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ANATOMY & PHYSIOLOGY OF VOICE PRODUCTION

Anatomy and Physiology of Voice Production: Highlights

Understanding Voice Disorders

Knowing how normal voice is produced and the roles the voice box and its parts play in speaking and singing helps patients understand their voice disorders.

Voice "As We Know It"

The "spoken word" results from three components of voice production: voiced sound, resonance, and articulation.

- **Voiced sound:** The basic sound produced by vocal fold vibration is called "voiced sound." This is frequently described as a "buzzy" sound. Voiced sound for singing differs significantly from voiced sound for speech.
- **Resonance:** Voice sound is amplified and modified by the vocal tract resonators (the throat, mouth cavity, and nasal passages). The resonators produce a person's recognizable voice.
- **Articulation:** The vocal tract articulators (the tongue, soft palate, and lips) modify the voiced sound. The articulators produce recognizable words.

Voice Mechanism

Speaking and singing involve a voice mechanism that is composed of three subsystems. Each subsystem is composed of different parts of the body and has specific roles in voice production.

Three Voice Subsystems

Subsystem	Voice Organs	Role in Sound Production
Air pressure system	Diaphragm, chest muscles, ribs, abdominal muscles Lungs	Provides and regulates air pressure to cause vocal folds to vibrate
Vibratory system	Voice box (larynx) Vocal folds	Vocal folds vibrate, changing air pressure to sound waves producing "voiced sound," frequently described as a "buzzy sound" Varies pitch of sound
Resonating system	Vocal tract: throat (pharynx), oral cavity, nasal passages	Changes the "buzzy sound" into a person's recognizable voice

Key Function of the Voice Box

The key function of the voice box is to open and close the glottis (the space between the two vocal folds).

- **Role in breathing:** Open glottis
- **Role in cough reflex:** Close, then open glottis
- **Role in swallowing:** Close glottis
- **Role in voice:** Close glottis and adjust vocal fold tension (plus additional functions for singing)

Key Components of the Voice Box

- Cartilages
- Muscles
- Nerves
- Vocal folds

Abnormalities or Changes in the Vibratory System Result in Voice Disorders

Breakdowns can occur in any one or all three subsystems of voice production. This patient education series focuses on voice disorders, specifically breakdowns in the vibratory system.

Understanding How Voice Is Produced

Voice as We Know It = Voiced Sound + Resonance + Articulation

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Voice Depends on Vocal Fold Vibration and Resonance

Sound is produced when aerodynamic phenomena cause vocal folds to vibrate rapidly in a sequence of vibratory cycles with a speed of about:

- 110 cycles per second or Hz (men) = lower pitch
- 180 to 220 cycles per second (women) = medium pitch
- 300 cycles per second (children) = higher pitch
  higher voice: increase in frequency of vocal fold vibration
  louder voice: increase in amplitude of vocal fold vibration

Vibratory Cycle = Open + Close Phase

The vocal fold vibratory cycle has phases that include an orderly sequence of opening and closing the top and bottom of the vocal folds, letting short puffs of air through at high speed. Air pressure is converted into sound waves.

Not Like a Guitar String

Vocal folds vibrate when excited by aerodynamic phenomena; they are not plucked like a guitar string. Air pressure from the lungs controls the open phase. The passing air column creates a trailing "Bernoulli effect," which controls the close phase.

The Process of Voice

Voice production involves a three-step process.

1. **A column of air pressure is moved towards the vocal folds:** Air is moved out of the lungs and towards the vocal folds by coordinated action of the diaphragm, abdominal muscles, chest muscles, and rib cage
2. **Vocal fold vibration – sequence of vibratory cycles:**
   Vocal folds are moved to midline by voice box muscles, nerves, and cartilages

