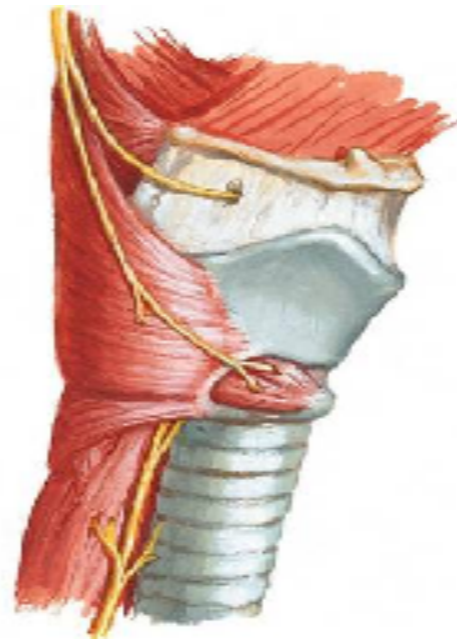


Advanced Laryngeal Physiology

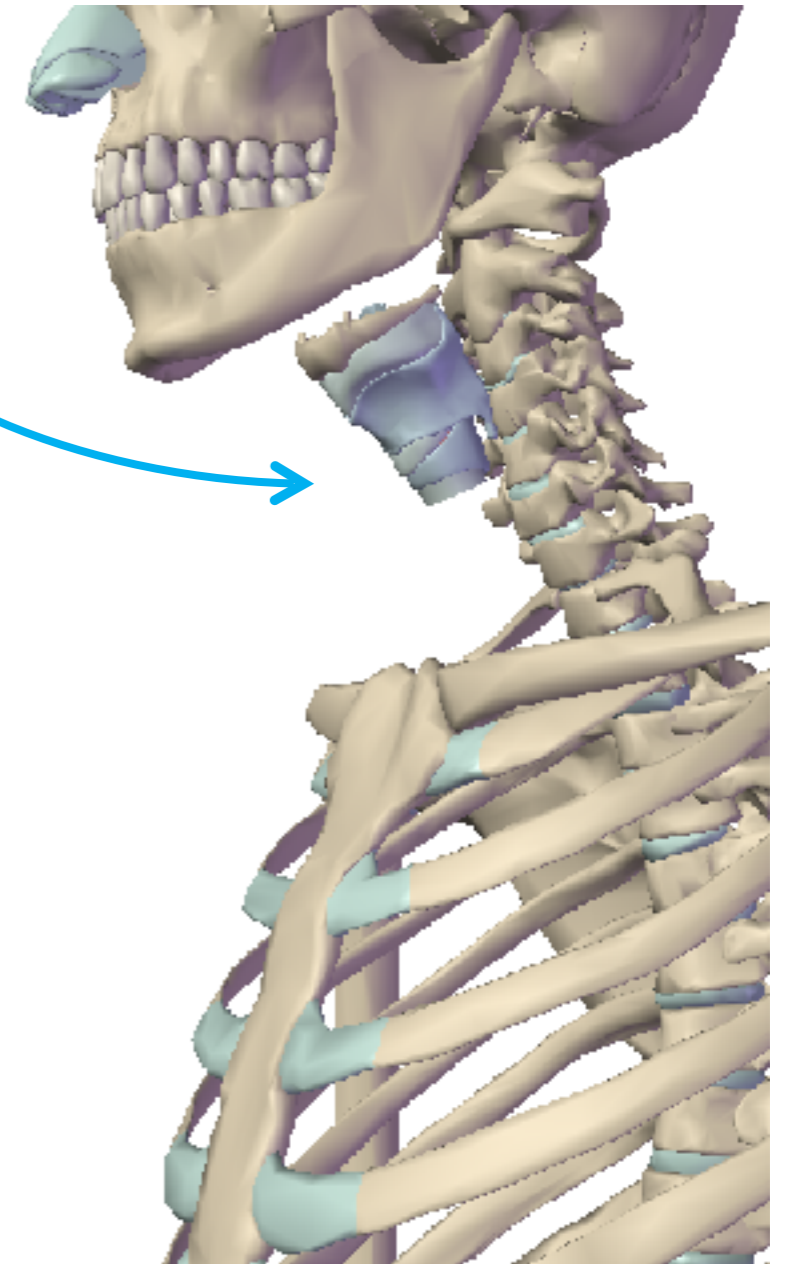
Sarah Perry, Ph.D. CCC-SLP



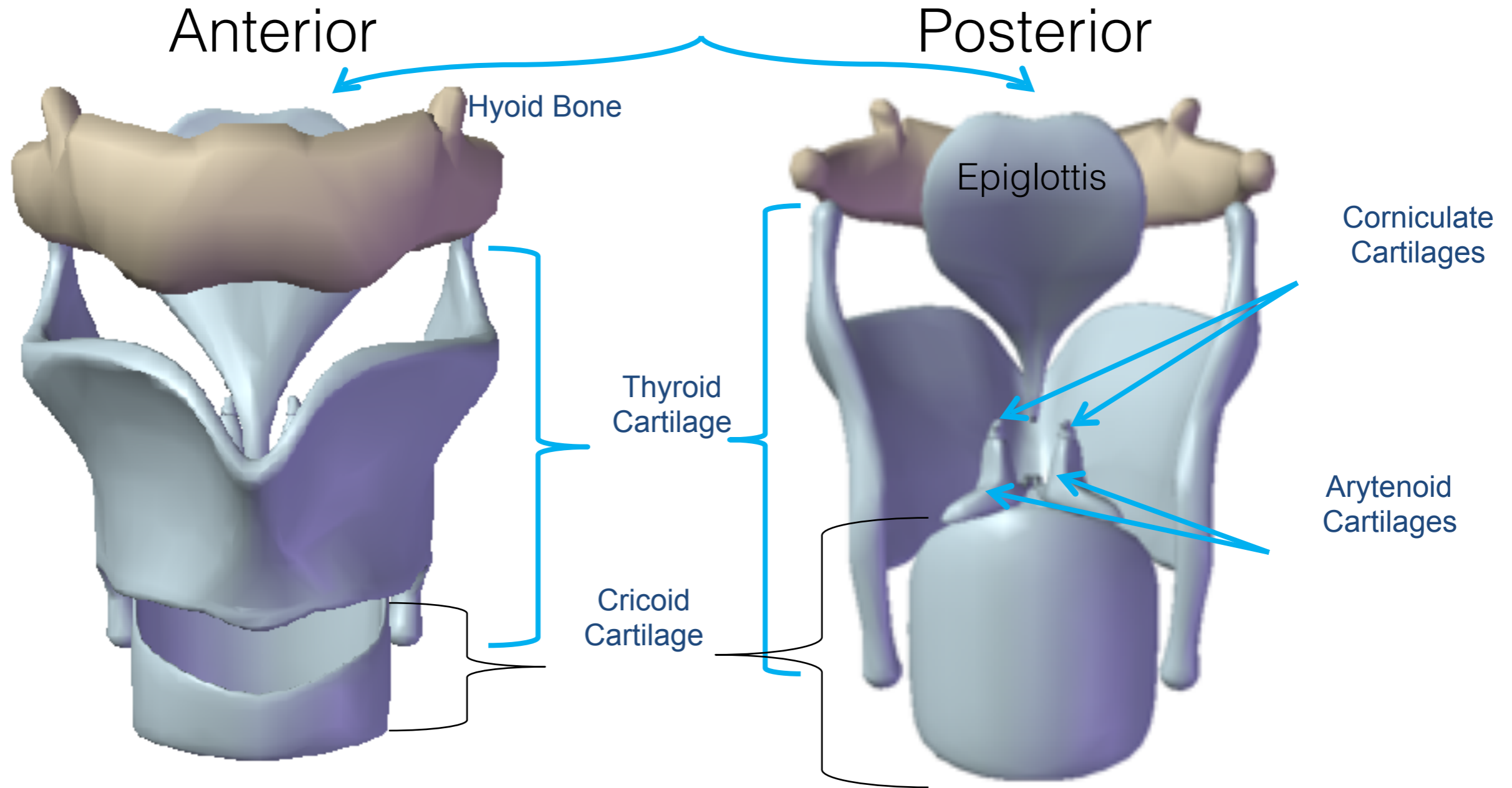
TEACHERS COLLEGE
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Position of the Larynx

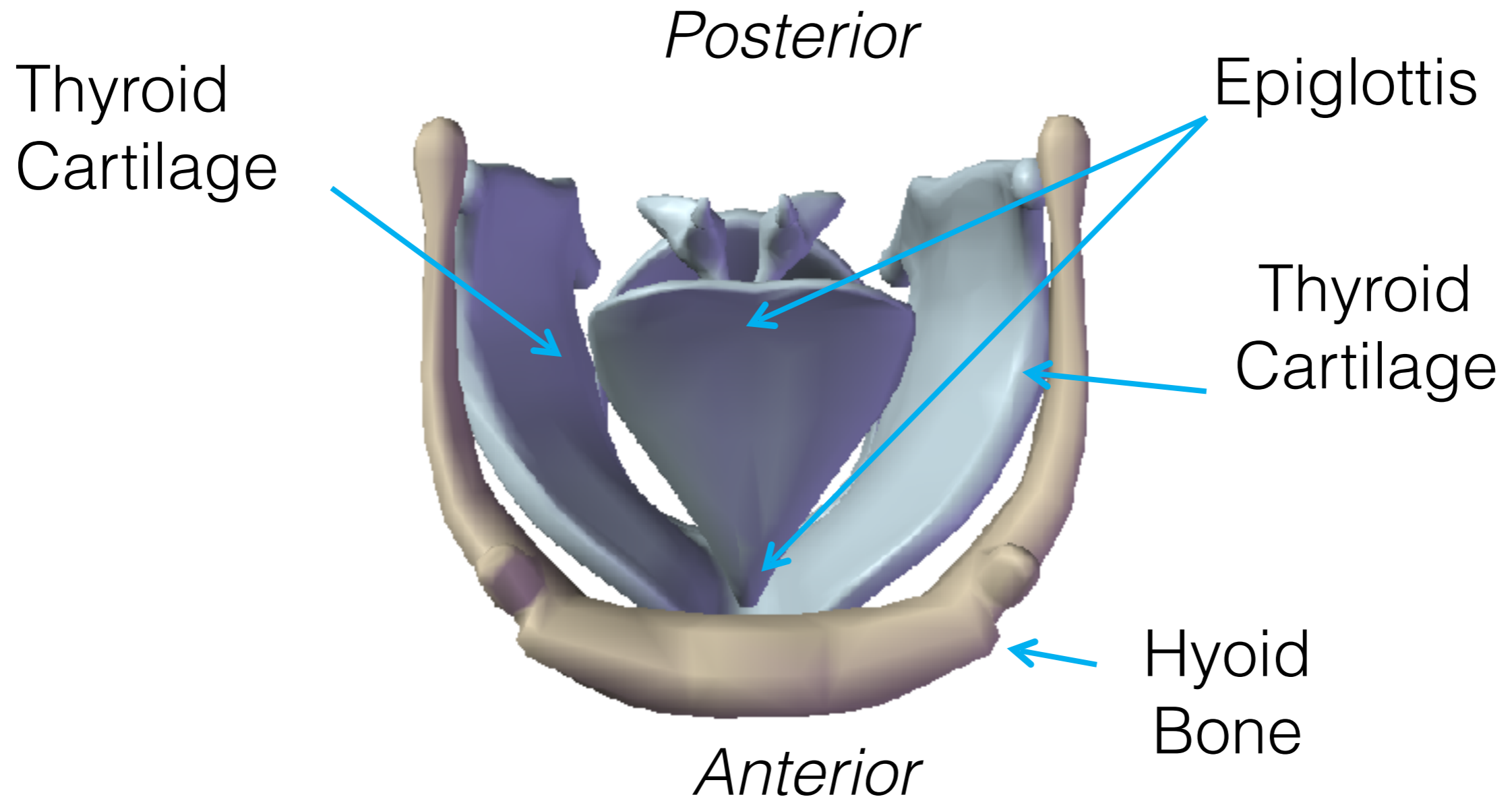
- The Larynx:
 - Sits opposite approximately the third, fourth, fifth, and sixth cervical vertebrae
 - In a child the larynx sits opposite approximately the fourth cervical vertebrae



Structure of Larynx

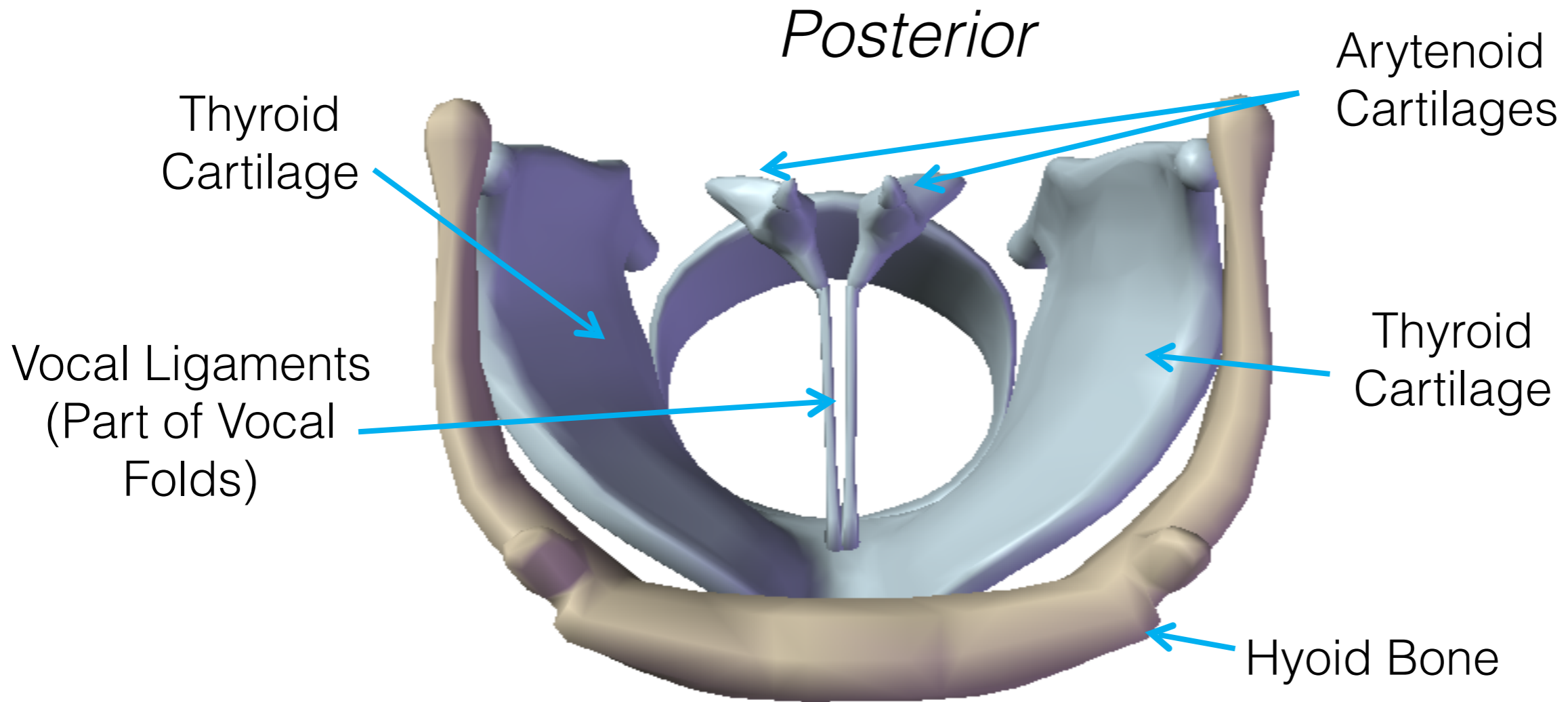


Structure of Larynx



Superior view

Structure of Larynx



Superior view
(Epiglottis removed)

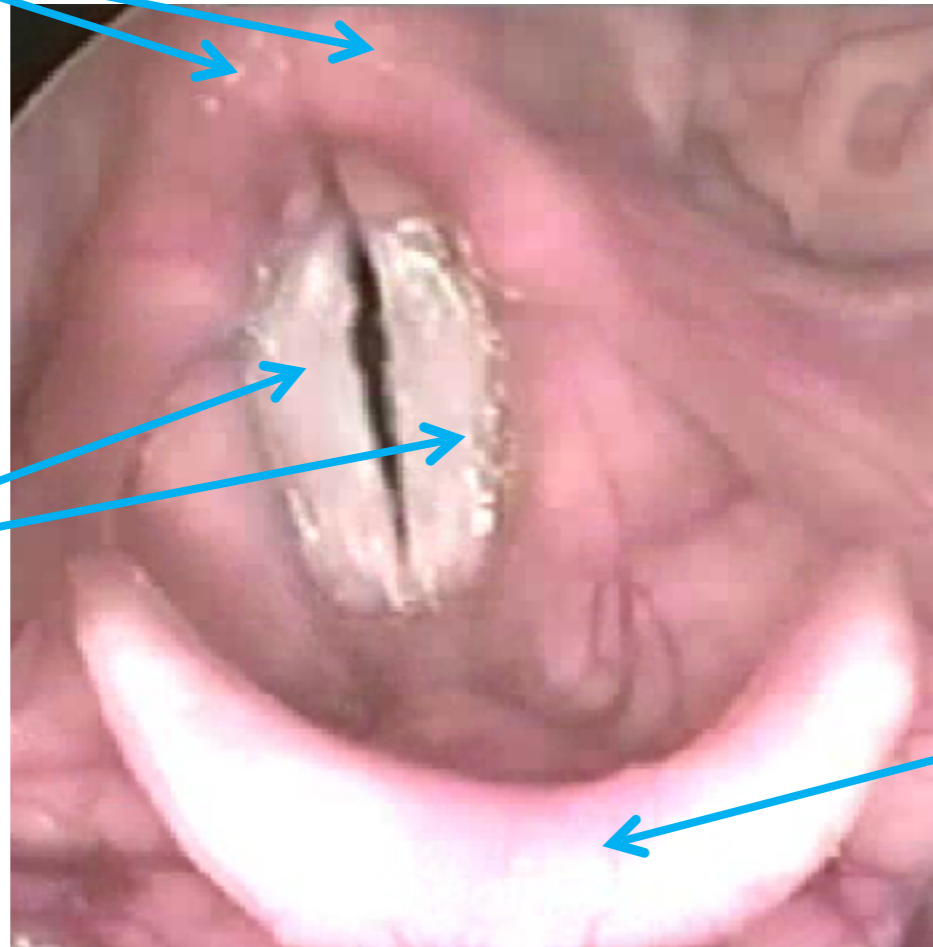
Structure of Larynx

Posterior

Arytenoid
Cartilages

Vocal Folds

Epiglottis

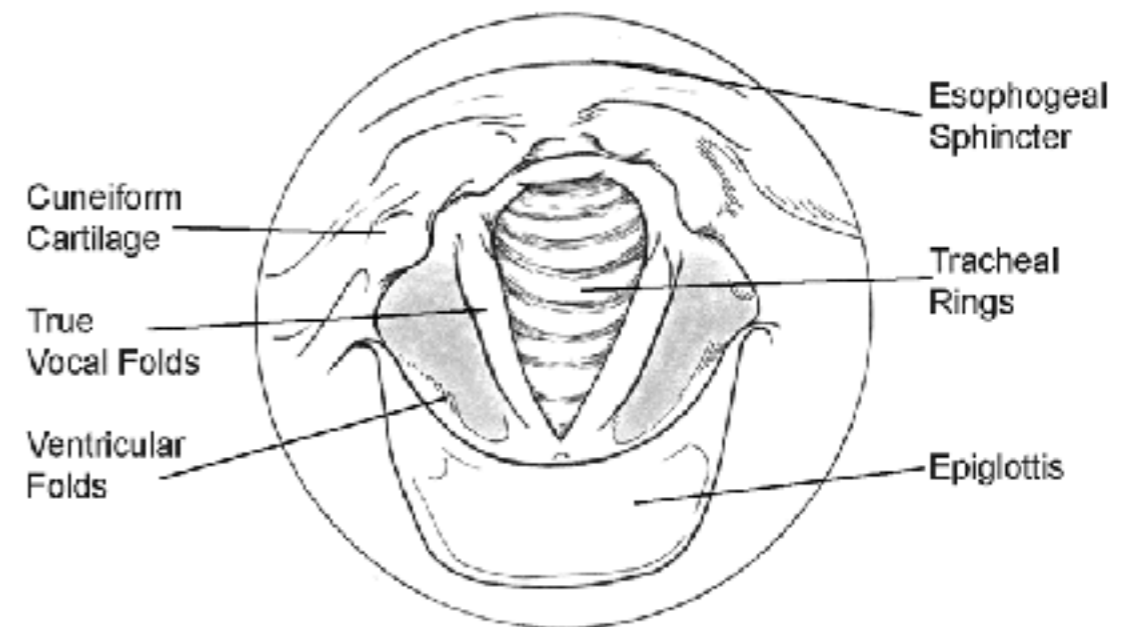
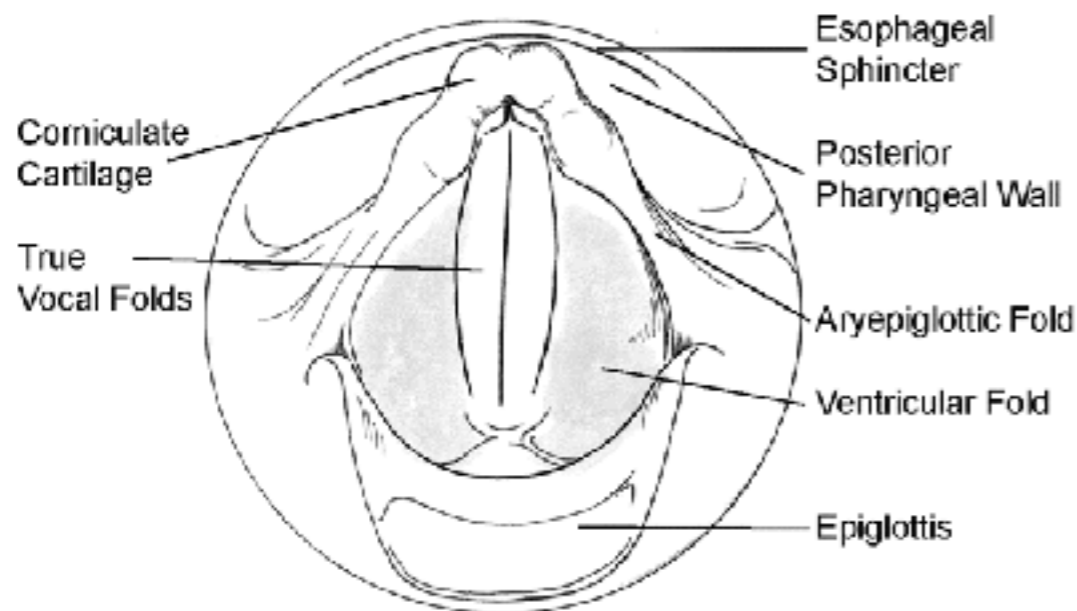


Anterior

Superior view

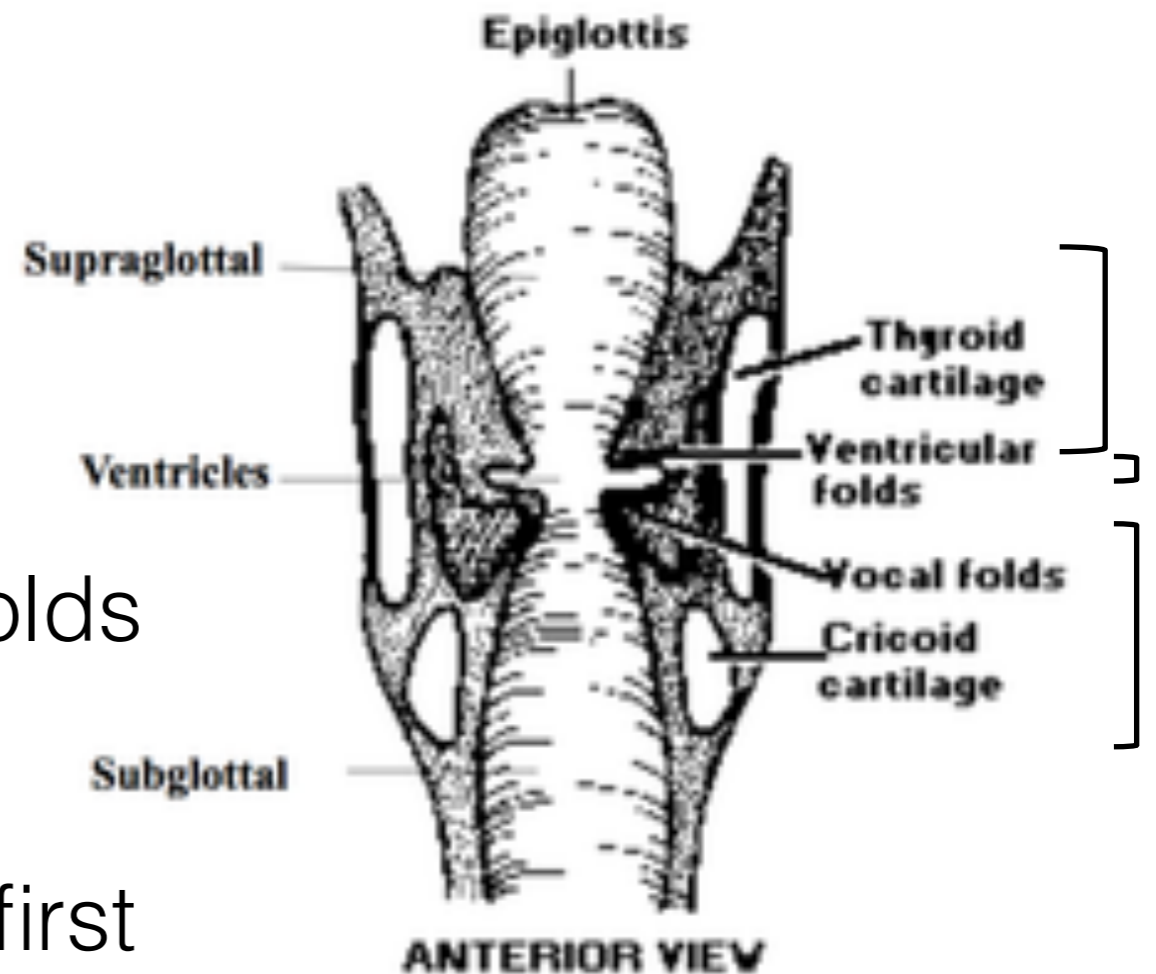
Basic Structures of the Larynx

- Glottis: the space between the vocal folds
 - Size and shape changes as a function of the vibratory behavior of the vocal folds
 - Abduction: wide glottis
 - Adduction: closed glottis



Framework of the Larynx

- Supraglottal cavity
 - From the vocal folds to the aryepiglottic folds
- Ventricles
 - Lateral space between ventricular and true vocal folds
- Subglottal cavity
 - From the vocal folds to the first tracheal ring

