Anatomy of the Larynx and Cervical Trachea

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KEYWORDS

• Larynx • Supraglottis • Glottis • Subglottis • Trachea • Anatomy

KEY POINTS

- The major cartilages of the larynx are the thyroid, cricoid, and paired arytenoids. Three additional paired cartilages occasionally seen on imaging are corniculate, cuneiform, and triticeal cartilages.
- The larynx is divided into 3 main regions: the supraglottis, glottis, and subglottis.
- The cervical trachea is a short segment of the trachea, spanning from the inferior edge of the cricoid to the level of the manubrial notch.

Abbreviations

AC	anterior commissure
AE	aryepiglottic
AJCC	American Joint Committee on Cancer
CAJ	cricoarytenoid joint
CT	computed tomography
FC	false vocal cord
ITA	inferior thyroid artery
MRI	magnetic resonance imaging
NRLN	nonrecurrent laryngeal nerve
PES	preepiglottic space
PGS	paraglottic space
RLN	recurrent laryngeal nerve
STA	superior thyroid artery
TAM	thyroarytenoid muscle
TC	true vocal cord

INTRODUCTION

The larynx is an anatomically complex organ of the upper airway that lies at the crossroads of the upper aerodigestive tract and the tracheobronchial tree. It connects the pharynx with the cervical trachea and serves several key functions related to normal respiration, swallowing, airway protection, and phonation. Cross-sectional imaging plays an important role in the evaluation of the larynx, particularly in the oncologic setting because it allows visualization of submucosal structures and spaces that cannot be readily assessed by direct laryngoscopy. A firm grasp of laryngeal anatomy is therefore critical to providing accurate and useful staging information in patients with cancers

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affecting the region; however, owing to its anatomic and functional complexity, the larynx can be a challenging area to master from a diagnostic imaging standpoint.

In this article, we review the anatomy of the larynx, beginning with an overview of the cartilaginous, muscular, and supporting tissues, which make up the organ. This will be followed by a discussion of the clinically defined sites of the larynx that are relevant to cancer staging with an emphasis on critical areas to assess when interpreting an oncologic staging scan. The anatomy of the cervical trachea will also be discussed, and at the conclusion of the article, we briefly review adjunctive imaging techniques that can be useful for more detailed laryngeal assessment in select circumstances.

OVERVIEW OF THE LARYNX

The larynx can be thought of as an undulating air-filled space defined by sets of mucosal folds draped over a cartilaginous and muscular skeleton. Functionally, the larynx acts as an important valve in the upper aerodigestive tract that regulates and directs the transit of air and ingested substances passing from the upper aerodigestive tract into their appropriate lower pathways (ie, the trachea or esophagus). In doing so, the larynx helps to maintain patency of the upper respiratory tract while preventing swallowed substances from being aspirated into the tracheobronchial tree and lungs. The other major function of the larynx is facilitating the act of phonation, in which various tones are produced through vibration of the vocal folds against each other as air is forced between them.[1]

The larynx communicates with the oropharynx above, the hypopharynx behind and around, and the trachea inferiorly. Other notable structures in the vicinity of the larynx include the thyroid gland, which is situated along the anterior and lateral aspects of the lower larynx and trachea and is bound to the larynx by the pretracheal fascia; the carotid spaces, which are situated posterolateral to the larynx; and the infrahyoid strap muscles, which are positioned anterolaterally to the larynx and drape over the thyroid gland more inferiorly.[2]

The larynx is situated in the anterior neck and, in a normal adult, spans from roughly the C3 to C6 levels.[2] In the newborn period, the larynx is located more cranially at the level of the second cervical vertebra, and throughout childhood, it remains more superiorly located relative to its position in adults. During puberty, there is a rapid lowering of the larynx and hyoid bone relative to the tongue base, with the final adult position of the larynx being as low as the sixth cervical vertebra.[1] In preadolescent children, there is no significant difference in laryngeal size between boys and girls; however in puberty, the male larynx lengthens and grows significantly compared with the female larynx, corresponding to the development of more marked voice changes in men at this stage in life. These age-based and gender-based differences in the size, configuration, and position of the laryngeal structures produce differences in vocal cord length and thickness, which account for the observed differences in vocal pitch between children and adults and between men and women.[2–7]

Bones and Cartilages of the Larynx

The rigid structure of the larynx is provided by the laryngeal cartilages, which are further supported by various anchoring ligaments and muscles that connect the cartilages with one another and to the hyoid bone, skull base, and trachea. There are 4 major laryngeal cartilages—the thyroid, cricoid, paired arytenoids, and the epiglottis—and 3 sets of paired minor cartilages—the cuneiform, corniculate, and triticeal cartilages (**Fig. 1**). The thyroid, cricoid, and arytenoid cartilages are made of hyaline cartilage, which provide a stiffer support system for the mobile components of the larynx, whereas the epiglottis and minor cartilages are composed of elastic fibrocartilage, which allows flexibility needed for airway protection during swallowing.[1,2]

The *hyoid bone* defines the upper extent of the larynx, functioning to suspend and anchor the larynx during movements related to respiration or phonation. It is a shaped like a horseshoe and is made up of a midline body, which is joined on either side to paired greater and lesser horns or cornua (**Fig. 2**). The hyoid bone does not articulate directly with other bones or cartilages but rather has attachments with the styloid processes of the temporal bone above via the stylohyoid ligament and with the thyroid cartilage below via the thyrohyoid membrane and muscle (discussed further later). In addition, it provides attachments for several extrinsic muscles of the floor of mouth, tongue, and anterior neck, as well as the middle pharyngeal constrictor muscle.[8]

The *thyroid cartilage* is the largest of the 4 laryngeal cartilages and is easily identifiable on axial imaging as the inverted "V" or chevron-shaped structure at the anterior most portion of the larynx[9] (**Fig. 3**). It forms protective anterior and lateral walls to the inner laryngeal structures. The thyroid cartilage consists of 2 lateral plates, referred to as the laminae (or alae), each of which gives off 2 sets of horns (or cornua) along their posterior margins

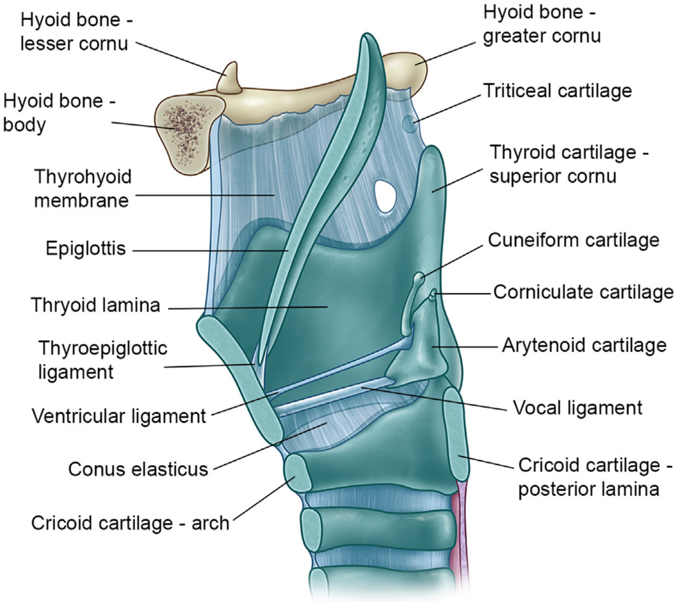

Fig. 1. Midline sagittal cross-sectional illustration of the larynx demonstrating laryngeal cartilages, ligaments, and membranes. (*Courtesy of* Joel Floyd, Jr, MA, CMI, Chapel Hill, NC.)