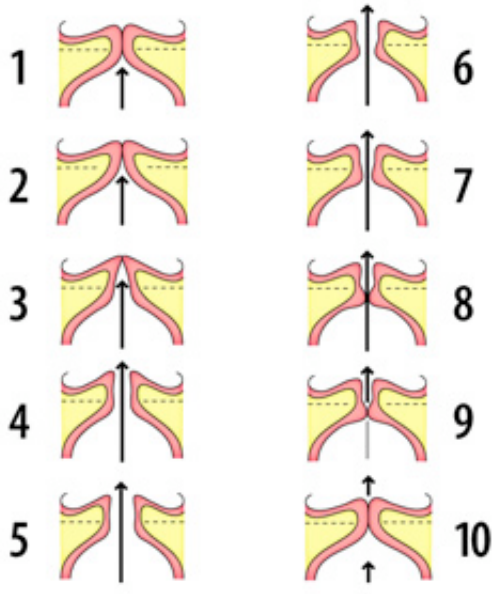
   The vibratory cycle occurs repeatedly; one vibratory cycle is as follows:
   1. Column of air pressure opens bottom of vocal folds
   2. Column of air continues to move upwards, now towards the top of vocal folds, and opens the top
   3. The low pressure created behind the fast-moving air column produces a "Bernoulli effect" which causes the bottom to close, followed by the top
   4. Closure of the vocal folds cuts off the air column and releases a pulse of air
   5. New cycle repeats

The rapid pulses of air created by repeat vibratory cycles produce "voiced sound" which is really just a buzzy sound, which is then amplified and modified by the vocal tract resonators, producing voice "as we know it." (See table below)

Loudness: Increase in air flow "blows" vocal folds wider apart, which stay apart longer during a vibratory cycle – thus increasing amplitude of the sound pressure wave

Pitch: Increase in frequency of vocal fold vibration raises pitch

Diagram of Vocal Fold Vibration

1 Column of air pressure moves upward towards vocal folds in "closed" position	 (click for larger image)	**6–10** The low pressure created behind the fast-moving air column produces a Bernoulli effect which causes the bottom to close, followed by the top
2, 3 Column of air pressure opens bottom of vibrating layers of vocal folds; body of vocal folds stays in place		**10** Closure of the vocal folds cuts off the air column and releases a pulse of air
4, 5 Column of air pressure continues to move upward, now towards the top of vocal folds, and opens the top		New vibratory cycle – repeat 1-10

In the closed position (---) maintained by muscle (■), the key vibrating layer of the vocal fold (■) opens and closes in a cyclical, ordered and even manner (1 – 10) as a column of air pressure (⬆) from the lungs below flows through. This very rapid ordered closing and opening produced by the column of air is referred to as the mucosal wave. The lower edge opens first (2-3) followed by the upper edge thus letting air flow through (4-6). The air column that flows through creates a "Bernouli effect" which causes the lower edge to close (7-9) as it escapes upwards. The escaping "puffs of air" (10) are converted to sound which is then transformed into voice by vocal tract resonators.

Any change that affects this mucosal wave – stiffness of vocal fold layers, weakness or failure of closure, imbalance between R and L vocal folds from a lesion on one vocal fold – causes voice problems. (For more information, see Anatomy: How Breakdowns Result in Voice Disorders.)

3. **Vocal tract – resonators and articulators:** The nose, pharynx, and mouth amplify and modify sound, allowing it to take on the distinctive qualities of voice

Similarities With Trombone

The way that voice is produced is analogous to the way that sound is produced by a trombone. The trombone player produces sound at the mouthpiece of the instrument with his lips vibrating from air that passes from the mouth. The vibration within the mouthpiece produces sound, which is then altered or "shaped" as it passes throughout the instrument. As the slide of the trombone is changed, the sound of the musical instrument is similarly changed.

Amazing Outcomes of Human Voice

The human voice can be modified in many ways. Consider the spectrum of sounds – whispering, speaking, orating, shouting – as well as the different sounds that are possible in different forms of vocal music, such as rock singing, gospel singing, and opera singing.

Key Factors for Normal Vocal Fold Vibration

To vibrate efficiently vocal folds need to be:

- **At the midline or "closed":** Failure to move vocal folds to the midline, or any lesion which prevents the vocal fold edges from meeting, allows air to escape and results in breathy voice.

  Key players: muscles, cartilages, nerves

- **Pliable:** The natural "built-in" elasticity of vocal folds makes them pliable. The top, edge, and bottom of the vocal folds that meet in the midline and vibrate need to be pliable. Changes in vocal fold pliability, even if limited to just one region or "spot," can cause voice disorders, as seen in vocal fold scarring.

  Key players: epithelium, superficial lamina propria

- **"Just right" tension:** Inability to adjust tension during singing can cause a failure to reach high notes or breaks in voice.

