Several membranes run bilaterally between the arytenoid cartilages and the epiglottic cartilages and are quadrangular in shape. The free corners of these membranes, along with the covering mucosa, produce the aryepiglottic fold.

Arytenoid, Corniculate, and Cuneiform Cartilages

The paired arytenoids are shaped like triangles that face each other and sit atop the posterior cricoid. The superior vertex, or apex, articulates with the corniculate cartilage. The anterior vertex, called the vocal process, acts as anchors for the mobile posterior ends of the vocal folds. The posterolateral vertex is named the muscular process given its attachment to the lateral and posterior cricoarytenoid muscles. The anterolateral surface serves as the attachment for the thyroarytenoid muscles, and the posteromedial surface acts as the attachment for the interarytenoid muscle. The arytenoids are thus the primary focus of intrinsic laryngeal muscle movement to produce adduction and abduction of the vocal folds. The corniculate and cuneiform cartilages sit above and anterolateral to the arytenoids, respectively.

Cricothyroid Joint

- Synovial joint
- Both rotation and tilting motion
- Movement changes length and tension of vocal folds.

The cricothyroid joint allows the thyroid cartilage to tilt anteriorly and inferiorly with cricothyroid muscle contraction. The cricoid simultaneously tilts in a mirror image of the thyroid. While the anterior portion of the cricoid moves superiorly, the posterior portion moves inferiorly along with the attached arytenoids. Because the vocal ligament is attached to the thyroid cartilage anteriorly and to the arytenoids posteriorly, this results in lengthening of the vocal folds to allow for an increase in pitch. The cricothyroid joint also permits sliding in the ventral-dorsal direction, which serves to further increase vocal fold length.[1]

Cricoarytenoid Joint

- Synovial joint
- Both rotation and gliding motion
- Movement associated with abduction and adduction of vocal folds and thus opening and closing of laryngeal inlet (rima glottidis).

The cricoarytenoid joints are a paired synovial joint. This is important to note as synovial joints can be affected by rheumatoid arthritis. The cricoarytenoid joint is the fulcrum around which vocal fold movement pivots. The base of the arytenoid is slightly concave for articulation with the slightly convex facet on the superolateral surface of the cricoid lamina, forming a shallow ball-and-socket joint and allowing for rotational movement of the arytenoids. As the vocal process swings medially during adduction, the arytenoids also move somewhat anteroinferiorly.[2] Conversely with abduction, the arytenoids rotate laterally but also posterosuperiorly.

Vocal fold motion therefore does not occur in only one plane but is rather three-dimensional. This bears relevance to clinical assessment of vocal fold paralysis, as any height difference in vocal folds, particularly of the posterior aspect, will prevent complete approximation with simple injection alone.

Ventricles, Folds, and Membranes

Cricothyroid Membrane and Vocal Ligament

The cricothyroid membrane extends superiorly from the cricoid arch and forms a thickened free edge, known as the vocal ligament, within the thyroid space. The vocal ligament attaches anteriorly to the interior surface of the thyroid cartilage and posteriorly to the vocal process of the arytenoid. It covers the thyroarytenoid muscle to form the basis of the vocal fold.

The cricothyroid membrane is thickened along the midline, forming the median, and lateral cricothyroid ligaments. The lateral cricothyroid ligament is also known as the conus elasticus and is continuous with the vocal ligament.

Quadrangular Membrane and Vestibular Ligament

The quadrangular membrane extends from the sides of the epiglottis to the arytenoid, forming the aryepiglottic fold superiorly, and the thickened vestibular ligament inferiorly. The membrane forms the medial wall of the pyriform recess. The vestibular ligament parallels the vocal ligament, attaching to the thyroid cartilage anteriorly and arytenoid posteriorly. However, it is positioned more superior and lateral to the vocal ligament and is covered by the vestibular fold, otherwise known as the false vocal fold.

Both the conus elasticus and the quadrangular membrane serve as barriers to the spread of malignancy.

Vestibular Folds and Laryngeal Ventricles

The vestibular folds or false vocal folds are folds of mucous membrane which cover the vestibular ligaments. These sit above the true vocal cords and function to help protect them. The false vocal folds extend between the arytenoid and thyroid cartilage. Mucosa bulges laterally through the gap between the vocal and vestibular ligaments to form a trough termed the laryngeal ventricle. The anterosuperior tubular projections of the ventricles are termed the laryngeal saccules, which secrete mucus to lubricate the vocal folds.

Extrinsic and Intrinsic Muscles

Extrinsic Muscles

Extrinsic laryngeal muscles act to elevate or depress the larynx, with most attaching to the hyoid bone.