(**Fig. 4**). The larger superior horns project upward and posteriorly to anchor the larynx to the hyoid bone through the lateral thyrohyoid ligament. The smaller and shorter inferior horns project downward and medially to articulate with the cricoid cartilage at the cricothyroid joint where rotation of the articular surfaces varies tension and length of the vocal folds.[1,10]

On clinical examination, the thyroid cartilage is palpable as the midline laryngeal prominence where the 2 laminae fuse with one another. Just above the thyroid prominence is a groove where the laminae remain unfused, referred to as the superior thyroid notch. In cadaver studies, the angle formed at the laryngeal prominence, known as the interlaminar angle (ILA), tends to be more acute in men, with reported ILA ranges of between 63° and 90° in men and 80° to 120° in women.[5] As alluded to previously, the thyroid cartilage is also generally

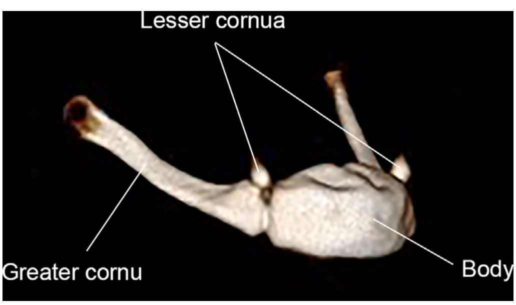

Fig. 2. 3D CT reconstruction of the hyoid .bone from a right anterior oblique view. The hyoid bone consists of a midline body joined on either side to paired greater and lesser cornua. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

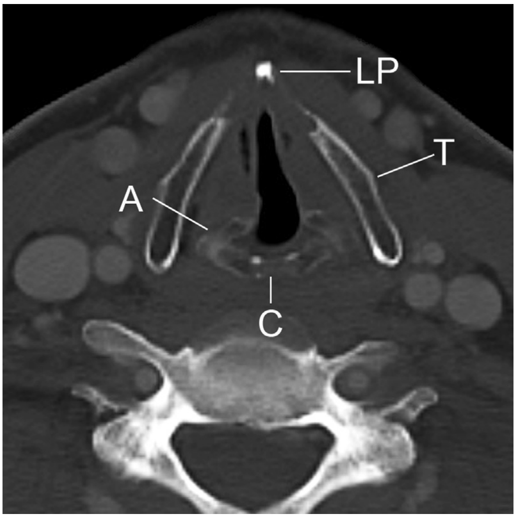

Fig. 3. Cartilages of the larynx on CT. Axial bone window CT at the level the true vocal cords (TC) and laryngeal ventricles demonstrates the cartilages of the larynx. The anteriorly located chevron-shaped cartilage is the thyroid cartilage formed by 2 laminae (T) with the anterior most point representing the laryngeal prominence (LP). The lamina of the cricoid cartilage (*C*) is partially visible posteriorly. The 2 arytenoid cartilages (*A*) are visible articulating at the cricoarytenoid joints. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

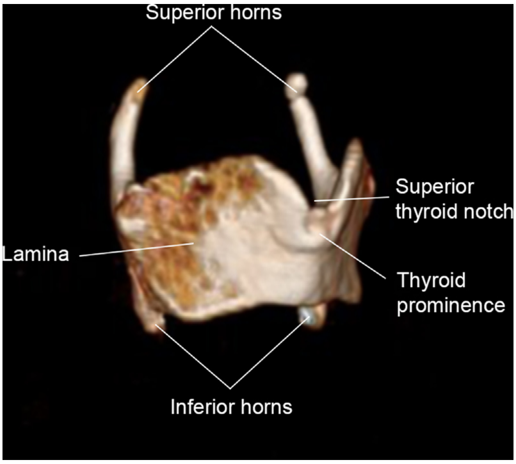

Fig. 4. 3D CT reconstruction of the thyroid cartilage from a right anterior oblique perspective. The thyroid cartilage consists of 2 laminae, which give rise to superior and inferior horns along their posterior margins. Just above where the laminae fuse at the midline, there is a superior midline groove known as the superior thyroid notch. The laryngeal prominence is located just below the notch. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

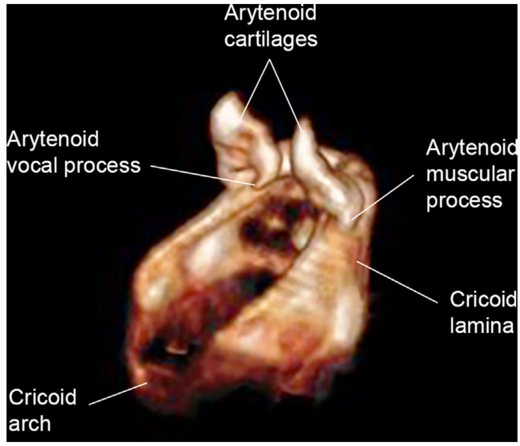

Fig. 5. 3D CT reconstruction demonstrating the cricoid and arytenoid cartilages from a left anterior oblique perspective. The cricoid forms a complete ring including a shorter anterior arch and a taller posterior lamina. The pyramid-shaped arytenoids articulate with the lamina at the cricoarytenoid joints. Two processes arise from the base of the arytenoid, including a muscular process extending posterolaterally and a vocal process projecting anteriorly and medially. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

larger and more anteriorly angulated in men than women.[3–6] In combination, these factors result in the typically more noticeable laryngeal prominence observed in men (the so-called Adam's apple).[1]

The *cricoid cartilage* defines the inferior extent of the larynx and is the only airway cartilage that forms a complete ring. The narrower anterior portion of the cricoid cartilage, known as the arch, measures approximately 0.5 to 1 cm in height, whereas the posterior portion of the ring, referred to as the posterior lamina, is taller, projecting more superiorly, and typically measures approximately 2 to 3 cm in height[1] (**Fig. 5**). The top of the posterior lamina extends to the level of the *true vocal cords* (TC), which is an important landmark in tumor staging. At the superior margins of the lamina are 2 facets that articulate with the arytenoid cartilages to form the cricoarytenoid joints.[10] There are also paired facets along the lateral aspects of the posterior lamina, which articulate with the inferior cornua of the thyroid cartilage to form the previously mentioned cricothyroid joints. The inferior edge of the cricoid demarcates the junction between the subglottic larynx and the trachea.[2]

The paired *arytenoid cartilages*, which are named after a Greek word meaning "ladle" or, more specifically, the "spout" of a ladle or jar,[11] resemble 3-sided pyramids that are located at the superior margins of the posterior lamina of the cricoid (see **Fig. 5**). The triangular base of each arytenoid contains an articular facet that contributes to its respective cricoarytenoid joint. At the cricoarytenoid joint, the primary motions of the arytenoid are translation in an inferolateral or superomedial direction and rocking and twisting motion around the long axis of the facet, which allow the vocal process to rock inferomedially with adduction and superolaterally with abduction.[1] Two processes extend from the base of the arytenoid, including a muscular process extending from the posterior lateral margin of the arytenoid that serves as the attachment site for the cricoarytenoid muscles, and a vocal process projecting anteriorly and medially where the vocal ligament attaches.