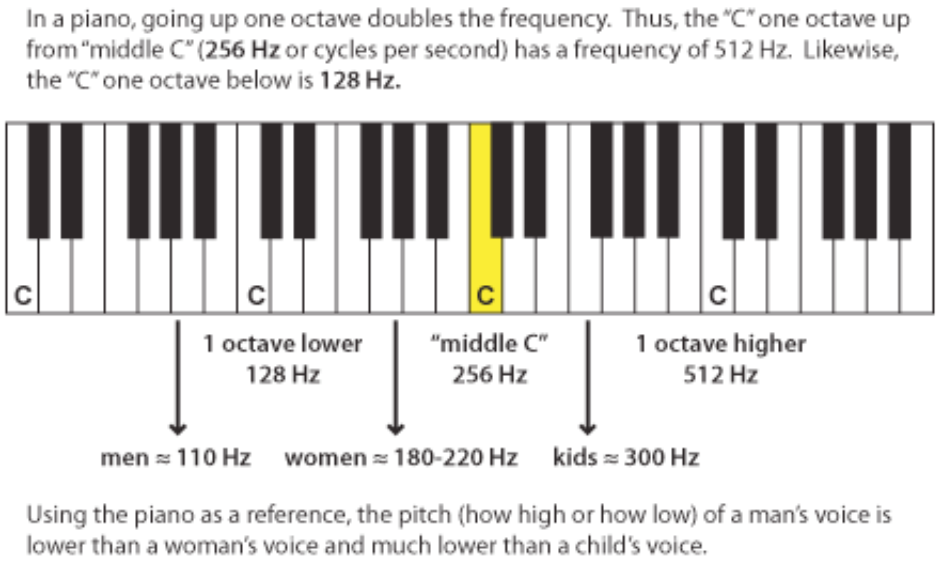
  Key players: muscle, nerve, cartilages

- **"Just right" mass:** Changes in the soft tissue bulk of the vocal folds – such as decrease or thinning as in scarring or increase or swelling, as in Reinke's edema, produce many voice symptoms – hoarseness, altered voice pitch, effortful phonation, etc. *(For more information, see Vocal Fold Scarring and Reinke's Edema.)*

  Key players: muscles, nerves, epithelium, superficial lamina propria

Anatomy: Vocal Fold Vibration and Resonance

Vocal Fold Vibration and Resonance



This diagram can be found in Anatomy and Physiology of Voice Production: Understanding How Voice is Produced.

Learning About the Voice Mechanism

Voice Mechanism

Speaking and singing involve a voice mechanism that is composed of three subsystems. Each subsystem is composed of different parts of the body and has specific roles in voice production.

Three Voice Subsystems

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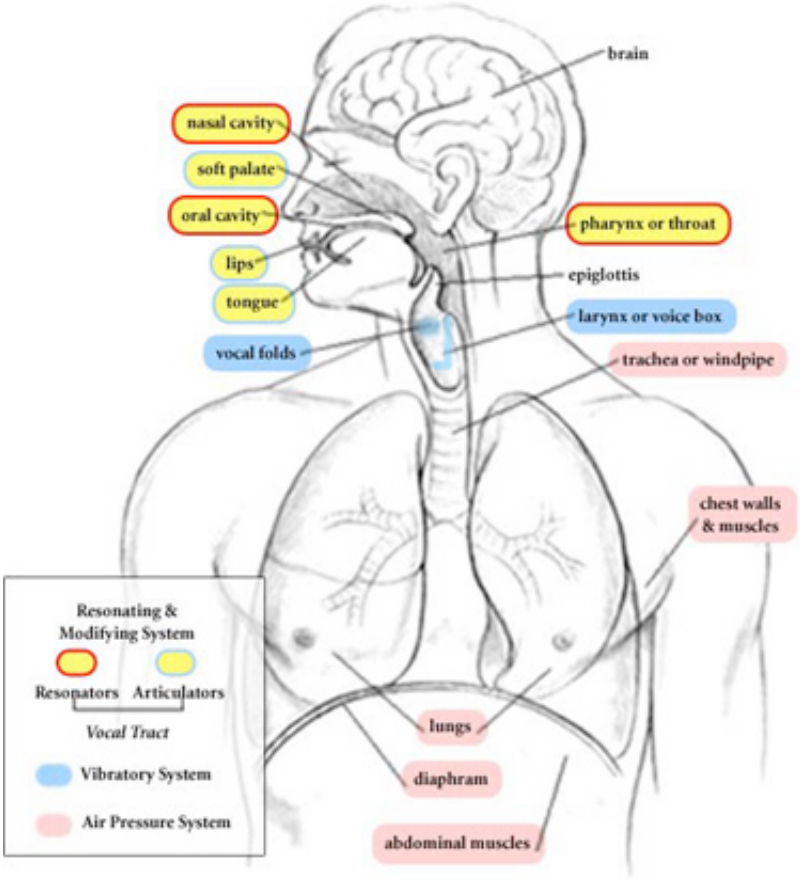
Diagram of Voice Subsystems