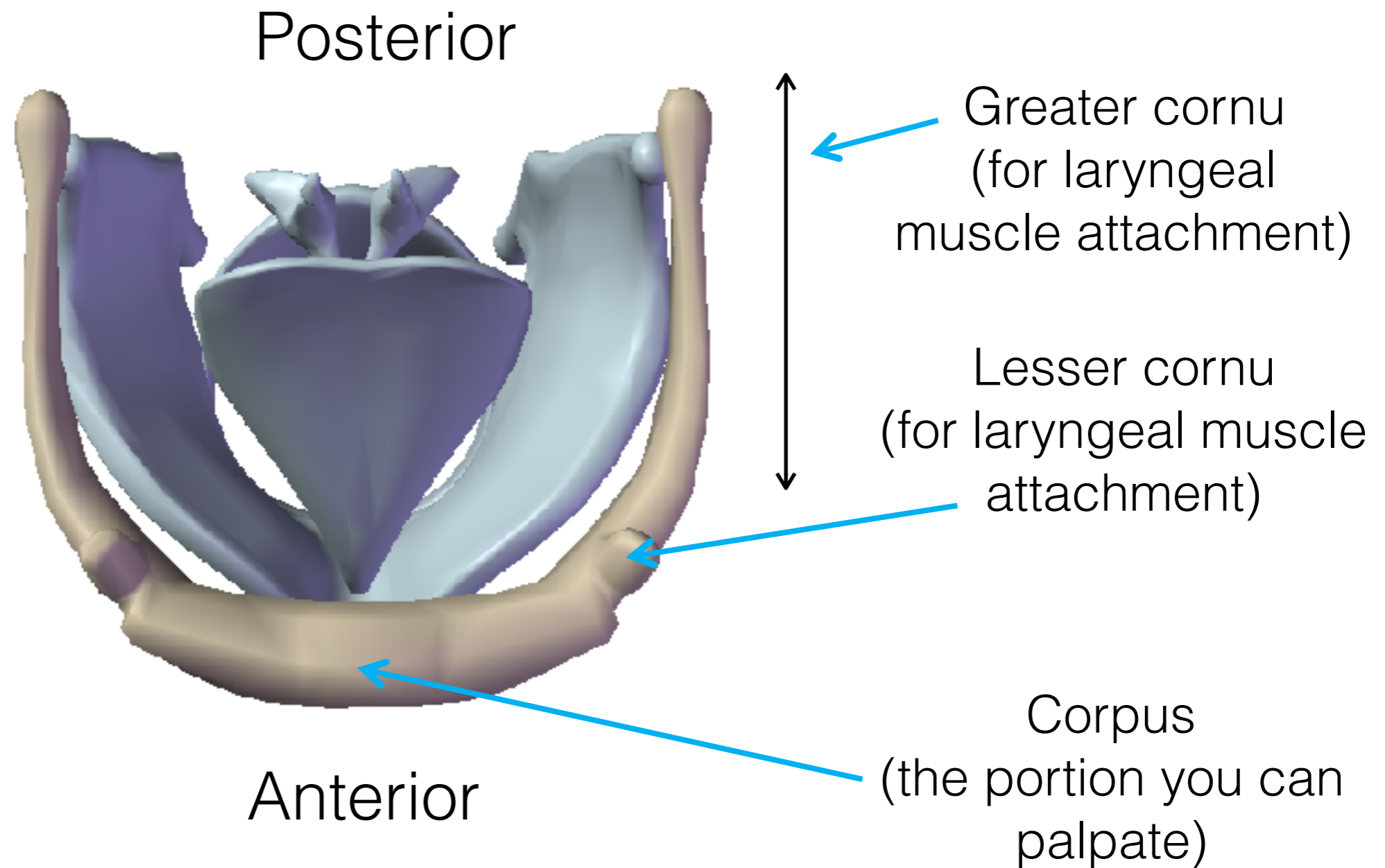


Hyoid Bone

- The only laryngeal bone
- U-shaped
- The only bone in the body that is not attached to another bone
- Hyoid has a body with lateral horns (greater and lesser cornu)



Prominent Landmarks of the Hyoid Bone

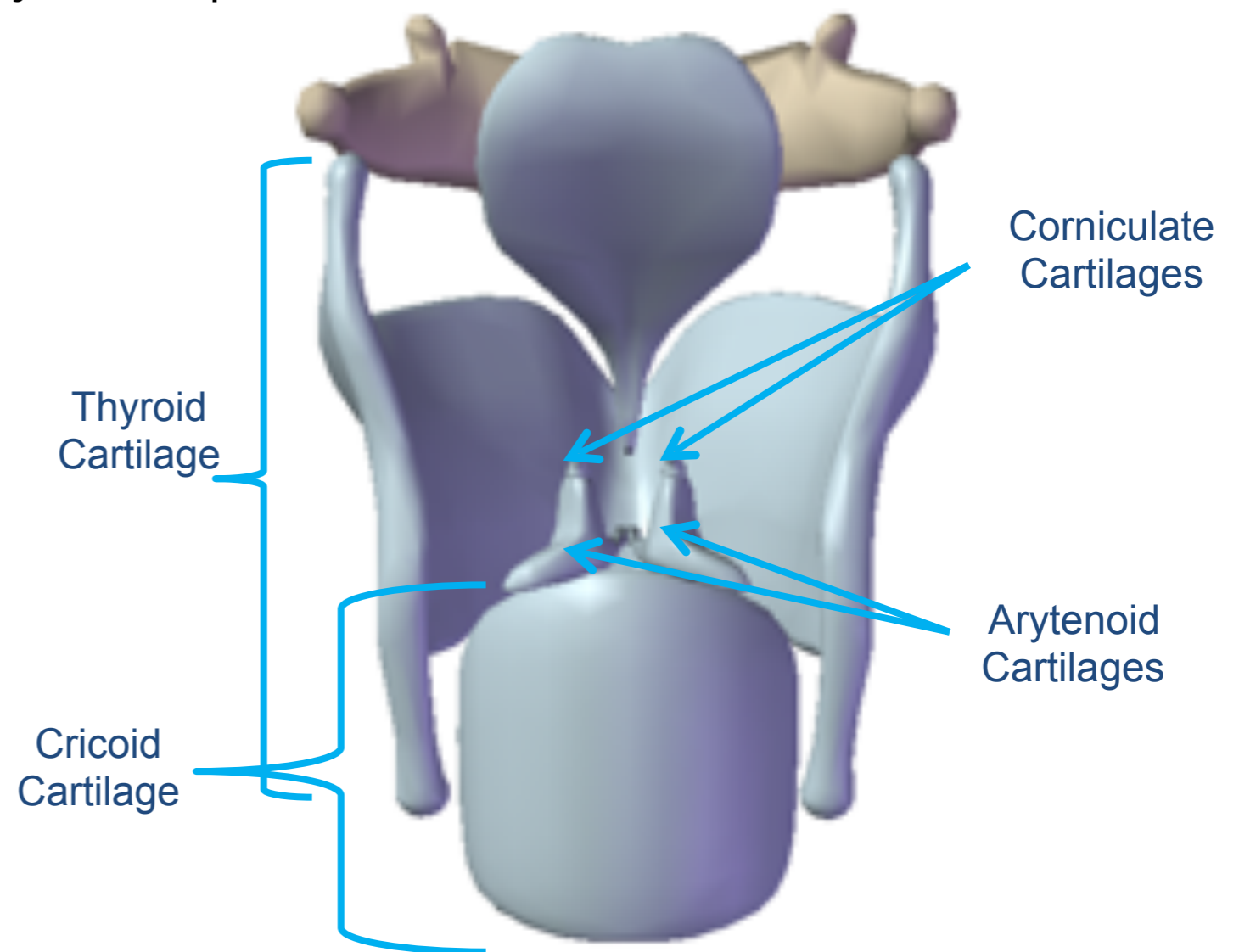


Superior view

Laryngeal Cartilages

Six cartilages that occur singly or in pairs

1. Thyroid (1)
2. Cricoid (1)
3. Arytenoids (2)
4. Corniculated (2)
5. Cuneiforms (2)
6. Epiglottis (1)

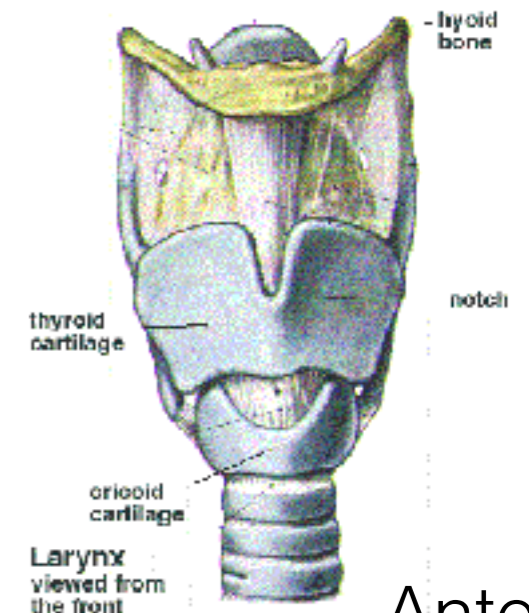
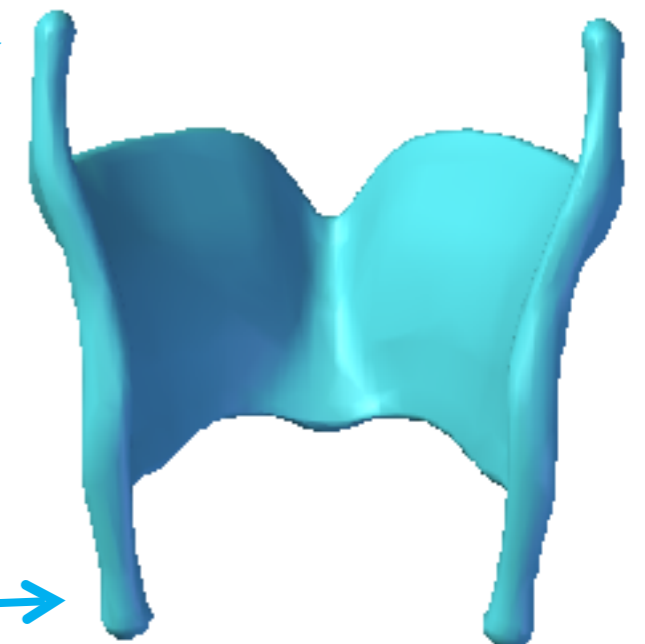


Posterior view

Thyroid Cartilage

- Unpaired
- Hyaline cartilage
- Superior cornu
 - Attaches indirectly to the greater cornu of the hyoid bone
- Inferior cornu
 - Attaches posteriorly to the cricoid cartilage
- Laryngeal prominence/Thyroid notch

Posterior View



Anterior

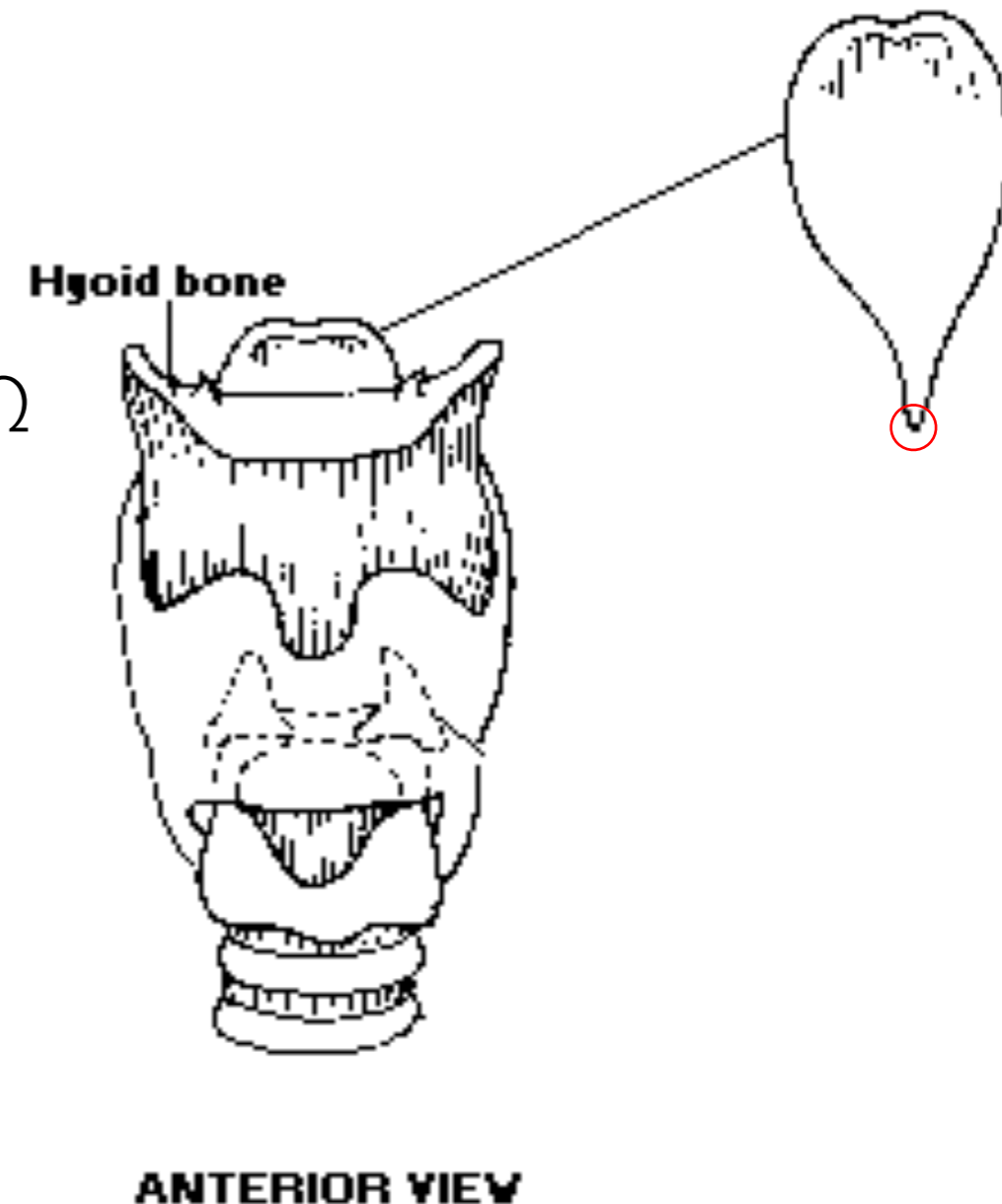
Cricoid Cartilage

- Unpaired
- Hyaline cartilage
- Sits on top of the trachea
- Shaped like a signet ring
- Complete circle



Epiglottis

- The only other unpaired cartilage
 - Leaf-shaped
 - Can sometimes be omega shaped Ω
- Elastic cartilage
- Petiolus: Attaches to the inside of the thyroid – epiglottis becomes very thin at this point
- Anterior surface attaches to the hyoid bone by ligaments
 - Also attaches to the root of the tongue

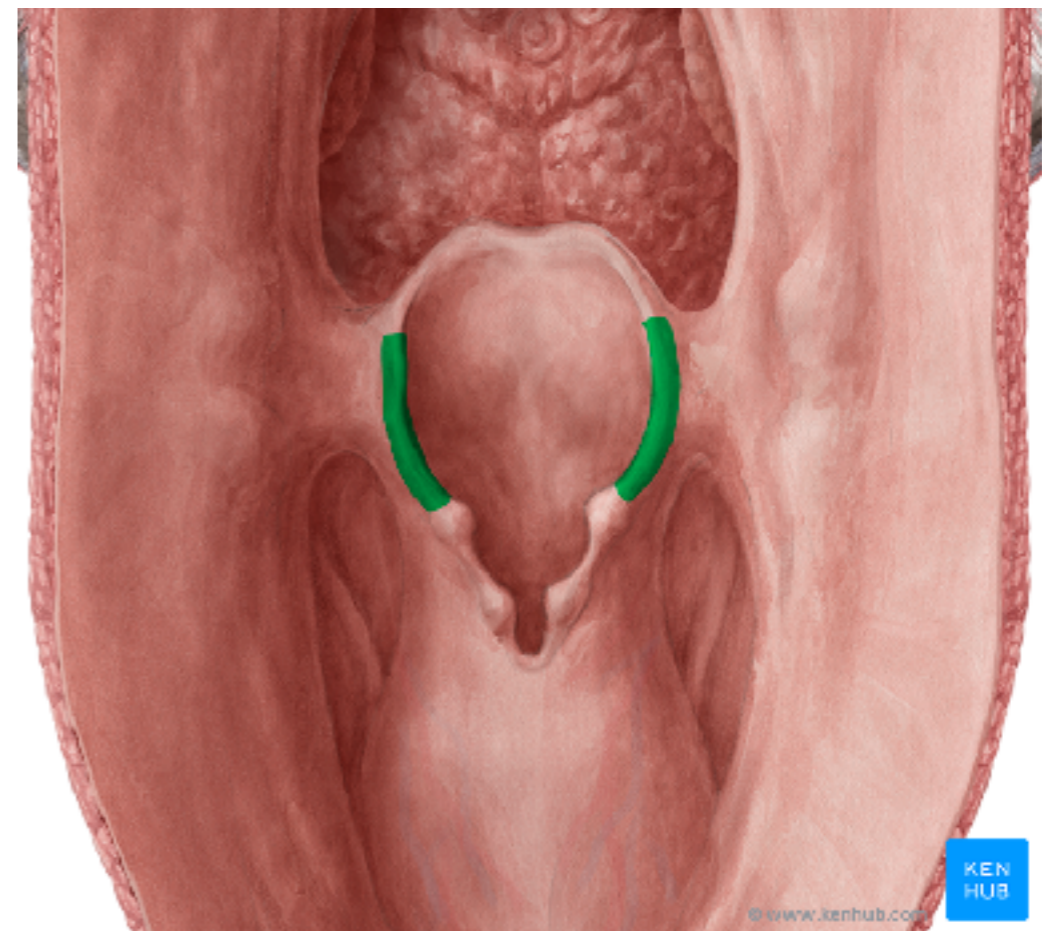


Epiglottis

- Biological function: inverts to close off airway directing food/bolus material toward esophagus during swallowing
- Non-biological function: Tongue position moves epiglottis but no real function for phonation or articulation
 - Exception: consonants in a few languages (e.g. Arabic, Hebrew)

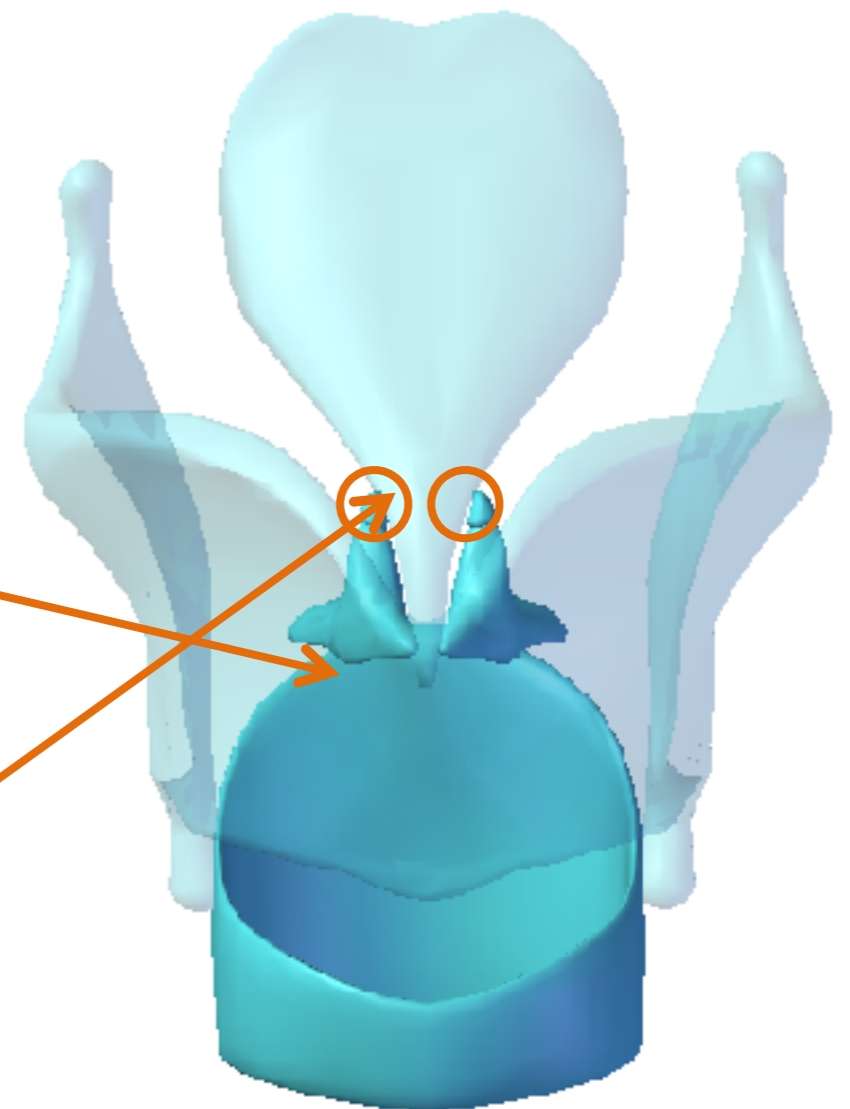
Aryepiglottic Fold

- A fold of mucous membrane, enclosing ligamentous and muscular fibers
- Stretches between the side of the epiglottis and the apex of the arytenoid cartilages
- The AE folds form the upper borders of the quadrangular membrane
- The AE folds can phonate (e.g. Louis Armstrong vocal growl)



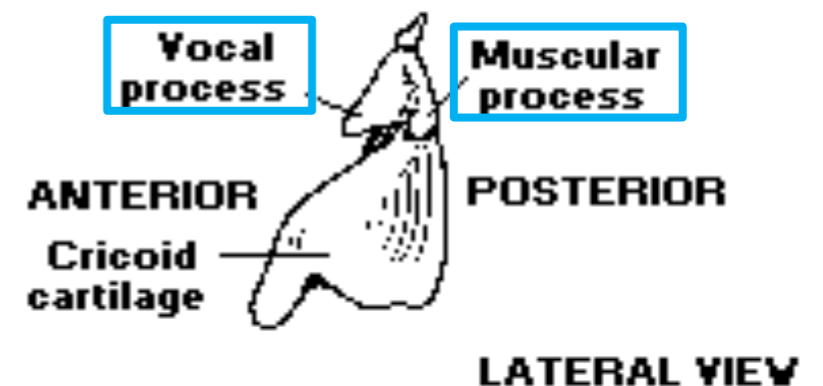
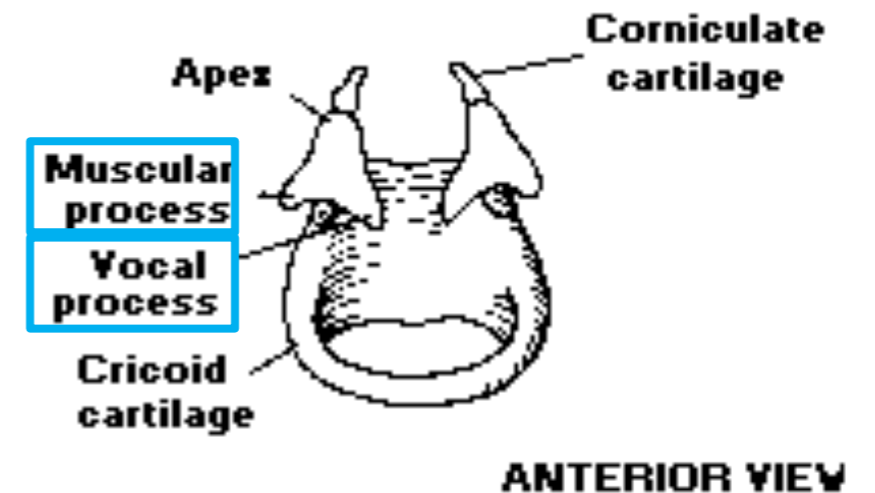
Arytenoid Cartilages

- Largest of the paired cartilages
- Hyaline (mostly) + elastic
- Sit on top of the superior surface of the posterior **cricoid cartilage**
- Control abduction and adduction of the vocal folds
- Pyramid shaped: apex and base
 - Corniculate cartilages rest on the apex



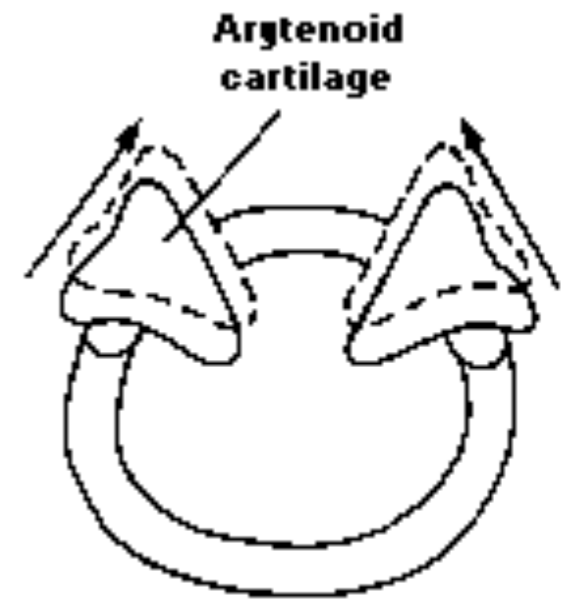
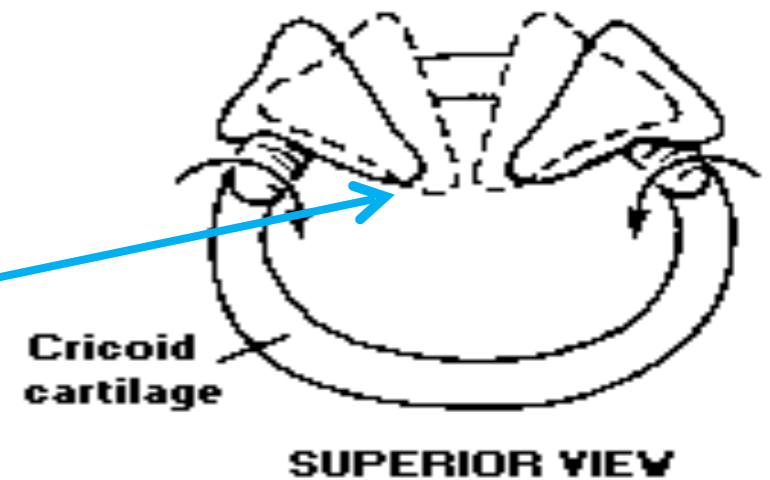
Arytenoid Cartilages

- Lateral projection
 - *Muscular process*
 - For adduction, abduction of vocal folds
- Anterior projection
 - *Vocal process*
 - Attached to posterior part of the vocal folds



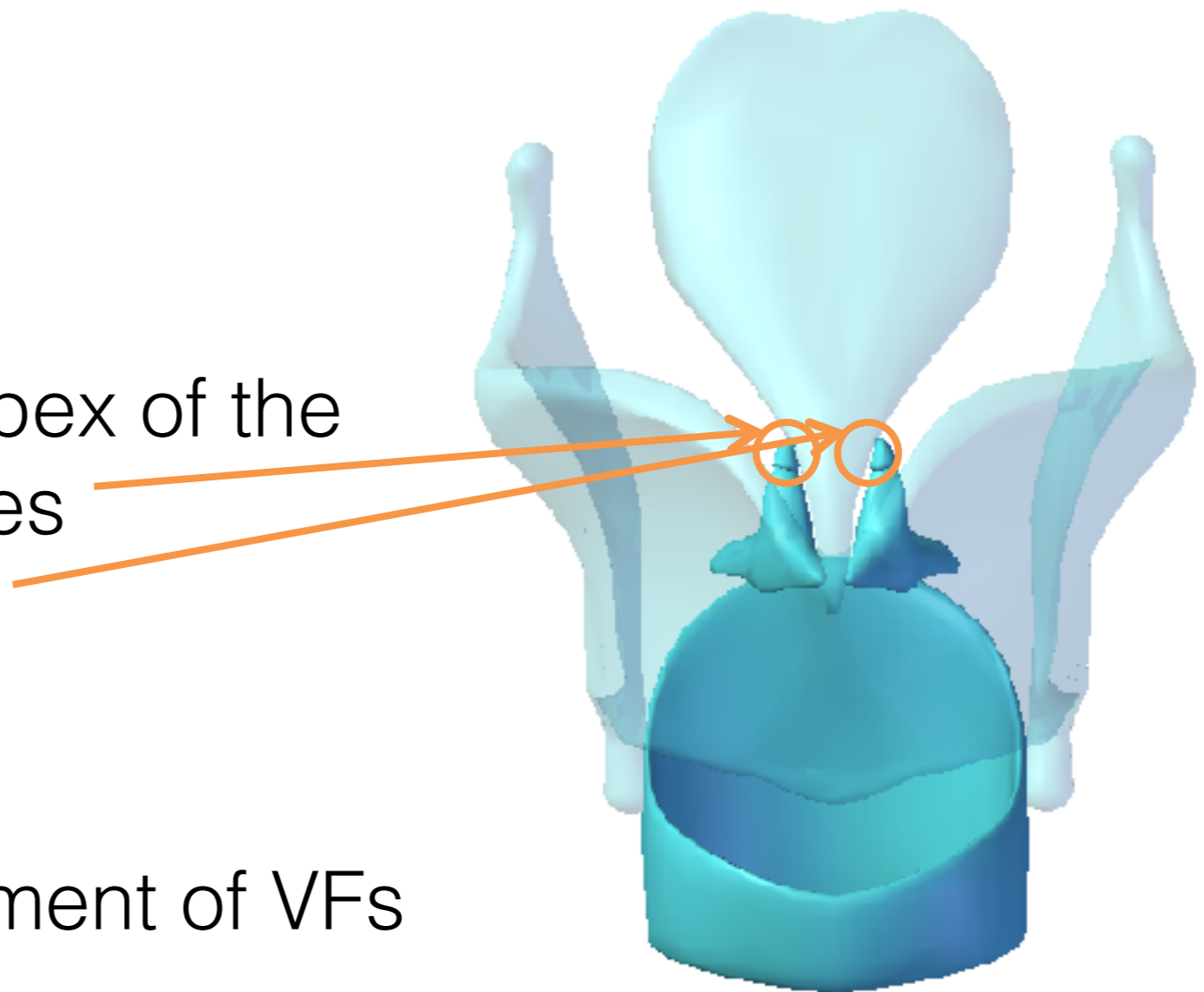
Movements of Arytenoid Cartilages

- Rocking: forward and backward
 - Moves vocal processes closer together for vocal fold vibration
- Gliding
 - Shortens or lengthens vocal folds