- Suprahyoid muscles move the laryngeal unit superiorly. They attach to points above the hyoid bone (mandible, skull, tongue). When they contract, they raise or elevate the larynx.
  - Mylohyoid

    - Geniohyoid
    - Hyoglossus
    - Stylohyoid
    - Digastric.
- Infrahyoid (strap) muscles move the laryngeal unit inferiorly. They attach to points below the hyoid bone. When they contract, they lower or depress the larynx.
    - Omohyoid
    - Sternohyoid
    - Thyrohyoid
    - Sternothyroid.

Intrinsic Muscles

The intrinsic laryngeal muscles are so named due to their origins and insertions on the laryngeal cartilages and are the primary movers of the vocal folds. We can divide the intrinsic muscles by their function (Table 1):

- Adductors: Pull the vocal folds together
    - Lateral cricoarytenoid muscles
    - Interarytenoid muscles.
        - Transverse arytenoid muscle
        - Oblique arytenoid muscle.
- Abductors: Pull the vocal folds apart
    - Posterior cricoarytenoid muscles.
- Tensors: Stiffen the vocal folds
    - Cricoarytenoid muscles
    - Some part of the vocalis muscle.
- Relaxors: Relax the vocal folds
    - Thyroarytenoid muscle
    - Some part of the vocalis muscle
    - Pitch is determined by relaxors and tensors.

Evidence exists for varying distributions of muscle fiber types among the intrinsic laryngeal muscles, with the adductors having more fast-twitch type 2 fibers and the cricothyroid and posterior cricoarytenoid with more slow-twitch type 1 fibers.[3] This may explain how adductors are able to be rapidly activated for coughing, laughing, and speech and singing, as well as how abnormal activation can occur in pathologies such as vocal tremor and dystonia. The medial portion of the thyroarytenoid, called the vocalis muscle, has a higher proportion of slow-twitch fibers, while the lateral portion has mostly fast-twitch fibers.[4]

Sensory and Motor Innervation

Sensory and motor innervation of the larynx are both achieved *via* branches of the vagus nerve, cranial nerve X, namely the superior and recurrent laryngeal nerves.

Superior Laryngeal Nerves

The superior laryngeal nerves originate from the inferior vagal ganglion and travels inferiorly medial to the internal carotid artery. As it descends, it divides into the internal and external laryngeal nerves above the level of the hyoid.

- The internal laryngeal nerve enters through the lateral aspect of the thyrohyoid membrane and provides sensory innervation down to the level of the vocal folds.
- The external laryngeal nerve penetrates the inferior pharyngeal constrictor and the cricothyroid muscle and provides motor innervation to these muscles.

Recurrent Laryngeal Nerves

The right recurrent laryngeal nerve loops around the subclavian artery and ascends in the tracheoesophageal groove to enter the larynx near the inferior constrictor. The left nerve, in contrast, loops

Table 1: Intrinsic laryngeal muscles functions

Muscle	*Origin*	*Insertion*	*Function*	*Innervation*	*Other*
Cricothyroid	Cricoid cartilage (lower border and lateral surface)	Thyroid cartilage (inferior cornu and lower border)	Lengthens and tenses vocal ligament	Superior laryngeal (external branch)	Only intrinsic muscle lying on external aspect
Thyroarytenoid	Thyroid cartilage (lower posterior half of angle of thyroid lamina)	Vocal process of arytenoid cartilage	Relaxes vocal ligament	Recurrent laryngeal nerve	
Vocalis	Lateral surface of vocal process of arytenoid cartilage	Vocal ligament and thyroid angle	Relaxes posterior vocal ligament while maintaining (or increasing) tension of anterior part	Recurrent laryngeal nerve	The superior portion of the thyroarytenoid muscle
Lateral cricoarytenoid	Cricoid cartilage (superior border of lateral arch)	Muscular process of arytenoid cartilage	Adductor; adducts and internally rotates the arytenoid cartilage	Recurrent laryngeal nerve	
Posterior cricoarytenoid	Cricoid cartilage (posterior surface of lamina)	Muscular process of arytenoid cartilage	Abductor; abducts and externally rotates the arytenoid cartilage	Recurrent laryngeal nerve	Only abductor of the larynx
Transverse arytenoid	Arytenoid cartilage	Contralateral arytenoid cartilage	Adductor; Adducts arytenoid cartilages and closes the glottis	Recurrent laryngeal nerve	Unpaired muscle
Oblique arytenoid	Arytenoid cartilage	Contralateral arytenoid cartilage	Adductor; Adducts arytenoid cartilages and closes the glottis	Recurrent laryngeal nerve	Unpaired muscle

around the aorta, rendering it more vulnerable to injury from any surgical manipulation of the aorta. The recurrent laryngeal nerves are responsible for:

- Sensory innervation to the larynx inferior to the glottis
- Motor innervation to intrinsic laryngeal muscles with exception of cricothyroid muscle.