Air Pressure System

The ability to produce voice starts with airflow from the lungs, which is coordinated by the action of the diaphragm and abdominal and chest muscles.

Vibratory System

The voice box (larynx) and vocal folds (sometimes called vocal cords) comprise the vibratory system of the voice mechanism.

Resonating System

The vocal tract is comprised of resonators which give a personal quality to the voice, and the modifiers or articulators which form sound into voiced sounds.

Key Function of the Voice Box

The key function of the voice box is to open and close the glottis (the space between the two vocal folds).

- **Role in breathing:** open glottis
  Voice box brings both vocal folds apart during breathing.
- **Role in cough reflex:** close, then open glottis
  Voice box closes the glottis to build up pressure, then opens it for the forceful expelling of air during cough.
- **Role in swallowing:** close glottis
  Voice box coordinates closing the glottis by bringing both vocal folds to the midline to prevent choking during swallowing.
- **Role in voice:** close glottis and adjust vocal fold tension
  Voice box brings both vocal folds to the midline to allow vocal fold vibration during speaking and singing.

  Voice box adjusts vocal fold tension to vary pitch (how high or low the voice is) and changes in volume (such as loud voice production).

Key Components of the Voice Box

- Cartilages
- Muscles
- Nerves
- Vocal Folds

Voice Box Cartilages

There are three cartilages within the larynx.

1. **Thyroid Cartilage**
   Forms the front portion of the larynx

   Most forward part comprises the "Adam's apple"

   Houses the vocal folds

   Vocal folds attach just below the Adam's apple
2. **Cricoid Cartilage**
   Below the thyroid cartilage

   Ring-like: front to back

Becomes taller in the back of the voice box

Platform for the arytenoid cartilages

3. **Arytenoid Cartilages** (left and right)

Pair of small pyramid-shaped cartilages

Connect with the cricoid cartilage at the back of the vocal folds

With the cricoid cartilage, forms the cricoarytenoid joint

Voice Box Muscles

Voice box muscles are named according to the cartilages to which they are attached.

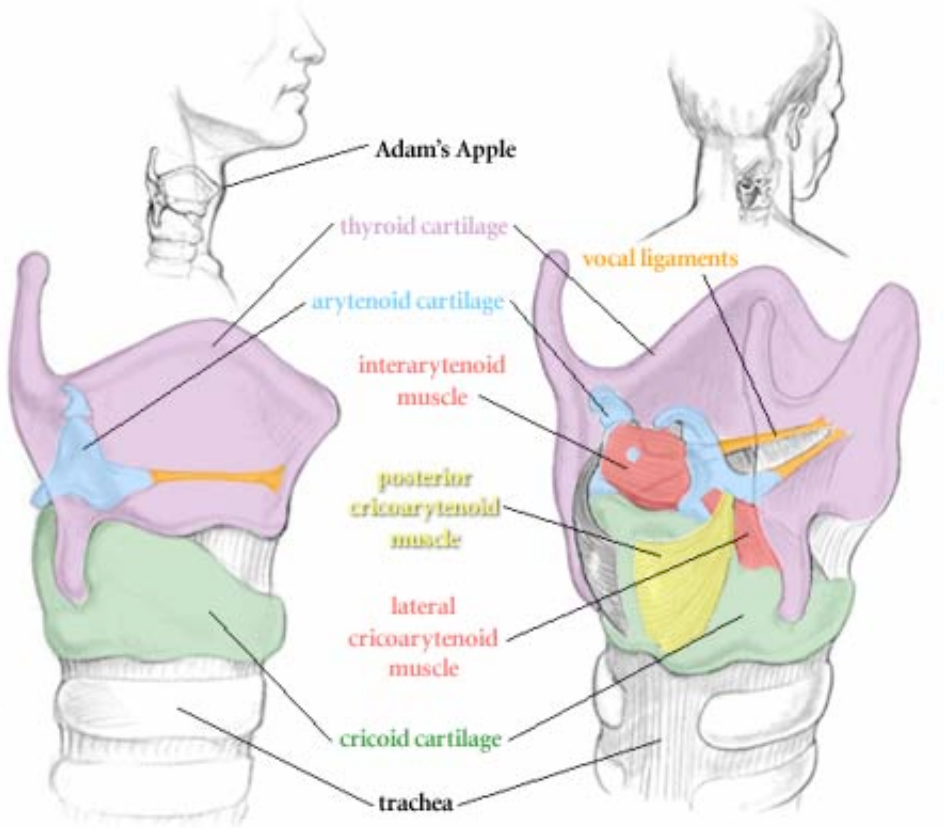
Voice Box Muscles – Cartilage Attachments, Role, Nerve Input