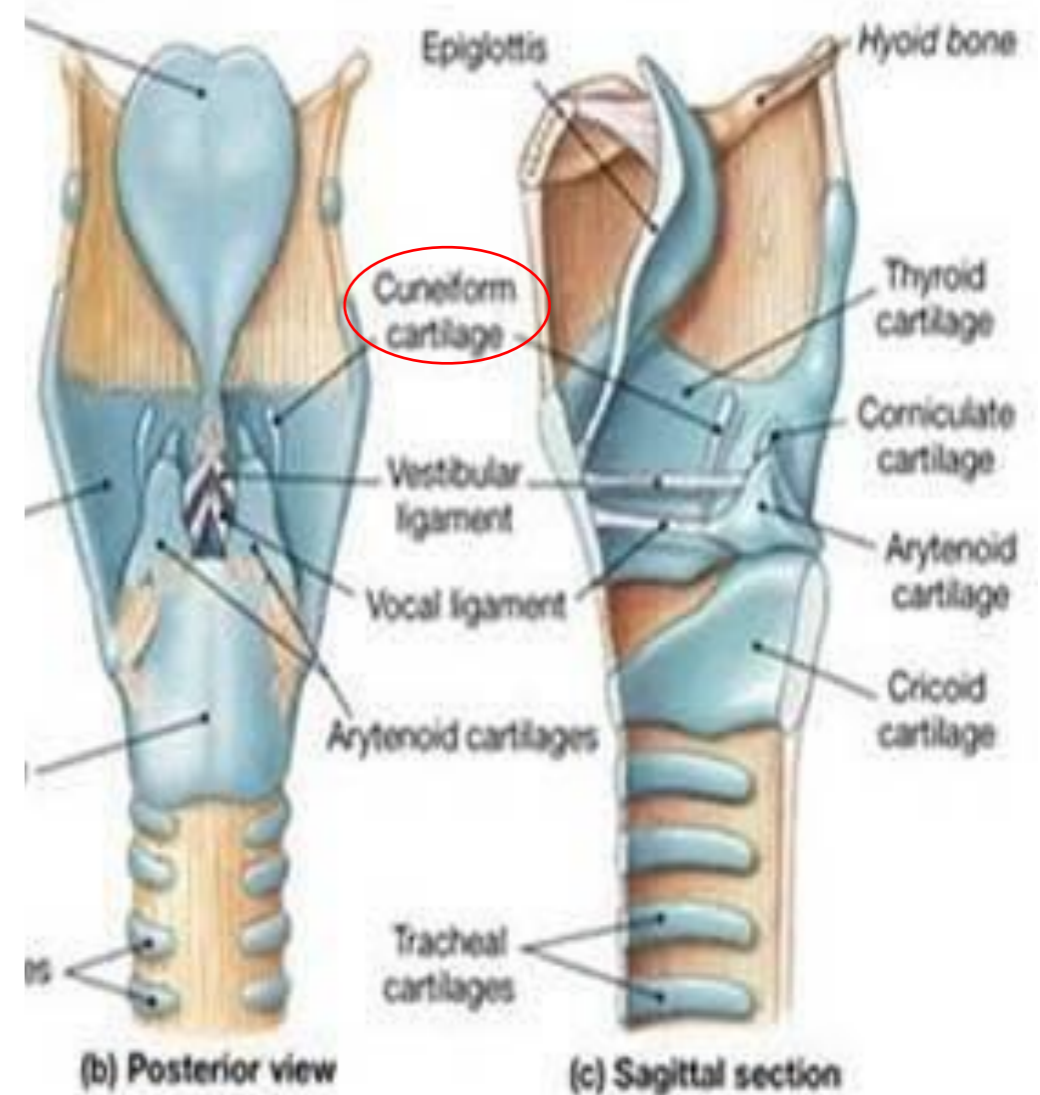
Corniculated Cartilages

- Paired cartilages
- Elastic cartilages
- Sit on top of the apex of the arytenoid cartilages
- Pyramid shaped
- Assist with attachment of VFs to arytenoids



Cuneiform Cartilages

- Tiny, paired, wedge-shaped cartilages
- Elastic cartilages
- Embedded in the mucous membrane
 - Superior and anterior to the corniculate cartilages
- Biological function:
 - Supportive framework for the aryepiglottic fold
 - Vestigial - not all people have them

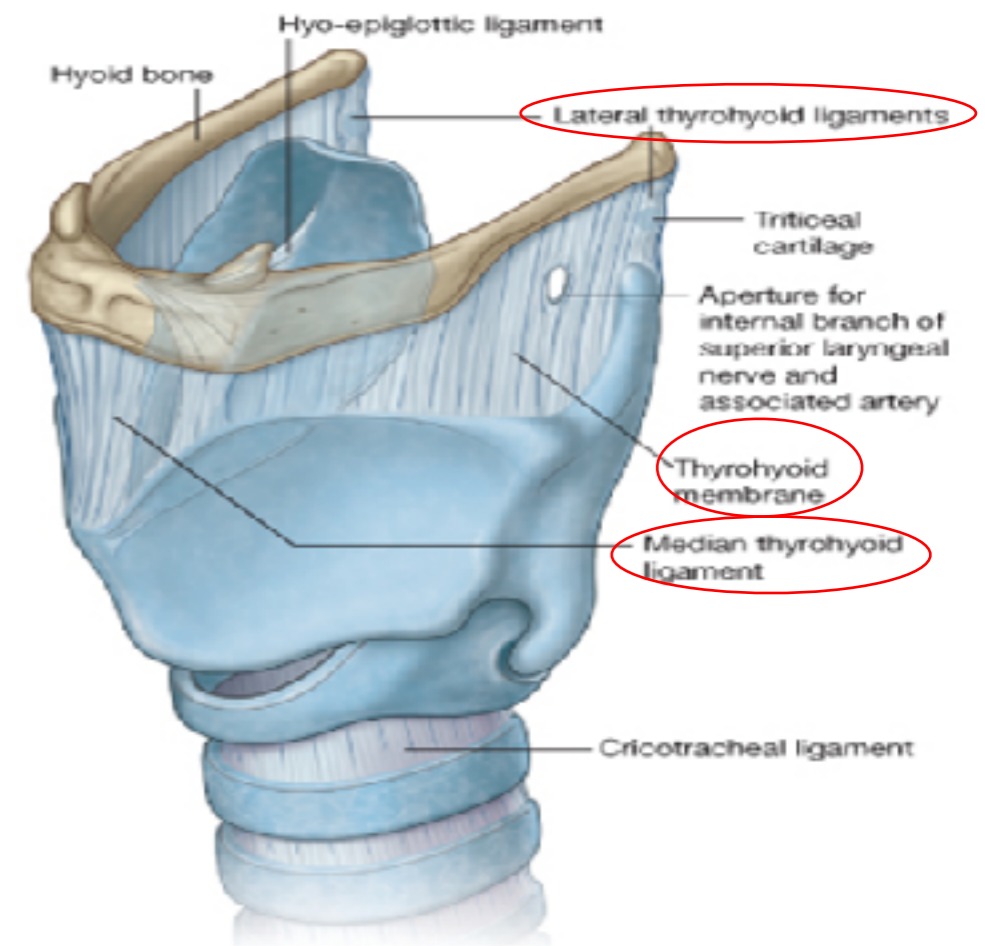


Framework of the Larynx

- The cartilages and bone of the larynx are held together by a series of ligaments (connective tissue)
 - Seven of these are extrinsic
 - They connect somewhere on the outer surface of the larynx
 - Three are intrinsic
 - Both attachments are within the larynx

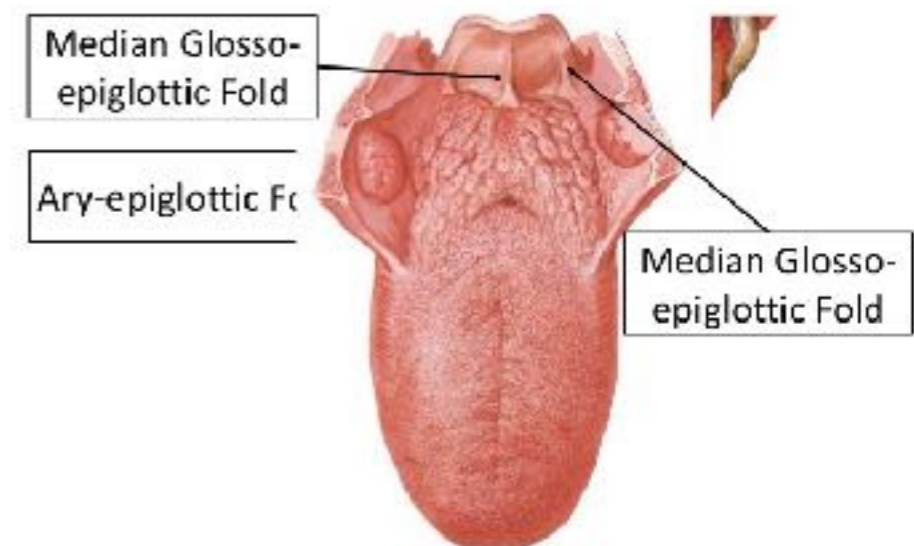
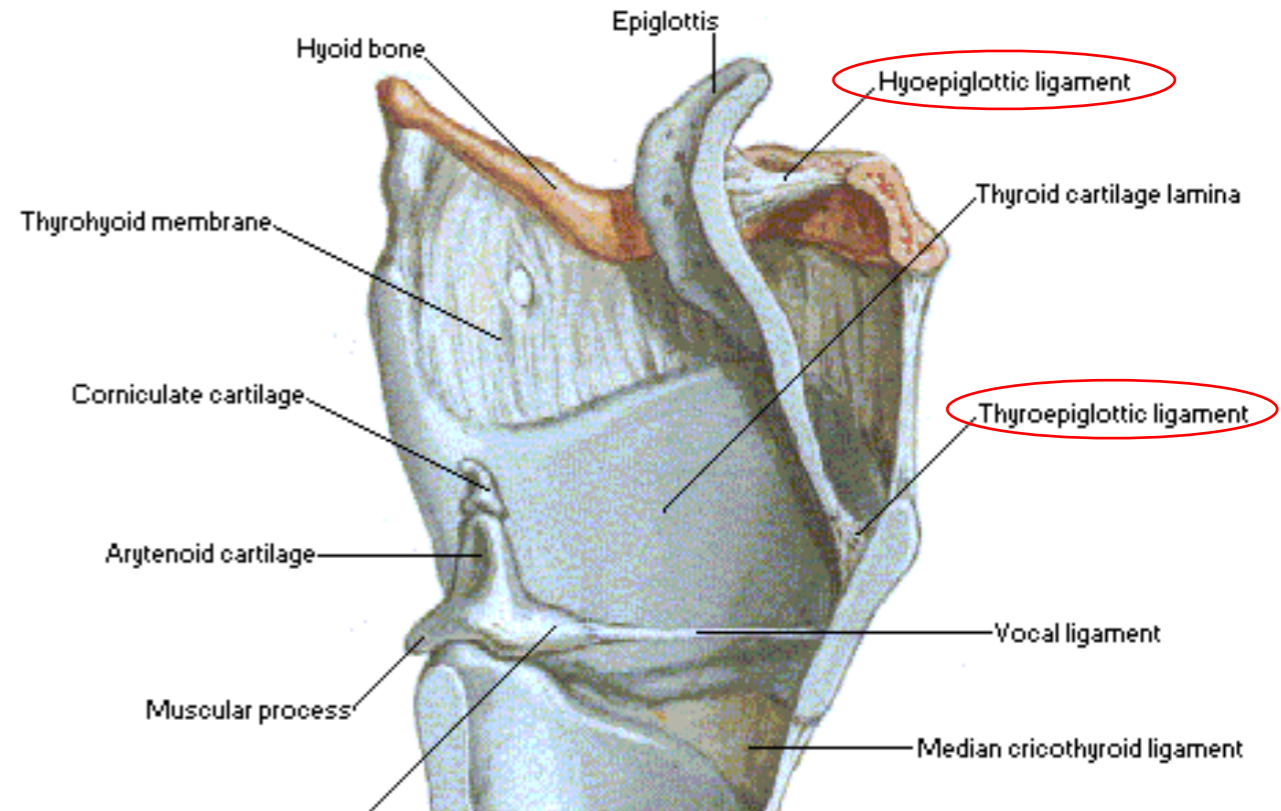
Extrinsic Ligaments/ Membranes

- Three ligaments connect the hyoid bone to the thyroid cartilage, and their names reflect this connection:
 - Thyrohyoid membrane
 - Lateral thyrohyoid ligament
 - Middle thyrohyoid ligament



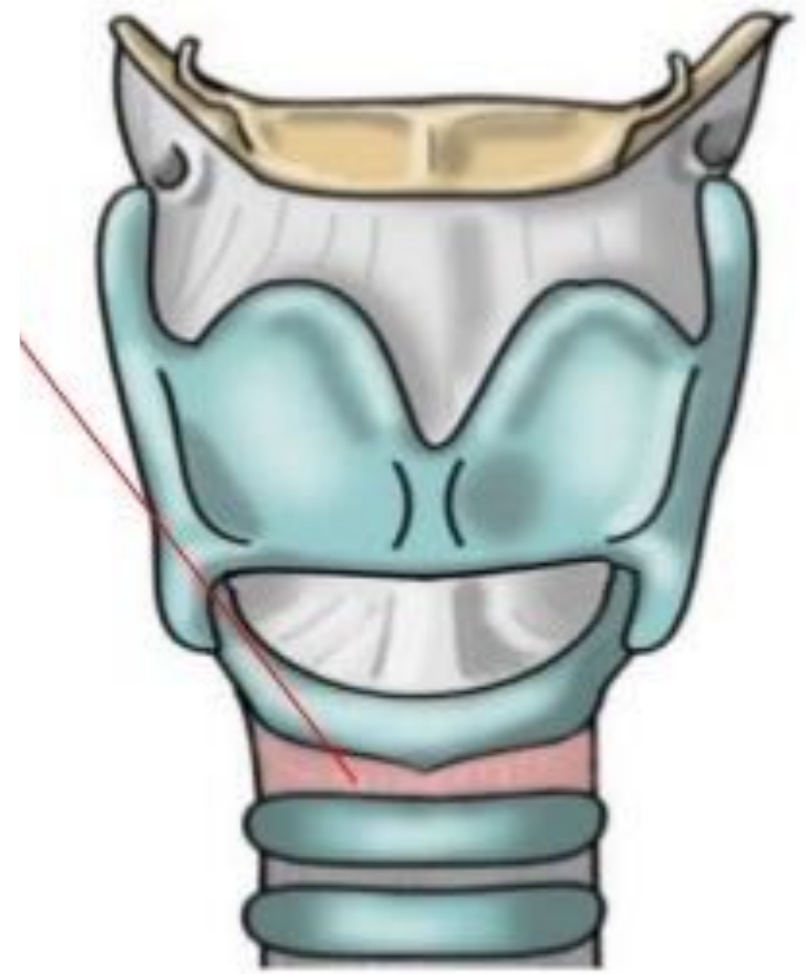
Extrinsic Ligaments/ Membranes

- Three ligaments connect the epiglottis to the:
 - Hyoid bone → Hyoepiglottic ligament
 - Thyroid cartilage → Thyroepiglottic ligament
 - Tongue → Glossoepiglottic ligaments



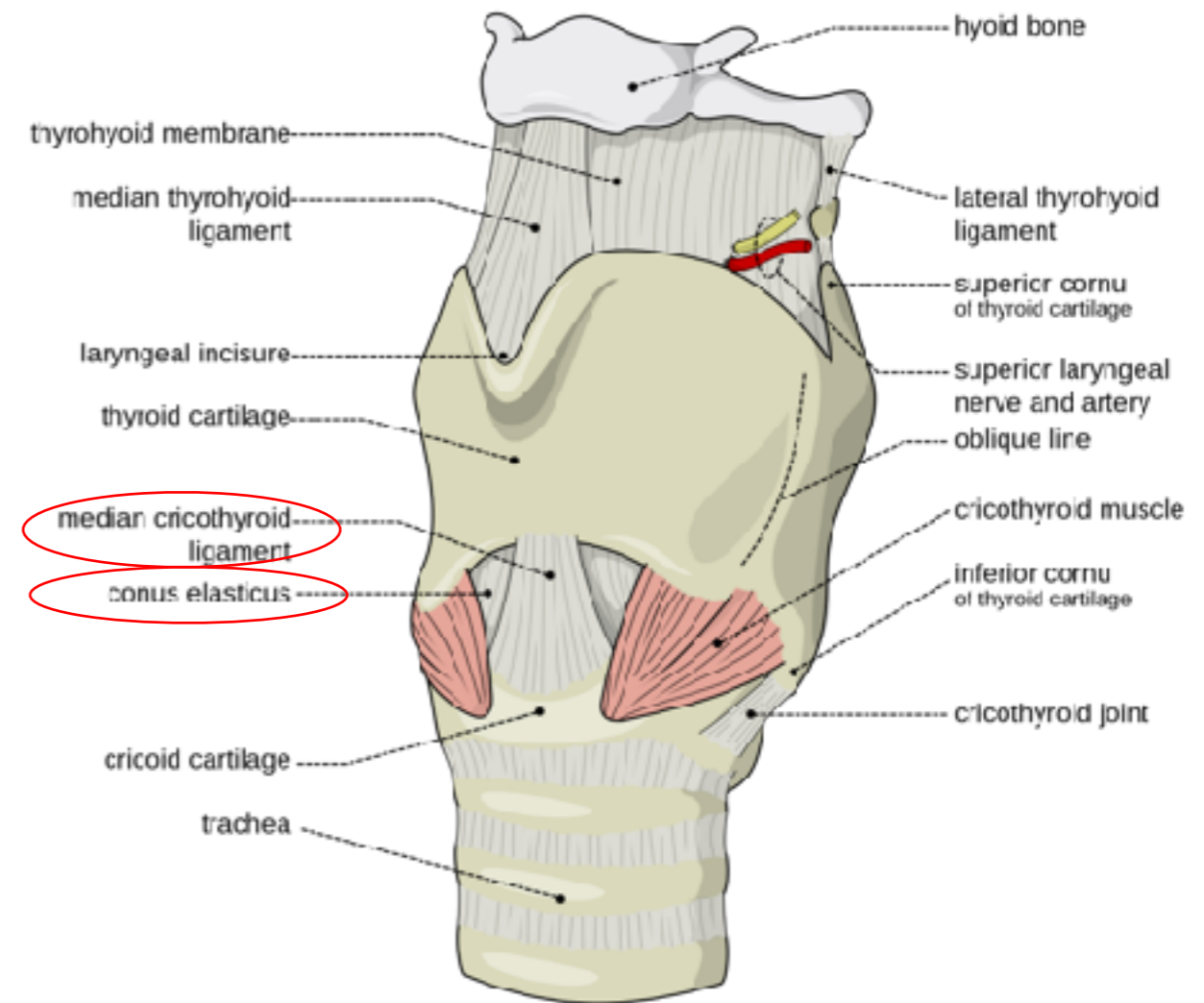
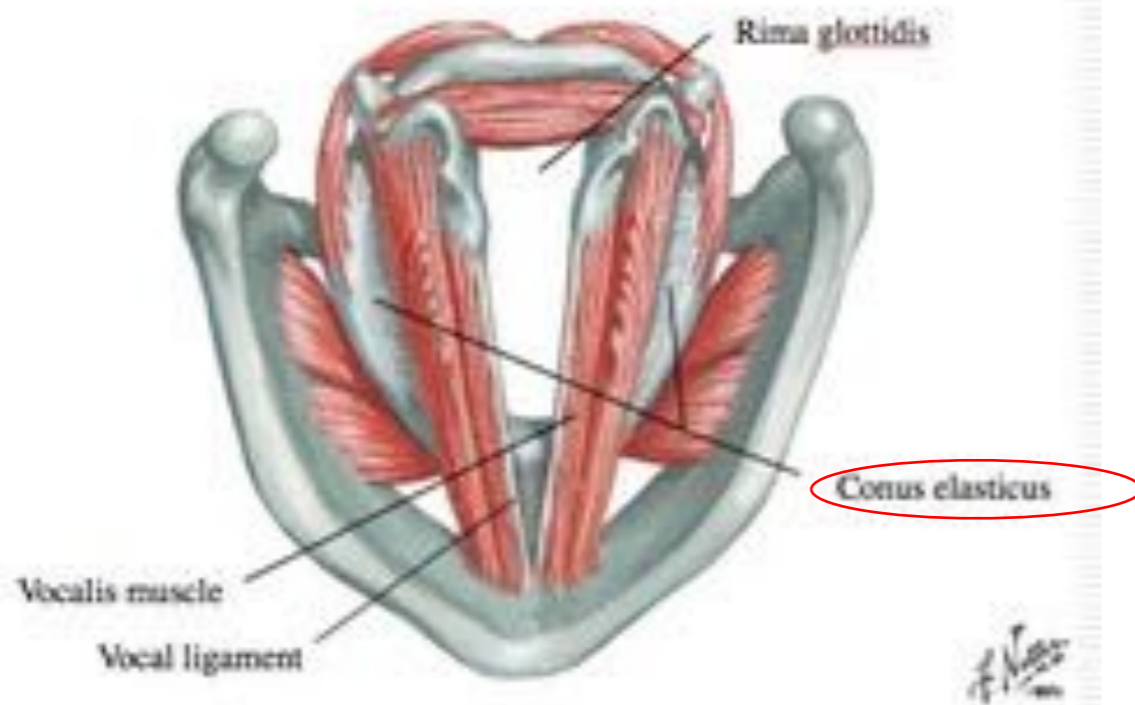
Extrinsic Ligaments/ Membranes

- Cricotracheal membrane
 - Connects the cricoid cartilage to the trachea



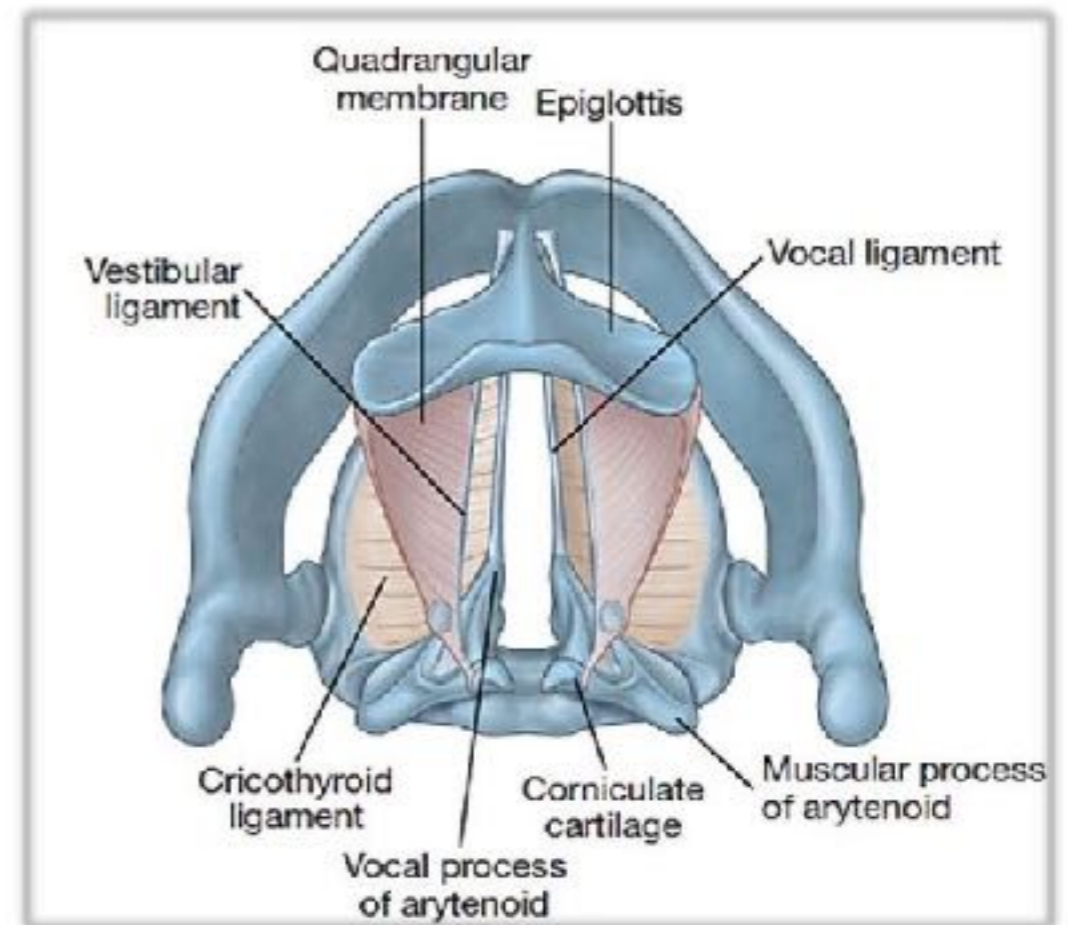
Intrinsic Ligaments/ Membranes

- Cricothyroid ligament
- Composed of 2 parts:
 - Median cricothyroid ligament
 - Lateral cricothyroid ligaments (conus elasticus)