The ansa of Galen has been classically considered the only anastomosis between the superior and recurrent laryngeal nerves. Although traditional teaching suggests a neat and clear separation between sensory and motor innervation as well as innervation of different parts of the larynx, the reality is likely more complex, with varying anastomoses and cross-innervation between different muscles and between motor and sensory branches depending on each individual's development.[5]

Composition of the True Vocal Folds

- Vocalis muscle
- Lamina propria
  - Deep lamina propria
  - Intermediate lamina propria
    - Deep and Intermediate layers = Vocal ligament
  - Superficial lamia propria.
- Squamous epithelium.

The function of the vocal folds is to produce sound by allowing the free edges of the vocal folds to vibrate against one another and also to act as the laryngeal sphincter when they are closed, thus protecting the airway. The glottis or rima glottidis is the narrowest part of the larynx with its level corresponding to the base of the arytenoid cartilages. This is the opening between the vocal folds. The width and size vary with breathing and speaking.

The source of phonation, the vocal folds, are composed of thyroarytenoid muscles covered in layers of soft tissues. The vocal fold is composed of several parts. The thyroarytenoid muscle fibers help form the muscular layer of the vocal cord. The superior portion of the thyroarytenoid muscle is often considered a separate muscle—the vocalis muscle. The medial portion of the vocalis muscle forms the vocal ligament. The vocal ligament is actually the free edge of the conus elasticus or cricothyroid ligament. The thyroarytenoid muscle fibers also support the wall of the ventricle.

Mucosa and Membranous Vocal Fold

The mucosa of the vocal fold, in contrast to the rest of the respiratory epithelium, is covered by stratified squamous cells, under which lies a layer of columnar epithelium and then the lamina propria.

The lamina propria is composed of extracellular proteins produced by fibroblasts, which lend the pliability and viscosity necessary for vocal fold vibration and movement, and is divided into superficial, intermediate, and deep layers. This division represents a gradient of varying compositions, with decreasing elastin fibers and increasing collagen fibers and thus decreasing elasticity and increasing stiffness with each descending layer. The intermediate and deep layers form the vocal ligament and are continuous with the conus elasticus.

Reinke's space, which is sometimes used as an eponym for the superficial lamina propria, is somewhat of a misnomer as it is a true layer of tissue rather than a potential space, although it is an area of potential fluid accumulation as seen with Reinke's edema in smokers.

The intermediate layer of the lamina propria forms a thickened oval mass anteriorly, called the anterior macula flava, and inserts into the anterior commissure tendon, which is connected to the thyroid cartilage. Similarly, the intermediate layer also forms a posterior macula flava that attaches to the vocal process of the arytenoid. Both the anterior and posterior macula flava are stiffer than the rest of the vocal fold, and this gradual transition in stiffness moving anteriorly and posteriorly may serve to protect the ends of the vocal folds from vibrational trauma. Most of the vibrational activity occurs in the membranous anterior half of the vocal folds, anterior to the vocal processes.

A key aspect of the anatomy that is crucial in understanding the physiology of phonation is the contour of the vocal fold in the coronal section. Rather than forming a distinct point medially, the vocal fold contour slopes inferiorly, forming a somewhat blunt edge. This structure is what provides the function of three-dimensional vibration as viewed from above and in cross-section.

Physiology

The larynx has four major functions:

- Phonation—produces sound and voice
- Breathing—allows air into the lungs
- Swallowing—elevation of the larynx to facilitate swallowing
- Protection—prohibits entry of foreign objects into the lungs.

Phonation

The production of speech requires four components:

- Power source—lungs.
- Phonation—the generation of sound by vocal fold vibration.
- Resonance—the amplification and modulation of that sound by vibration in the structures distal to the larynx (pharynx, oropharynx, nasopharynx, oral cavity, nasal passages).
- Articulation—complex interaction of lips, teeth, tongue, palate, and pharynx to shape and modify the sound.

Phonation is the result of the complex interaction between the generation of force to move air from the lungs and tracheobronchial tree, the modification of airflow from the larynx, and the resonance of the pharyngeal, oral, and nasal cavities that uniquely defines a person's voice.