Muscles, Cartilage Attachments, and their Main Roles	Nerve Input
Muscles That Position Vocal Folds in the Midline During Sound Production *(close glottis)*	
• Thyroarytenoid muscle R & L muscles; attached to thyroid and arytenoid cartilages on each side Action shortens and relaxes vocal ligament Note: deeper inner fibers referred to as "vocalis muscle" (see below) • Lateral cricoarytenoid muscle (R & L muscles) Attached to cricoid and arytenoid cartilage on each side Closes or adducts vocal folds • Inter-arytenoid muscle (transverse and oblique) Attached between right and left arytenoid cartilages Closes inlet of larynx These muscles work coordinately to position both vocal folds in the midline for vocal fold vibration during sound production. • Role in voice production • Role in protection of airway during swallowing	Recurrent laryngeal nerve (RLN)
Muscle That Moves Vocal Folds Apart *(open glottis)*	
• Posterior cricoarytenoid muscle Attached to cricoid and arytenoid cartilages o Move arytenoid cartilages so as to move both vocal folds apart, "open" of abduct vocal folds Role in breathing	Recurrent laryngeal nerve (RLN)
Muscles That Adjust Length and Tension of Vocal Folds	
• Vocalis muscle (derived from inner and deeper fibers of thyroarytenoid msucle] Alters vocal fold tension/relaxation during speaking or singing Role in voice production	Recurrent laryngeal nerve (RLN)

• Cricothyroid muscle Attached to cricoid and thyroid cartilages Tilts the thyroid cartilage, thus increasing tension of vocal folds Role in high-pitch singing Role in pitch glide in singing	Superior laryngeal nerve (SLN)

Diagram of Voice Box Cartilages and Muscles

Voice box muscles are named according to the cartilages to which they are attached.



Nerve Input to the Voice Box

- The brain coordinates voice production through specific nerve connections and signals
- Signals to the voice box for moving voice box muscles (motor nerves) come from:
  - Motor branches of recurrent laryngeal nerve (RLN)
  - Superior laryngeal nerve (SLN)
- Signals from the voice box structures for feeling (sensory nerves) travel through sensory branches of the RLN and SLN

Key Information

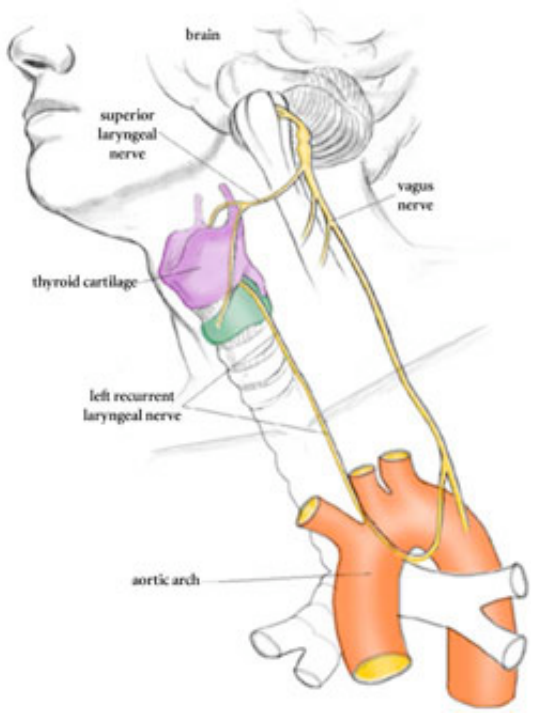
"Recurrent" laryngeal nerve: The recurrent laryngeal nerve is so named because on the left side of the body it travels down into the chest and comes back (recurs) up into the neck to end at the larynx. [see figure below]