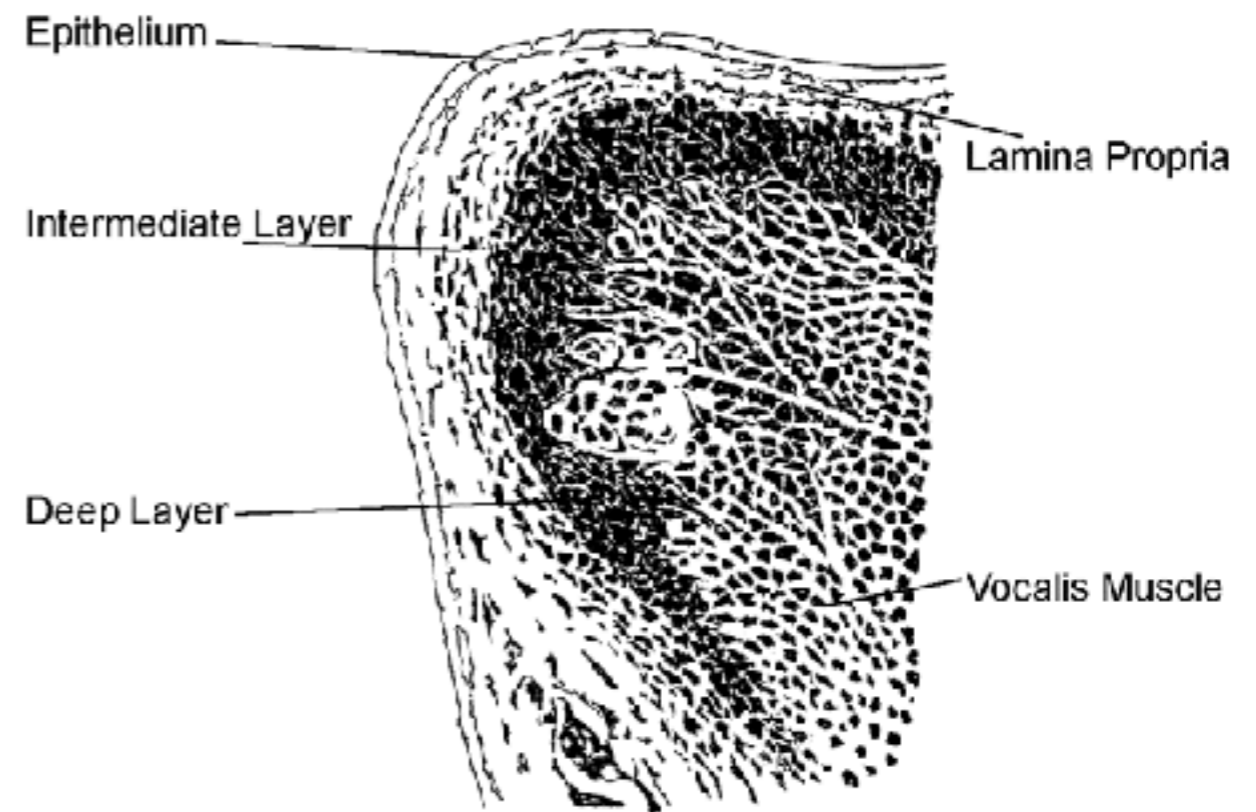
Intrinsic Ligaments/ Membranes

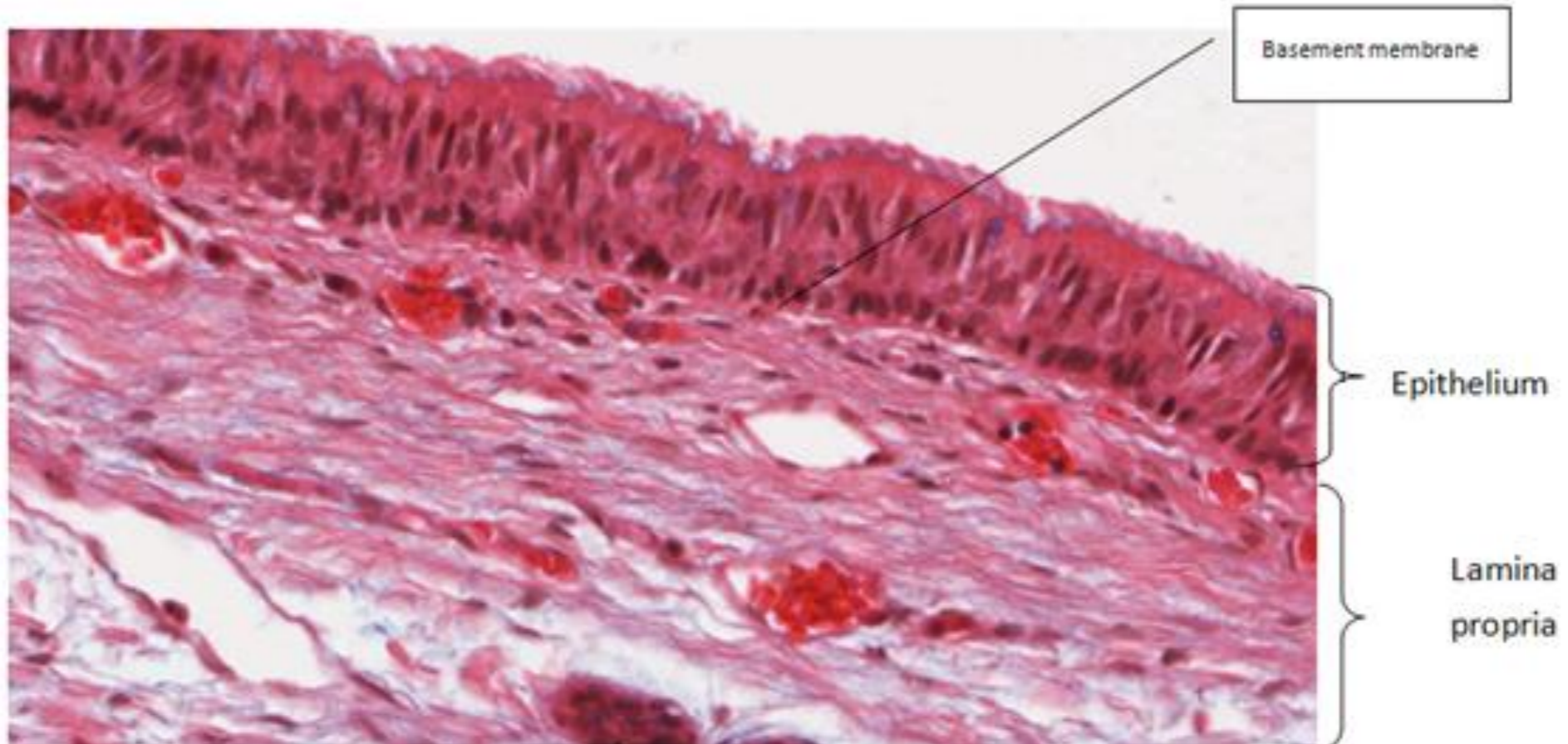
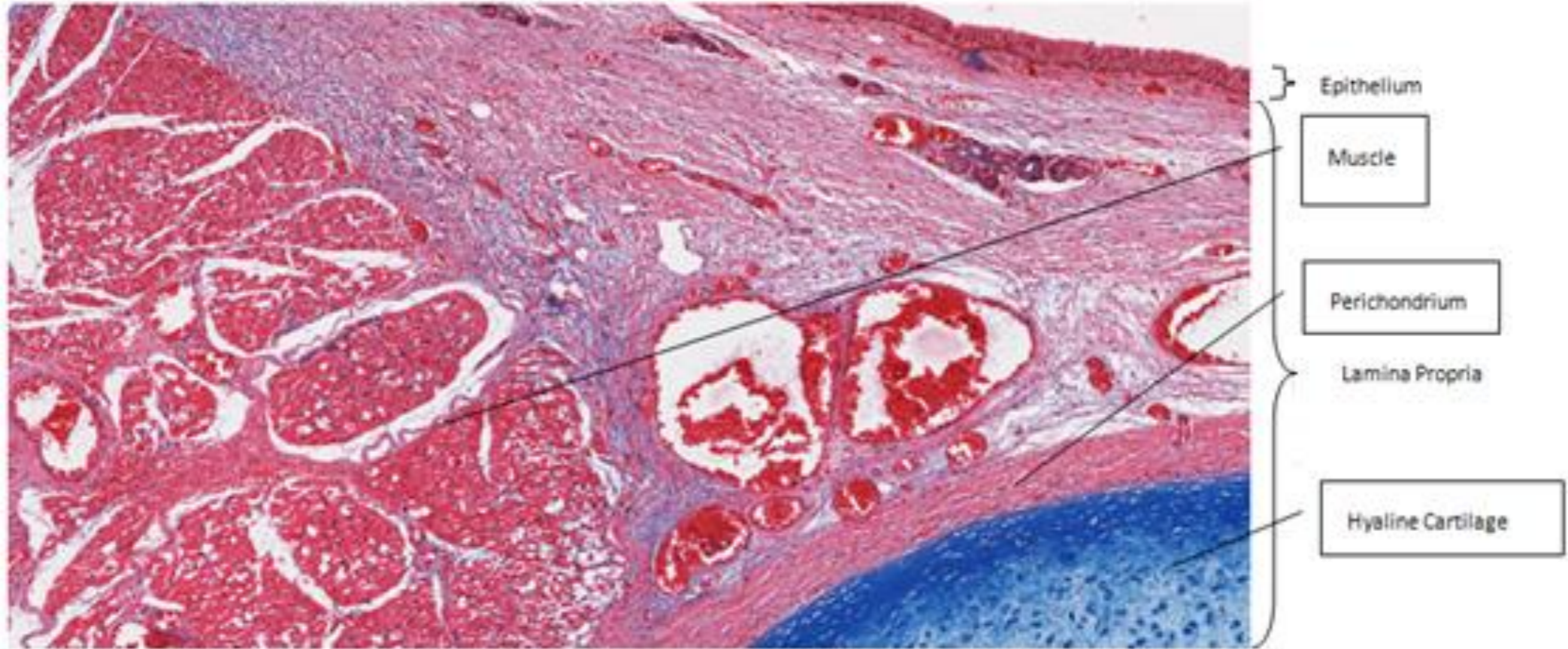
- Vocal ligament
 - An intrinsic ligament within the vocal folds; connects the vocal process of the arytenoid to the thyroid cartilage



The Vocal Folds

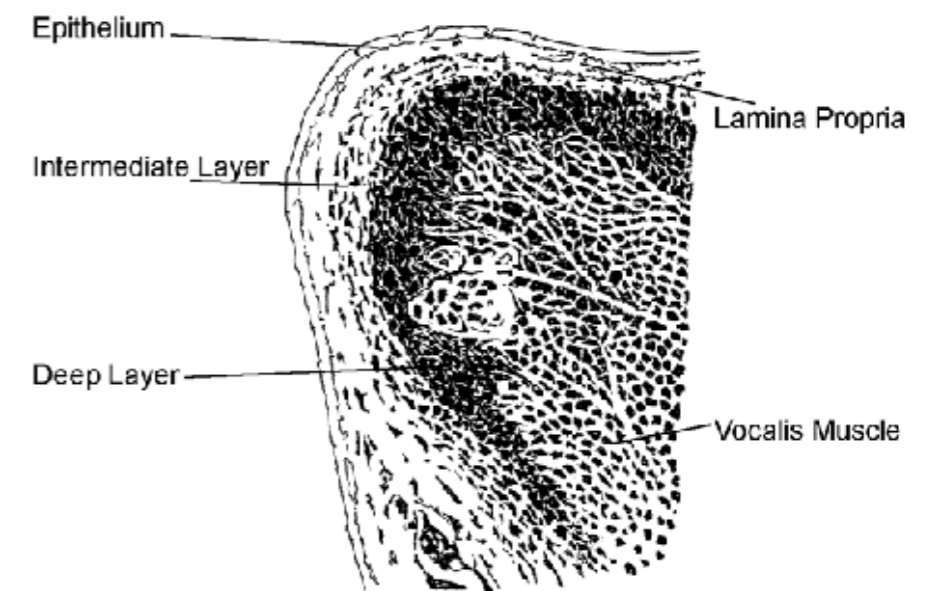
- Consist of 5 layers (as per Hirano)
 1. Epithelium
 2. Superficial Layer of the Lamina Propria
 3. Intermediate Layer of the Lamina Propria
 4. Deep Layer of the Lamina Propria
 5. Thyrovocalis muscle





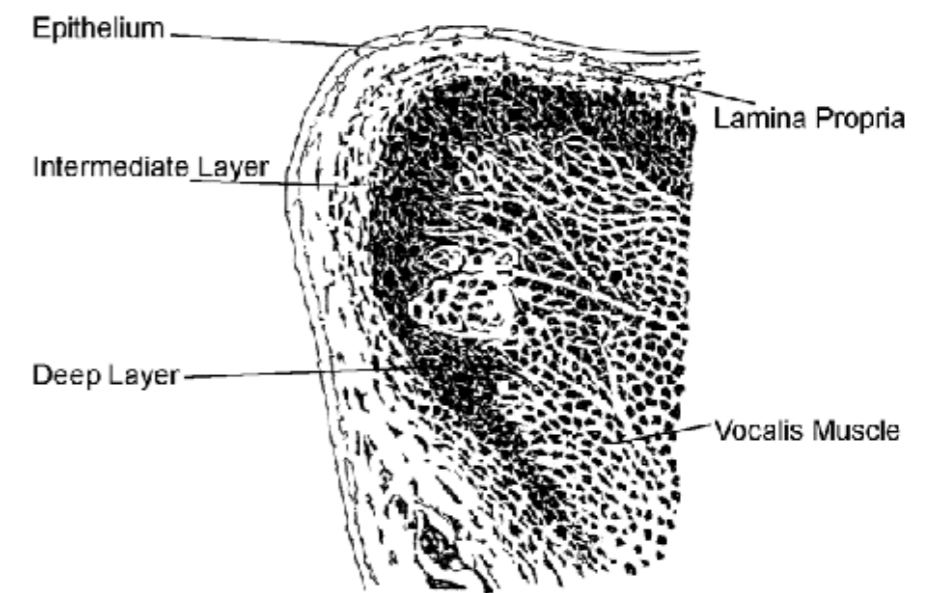
Epithelium

- Epithelium
 - Thin covering (100–180 μm) of the vocal folds, protecting them from their intrinsic and extrinsic environment
 - Pearly white tissue
 - Hydrates the tissue
 - Can regenerate



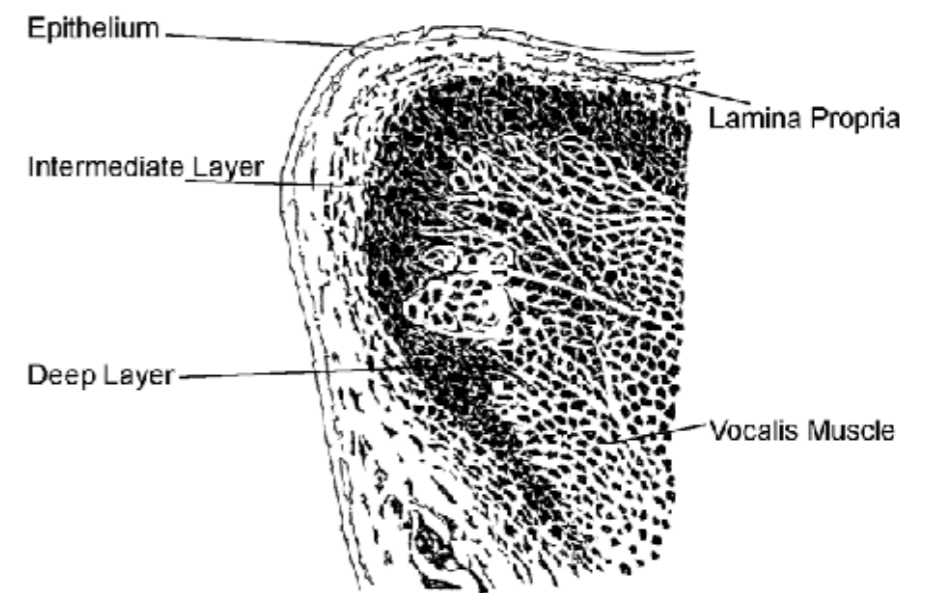
Lamina Propria

- Superficial Layer (“Reinke’s Space”)
 - The main vibrating proportion of the vocal folds
 - The epithelium and superficial layer are commonly referred to as the “cover”
- Cushions the vocal folds; lots of elastin fibers



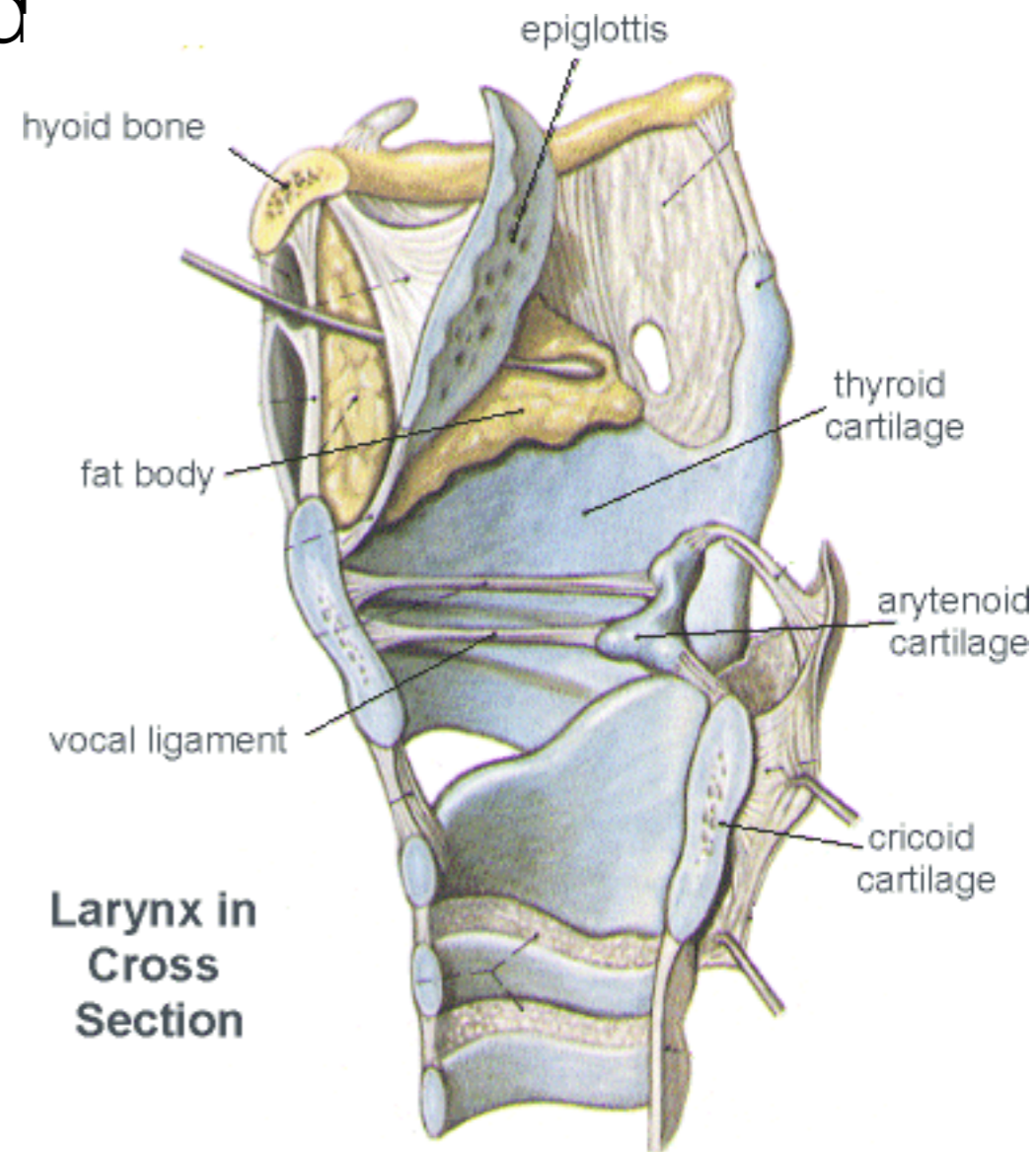
Lamina Propria

- Intermediate Layer
 - Composed mainly of elastic fibers which run parallel to the vibrating edge of the vocal fold, allowing this layer to only stretch in an antero-posterior direction



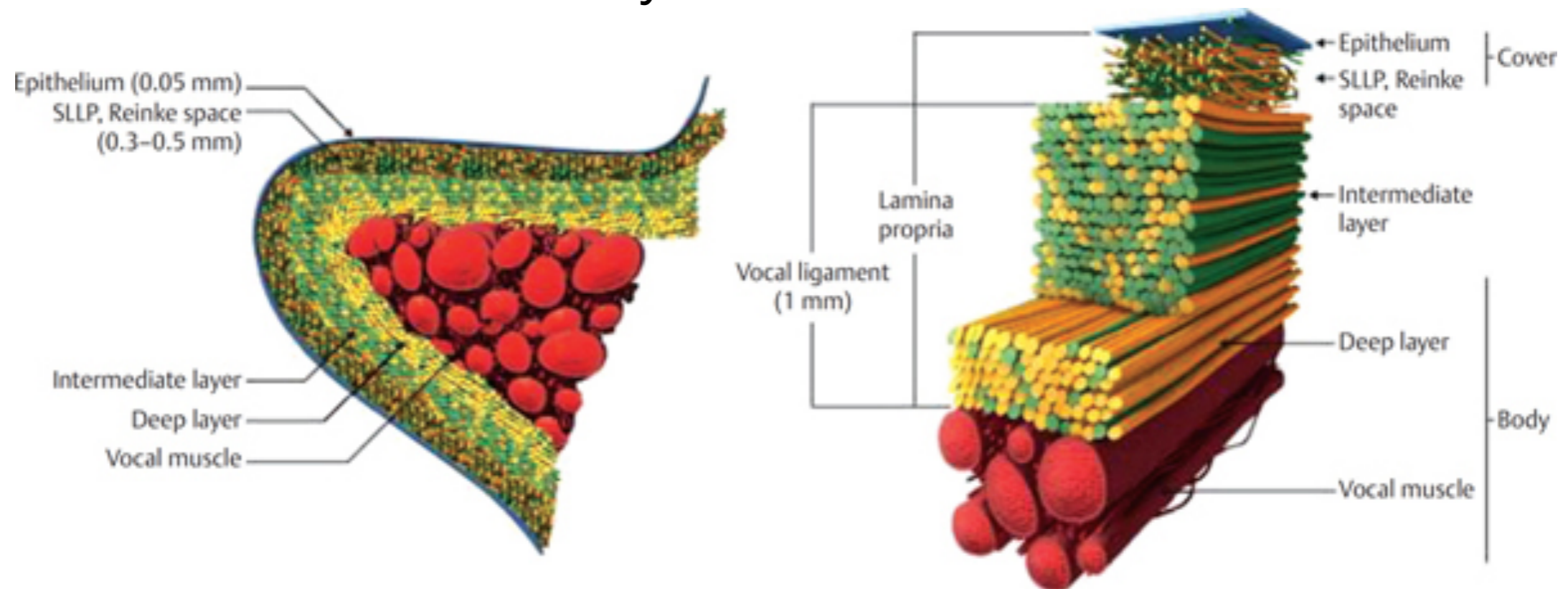
Lamina Propria

- Intermediate + deep layers = vocal ligament
- Each vocal ligament is a band of yellow elastic tissue attached anteriorly to the thyroid cartilage and posteriorly to the vocal process of the arytenoid cartilage



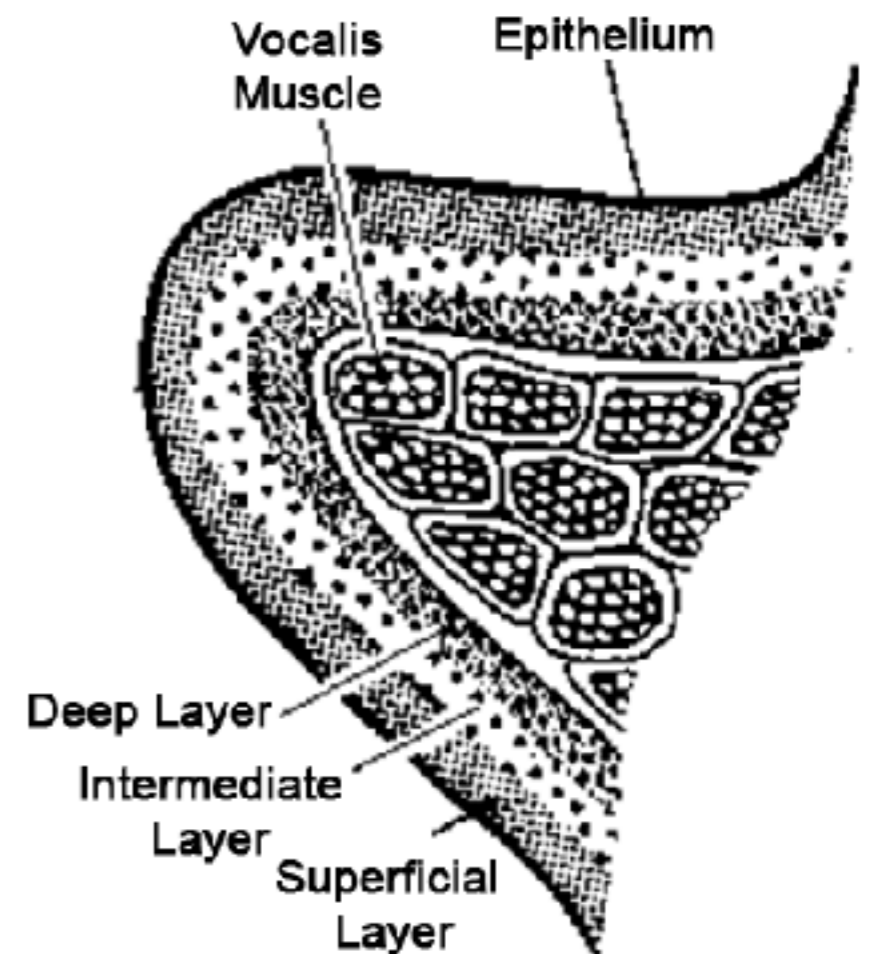
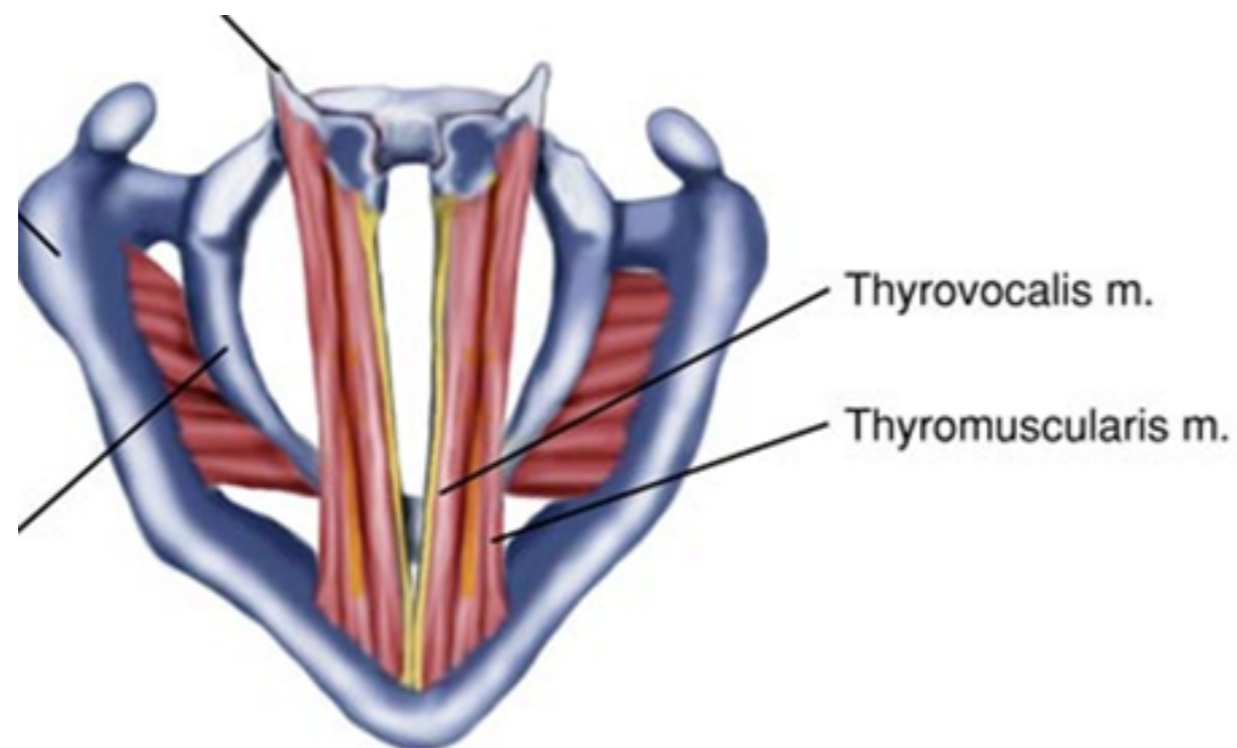
Lamina Propria

- Deep Layer
 - Composed mainly of collagenous fibers which run parallel to the vibrating edge of the vocal fold
 - Deep layer of lamina propria + thyrovocalis muscle = the “body”



Anatomy of the Vocal Folds

- The most medial portion of the thyrovocalis muscle makes up the bulk of the vocal fold structure
- Tenses the vocal folds for vibration



The Extracellular Matrix (ECM)

- “Filler” substance that exists between cells in an organism
- The ECM plays an important role in cell function, particularly in protection against damage and in recovery
- In the vocal folds, the lamina propria is rich in ECM within all layers (superficial, intermediate and deep)

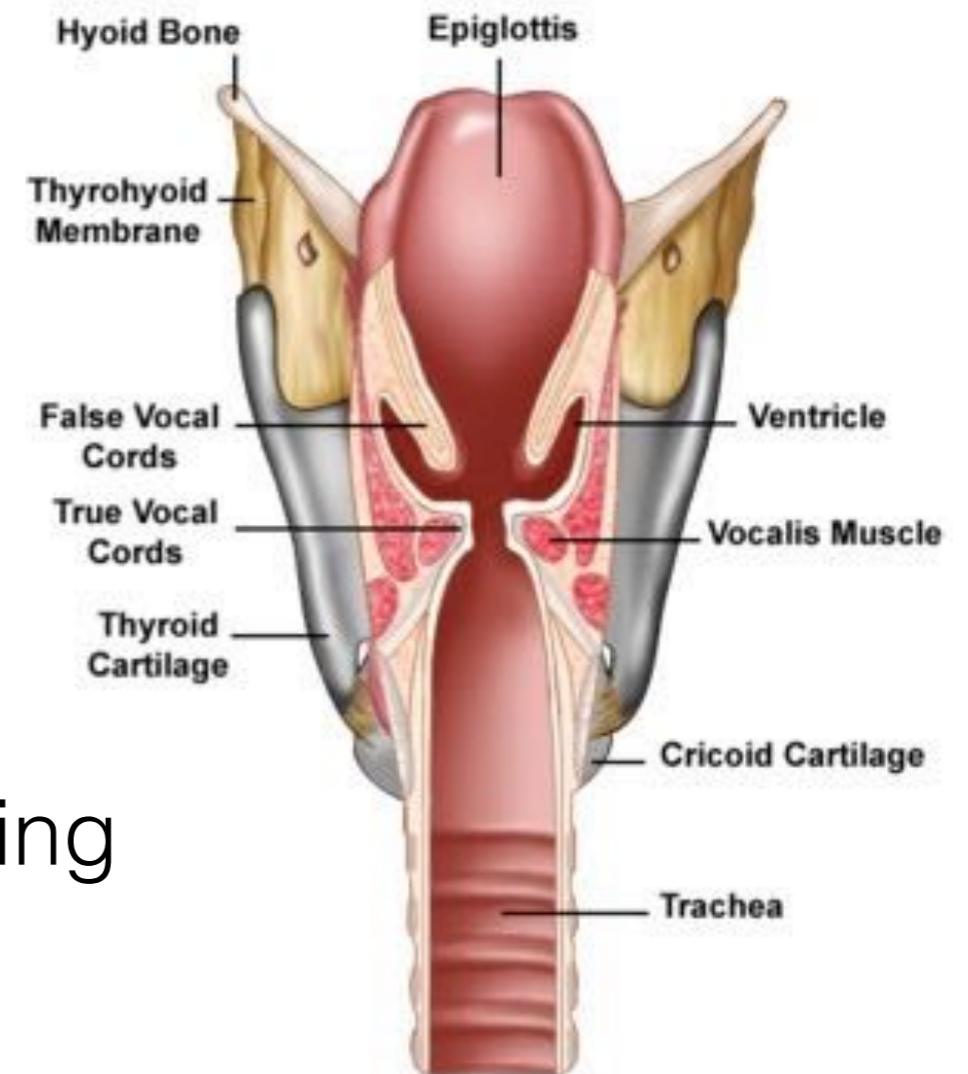
Hyaluronic Acid (HA)