Projecting upward from the base of the arytenoid are 3 surfaces forming the respective sides of the pyramid. The posterior facing surface provides attachments for the transverse and oblique interarytenoid muscles; the anterolateral surface gives attachment to the thyroarytenoid muscle and the vestibular ligament; and the medial surface is mucosa covered.[12] The apex of the pyramid formed by each arytenoid cartilage is located at the level of the false vocal cords.[13]

The final major cartilage of the larynx is the *epiglottis*, which is a leaf-shaped structure that narrows inferiorly to a base called the petiole (or stem). It is located at the superior margin of the larynx with the petiole anchored anteriorly to the inner thyroid lamina via the thyroepiglottic ligament (see **Fig. 1**).[2] More superiorly, the epiglottis connects to the back of the body of the hyoid bone by the hyoepiglottic ligament. The mucous membrane covering the anterior aspect of the epiglottis sweeps forward to the tongue base as the median glossoepiglottic fold anteriorly and to the pharyngeal walls laterally as the paired pharyngoepiglottic folds, forming 2 pouch-like areas to either side of the glossoepiglottic fold, which are known as the valleculae.[8] In the center of the posterior wall of the epiglottis there is a normal subtle bump called the tubercle, which can sometimes be observed as a small posterior projection located above the petiole. The hyoid bone is the landmark that divides the epiglottis into 2 portions, a suprahyoid portion, which projects upward into the oropharyngeal airway, and an infrahyoid portion that extends to the inferior tip of the petiole.[14]

Additional small cartilages present in the larynx include the paired *corniculate*, *cuneiform*, *and triticeal cartilages* (see **Fig. 1**). These are often not evident on imaging but occasionally they will ossify and be visible as additional small, calcified structures not corresponding to any of the major cartilages. The corniculate cartilages (**Fig. 6**) sit atop the superior processes of the arytenoid cartilages. The cuneiform cartilages are curved cartilages at the margins of the aryepiglottic (AE) folds situated just anterior and lateral to the arytenoid and cuneiform cartilages[8] (see **Fig. 1**). The triticeal cartilages are located in the free edges of the thyrohyoid membrane above the superior thyroid cornua, within the lateral thyrohyoid ligament (**Fig. 7**).

There is considerable variability in the degree of cartilage ossification, which is frequently discontinuous and asymmetric, occasionally making it difficult to differentiate tumor invasion from normal cortical discontinuity on computed tomography (CT).[14] Ossification of the cartilages typically progresses with age, usually beginning in the second decade of life, and men generally demonstrate greater laryngeal cartilage ossification than women.[15] On CT, nonossified cartilage may only be slightly hyperdense relative to soft tissue (**Fig. 8**).[9] On MR imaging, nonossified cartilage demonstrates intermediate-to-low signal on both T1-weighted and T2-weighted pulse sequences (**Fig. 9**). Ossification of the cartilages is usually best depicted on CT but it can also be appreciated with MR imaging. With progressive ossification, the cortex eventually becomes calcified and demonstrates very-low signal intensity on all MR sequences, whereas the medullary portion transitions to the signal intensity of fat[16–18] (see **Fig. 9**).

Supporting Connective Tissue Structures in the Larynx

In addition to those already mentioned, there are several other ligaments and membranes in the larynx that provide support and connections

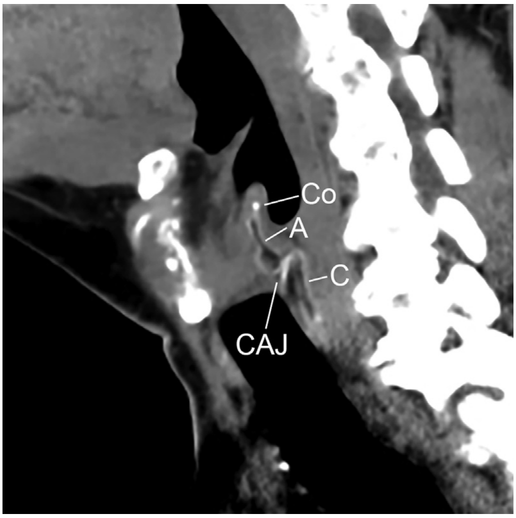

Fig. 6. Sagittal CT showing the ossified corniculate cartilage (Co) at the superior margin of the arytenoid cartilage (A) and the articulation between the arytenoid and cricoid cartilages (C) at the cricoarytenoid joint (CAJ). (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

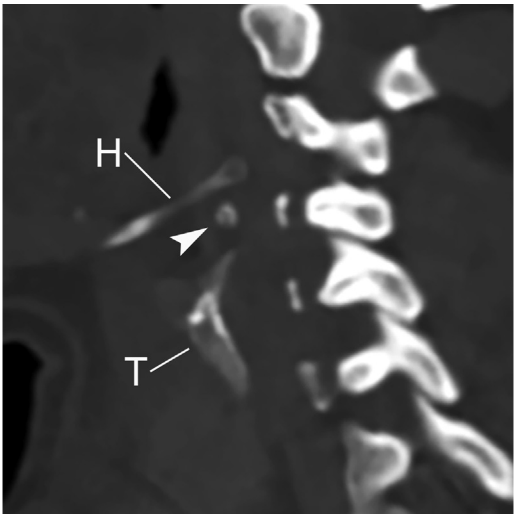

Fig. 7. Sagittal CT image through the lateral aspect of the larynx in a bone window demonstrates an ossified triticeal cartilage (*arrowhead*) positioned between the hyoid bone (H) and the thyroid cartilage (T) within the edge of the thyrohyoid membrane. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

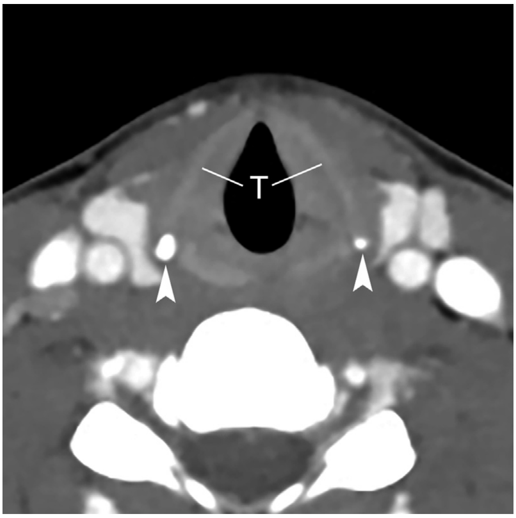

Fig. 8. Variable ossification of the thyroid cartilage on CT in a 17-year-old woman. With the exception of its most posterior margins (*arrowheads*), the thyroid cartilage (T) is mostly unossified and demonstrates densities slightly higher than the adjacent soft tissues (compared with the appearance of the more ossified thyroid cartilage in Fig. 3). (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

between the laryngeal cartilages. Several of these membranes also serve a protective function by forming anatomic barriers to disease spread within the larynx and between the larynx and other parts of the neck. Although these connective tissues are not usually resolvable as discrete structures on imaging, their general positions can be inferred based on the locations of the more easily identifiable structures that they attach to and support.

The *vocal ligaments* are paired ligaments that attach to the vocal processes of the arytenoids and extend anteriorly and medially to insert on the inner surface of the thyroid lamina, just off midline below the stem of the epiglottis. The small gap between the anterior vocal ligament insertions is referred to as the *anterior commissure* (AC), which is an important landmark in tumor imaging. The AC normally measures no more than 2 mm in thickness, and thickening of the AC can indicate tumor involvement, which may affect surgical treatment options.[19] The AC tendon, also referred to as Broyles ligament, connects the vocal ligaments to the thyroid cartilage and forms part of the AC. The point at which Broyles ligament attaches to the thyroid cartilage lacks perichondrium, leading some authors to think that this site in the cartilage may be particularly susceptible to tumor invasion.[13,20] The space between the posterior insertions of the vocal ligaments on the arytenoids is called the posterior commissure (PC) and is wider than the AC at rest and during quiet respiration.