Long path of left RLN: The circuitous path of the left RLN throughout the chest is one reason why any type of open-chest

surgery places patients at risk for a recurrent laryngeal nerve injury, which would result in vocal fold paresis or paralysis. [see figure below] *(For more information, see Vocal Fold Scarring and Vocal Fold Paresis / Paralysis.)*

Shorter path of right RLN: The right recurrent laryngeal nerve continues in the upper chest and loops around the right subclavian artery, just behind the clavicle (collarbone), then travels the short distance in the neck to the larynx.

Diagram of Key Nerves for Voice Production



This diagram shows the "long path" of the left recurrent laryngeal nerve (left RLN). After it branches off the vagus nerve, the left RLN loops around the aortic arch in the chest cavity and then courses back into the neck.

This long course makes it at higher risk for injury compared with the shorter course of the right RLN which does not run through the chest cavity.

Vocal Folds

The left and right vocal folds are housed within the larynx. The vocal folds include three distinct layers that work together to promote vocal fold vibration.

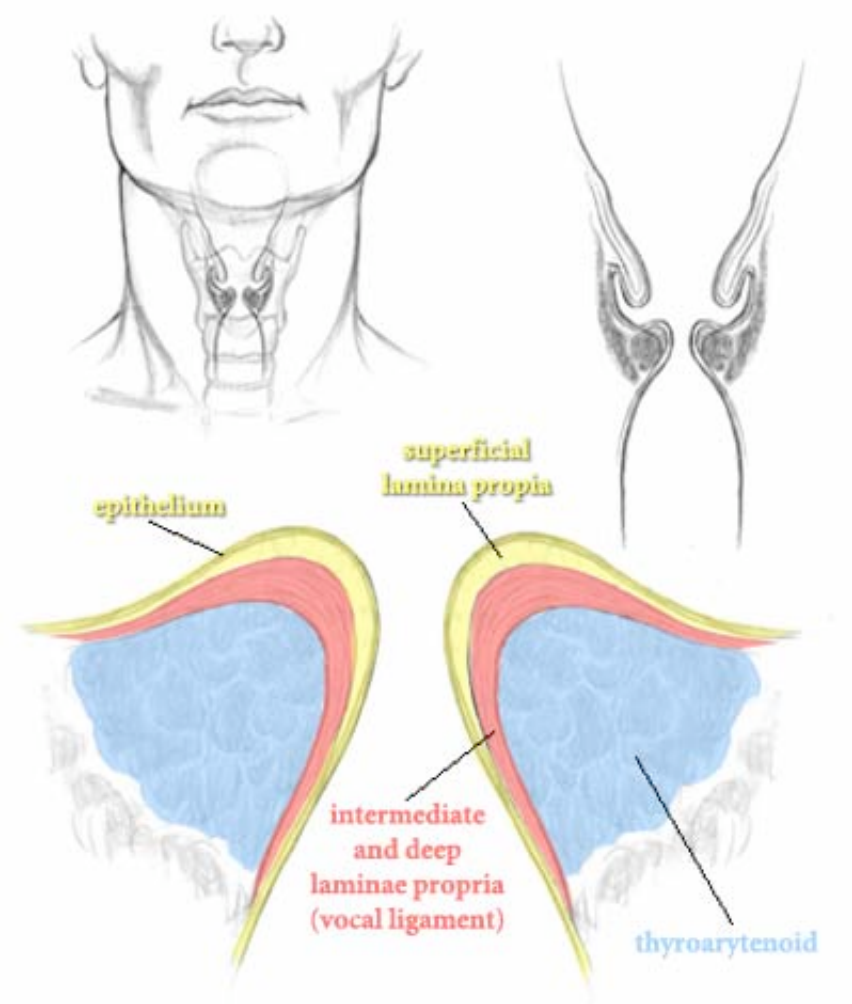
1. **Covering/mucosa:** Loose structure that is key to vocal fold vibration during sound production; is composed of:
   Epithelium