- A chief component in the ECM
- HA molecules hold up to 100x their weight in water
 - Important for impact absorption
- Amount of HA is variable between individuals (genetic factors?)
- The abundant amount of HA observed in the female vocal folds is thought to be related to impact absorption
- Acts as protection against the characteristic high vibration frequency of the female vocal folds

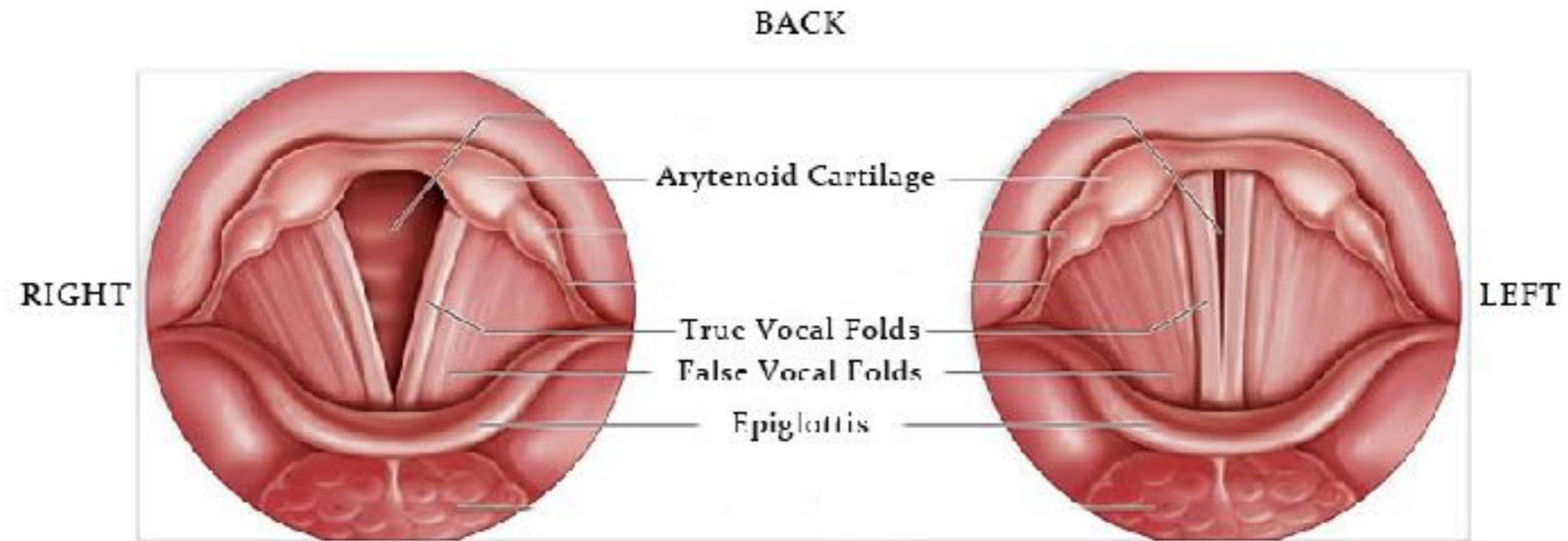


Ventricular Vocal Folds

- Consist of a thick layer of mucous membrane and a supportive ligament (lower edge of quadrangular membrane)
- Not directly involved in voice
 - When they are, it is called diplophonia
- Lubricate vocal folds with mucous and assist in airway protection during swallowing

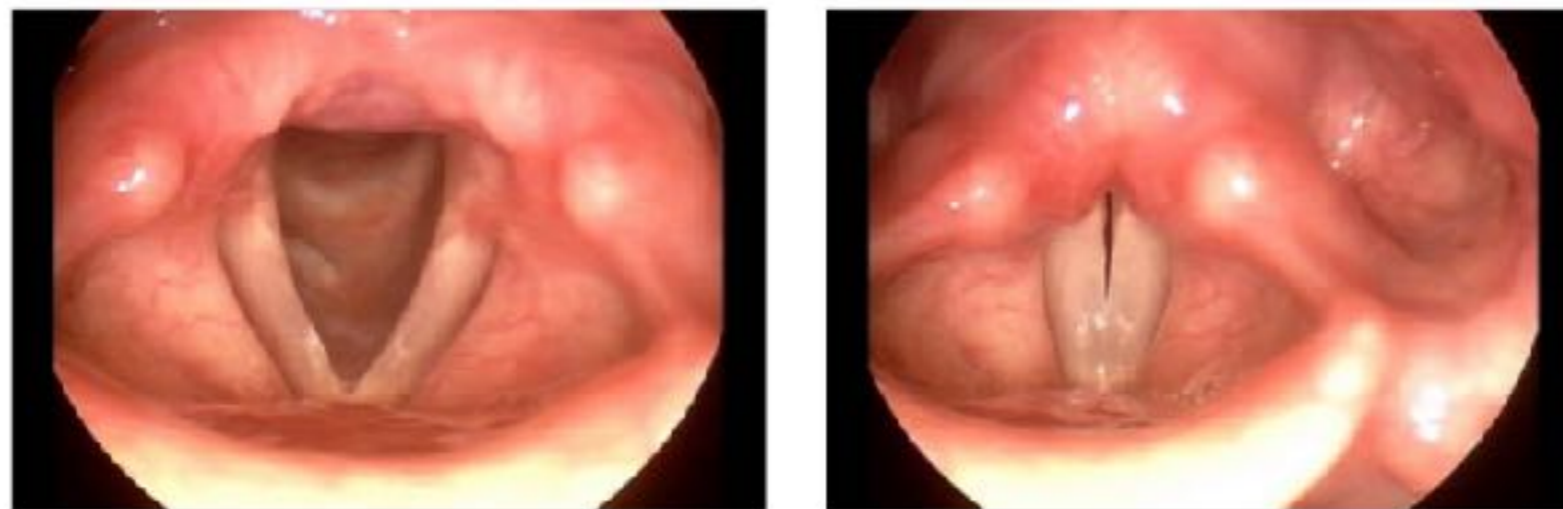


Ventricular Vocal Folds



FRONT

BACK



FRONT

Adult Male and Female Differences in Laryngeal Anatomy

- The most apparent differences:
 - A larger thyroid lamina in males
 - A more acute thyroid angle in males, giving prominence to the thyroid notch or “Adam’s apple”
 - Thicker vocal folds in males
 - Larger glottal space in males

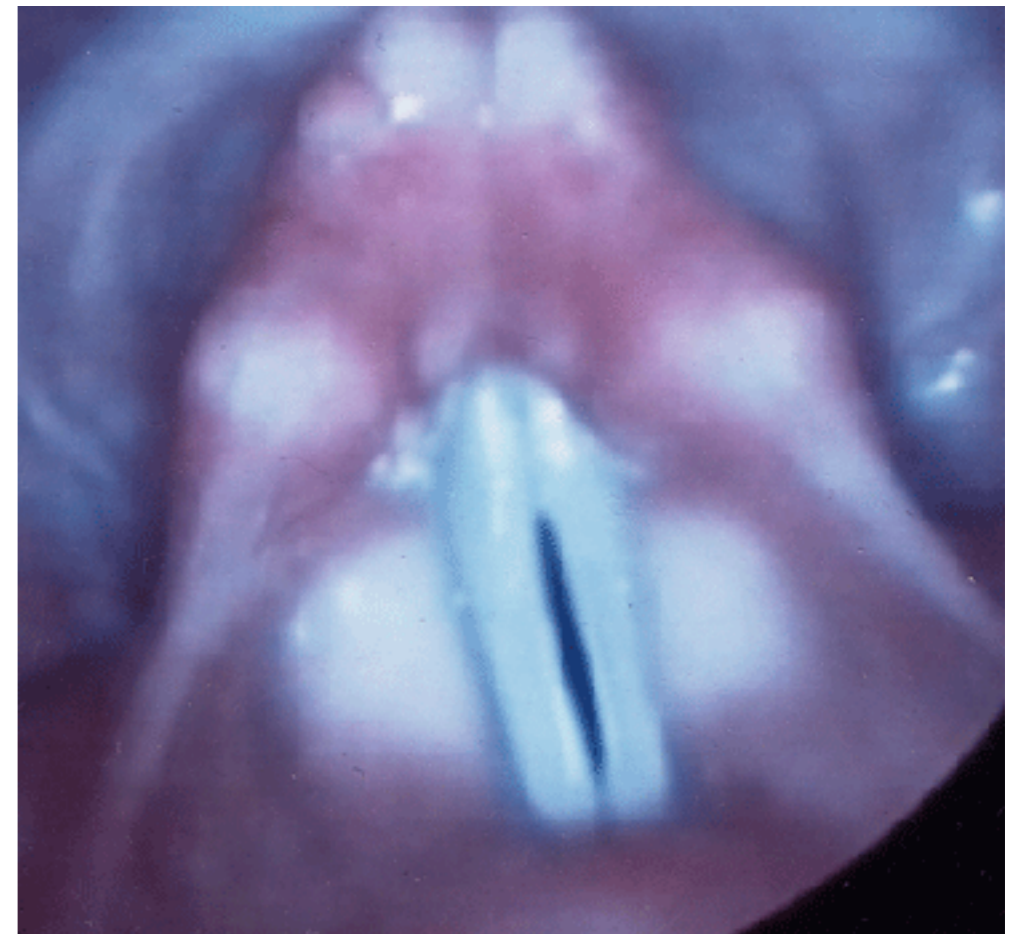
Changes in VF Structure Through the Lifespan

- Newborns
 - No layered structure of LP
 - LP loose and pliable
- Children
 - Vocal ligament appears 1-4 yrs
 - 3-layered LP is not clear until 15 yrs

- Old age
 - Superficial layer becomes edematous & thicker
 - Thinning of intermediate layer and thickening of deep layer
 - Changes in LP more pronounced in men
 - Muscle atrophy

Age Effects on Laryngeal Anatomy

- The following parameters differentiate a young from an older larynx:
 - Vocal fold bowing (inward curvature)
 - Prominence of the vocal process
 - Tremor of the laryngeal structures
- Presbylaryngis: age-related changes to the larynx
- Presbyphonia: age-related changes to the voice



Muscles of the Larynx

Introduction to the Muscles of the Larynx

- 2 types
 - Extrinsic muscles
 - When contracted, set the entire larynx in motion (raising it or lowering it)
 - Intrinsic muscles
 - When contracted, affect the structure of the vocal folds during phonation

Extrinsic Laryngeal Muscles

- We have eight paired extrinsic laryngeal muscles:

Four Elevators

Digastrics: anterior + posterior bellies

Geniohyoids

Mylohyoids

Stylohyoids

Four Depressors

Thyrohyoids

Sternohyoids

Omohyoids

Sternothyroids

Extrinsic Laryngeal Muscles

- Suprahyoids:

- Four Elevators

- Digastrics: anterior + posterior bellies
- Geniohyoids
- Mylohyoids (largest)
- Stylohyoids

Di = two, gastric = belly

Genio = chin

Hyoid = Hyoid Bone

Mylo = molar (lower jaw)

Stylo = Styloid process of the temporal bone of the skull

Extrinsic Laryngeal Muscles

- Infrahyoids:
 - Four Depressors
 - Thyrohyoids
 - Sternohyoids
 - Omohyoids (most superficial)
 - Sternothyroids (deepest)
-
- Thyro = Thyroid Cartilage
Sterno = Sternum
Omo = Shoulder

Mnemonic

- Experts Don't Get Many Stylish Or Sexy Things, Sadly

Extrinsics:

Digastrics
Geniohyoids
Myllohyoids
Stylohyoids

Omohyoids
Sternohyoids
Thyrohyoids
Sternothyroids

Suprahyoids
'Elevators'

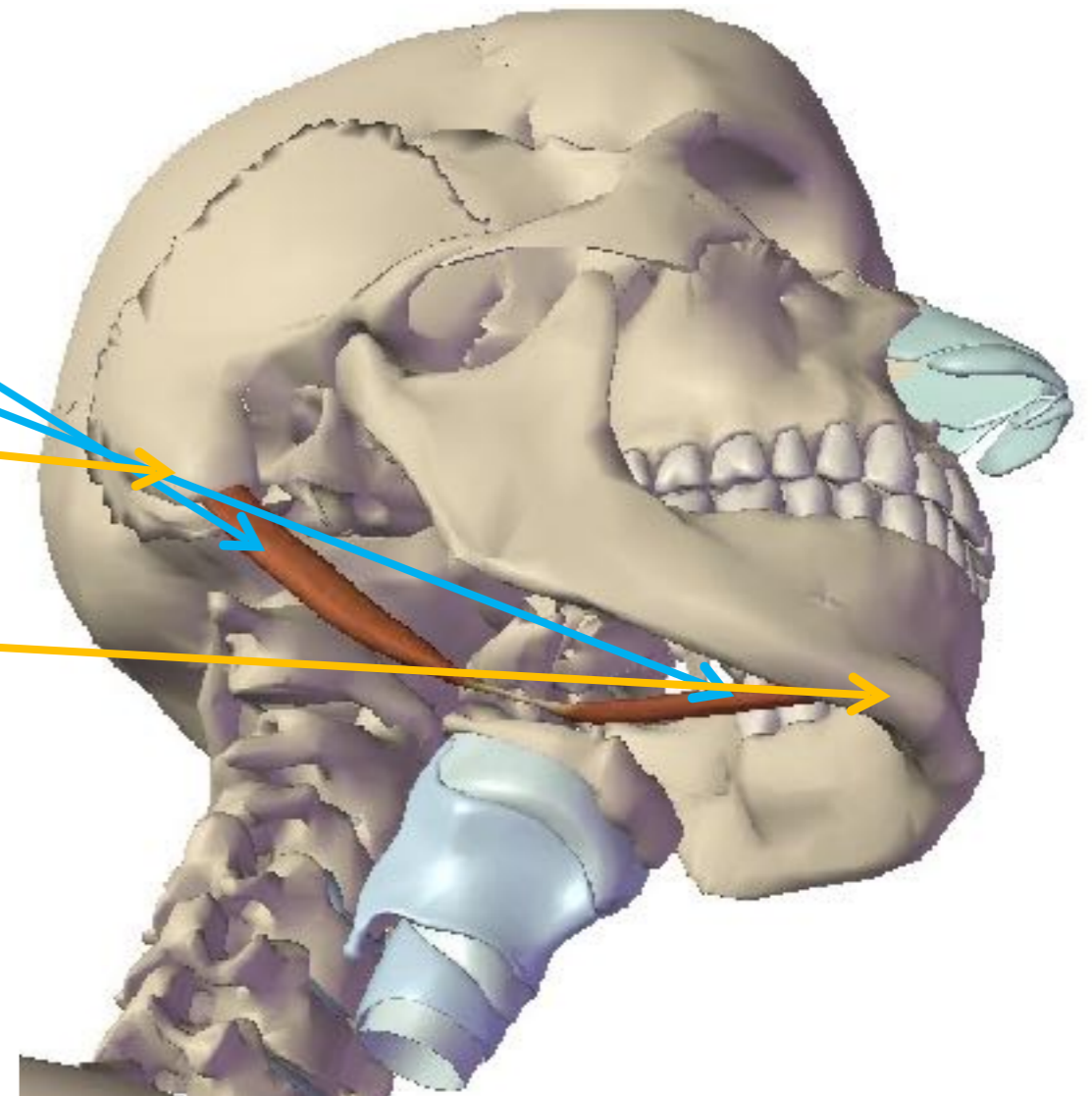
Infrahyoids
'Depressors'



Suprahyoids

Digastrics

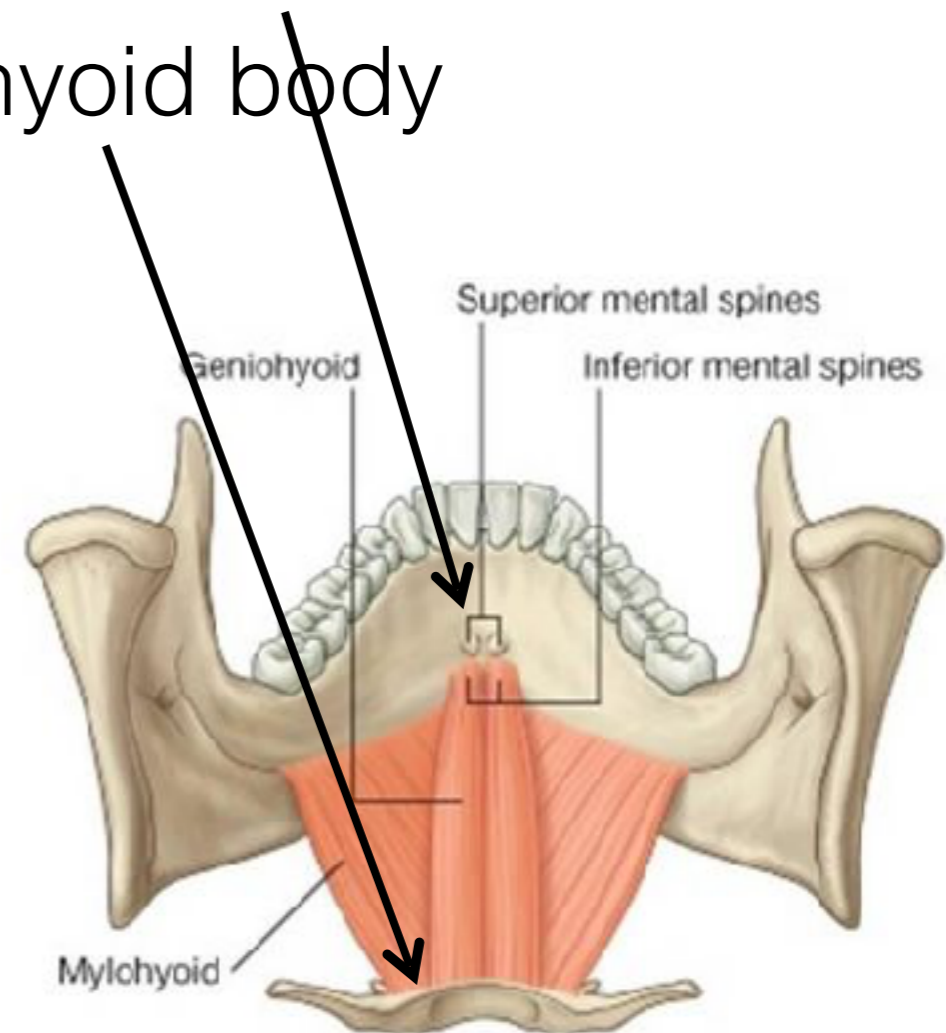
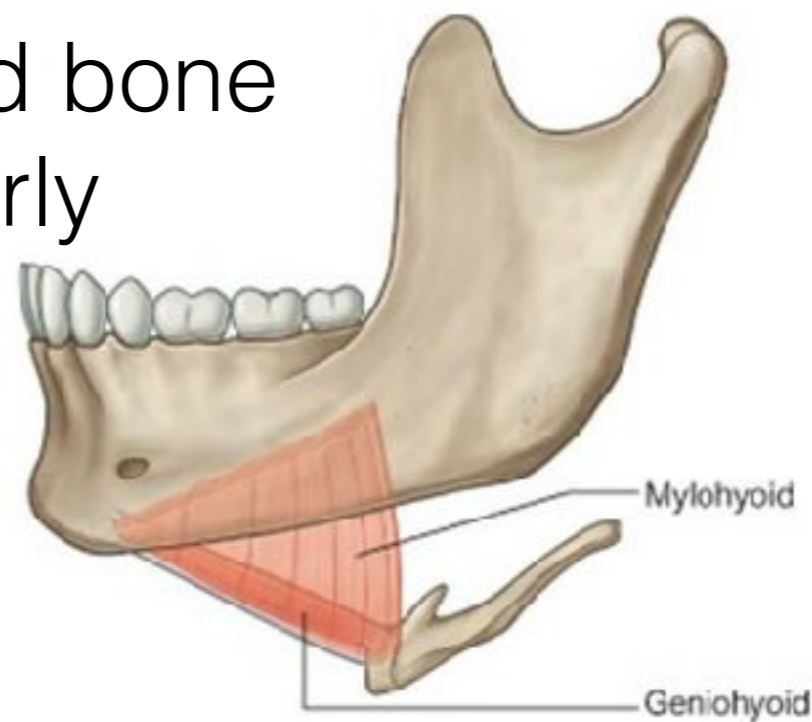
- 2 muscle sections:
 - Posterior belly
 - Anterior belly
- Origin:
 - Mastoid process (for the posterior belly)
 - Mandible (for anterior belly)
- Insertion: intermediate tendon connected with the hyoid bone



Note: Only Right Digastric shown

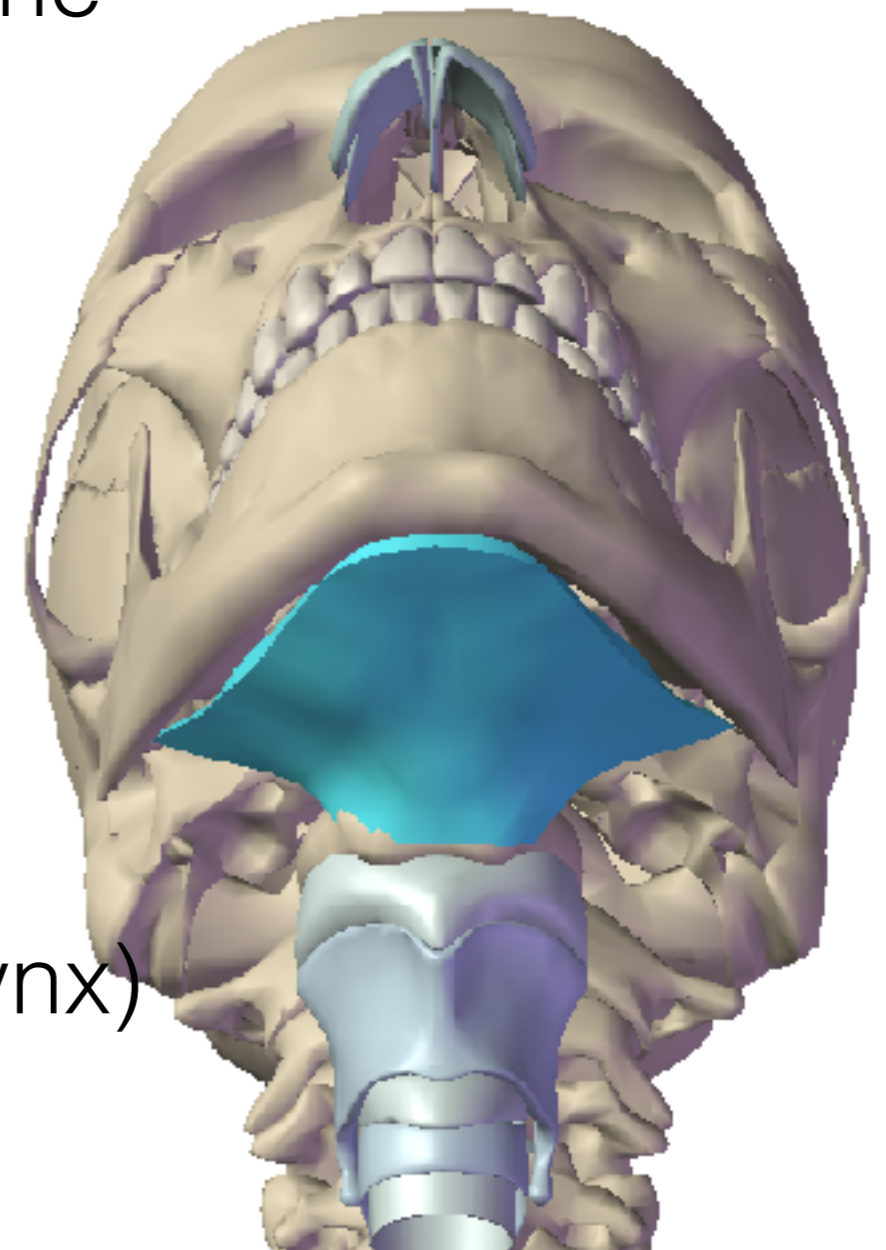
Geniohyoids

- Cylindrical muscle, lies deep (relative to the skin) on the surface of the mylohyoids
- Origin: mandibular symphysis of mandible
- Insertion: anterior surface of the hyoid body
- Function: pulls the hyoid bone anterosuperiorly (and thus the larynx)



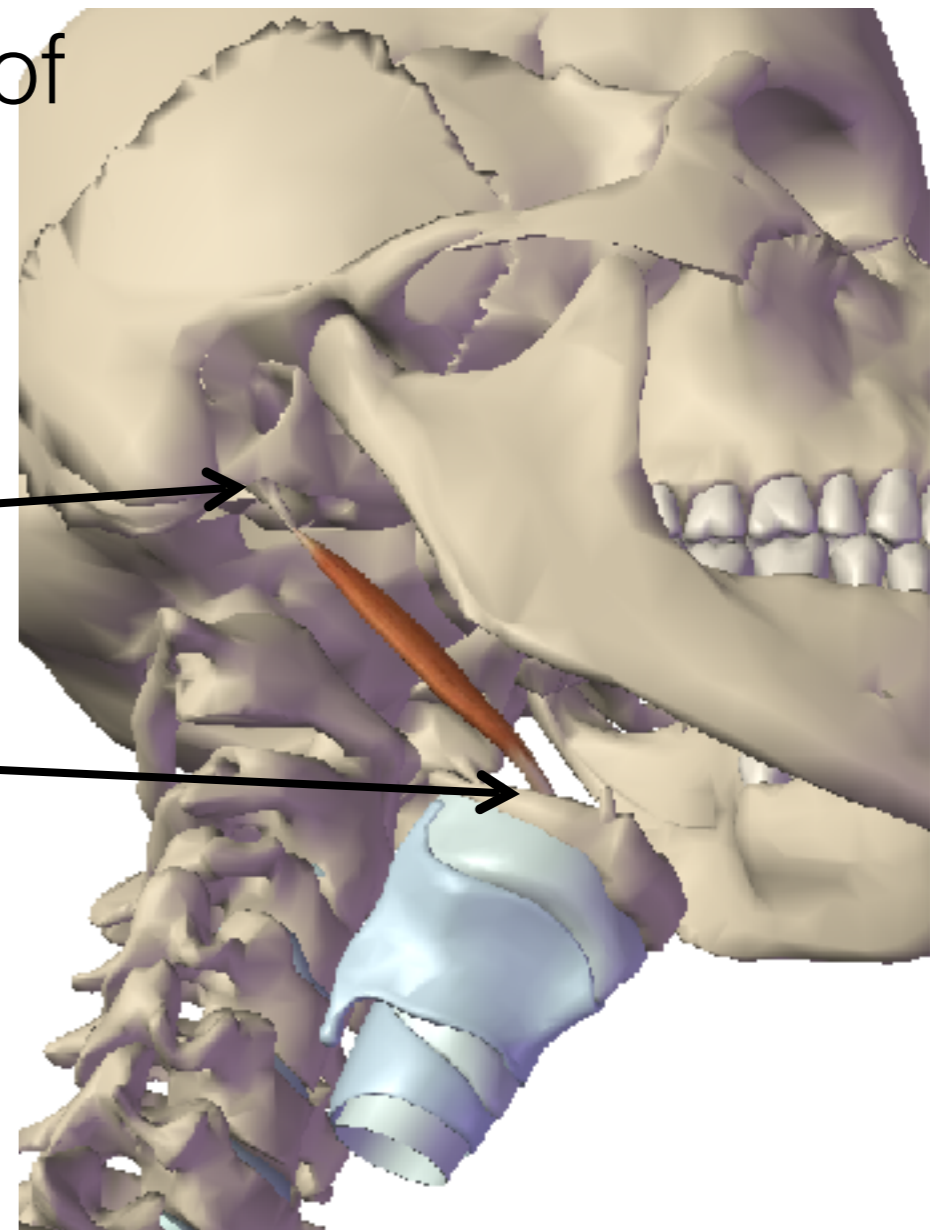
Mylohyoids

- Thin muscles forming the floor of the mouth
- Origin: inner surface of the mandible
- Insertion: fibers unite at midline raphe and extend to the hyoid body
- Function: Pulls the hyoid bone anterosuperiorly (and thus the larynx)