The vocal ligaments actually represent the thickened free margins of an elastic connective tissue structure known as the *conus elasticus* (Fig. 10), which is also variably referred to as the cricothyroid or triangular membrane. The anterior portion of the conus elasticus is made up of the deep fibers of the median (or anterior) cricothyroid ligament, which connects the cricoid arch to the inferior margin of the thyroid cartilage at the midline.[21] Posterior to this, the conus elasticus attaches inferiorly at the superior and medial surfaces of the cricoid cartilage and continues

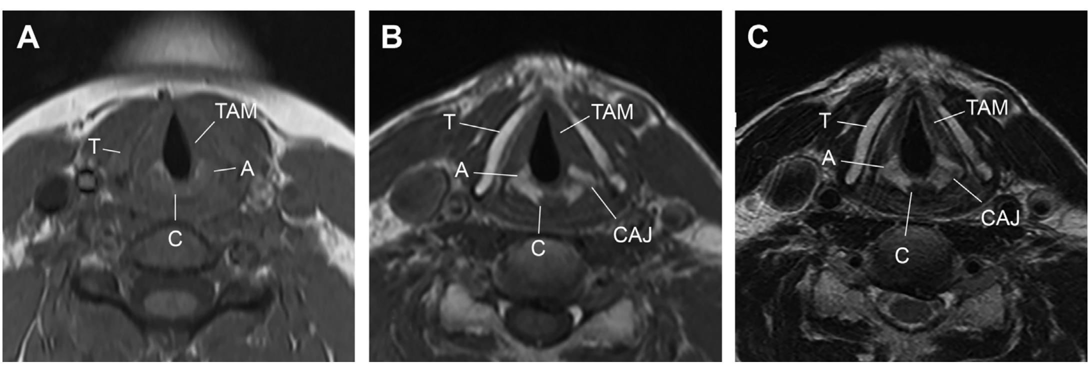

Fig. 9. MR of cartilages with different ossification. (*A*) T1-weighted axial image through the level of the glottis in a 17-year-old woman with mostly unossified laryngeal cartilages. The thyroid (T), cricoid (C), and arytenoid (A) cartilages demonstrate signal intensities very similar to the adjacent strap muscles with only a thin, faintly hypointense rim. In contradistinction, an axial T1-weighted image (*B*) and axial T2-weighted image (*C*) in a 50-year-old man with ossified cartilages demonstrates high signal intensity within thyroid (T), cricoid (C), and arytenoid (A) cartilages owing to the presence of fatty marrow in the medullary spaces, with a more conspicuous low signal intensity rim due to cortical calcification. CAJ, cricoarytenoid joint; TAM, thyroarytenoid muscle. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

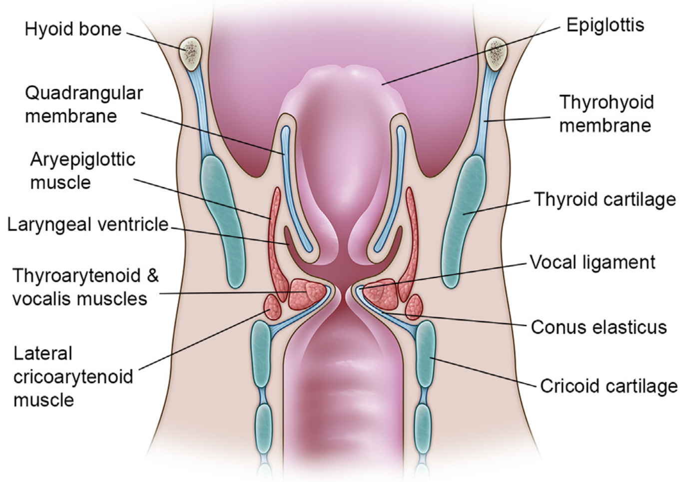

Fig. 10. Coronal cross-sectional illustration of the larynx at the ventricular level showing the relationships of the cartilages, muscles, and ligaments to the mucosal surfaces of the larynx. Note the locations of the quadrangular membrane and conus elasticus, whose free margins form the vestibular and vocal ligaments, respectively. (*Courtesy of* Joel Floyd, Jr, MA, CMI, Chapel Hill, NC.)

superiorly and medially as the lateral cricothyroid ligaments that attach at the AC and vocal processes of the arytenoids, with the superior free margins of the conus elasticus in between forming the vocal ligaments.[1,2,21]

Just above and running parallel to the vocal ligaments are the *ventricular ligaments*. These insert on the anterolateral surface of the arytenoids posteriorly, slightly superior to the level of the vocal processes, and at the inner surface of the thyroid lamina anteriorly, a few millimeters above the vocal ligament insertion. The ventricular ligaments mark the level of the free margin of the *false vocal cords (or vestibular folds)* and represent the lower margins of a second major elastic membrane in the larynx, known as the *quadrangular membrane* (see **Fig. 10**). The quadrangular membrane is part of the epiglottis support system, attaching to the lateral edges of the epiglottis and extending inferiorly and posteriorly to the arytenoid and corniculate cartilages. The mucosal covered upper margins are the *AE folds*, which separate the laryngeal vestibule anteromedially from the piriform recesses of the hypopharynx posterolaterally. The previously mentioned cuneiform cartilages are contained within the quadrangular membrane, helping to add rigidity to the AE folds.[1] On laryngoscopy, the corniculate and cuneiform cartilages can be identified as elevations of the mucosa (referred to as the corniculate and cuneiform tubercles, respectively) along the posterior aspects of each AE fold, above the arytenoid cartilages[8] (**Fig. 11**).

The *thyrohyoid membrane* is a fibroelastic sheet connecting the top of thyroid cartilage to the inner surfaces of the hyoid bone. At the posterior margins of the thyrohyoid membrane lie the paired lateral thyrohyoid ligaments, which extend

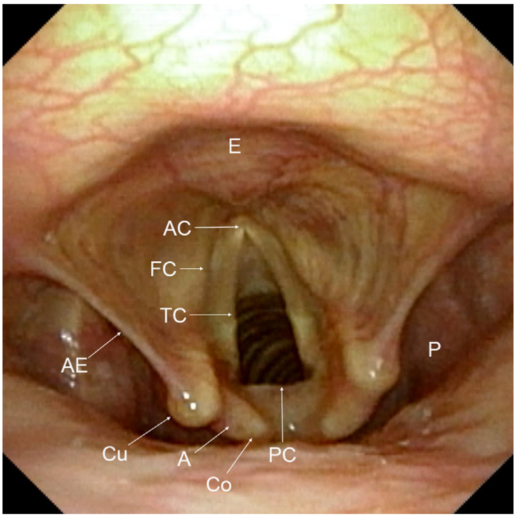

Fig. 11. Image from an in-office flexible fiberoptic laryngoscopy video. Note that the image has been rotated 180° to more closely approximate the typical orientation of the larynx on axial CT imaging. This depicts the major mucosa-lined structures of the larynx including: anterior commissur (AC), false vocal cords (FC), true vocal cords (TC), aryepiglottic folds (AE), arytenoids (A), corniculate tubercles (Co), cuneiform tubercles (Cu), and posterior commissur (PC). The distended piriform sinuses (P) are also well visualized posterolateral to the AE folds. The epiglottis (E) is partially seen as the anterior wall in the image. Portions of the subglottis and upper trachea are also seen deep to the opening between the TC. (Courtesy of R Shah, MD, Chapel Hill, NC.)

between the greater horns of the thyroid cartilage and hyoid bone and contain the small triticeal cartilages. The medial thyrohyoid ligament lies at the midline of the thyrohyoid membrane.

One other important pair of ligaments that support the larynx are the stylohyoid ligaments. Although not technically part of the larynx, the stylohyoid ligaments indirectly help to suspend the larynx through the hyoid bone.[2] These ligaments originate from their respective styloid processes and attach to the ipsilateral lesser horns of the hyoid bone.

Muscles of the Larynx

The laryngeal muscles are named after their origin and insertion sites, making it relatively easy to remember their names, and are traditionally divided into intrinsic and extrinsic groups. The intrinsic muscles facilitate movement of the laryngeal cartilages against one another and directly affect glottic movement, whereas the extrinsic muscles connect the larynx with its anatomic neighbors and act to elevate or depress the larynx.