   Basement membrane

   Superficial lamina propria (SLP)
2. **Vocal ligament:** The vocal ligament is composed of:
   Intermediate lamina propria

   Deep lamina propria (contains collagen fibers that are stronger and more rigid than the superficial lamina propria)
3. **Body:** The vocal fold body is composed of the thyroarytenoid muscle. This muscle helps close the glottis and regulate tension of vocal fold during speaking and/or singing. The medial portion of this muscle is also called "vocalis muscle."

Diagram of Vocal Folds

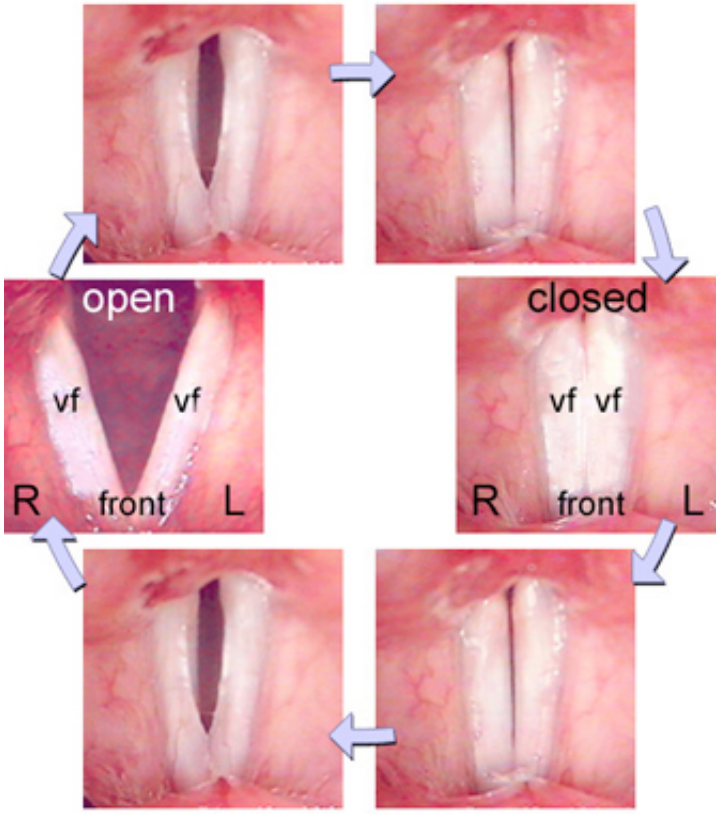


"Wiper-Like" Movement of Vocal Folds

The vocal folds move similar to a car's windshield wipers that are attached to the middle of the windshield and open outwards. (See figure below.)

- The front ends of both vocal folds are anchored to the front-middle (anterior commissure).
- The back ends of both vocal folds are anchored to the arytenoid cartilages.
- When arytenoids are moved to the open position by the posterior cricoarytenoid muscle, vocal folds open, resulting in glottal opening.
- When arytenoids are closed by the lateral cricoarytenoid and inter arytenoid muscles, vocal folds are brought to the midline resulting in glottal closure.

Vocal Folds (vf) Opening and Closing



How Breakdowns Result in Voice Disorders

In Brief

Voice disorders refer to breakdowns in the vibratory system. Breakdowns can affect any one or all of the three subsystems of voice production.

Air Pressure System

If the airflow source is weak or inefficient (making it difficult to push enough air out of lungs), the voice will be weak and hampered by shortness of breath.

- For example: Patients with asthma, lung cancer, emphysema and other lung conditions often find it difficult to speak loud or for long periods of time.

Vibratory System

Any compromise or change to vocal fold vibration causes hoarseness and other voice symptoms.

- For example: Patients with stiffness in the vocal folds from swelling from a common cold develop hoarseness.
- For example: When focal folds cannot come perfectly together from partial nerve input loss, air leak occurs and the voice is "breathy."