Power Source and Respiration

- A column of air moves past the vocal folds and into the lungs.
- There is a coordinated action of the diaphragm, abdominal muscles, chest muscles, and rib cage to force the air out of the lungs and through the vocal folds.
- The vocal folds are moved to the midline by the vocal fold muscles, nerves, and cartilage.

The Glottic Cycle

- Closed phase—air pressure builds up below the vocal folds.
- Opening phase—when the subglottic pressure reaches a point where it exceeds muscular opposition, the glottic slit is forced open. Vocal cords start opening from complete closure. They open in a posterior to anterior direction with the posterior portion of the glottis opening first. In addition, they open from bottom to top.

- Open phase—the vocal folds are completely open and air column rushes through the vocal folds. This begins the sound wave.
- Closing phase—after release of the puff of air, there is a reduction of subglottic pressure and the vocal cords approximate each other again (myoelastic forces of the vocal cords have exceeded the aerodynamic forces). The vocal folds are forced back together in an adducted state until the subglottic air pressure can overcome the myoelastic forces of the reapproximated cords.
- The cycle is then repeated.
- Vertical phase difference—vocal folds open at the bottom first. As the top part opens, the bottom part closes. This results in a wave like motion.
- Bernoulli effect—the low pressure created behind the fast moving air column produces a "Bernoulli effect" which causes the bottom of the vocal folds to close together followed by the superior portion of the vocal folds.
- Mucosal wave—the rapid ordered opening and closing of the vocal folds produced by the puff of air. The vibration of the vocal fold mucosa due to the column of air rushing past the vocal folds.
- The above leads to "voiced" sound which initially is just a buzz-like noise. This is then modified and formed into words through resonance and articulation.

Two major theories have contributed to our understanding of the physiology of phonation:

- Myoelastic-aerodynamic theory of phonation[6]
- Cover-body theory of vocal fold vibration.[7]

Myoelastic-aerodynamic Theory of Phonation

As discussed in the anatomy section, the vocal folds meet in a vertical dimension. The lungs and respiratory tract generate pressure to form a column of air that rises and begins to push the vocal folds apart starting inferiorly and progressing superiorly.

The original myoelastic-aerodynamic theory is as follows. As air passes through the narrowed lumen of the glottis, velocity increases due to the continuity principle. Pressure then decreases, as dictated by Bernoulli's equation. This lower pressure in combination with the elasticity of the vocal fold cover helps to pull the vocal folds closed starting inferiorly. Combining these elements—the elastic properties of the vocal fold which can be altered by laryngeal muscles and the properties of air pressure and movement—forms the myoelastic-aerodynamic theory of phonation.

This theory, as originally described in 1958, is somewhat inaccurate. Further studies have found that with glottal constriction during phonation, subglottic pressure becomes higher than supraglottic pressure, thus pushing the lower margins of the vocal folds apart. The vertical phase differences between the lower and upper margins creates a mucosal wave that travels superiorly along the medial surface of the vocal folds.

The elasticity of the vocal folds then causes the movement to reverse and the lower margin will begin closing. This causes the intraglottal pressure to drop and pulls the vocal folds together. Vocal fold elasticity then allows this cycle to repeat.[8]

Cover-body Theory of Vocal Fold Vibration

This theory proposes that the body of the vocal fold, which consists mainly of the thyroarytenoid muscle, and the cover of the vocal fold, namely the epithelium and superficial lamina propria, have distinct biomechanical properties affecting their movement during vocal fold vibration. What appears to be vibration of a single structure is thus in reality vibration of a multiple layers with phase differences as a result of a relatively stiff body and pliable cover.[7]

Five basic requirements must be met for phonation to occur:[9]

- Sufficient breath support and expiratory force
- Proper positioning and alignment of vocal folds
- Vocal fold elasticity to facilitate vibration and movement
- Favorable vocal fold contour
- Ability to control vocal fold tension and length.

Breath Support and Expiratory Force

The expiratory force required to power phonation is typically generated by passive expiration, which depends on sufficient inspiratory volume as well as chest wall and diaphragmatic recoil. Active expiration, which requires the additional strength of intercostal and abdominal wall muscles, is only required with singing, shouting, and coughing. Given the role of pulmonary function, dysphonia will be exacerbated by any underlying pulmonary disease.

Vocal Fold Positioning

As discussed in the anatomy section, not only must the vocal folds meet at the midline, but they must also be properly aligned in height. The glottic gap cannot be too wide, which leads to a breathy and weak voice, or too narrow, which leads to a strained voice and reduced airway. The rotational movement of the arytenoid joint arcs superomedially with phonation. Thus, if unilateral vocal fold paralysis occurs, there often can be a height difference in the vocal folds in addition to a glottic gap. This is relevant clinically as the height difference cannot be ameliorated with vocal fold injection alone.