Stylohyoids

- Long slender muscle located on the surface of the posterior belly of the digastrics
- Origin: styloid process of the temporal bone
- Insertion: body of the hyoid
- Function: Elevate the hyoid bone

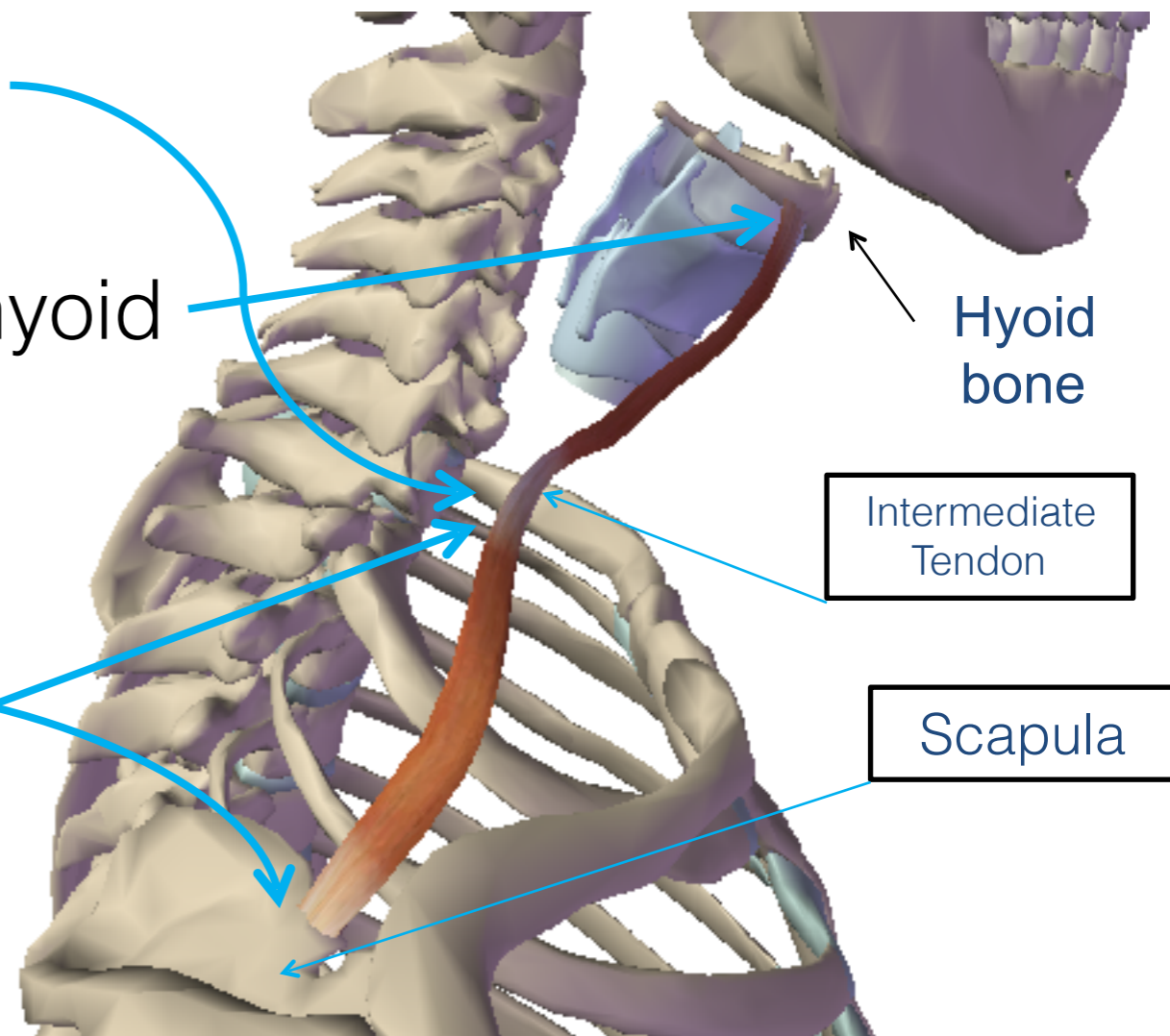


Note: Only Right Stylohyoid shown

Infrahyoids

Omohyoids

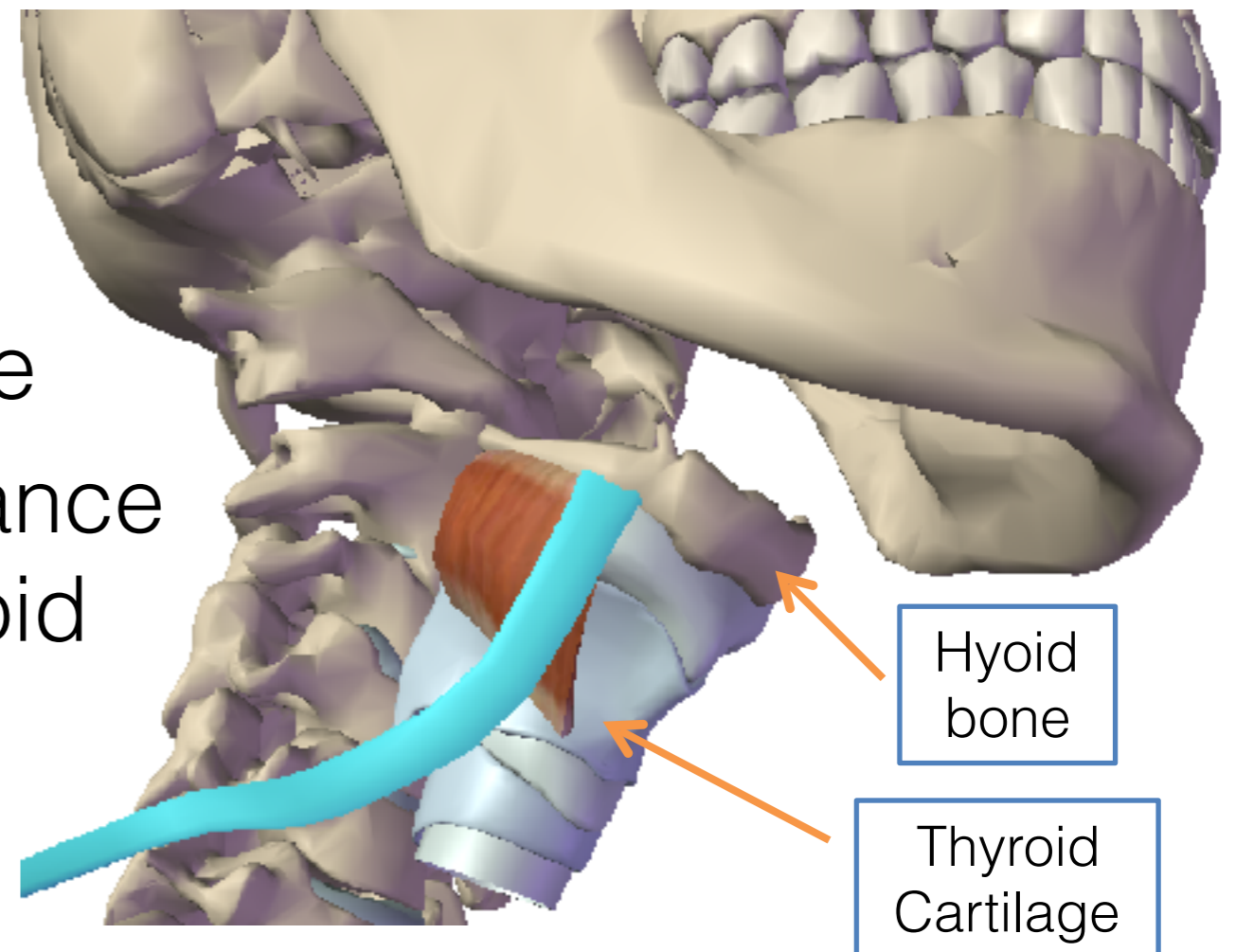
- 2 bellies: inferior + superior
- Function: Lower the thyroid
- Superior belly
 - Origin: intermediate tendon connected with the hyoid
 - Insertion: great horn of the hyoid
- Inferior belly
 - Origin: surface of the scapula
 - Insertion: intermediate tendon



Note: Only Right Omohyoid shown

Thyrohyoids

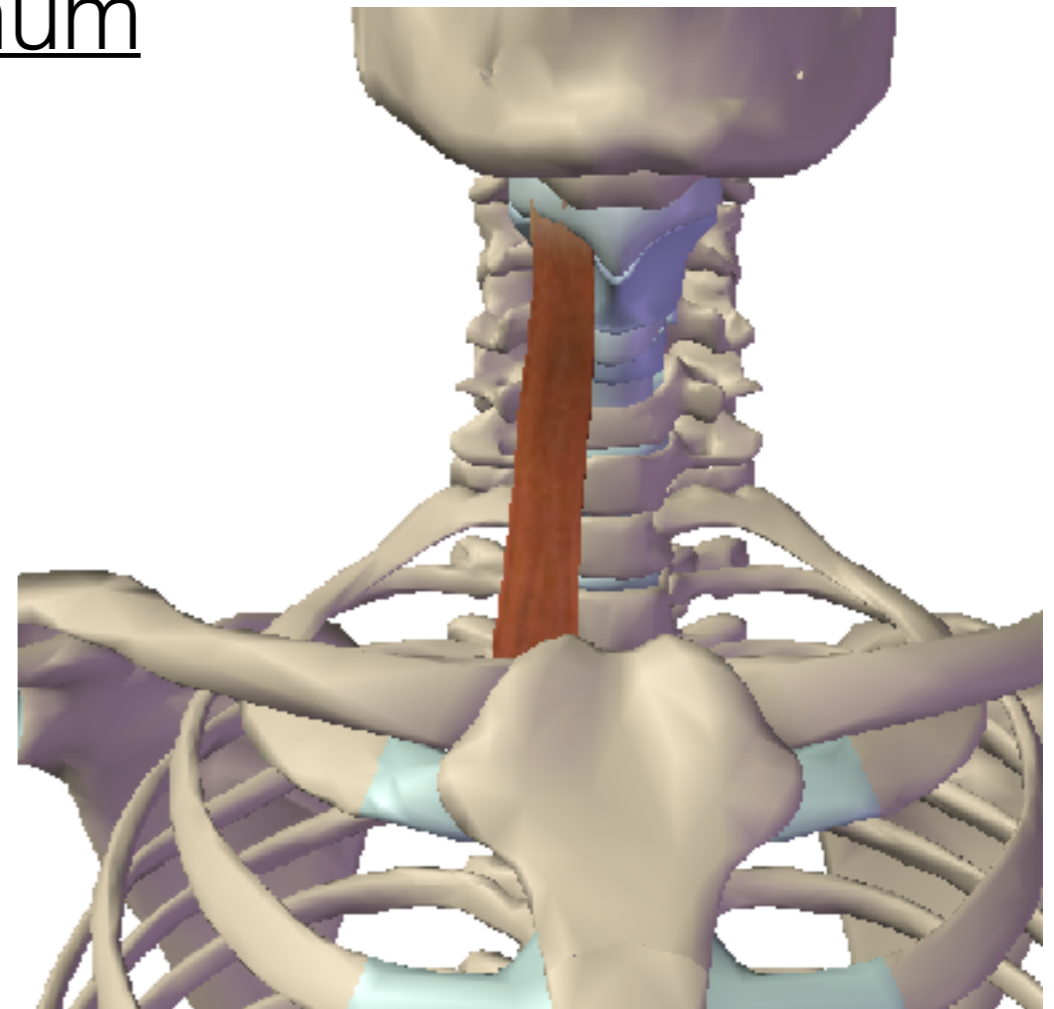
- Shown in red
- Thin muscle lying deep to the omohyoids (shown in blue)
- Origin: oblique line of the thyroid lamina
- Insertion: greater horn (cornu) of the hyoid bone
- Function: decrease distance between thyroid and hyoid



Note: Only Right Thyrohyoid shown

Sternohyoids

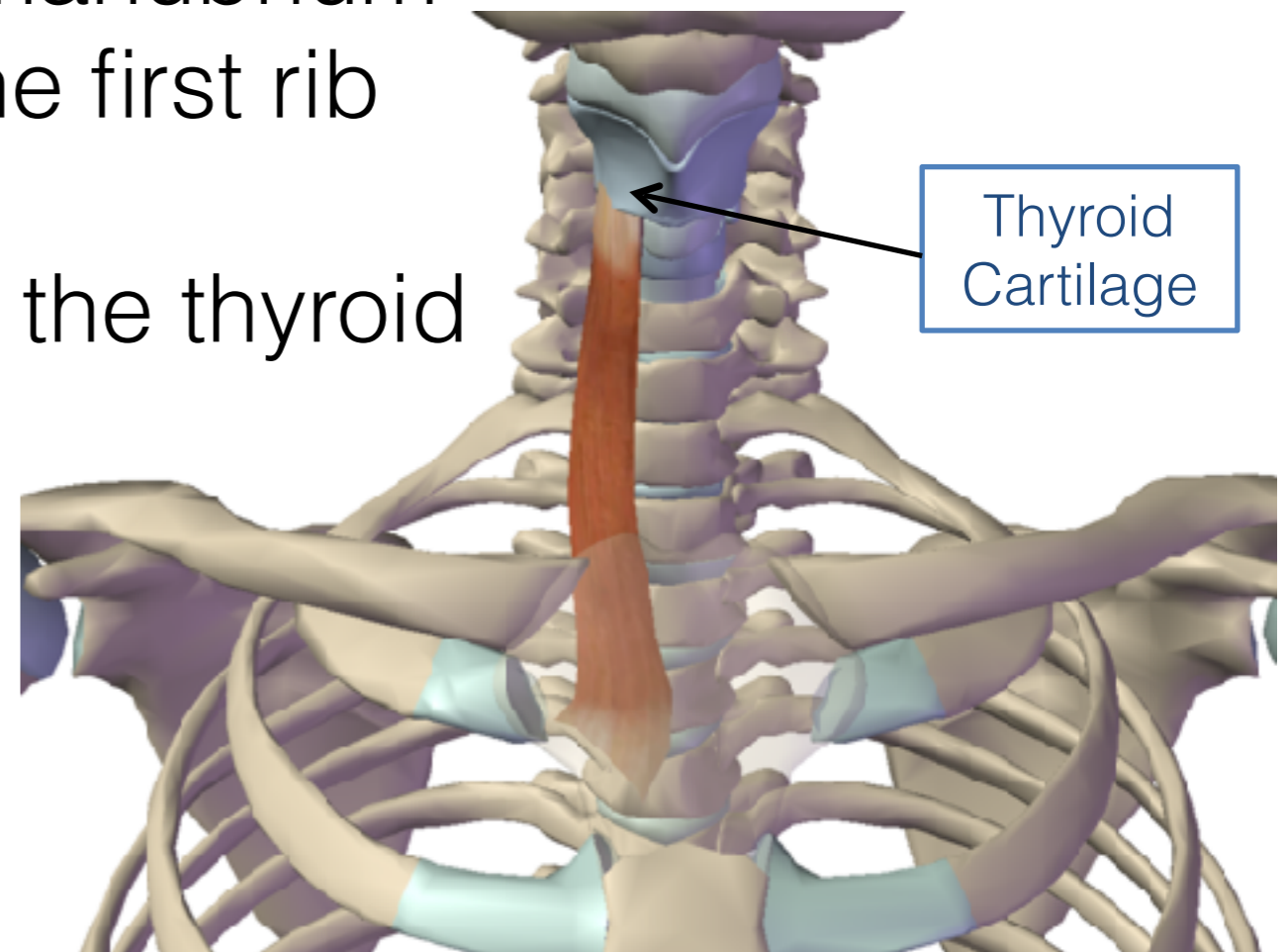
- Thin muscle lying on anterior side of the neck
- Origin: Manubrium of the sternum and end of the clavicle
- Insertion: hyoid
- Function: Pulls down the hyoid bone



Note: Only Right Sternohyoid shown

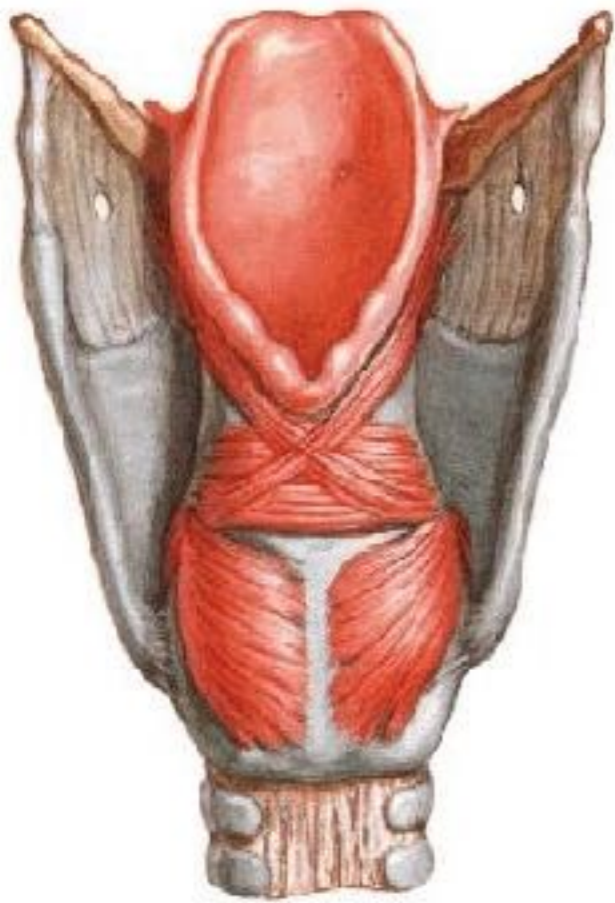
Sternothyroids

- Long thin muscle on anterior side of the neck
- Origin: Underneath the manubrium and costal cartilage of the first rib
- Insertion: Oblique line of the thyroid
- Function: Pulls down the thyroid



Note: Only Right Sternothyroid shown

Intrinsic Laryngeal Muscles



Intrinsic Laryngeal Muscles

- Responsible for controlling sound production
- Interarytenoid:
 - Oblique
 - Transverse
- Cricoarytenoids:
 - Lateral
 - Posterior
- Cricothyroids
- Thyroarytenoids

Mnemonic

- In Indianna, On Thursdays, Crazy, Lanky People Cook Tacos

Intrinsics: Interarytenoid:
- Oblique
- Transverse

Cricoarytenoids:
- Lateral
- Posterior

Cricothyroids
Thyroarytenoids

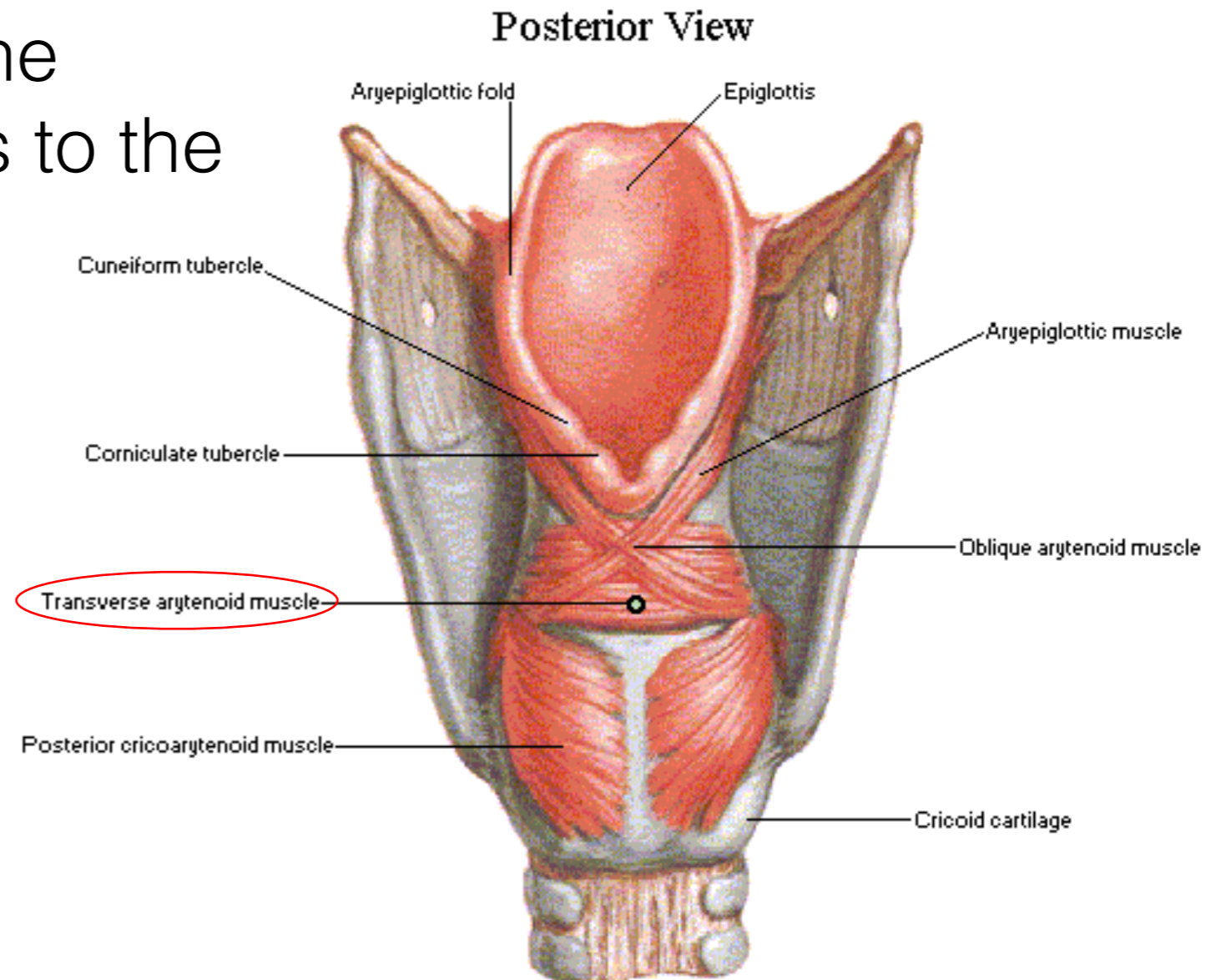
I DON'T WANNA



TACO BOUT IT

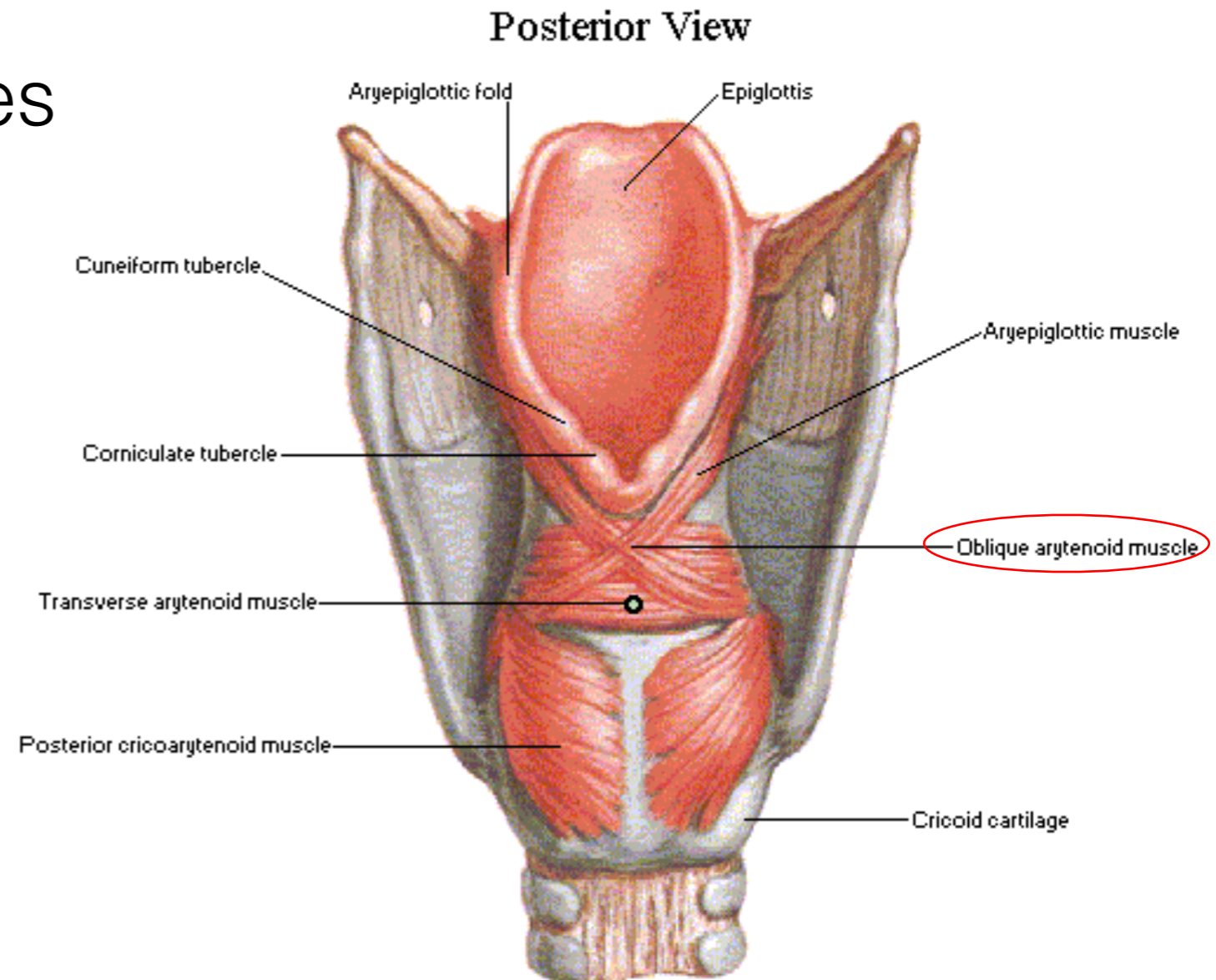
Transverse Interarytenoid

- Unpaired muscle
- Origin: Lateral margin and posterior surface of one arytenoid and courses to the lateral margin of the other arytenoid
- Insertion: Arytenoid of the opposite side
- Function: Adducts arytenoids/closes the glottis



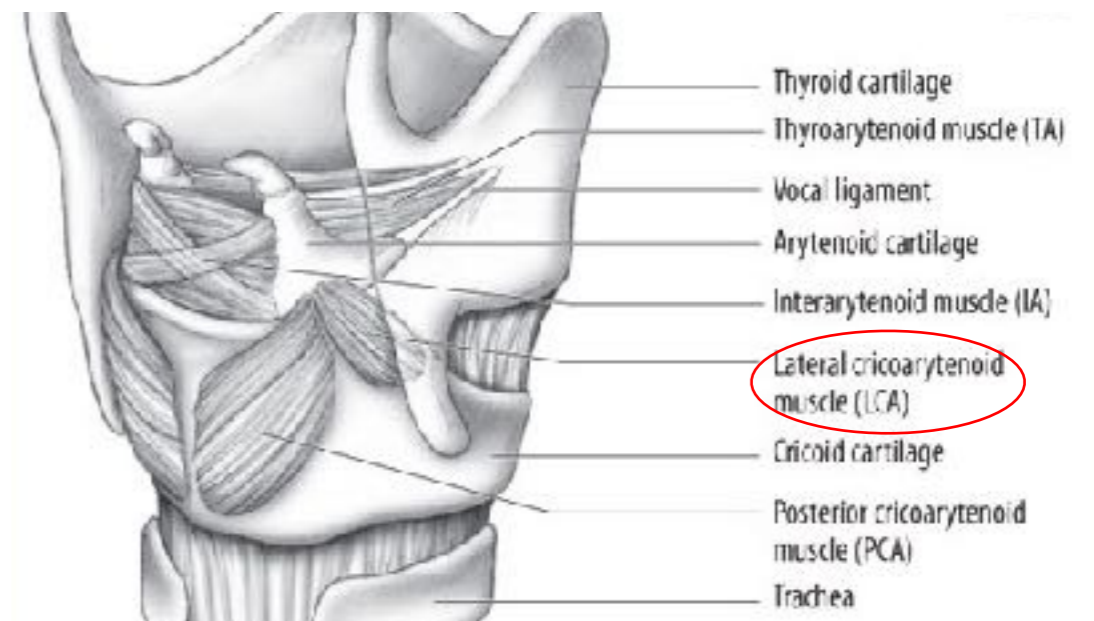
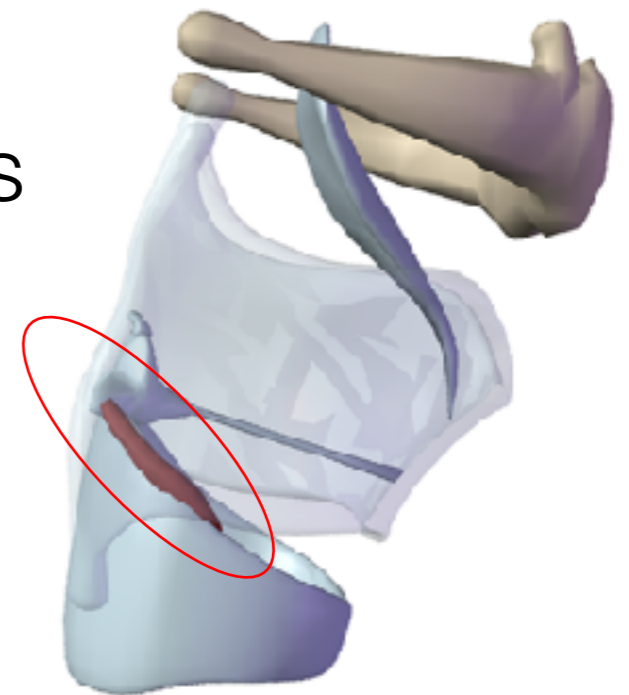
Oblique Interarytenoids