Resonating System or Vocal Tract

A breakdown of the vocal tract can affect voice quality.

- For example: When nasal passageways are swollen and inflamed during the "common cold," the voice takes on a nasal quality.

Making Sense of It All

The following are a few examples depicting how breakdowns result in voice disorders and a few of the many possible voice symptoms.

Correlating Anatomy, Voice Function, Abnormalities, and Possible Voice Disorder Symptoms

Sound Process	Brief Description	A Glimpse – *"who does what"* in Sound Production	Examples of "Breakdowns" that Affect Sound Process	Possible Symptoms
Generating Air Pressure	**"Breath Support"** Coordinated functions of diaphragm, abdominal and chest muscles, lungs and chest cavity move air column upwards through vocal folds	Diaphragm, abdominal and chest muscles move air into and out of lungs Lungs are the organs for air Bronchi and trachea are the passageway for air from lungs	Lung disease Airway obstruction: asthma, subglottic stenosis Paresis/paralysis of muscles	Shortness of breath Weak voice

Glottic Closure Position of vocal folds	**Vocal Fold Position Critical** Vocal folds are in closed position for speech or singing [Note: Vocal folds are open for breathing]	Laryngeal muscles contract to close vocal folds Arytenoid cartilages pivot to move vocal folds towards midline ["closed"] RLN and SLN bring nerve inputs to muscles Vocal fold mass and edge contribute to glottic closure	Paresis/paralysis–RLN/SLN Muscle weakness Neurological diseases; muscular disorders Arytenoid arthritis Vocal fold granuloma Vocal fold nodules, polyps, cysts Vocal fold atrophy Vocal fold scarring	Hoarseness Breathiness Effortful phonation Vocal fatigue Diplophonia
Vocal Fold Vibration Produces Voiced Sound	**Wavelike Vibration from Bottom to Top**–repeat vibratory cycles With each vocal fold vibratory cycle, a puff of air escapes, producing voice sound ("buzzy sound") Singing voice produces unique sound spectra (singing formants) that are distinct from spoken voice	Superficial lamina propria is the main vibrating layer in vocal fold mucosa Vocal fold pliability is critical for vibration Vocal fold surface integrity allows mucosal wave propagation Vocal fold mass and edge contribute to glottic closure	Vocal fold scar Vocal fold lesions: cysts, nodules, polyps, papilloma Vocal fold granuloma Swelling and inflammation (reflux laryngitis, viral laryngitis) Reinke's edema Paresis/paralysis Hemorrhage, vascular ectasias	Hoarseness Effortful phonation Weak voice Speaking voice lower than usual "Vocal fry" Voice fatigue
Voice Volume or Loudness	**Amplitude of Sound Waves** Loudness is achieved by: Increasing air pressure/flow Increasing vocal fold resistance	Breath support Laryngeal muscles contract to adjust tension of vocal folds Vocal fold elasticity allows folds to "open wider" and "stay apart" longer	Vocal fold scar Paresis/paralysis Vocal fold lesions: cysts, nodules, polyps, papilloma Vocal fold granuloma Swelling and inflammation (reflux laryngitis, viral laryngitis)	Unable to project voice Weak voice Voice breaks
Voice Pitch or Highness / Lowness	**Frequency of Sound Waves** Increased tension for high notes (high frequency) Decreased tension for low notes (low frequency) Greater air pressure and increased tension for high notes	Laryngeal muscles contract to adjust tension of vocal folds–especially for high notes Vocal fold elasticity/pliability Vocal fold edge integrity	SLN paresis/paralysis Vocal fold scar Reinke's edema Vocal fold lesions	Unable to hit high notes Loss of glissando Voice breaks

Voice Quality or Timbre	**Person's "Own" Voice** Vocal tract resonators amplify and modify voiced sound, giving personal quality to a person's voice e.g., John's voice not equal to Jim's voice	Vocal fold elasticity/pliability Vocal fold resistance Vocal fold mass Person's vocal fold features: e.g., stiffness, bulk, size Vocal tract resonators (throat, oral cavity, nasal cavities)	Vocal fold scar Vocal fold inflammation Reinke's Edema Common cold	Hoarseness, etc. Off expected pitch Nasal quality to voice