Intrinsic Muscles

The intrinsic muscles of the larynx are summarized in **Table 1** and shown in **Fig. 12**. Each of the intrinsic laryngeal muscles is confined entirely within the larynx and provides subtle changes in the vocal cord length, tension, and abducted or adducted position, allowing for a wide range of pitches during phonation. These muscles also function to open the vocal cords during inspiration and to close the cords and laryngeal inlet during deglutition and phonation.[8] On imaging, of primary importance are the *thyroarytenoid muscles* (TAMs), which demarcate the level and make up the bulk of the TC.[13]

The TAMs are the dominant component of the vocal folds, running in parallel and just lateral to the vocal ligaments. Each TAM originates on the posterior aspect of the thyroid lamina and median cricothyroid ligament and inserts on the base and anterolateral surface of the ipsilateral arytenoid cartilage. The medial fibers of the TAM are sometimes considered a separate muscle, referred to as the *vocalis muscle*.[8] The vocalis similarly originates at the posterior thyroid lamina and median cricothyroid ligament but inserts on the vocal ligament. Contraction of both the vocalis muscles and TAMs shortens the vocal ligaments (leading to relaxation of the vocal cords) providing bulk and contributing to adduction.[10,22] The superior margin of the TAM demarcates the upper border of the TC but a few fibers of the muscle can insert higher than the AC.

The *lateral cricoarytenoid muscles* originate at the lateral arches of the cricoid and insert on the muscular processes of the arytenoids. They are the primary adductors of the vocal cords, with contraction of these muscles producing rotation of the arytenoids to bring the vocal ligaments together. The *posterior cricoarytenoid muscles* also insert on the muscular processes of the arytenoids but originate on the posterior cricoid lamina. As a result, these muscles work in opposition to the lateral cricoarytenoids to rotate the arytenoid cartilages in the opposite direction thus abducting the vocal ligaments. The posterior cricoarytenoid muscles are the only true abductors of the vocal folds.[8]

The *arytenoid (or interarytenoid) muscle* is unpaired, with 2 components, located on and between the posterior margins of the arytenoid cartilages. The transverse component extends horizontally between the 2 arytenoid cartilages, and the oblique components extend from the muscular process of one arytenoid cartilage to the apex of the other cartilage. Both these components work together to adduct the vocal cords.[8]

Table 1
Intrinsic muscles of the larynx and their innervation

Muscle	Innervation	Function
Cricothyroid	Superior laryngeal	Tenses cords
Posterior cricoarytenoid	Recurrent laryngeal	Abducts vocal cords
Lateral cricoarytenoid	Recurrent laryngeal	Adducts arytenoids and closes glottis
Transverse arytenoid	Recurrent laryngeal	Adducts arytenoids
Oblique arytenoid	Recurrent laryngeal	Closes glottis
Aryepiglottic	Recurrent laryngeal	Closes glottis
Vocalis	Recurrent laryngeal	Relaxes cords
Thyroarytenoid	Recurrent laryngeal	Relaxes cord tension

Adapted from Krohner RG, Ramanathan S. Functional Anatomy of the Airway. In: Hagberg CA, ed. *Benumof's Airway Management: Principles and Practice*. 2nd ed. Mosby Elsevier; 2007:3-21.

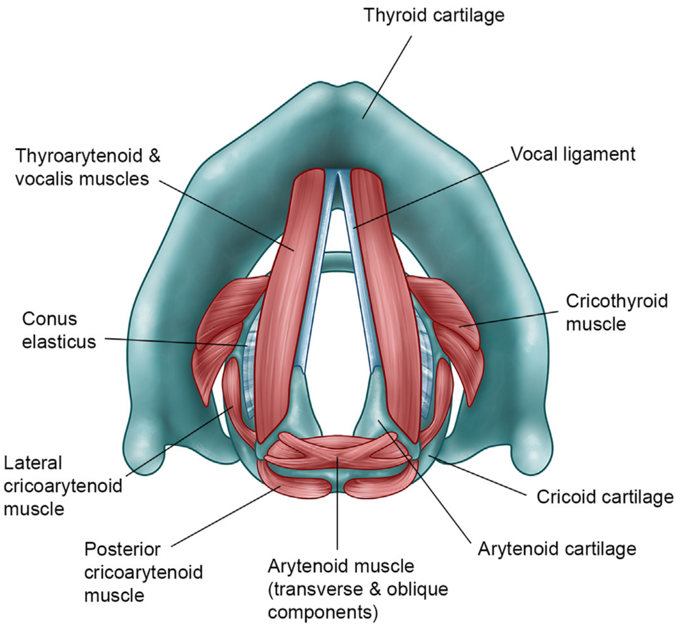

Fig. 12. Superior illustrative view of the larynx without the mucosal covering to show the major intrinsic muscles of the larynx. (*Courtesy of* Joel Floyd, Jr, MA, CMI, Chapel Hill, NC.)

The *cricothyroid muscles* attach to the anterolateral aspects of the cricoid arch and insert on the inferior cornua and laminae of the thyroid cartilage. Contraction of these muscles tips the thyroid cartilage slightly forward and inferiorly, pivoting at the cricothyroid joints. This leads to lengthening of the vocal ligaments and, therefore, increased tension in the vocal cords and pitch. The cricothyroid is the only tensor muscle of the larynx, and some authors consider it to be both an extrinsic and intrinsic muscle because its actions affect both laryngeal movement and glottic tension.[8] It is also the only intrinsic muscle not innervated by the recurrent laryngeal nerve, receiving its innervation from the external branch of the superior laryngeal nerve.

Finally, the *thyroepiglottic and AE muscles* are thin bands of muscle found within the AE folds and along the epiglottis,[13] which work in conjunction with the transverse arytenoid and TAMs to close the epiglottis and laryngeal vestibule during swallowing. The thyroepiglottic muscle actually represents the most lateral portions of the TAM, which attach to the lateral arytenoids, AE fold, and epiglottis, whereas the AE muscle is a continuation of the oblique portion of the arytenoid muscle which courses through the AE fold to attach to the lateral aspect of the epiglottis.[8]

Extrinsic Muscles

The extrinsic muscles of the larynx, also referred to as the strap muscles, act to raise, lower, or stabilize the larynx but have their origins elsewhere in the neck. These muscles are typically divided into an infrahyoid group, which together depress the larynx and displace it downward during inspiration, and a suprahyoid group, which helps suspend the larynx from the skull base and mandible via the hyoid bone and elevates and anteriorly displaces the larynx during swallowing. The infrahyoid group includes the omohyoid, sternothyroid, thyrohyoid, and sternohyoid muscles, which are innervated by the ansa cervicalis. The suprahyoid group includes the digastric, stylohyoid, geniohyoid, mylohyoid, and stylopharyngeus muscles. The middle and inferior pharyngeal constrictor muscles and the cricopharyngeus muscles are also considered extrinsic larynx muscles, which affect the larynx during the act of swallowing.[1]

Mucosa, Submucosal Spaces, and Air-containing Spaces of the Larynx

The laryngeal cartilages, muscles, and ligaments provide a framework for the overlying mucosal surfaces, creating various folds, air-filled spaces, and submucosal spaces. These are important to recognize on imaging because correct anatomic localization provides a better differential of pathologies and allows clearer communication to clinicians regarding sites of tumor involvement. Many of the important mucosal spaces and folds of the larynx have already been mentioned but will be reemphasized here.

The mucosa of the larynx is primarily pseudostratified ciliated columnar epithelium with scattered goblet cells, as seen in the trachea.[23,24] However, regions that often appose other surfaces during phonation and swallowing are covered in nonkeratinized stratified squamous epithelium and include the vocal folds, edges of the AE folds, parts of the epiglottis and parts of the pyriform fossae, although there is variability in the distribution of this squamous epithelium.[23,25] Other important tissues of the mucosa are the small subepithelial mucus secreting glands, which are in higher concentrations along the subglottis, AC, ventricular saccules, false vocal cords, and arytenoid region.[24]

The *laryngeal vestibule* is the superior most air space of the larynx spanning from the superior tip of the epiglottis to the true cord. The lateral margins of the vestibule are formed by the paired AE folds. The inferior aspect of the posterior margin is the interarytenoid fold, which is formed by the mucosal covered interarytenoid muscle.[2,13]

The *laryngeal ventricles* are paired thin air-filled spaces between the true and false vocal cords (see **Fig. 10**). There is a superior lateral outpouching of each ventricle that protrudes into the paraglottic space (PGS) known as the laryngeal saccule or appendix.[2] The ventricles are best seen on coronal imaging (**Fig. 13**) and are landmarks for dividing the larynx into supraglottic and glottic regions (as discussed later).