- Superficial to the transverse interarytenoid
- Origin: Base of one arytenoid and courses to the apex of the other arytenoid
- Insertion: Arytenoid of the opposite side
- Function: Adducts arytenoids/closes the glottis



Lateral Cricoarytenoids

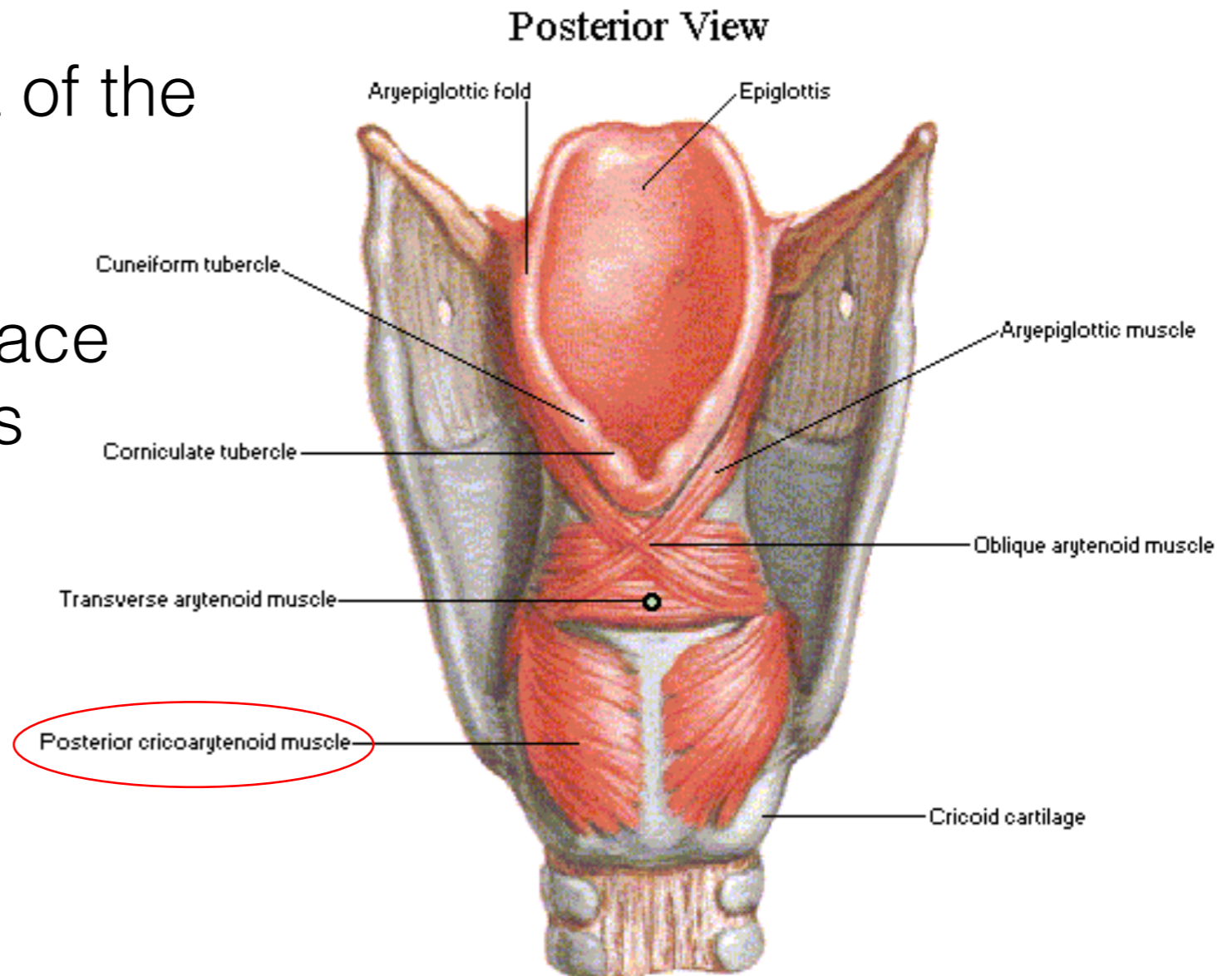
- Located along the upper surface of the cricoid cartilage, *lateral* to the vocal folds
- Origin: Upper border of the cricoid
- Insertion: Anterior surface of the muscular process of the arytenoid
- Function: Adducts the vocal processes of the arytenoids, i.e. closing the glottis



Note: Only Right Lateral Cricoarytenoid shown

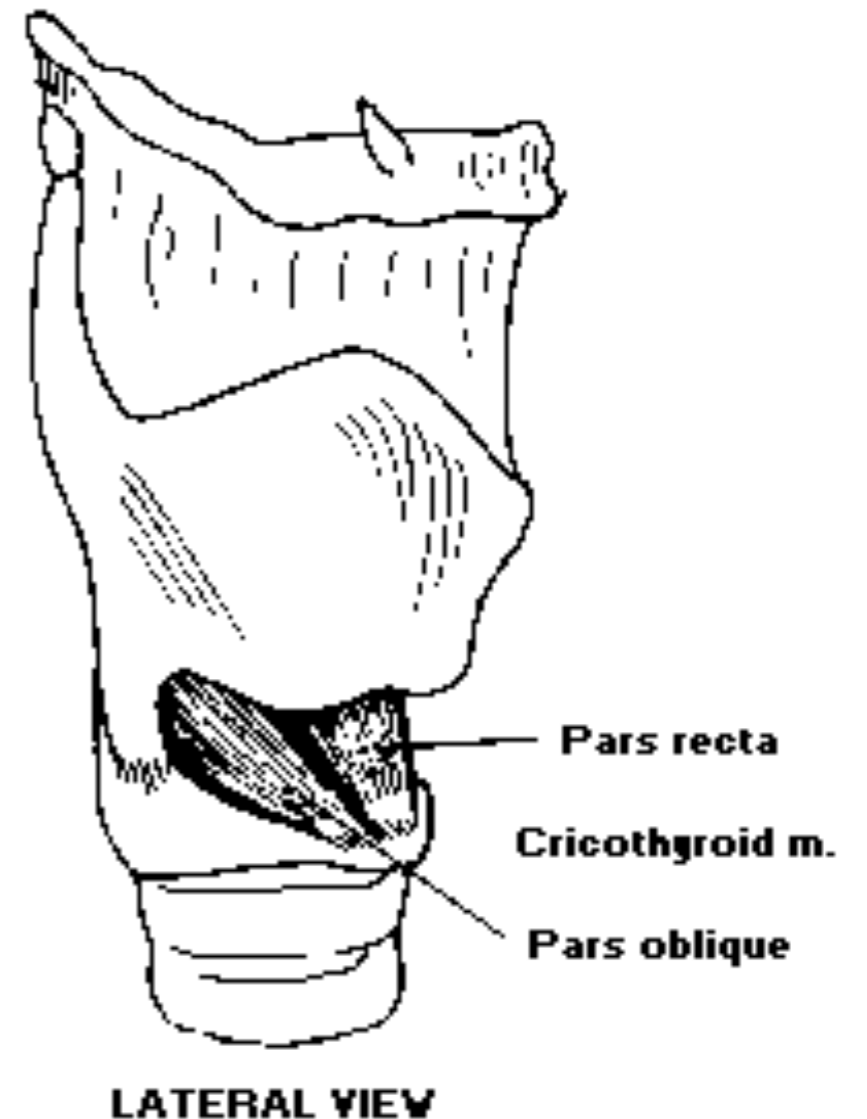
Posterior Cricoarytenoids

- A fan-shaped muscle located on the posterior surface of the cricoid
- Origin: Posterior lamina of the cricoid
- Insertion: Posterior surface of the muscular process of the arytenoid
- Function: Abducts the arytenoids i.e. opens the glottis



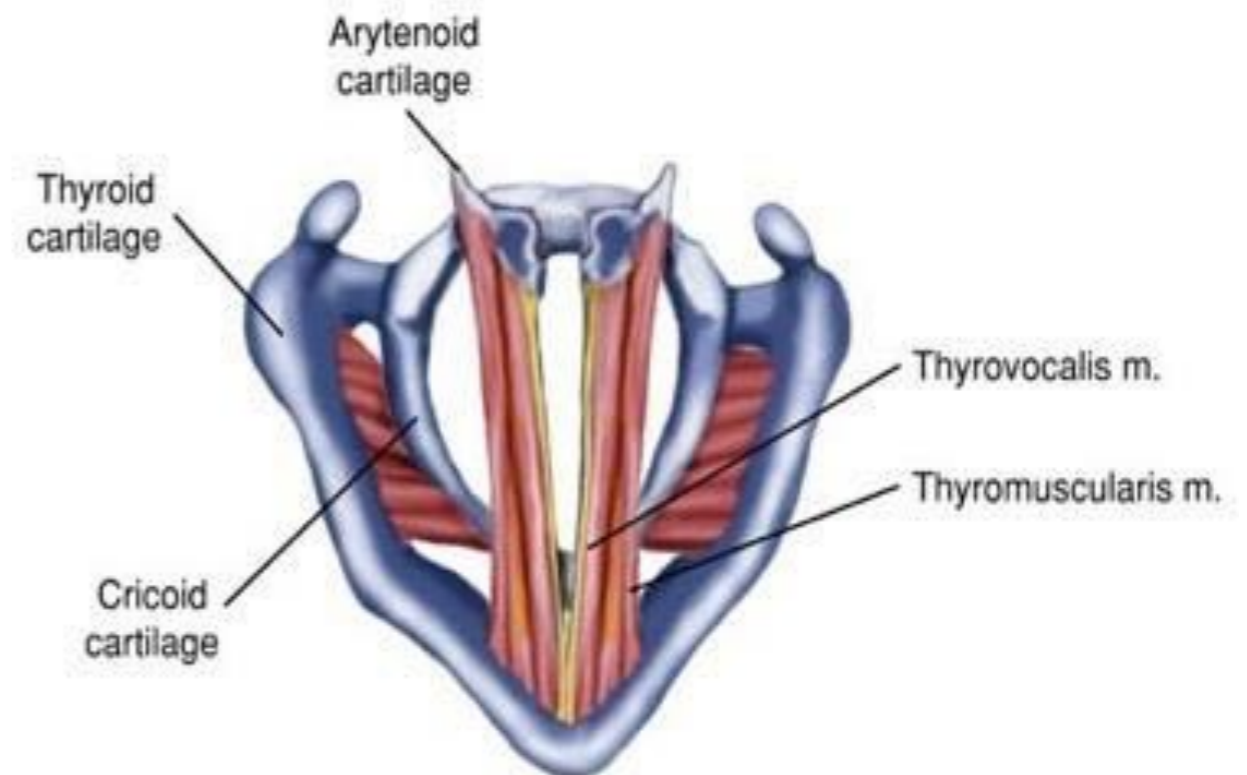
Cricothyroid

- Located between the cricoid and thyroid consisting of fibers oriented in 2 directions:
 - pars oblique and pars recta
- Origin: Arch of cricoid
- Insertion: Inferior margin of the thyroid
- Function: decrease the distance between thyroid and cricoid, i.e. increase the distance between the thyroid and arytenoids → increase vocal fold tension → increase their vibration rate



Thyroarytenoid

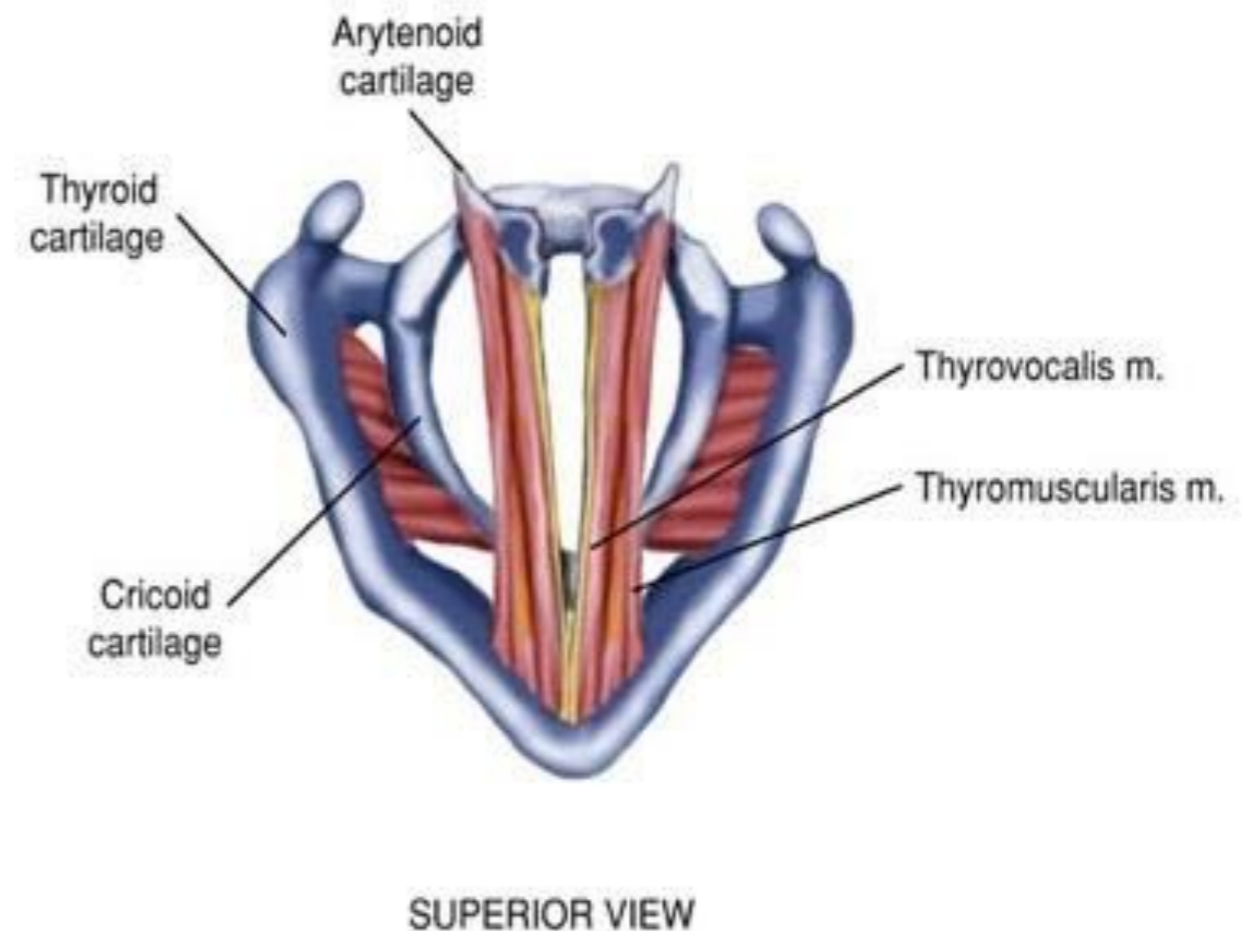
- A bundle of fibers making up the true vocal folds, divided into:
 - Thyrovocalis muscle (medially and more active)
 - Increases VF tension to increase pitch
 - Thyromuscularis muscle (laterally and less active)
 - Decreases VF tension to decrease pitch



SUPERIOR VIEW

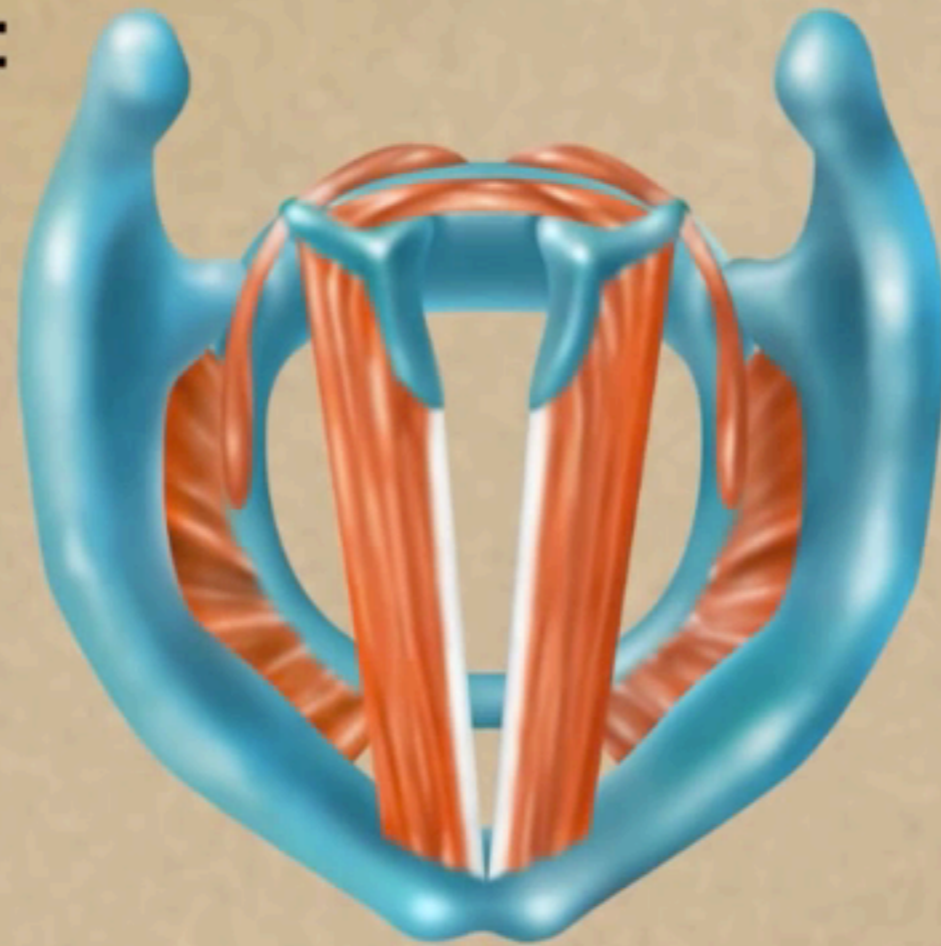
Thyroarytenoid continued

- Origin: Anteriorly, from the inner anterior surface of the thyroid
- Insertion: Along the lateral base of an arytenoid from the vocal process to the muscular process



Putting it all together

Part III:



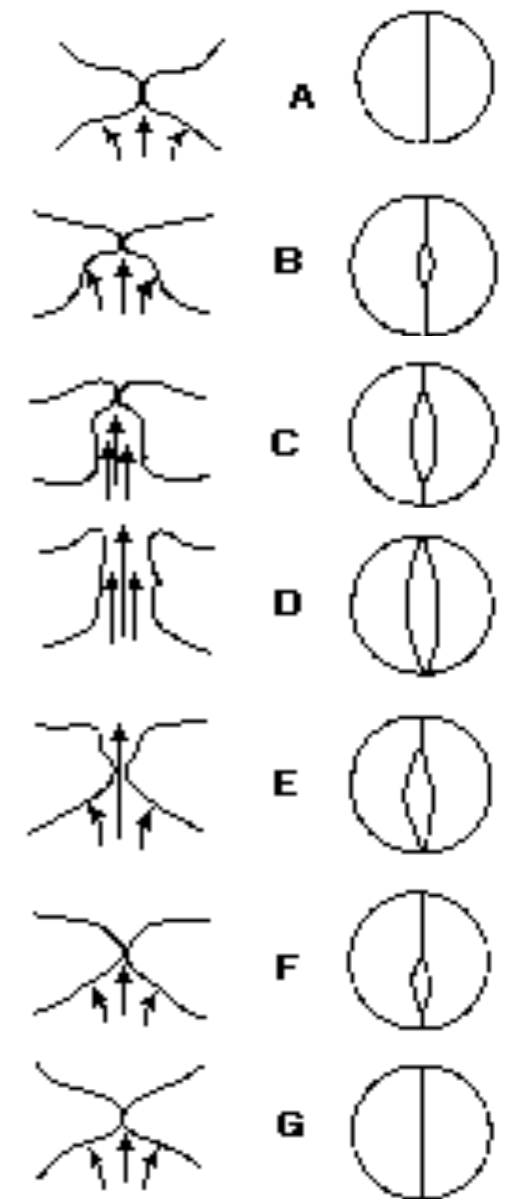
Summary of Vocal Fold Function

- Adduction
 - Interarytenoids (transverse + oblique)
 - Lateral cricoarytenoid (LCA)
- Abduction
 - Posterior cricoarytenoid (PCA)
- Raising pitch
 - Cricothyroid, thyrovocalis
- Lowering pitch
 - Thyromuscularis

Theories of Phonation

Myoelastic Aerodynamic Theory of Voice Production

1. Vocal folds adduct
2. Air pressure builds under the vocal folds
3. Pressure moves the vocal folds laterally (lateral direction is due to elasticity of folds). Inferior border separates first
4. Vocal folds return to adducted position (Bernoulli effect)
5. Cycle is repeated hundreds of times per second





Direct Simultaneous Measurement of Intraglottal Geometry and Velocity Fields in Excised Larynges

Sid Khosla, MD; Liran Oren, PhD; Jun Ying, PhD; Ephraim Gutmark, PhD

Flow separation vortices produce negative pressure which induces rapid closing

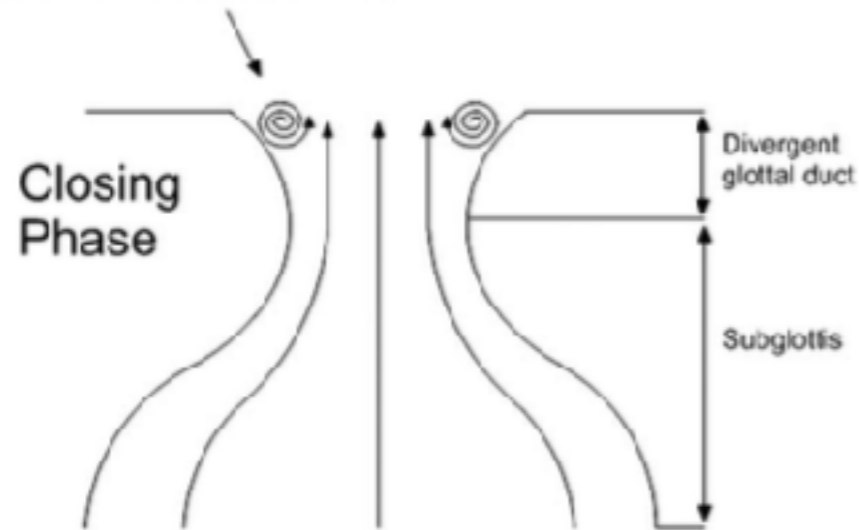
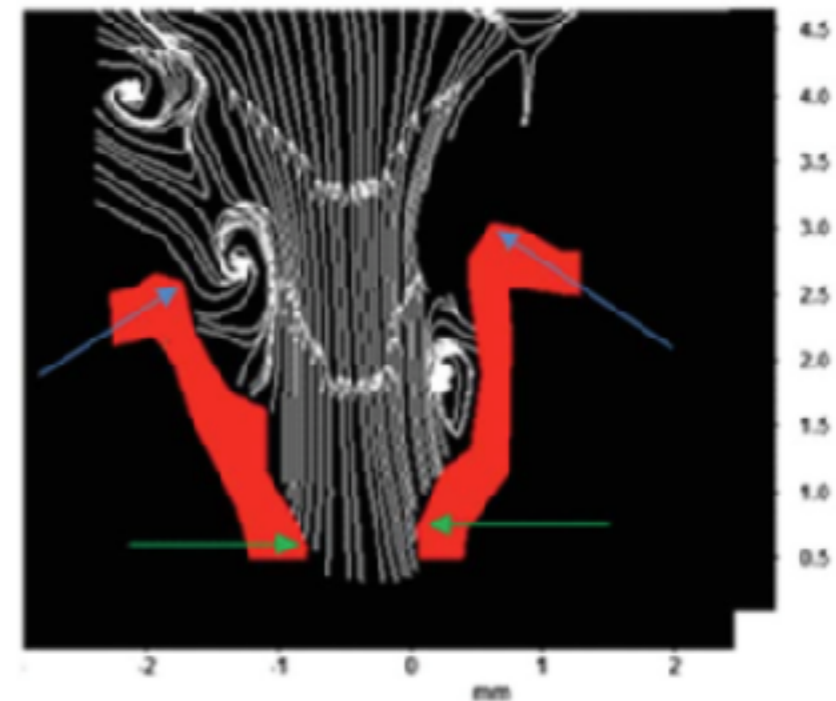


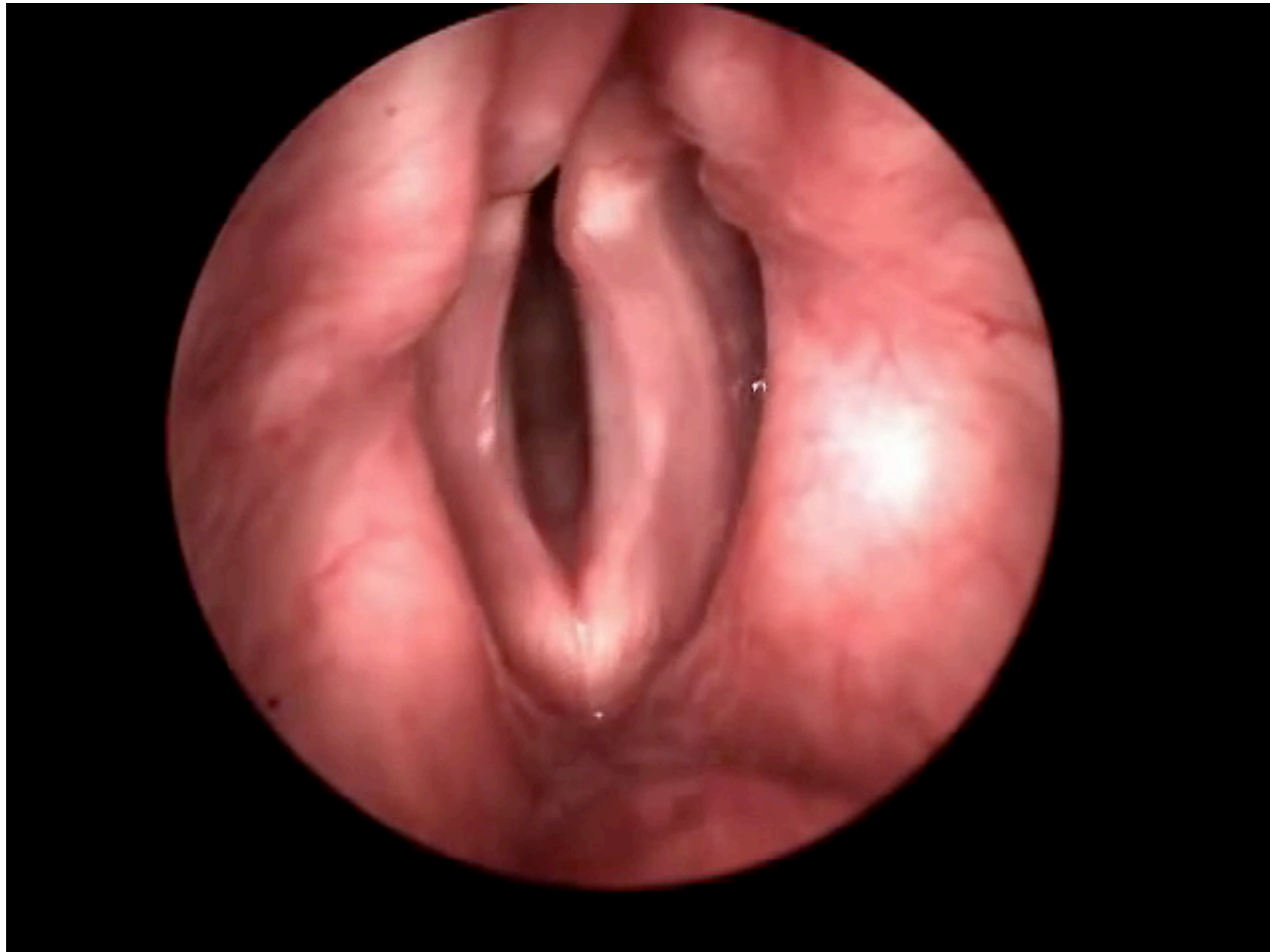
Fig. 4. Intraglottal vortices shown in divergent glottal duct.