Vocal Fold Vibratory Capacity

The vibratory capacity is dependent on the physical properties of the vocal folds, as discussed previously. Any pathology that interferes with the elasticity of the vocal folds, such as seen in Reinke's edema or any vocal fold lesion, will thus interfere with the vibratory capacity and cause dysphonia. A decrease in elastin and an increase in collagen of vocal folds is seen with aging, thus accounting for the thinning and stiffening of vocal folds resulting in age-related voice changes.[10]

Vocal Fold Shape

The contour of the vocal folds as viewed in cross-section contributes to the ability to phonate. The medial edges must be almost parallel for proper vibration from inferior to superior.

Pitch Control

This lies in the stiffness of the vocal folds resulting from lengthening and contraction of the thyroarytenoid muscles, particularly the vocalis portion. Thyroarytenoid muscle contraction brings the arytenoids closer to the thyroid cartilages, thus shortening and relaxing the vocal fold and allowing for lower pitch. The cricothyroid muscle draws the thyroid cartilage anteroinferiorly toward the cricoid, thus elongating and tensing the vocal fold for higher pitch. Laryngeal size determines the range of pitch that a person can produce. Adjustments in vertical tension such as depressing or elevating the larynx *via* the suprahyoid and infrahyoid muscles can also control pitch.

Fundamental Frequency

Phonation is made up of a fundamental frequency or F_0 and harmonic multiples of the F_0. The fundamental frequency (F_0) is the number of times the vocal folds open and close per second. This is also known as the vibratory cycle. Harmonic multiples of F_0 are two times the F_0, three times the F_0, etc. The fundamental frequency has an inverse relationship with volume. As the harmonics rise in frequency or as the pitch rises, the volume will fall.

- F_0 Averages
  - Baby: 500 Hz
  - Children: 250–400 Hz
  - Men: 110–125 Hz
  - Women: 180–220 Hz
  - Higher pitch: increase in frequency of vocal fold vibration
  - Increased loudness: increase in amplitude of vocal fold vibration.
- Chest (Modal Register)
  - Low fundamental frequency
  - Vocalis muscle activity
  - Vocal folds are short and thick
  - Low stiffness.
- Falsetto Register
  - High fundamental frequency
  - Vocal folds are long and thin
  - Stiff vocal folds
  - Small amplitude of vibration
  - Incomplete closure of the vocal folds
  - Shutter like appearance where they appear to vibrate more like strings.

Resonance

The sound produced by the glottis is modified by sympathetic resonance of structures as the vibrating air column passes through them. The chest, pharynx, oral, and nasal cavities all contribute to the characteristics that define each unique human voice. The shape of these structures determine which frequencies are filtered and amplified and can be controlled to some degree by moving the palate, the larynx, pharynx, tongue, or jaw.

Articulation

Lastly, speech production is made possible by the shaping of sound into consonants and vowels from the complex interaction between the lips, teeth, tongue, palate, and pharynx.

Breathing

Normal breathing requires the vocal folds to be fully abducted. During forced exhalation, such as when exercising, the need for air causes one to increase the abduction of the vocal folds.

Protection

Protection is the most important role of the larynx. Vocal fold closure prohibits entry of foreign objects into the lungs. The cough reflex and throat clearing also help to expel foreign objects that have irritated the vocal folds and lungs.

Cough Reflex

Despite the larynx's sophisticated ability to produce voice, its most important function is still to protect the airway, which is achieved *via* the cough reflex. Sensory receptors respond to a variety of both mechanical and chemical stimuli[11] that trigger the afferent portion of the cough reflex, the superior laryngeal nerve, and results in glottic closure from activation of the recurrent laryngeal nerve. The cough reflex consists of three phases:

- Inspiratory—larynx opens wide to permit rapid and deep inspiration
- Compressive—tight closure of the glottis and strong activation of expiratory muscles
- Expulsive—larynx opens widely and a sudden outflow of air in the range of 6–10 liters/second.

Swallowing

Swallowing Reflex

The swallowing reflex is when a bolus of food will trigger automatic closure of structures to restrict food from entering the airway. The bolus of food will trigger the reflex as it passes the tongue above the larynx. The laryngeal structures will elevate. Then, the epiglottis will drop down to cover the opening of the larynx from the pharynx and the vocal folds will close (adduct). This will help prevent food from entering the airway and direct the bolus of food into the esophagus.

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