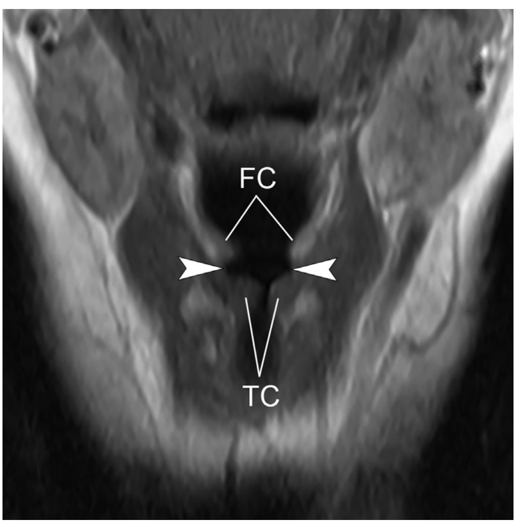

Fig. 13. Laryngeal ventricle on a coronal T1-weighted MR image through the larynx. The laryngeal ventricles (*arrowheads*) are paired thin air-filled spaces located between the FC and TC. The apex of the laryngeal ventricle is the landmark that indicates the transition point from the supraglottis above to the glottis below. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

The median slit-like airspace between the TC is referred to as the *rima glottidis.*[2] The more posterior aspect of the rima glottidis is bordered laterally by the mucosally covered medial surfaces of the paired arytenoid cartilages.[12]

Two important submucosal spaces of the larynx are the *preepiglottic space* (PES) and PGS. Above the level of the vocal cords, these spaces are predominantly fat containing and have a rich vascular and lymphatic supply. The PES, as its name suggests, is anterior to the epiglottis and the quadrangular membrane that together comprise its posterior boundary. The anterior boundary is the hyoid bone, thyrohyoid membrane, and the upper thyroid cartilage. The upper boundary is the hyoepiglottic ligament, and the lower boundary is the thyroepiglottic ligament.[26,27] The PES is generally easily visualized on both sagittal (**Fig. 14**) and axial images. The PGS is located laterally in the larynx, spanning the levels of the true and false cords (FC) and extending slightly below the level of the true cords. The lateral margins are the inner surface of the thyroid, cricothyroid membrane, and, to a lesser extent, the cricoid. It is medially bounded by the quadrangular membrane and conus elasticus.[28]

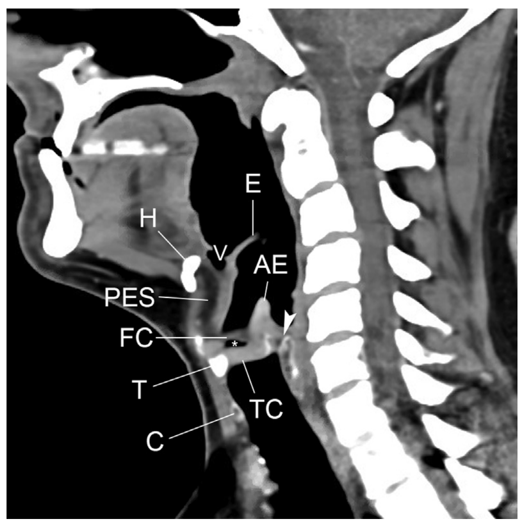

Fig. 14. Paramidline sagittal CT view through the larynx nicely demonstrates the location of the PES in relationship to the surrounding laryngeal structures. The PES is a fat-containing space situated anterior to the epiglottis and the quadrangular membrane and posterior to the hyoid bone, thyrohyoid membrane, and the upper thyroid cartilage. AE, aryepiglottic fold; *arrowhead*, cricoarytenoid joint; *asterisk*, laryngeal ventricle; C, cricoid; E, epiglottis; FC, false vocal cord; H, hyoid; T, thyroid cartilage; TC, true vocal cord; V, vallecula. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

A discrete division between the preepiglottic and PGSs is not visible on imaging.[26] The thyroglottic ligament has been described as a division between the spaces but is discontinuous especially at its superior margin.[27] Others have described this ligament as poorly formed and part of the PGS.[28] In either case, the discontinuity of the ligament can allow passage of tumor between the fat of the preepiglottic and PGSs.[26]

Major Larynx Regions Relevant to Cancer Staging

For the purposes of cancer staging, the larynx is traditionally divided into 3 main sites: the supraglottis, the glottis, and the subglottis (**Fig. 15**), the first 2 of which are further subdivided into additional subsites. Tumor classification (T-category) and treatment planning may differ significantly based on the primary site of disease as well as the extent of spread to other sites within and outside of the larynx, so familiarity with these divisions and their subsites is essential to accurately describe and stage cancers of the larynx. In general, visualization of the mucosal surfaces of the larynx is best achieved by laryngoscopy; however, in cases of confirmed or suspected tumor, imaging plays an important role in evaluating for deep soft tissue or cartilaginous involvement and regional nodal spread.

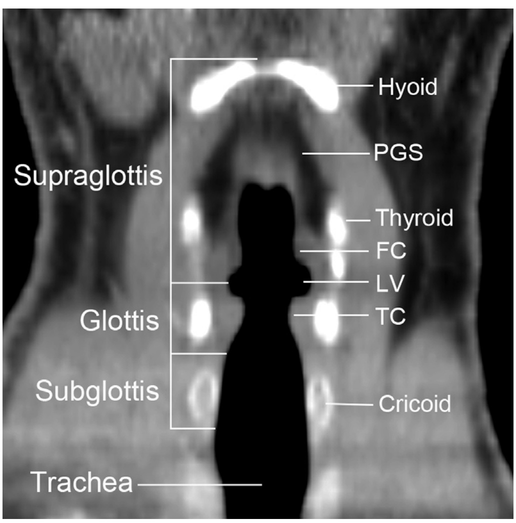

Fig. 15. Reformatted coronal CT image showing the regions of the larynx. The supraglottis is defined superiorly by the epiglottis (not well seen in this plane) and inferiorly by the laryngeal ventricle (LV). The glottis extends from top of the TC, which can be approximated by the apex of the LV to 1 cm inferior to the ventricle. The subglottis extends from the lower margin of the glottis to the inferior margin of the cricoid. Note the fat-containing portion of the PGS at the supraglottic level. FC, false cord. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

The *supraglottis* (**Fig. 16**) is defined superiorly by the glossoepiglottic and pharyngoepiglottic folds, although the suprahyoid portion of the epiglottis, which is also a supraglottic structure usually projects above these landmarks, with its free margin extending into the oropharyngeal airway. Inferiorly, the supraglottis is demarcated by and includes the laryngeal ventricle, which separates the supraglottis above from the glottis below. For the purposes of cancer staging, the subsites of the supraglottis are the epiglottis (divided into suprahyoid and infrahyoid components), the laryngeal facing mucosa of the AE folds, the mucosa overlying the arytenoid cartilages, and the false vocal folds.[29] Although not specifically a subsite of the supraglottis, an important midline-imaging landmark in the region is the previously mentioned PES, the fat-containing space situated anterior to the infrahyoid epiglottis.[2,30]

The *glottis* (**Fig. 17**) is the short segment of the larynx whose subsites include the TC (including its superior and inferior surfaces), the AC, and the PC. The upper limit of the glottis can be identified as the inferior margins of the laryngeal ventricles, which are generally best seen on coronal imaging slices. The histologic landmark that demarcates the lower margin of the glottis is the transition zone from the stratified squamous epithelium covering the TC to the respiratory epithelium of the subglottic airway, which is usually located 5 to 10 mm below the free edge of the TC.[31] However, this zone is not resolvable by imaging, so the inferior limit of the glottis is arbitrarily defined as the plane situated 1 cm inferior to the laryngeal ventricles for imaging purposes.[2,19,29]