(7b) High P_{SG} , $\theta = 127^\circ$

- At mid and high pressures, flow separation vortices create negative pressure, sucking the VFs together along with elastic tissue recoil forces
- At low pressures, Bernoulli's law still stands

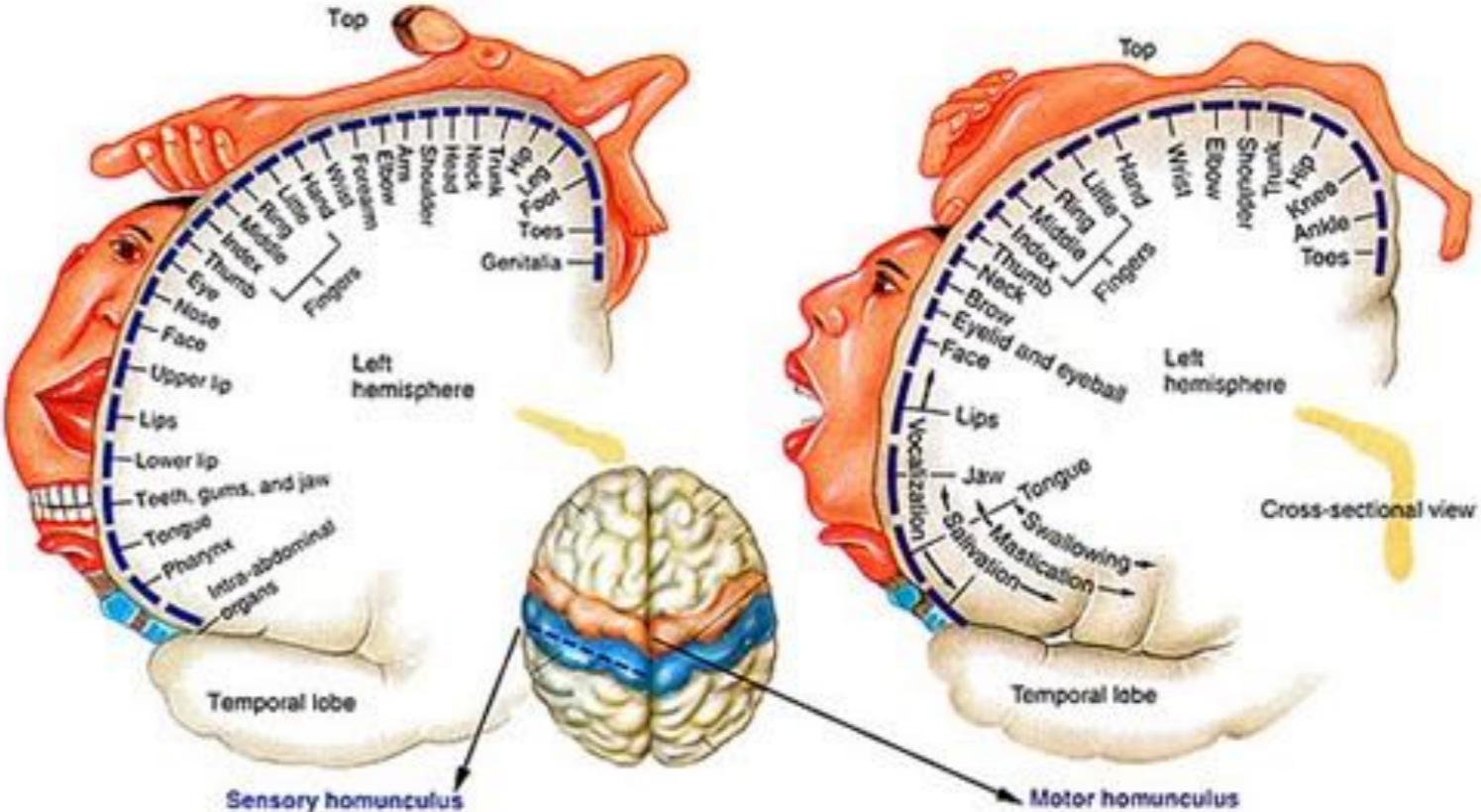
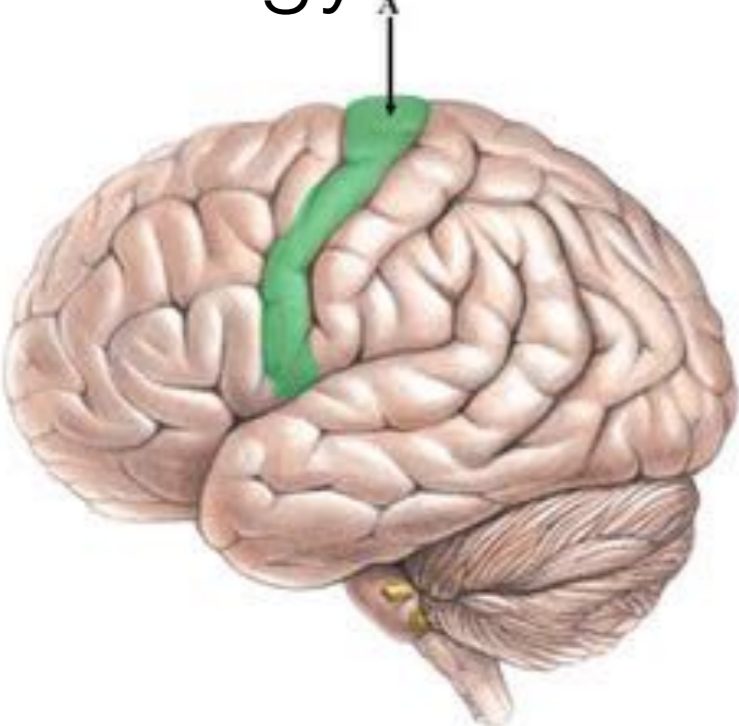
High resolution stroboscopy of the vocal folds in motion



Neural Control of Voice Production

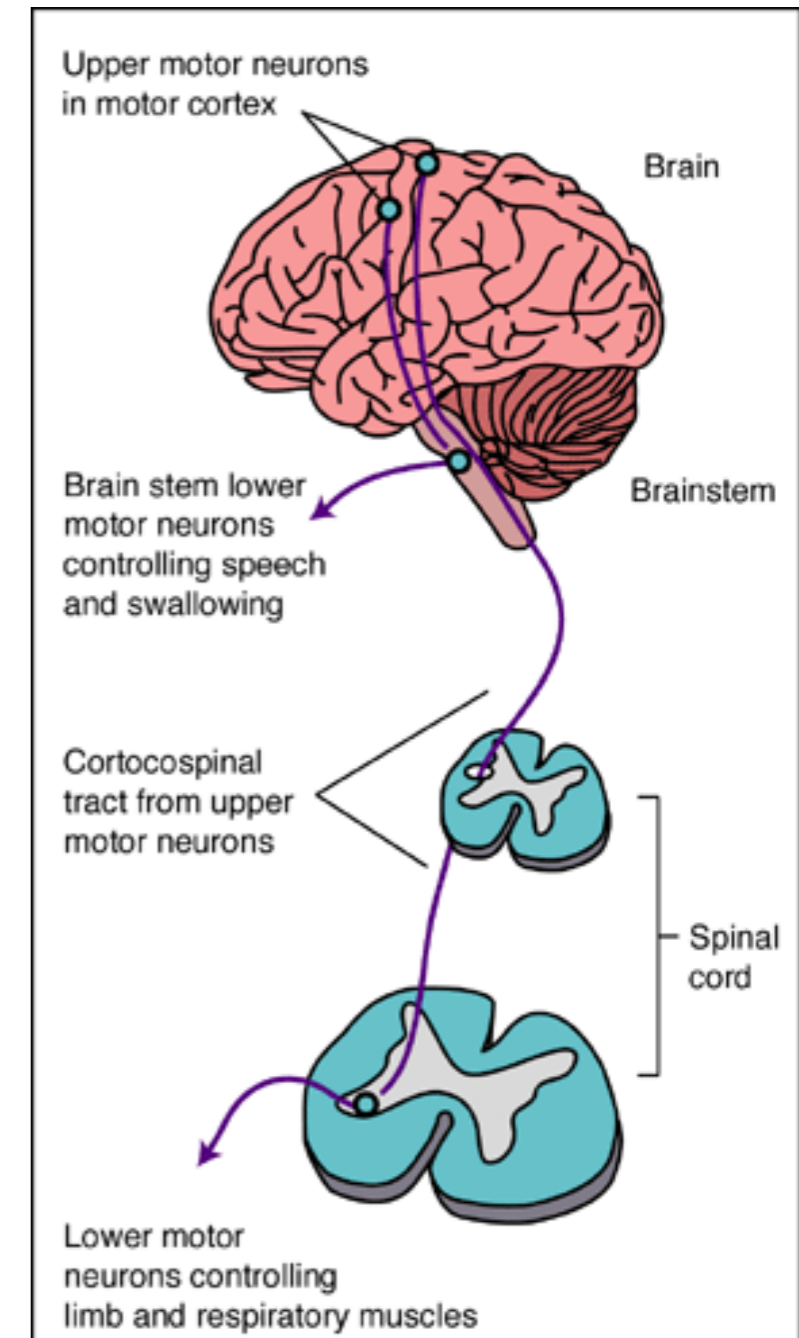
Central Nervous System Control

Precentral gyrus



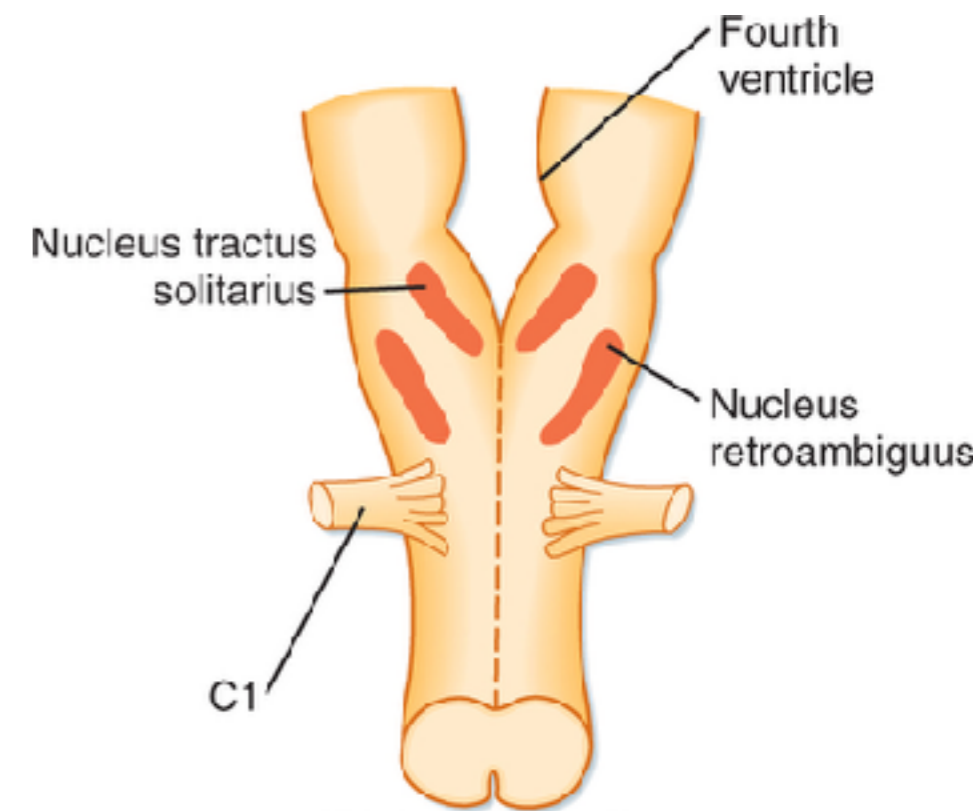
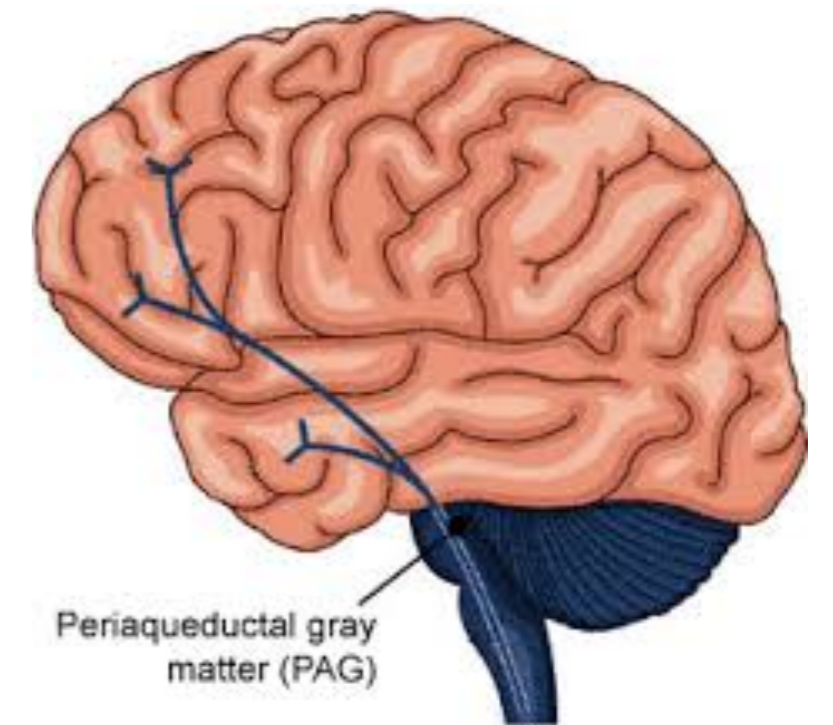
Upper Motor Neuron Pathway

- UMNNs initiate voluntary movement
- Originate in the motor cortex and synapse on CN nuclei in the contralateral brainstem or spinal cord
- Decussate at level of the brainstem



Central Nervous System Control

- PAG projects motor commands through the nucleus retroambiguus (in the medulla)
- Nucleus retroambiguus → nucleus ambiguus (in the reticular formation of the brainstem)
- NA contains motor nuclei for all of the intrinsic laryngeal muscles, plus motoneurons for esophageal and respiratory control



Corticobulbar Tract

- Comprised of UMNs originating in the motor cortex, decussate in the brainstem
- Innervates CN nuclei
- Damage to this tract results in spasticity as well as poor initiation of motor movement

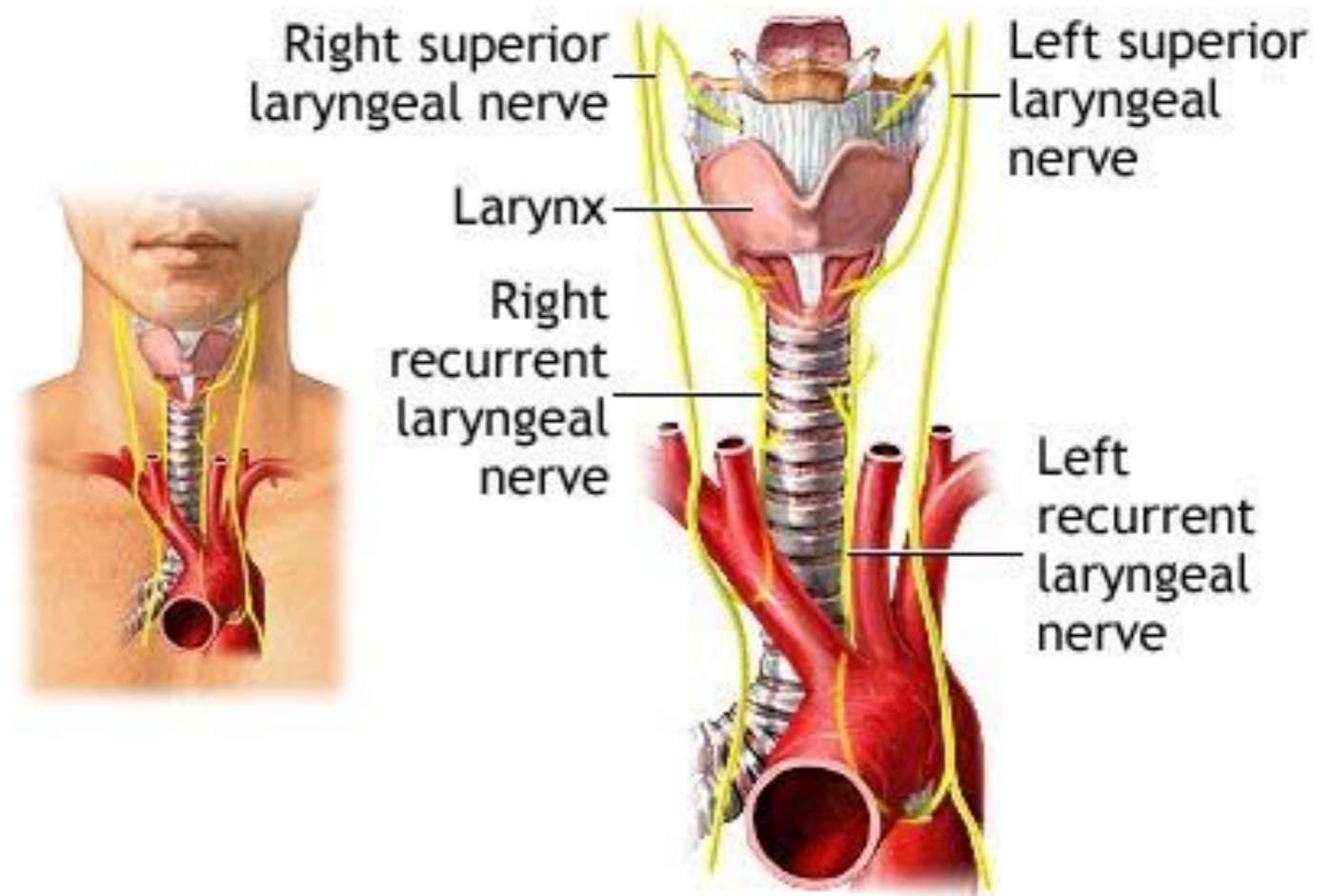
Peripheral Control of Voice Production

Lower Motor Neuron Pathways

- LMNs that originate in the CN nuclei are called CNs
- Synapse onto muscles

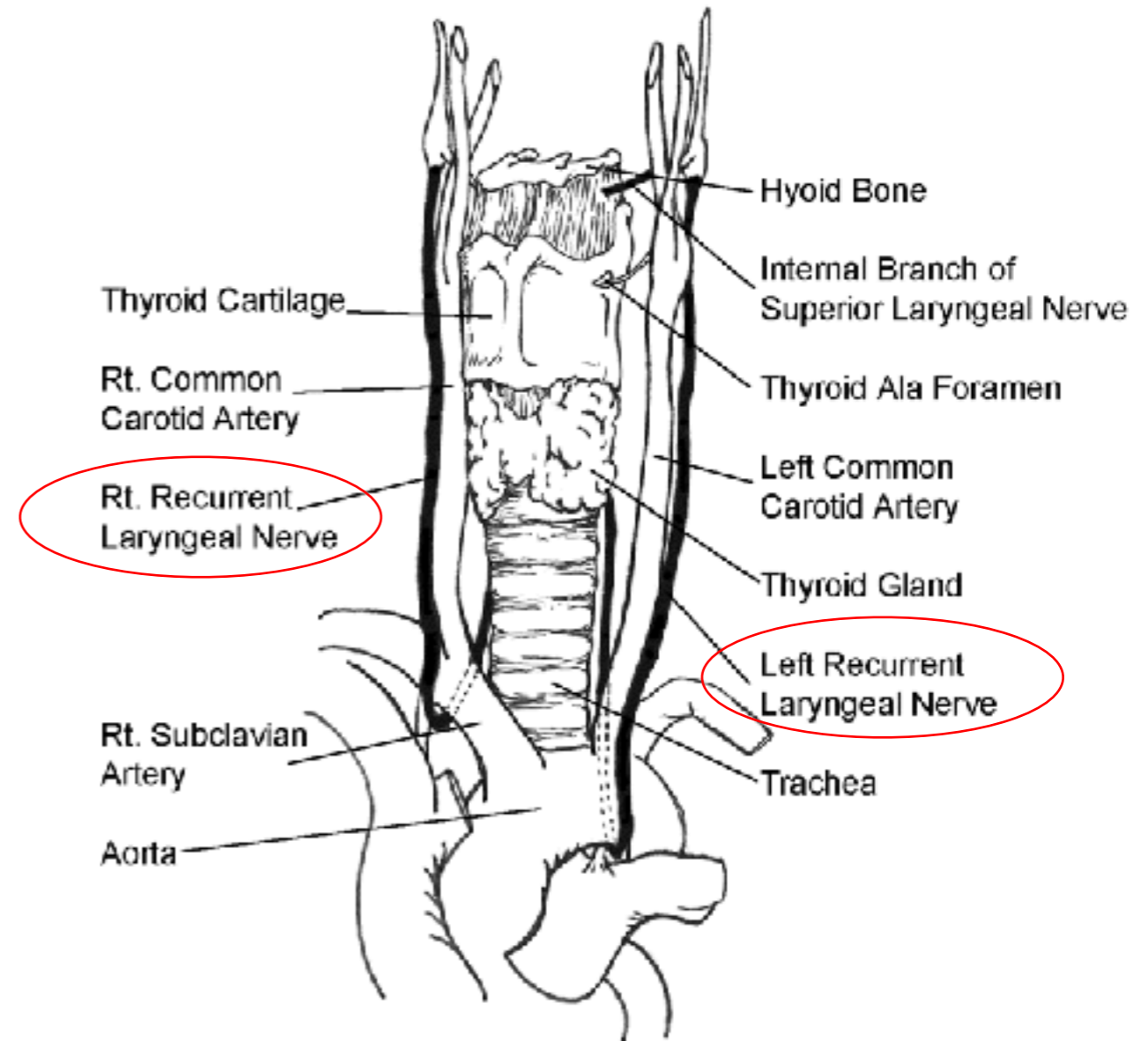
Innervation of the Larynx

- Primarily by the vagus nerve (CN X). Two branches:
 1. Recurrent laryngeal nerve
 - Motor: IA, PCA, thyrovocalis, LCA
 - Sensory: subglottis
- Unilateral injury: hoarseness
- Bilateral injury: possible breathing/voicing difficulty, depending on position of vocal fold paralysis



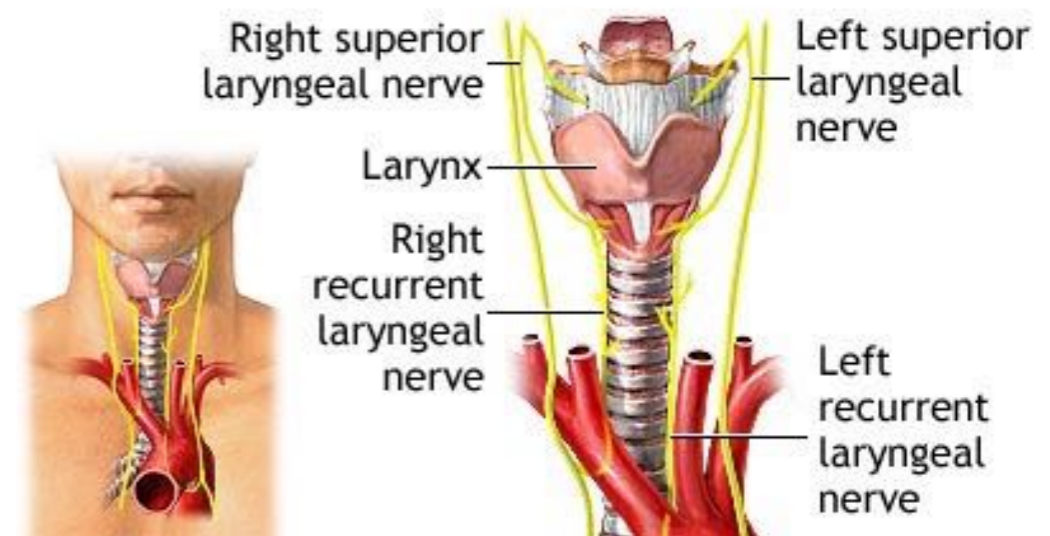
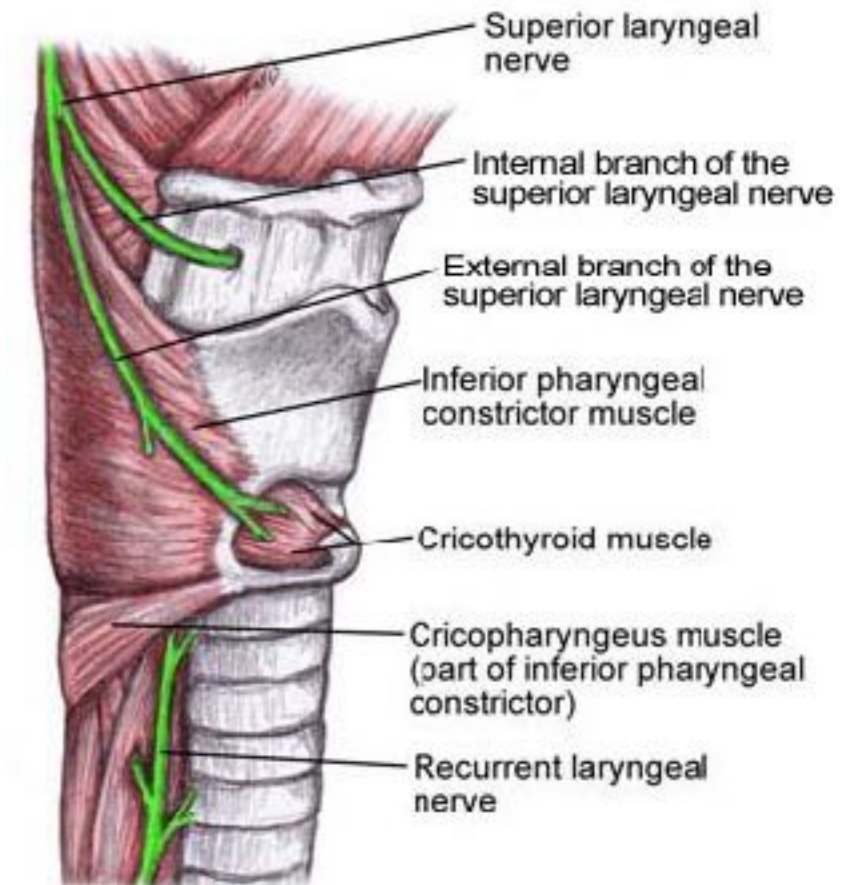
The Recurrent Laryngeal Nerve (RLN)

- Motor innervation to all intrinsic muscles except cricothyroid
- Sensation to the subglottic region
- Note that the left and right branches have different routes



Innervation of the Larynx

2. Superior laryngeal nerve
 - Internal branch
 - Sensory innervation to glottis and laryngeal vestibule
 - External branch
 - Motor innervation to the **cricothyroid** muscle
 - Injury to this branch: weak phonation as VFs cannot be tightened



Vagus Nerve – Unilateral LMN Damage

- Palate droops on ipsilesional side → mild hypernasality
- VF paralysed on ipsilesional side → breathy/hoarse voice



Vagus Nerve – Bilateral LMN Damage

- Low survival rate
- Bilateral palatal droop → severe hypernasality
- Bilateral VF paralysis → severe breathiness, inspiratory stridor

Vagus Nerve – Unilateral UMN Damage

- Minimal effect on phonation and resonance because of bilateral innervation
- Harsh voice quality

Vagus Nerve – Bilateral UMN Damage

- Spasticity/paralysis of vocal folds
- Strained-strangled OR very breathy voice, hypernasality