Although tumor involvement of the AC and PC alone does not change cancer staging for primary glottic carcinomas, spread to either of these structures can have important treatment implications, particularly when partial laryngectomy is being considered.[30,32] Furthermore, tumors involving the AC are associated with early invasion of the adjacent thyroid cartilage (due to spread along Broyles ligament), subglottic extension, and early extralaryngeal extension; as a result, these tumors tend to be more difficult to treat both surgically or with radiation, are associated with higher recurrence rates, and are frequently understaged initially.[14,20,26,33]

As mentioned earlier, the PGS spans the lateral submucosal portions of the supraglottis and glottis, including the potential space lateral to the laryngeal ventricles. In the supraglottis, the PGS is located lateral to the false cord and is primarily

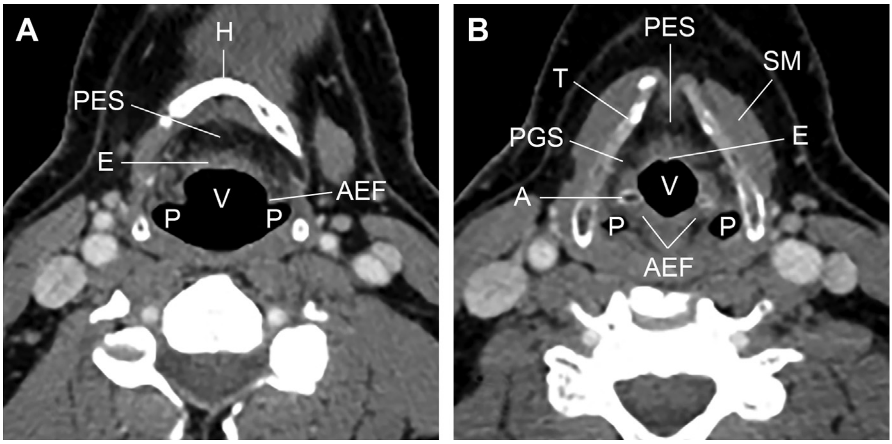

Fig. 16. Axial CT images through the supraglottis. (*A*) Axial slice at the level of the hyoid bone (H) shows the fat-containing PES situated between the hyoid bone and the epiglottis (E). The airspaces visible at this level are the laryngeal vestibule (V) just posterior to the epiglottis and a portion of bilateral piriform sinuses (P), which are separated from the vestibule by the partially imaged aryepiglottic folds (AEF). (*B*) Axial slice slightly inferior to (A) at the level of the false vocal cords. The apices of the arytenoids (A), which mark the false cord level, are visible. The PGSs are the fat-containing space seen bilaterally positioned between the inner surface of the thyroid cartilage (T) and the vestibular airway (V) and communicate anteromedially with the PES. The small pockets of air posteriorly are the inferior aspects or apex of the piriform sinuses (P). SM, infrahyoid strap muscles. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

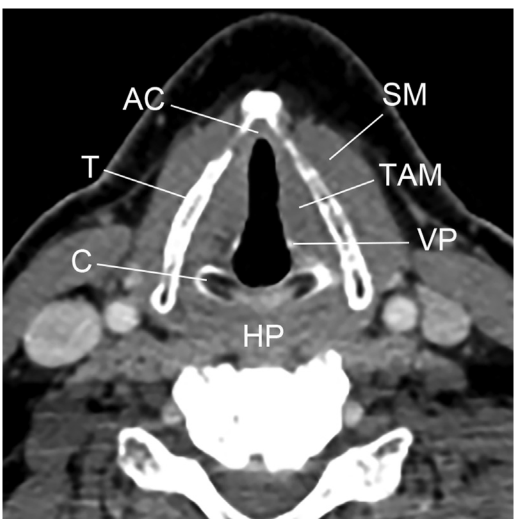

Fig. 17. Axial CT image at the level of the glottis, defined by the TC, which are composed of the vocal ligaments and the TAMs. The AC is located at the insertion site of the vocal ligaments at the inner surface of the thyroid cartilage. The vocal ligaments attach posteriorly to the vocal processes (VP), which are just visible on the slice. The posterior lamina of the cricoid (C) is clearly seen at this level. The airspace between the TC is called the rima glottidis. HP, hypopharynx; SM, infrahyoid strap muscles; T, thyroid cartilage. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

fat containing, whereas at the level of the glottis, the PGS represents a potential space situated between the TAM and the thyroid cartilage. Unlike in the supraglottis, the PGS at the level of the glottis is not generally resolvable on imaging as a discrete space. Thus, on axial CT and MR images, noting the contents of the space between the laryngeal mucosa and the thyroid cartilage can help determine whether the slice is situated at the supraglottic level, where the PGS will seem primarily fat containing, or the level of the glottis, where there will be almost exclusively soft tissue rather than fat between the airway and the cartilage. From an oncologic imaging standpoint, submucosal invasion of either the PGS or the PES by a laryngeal carcinoma, evident as replacement of the normal fat in these spaces, is critical to recognize because the involvement may not be detectable on laryngoscopic examination but when present, may place the tumor into a higher T-category (at least T3) and prognostic group (at least stage III) than initial clinical staging might suggest.[29] It is also important to remember that the PGS directly abuts the cricoid and thyroid cartilages, so tumors within these spaces can readily erode these cartilages. Furthermore, small defects in the cricothyroid membrane can allow also passage of tumor from the PGS to the overlying extralaryngeal soft tissues.[26]

Finally, the *subglottis* represents the portion of the larynx located immediate inferior to the glottis, extending from the undersurface of the TC to the inferior edge of the cricoid cartilage. The region consists of a single subsite, which is bounded laterally by the cricoid cartilage and the conus elasticus.[2] On axial imaging at the subglottic level, the cricoid can be seen positioned just posterior to the thyroid cartilage with the opening of the ring formed by the anterior arch and lamina visible in plane (**Fig. 18**). Evaluation of the subglottis on imaging is generally straightforward because the subglottis features only a thin layer of mucosa along the endoluminal surface of the cricoid and tracheal cartilages. Therefore, any soft tissue thickening along the walls of the subglottic airway in this region should be viewed with suspicion on cancer staging scans. Subglottic extension generally precludes most types of partial laryngectomy, leaving only total laryngectomy or near total laryngectomy as the only surgical options.[9]

In addition to closely scrutinizing the structures intrinsic to the larynx on oncologic staging scans, it is also important to look for involvement of neighboring extralaryngeal sites. For tumors of the supraglottis, these include the base of tongue, valleculae, pyriform sinuses, and postcricoid hypopharynx. Other structures that may be involved by advanced primary laryngeal malignancies include surrounding visceral space structures such as the trachea, strap muscles, thyroid gland, and the esophagus, whereas very advanced tumors may involve the carotid and prevertebral spaces or even extend into the mediastinum.

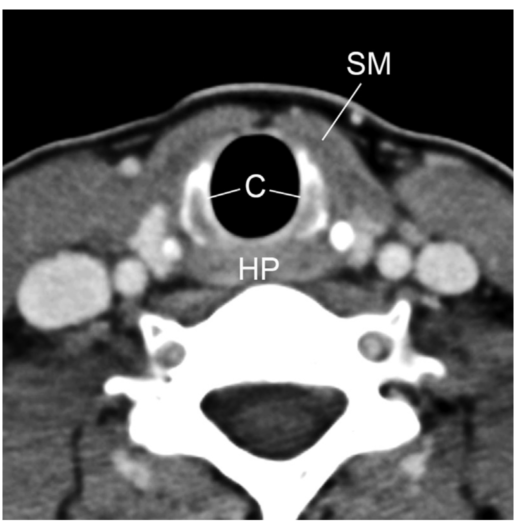

Fig. 18. Axial soft tissue window CT through the subglottis demonstrating the ring of the cricoid cartilage (C). Notice the lack of soft tissue along the wall of the laryngeal airway at this level. HP, hypopharynx; SM, infrahyoid strap muscles. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

Blood Supply, Innervation, and Lymphatics of the Larynx

Vasculature

The primary blood supply to the larynx is through the *superior thyroid artery* (STA) and *inferior thyroid artery* (ITA; **Fig. 19**). The STA arises from the external carotid artery and divides into several branches including the superior laryngeal artery and the cricothyroid artery. The internal branch of the superior laryngeal artery pierces through the thyrohyoid membrane along with the superior laryngeal nerve to supply the deeper structures of the larynx.[23] Rarely the superior laryngeal artery may enter the larynx more inferiorly through a foramen in the thyroid cartilage lamina or through the cricothyroid ligament.[34]

The ITA is a branch from the thyrocervical trunk, which arises from the subclavian artery. The ITA branches into the inferior laryngeal artery, which follows the course of the recurrent laryngeal nerve to enter the larynx superior to the cricothyroid joint and below the inferior pharyngeal constrictor muscle.

Venous drainage of the larynx reflects the arterial supply with superior and inferior laryngeal veins. Each superior laryngeal vein drains to the ipsilateral superior thyroid vein, then to the internal jugular vein. The inferior laryngeal vein drains to the middle thyroid vein, then to the internal jugular vein. Some of the veins along the cricothyroid membrane also drain into the thyroid isthmus and then to the inferior thyroid veins, which typically drain to the brachiocephalic veins.[23,35]

Innervation

The larynx is innervated by the vagus nerve via 2 major branches, the *superior laryngeal nerve* and the *recurrent (or inferior) laryngeal nerve* (RLN; see **Fig. 19**). The dual innervation is explained by the embryologic divisions of the larynx, which are formed by the fourth and sixth branchial arches, respectively. The superior laryngeal nerve supplies the fourth arch derivatives, which include the epiglottis, thyroid and cuneiform cartilages, cricothyroid muscles, and pharyngeal constrictor muscles, whereas the recurrent laryngeal nerve supplies the sixth arch derivatives including the arytenoid, corniculate and cricoid cartilages, and the remaining intrinsic larynx muscles.[36,37]

Sensory innervation above the vocal cords is through the internal laryngeal branch of the superior laryngeal nerve. The internal branch courses with the superior laryngeal artery through the thyrohyoid membrane to reach the mucosa of the epiglottis, AE folds, and larynx. Taste buds located in this region are also innervated by the internal

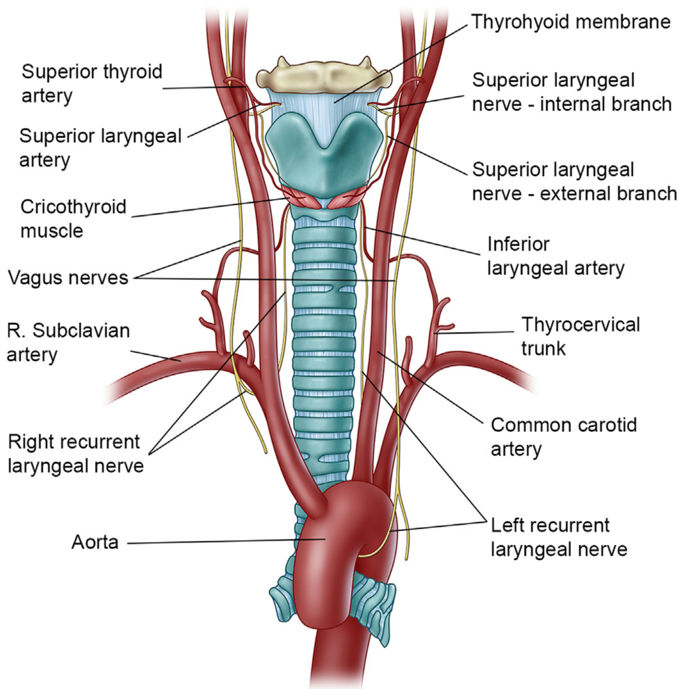

Fig. 19. Coronal illustrative view of the blood supply and innervation to the larynx and trachea. (*Courtesy of* Joel Floyd, Jr, MA, CMI, Chapel Hill, NC.)

laryngeal branch.[38] The superior laryngeal nerve also gives off a smaller external branch that descends along the anterolateral aspect of the larynx to innervate the cricothyroid muscle, which, being a fourth branchial arch derivative, is the only intrinsic larynx muscle not innervated by the RLN.[36]

Motor innervation to all of the other intrinsic muscles of the larynx and sensory innervation below the vocal cords are provided by the RLN. The arytenoid muscles receive bilateral innervation from both RLNs, whereas all of the other laryngeal muscles have unilateral innervation.[13]

It is important to understand the origin and course of the RLN and include its full course from the skull base through the aortic arch in imaging protocols for vocal cord paralysis because an injury or mass effect at any site along this course could produce vocal cord motion abnormalities. The vagus nerve exits the skull through the jugular foramen and runs posterolateral to the carotid artery in the carotid space.[13] The right RLN branches from the vagus nerve just inferior to the right subclavian artery, wraps posteromedially under the origin of the subclavian artery and courses cranially through the right tracheoesophageal groove.[39] Owing to embryologic development, the left RLN has a longer course. It branches from the vagus nerve just inferior to the aortic arch, wraps posteriorly under the arch just lateral to the ligamentum arteriosum, then courses cranially through the left tracheoesophageal groove to reach the larynx.[39] Each RLN then enters the larynx through a sulcus between the thyroid and cricoid cartilages, just superior to the cricothyroid joint.[13,38]

An important anatomic variant to be aware of is the *nonrecurrent laryngeal nerve* (NRLN), which occurs when the inferior laryngeal nerve enters the larynx directly from the cervical vagus nerve without descending to the thoracic level. This variant almost always appears on the right in association with an aberrant right subclavian artery and has been reported with an incidence of 0.3% to 1.6%.[40] Left-sided occurrence of an NRLN has been described but is extremely rare and seen only in association with situs inversus.[41] Due to its course, an NRLN is highly predisposed to injury during thyroidectomy. Although the nerve cannot be visualized on conventional imaging, its presence can be predicted based on its association with an aberrant right subclavian artery, making it important to identify subclavian artery aberrance preoperatively in patients undergoing thyroid or parathyroid surgery.

Lymphatics

The lymphatic system of the larynx is a complex network with multiple anastomatic communications and directions of flow. However, there are typical patterns of flow that have been documented on dye injection studies and correlate with common sites of metastatic lymph node spread in cases of laryngeal malignancies.[42–44] The supraglottic and glottic regions drain primarily to the level II and III cervical lymph nodes and the subglottic region drains to levels III and VI.[43,44] In laryngeal cancers, cervical lymph node metastases are typically unilateral on the same side as the tumor, but can be bilateral, or occasionally contralateral.[43]

The lymphatic system of the larynx has 2 networks, one located superficially in the mucosa and one deeper in the submucosal layers with numerous communications between each layer and with the adjacent networks of the hypopharynx and trachea.[44] There is variability in the density of the lymphatic tissue throughout the larynx. It is highest in the supraglottic region, which is extremely rich in lymphatics, with lymphatic density being greatest in the epiglottis, false vocal fold, and AE folds and lowest near the petiole of the epiglottis, thyroepiglottic ligament, and vocal ligament.[44] In fact, some authors note that the free margins of the vocal cords are virtually devoid of lymphatics.[29,45] This may account in part for the higher incidence of occult nodal metastases observed in supraglottic primaries compared with glottic carcinomas. In general, the supraglottic region drains medial to lateral through the thyrohyoid membrane to reach the level II and III cervical lymph nodes.[44]

At the subglottic level, drainage anteriorly is through the cricothyroid ligament and posteriorly through the cricotracheal ligament with subsequent drainage to both level III and VI nodes.[44] In addition, the inferior surface of the vocal cord has been shown to have lymphatic drainage similar to the subglottis.[46] Enlargement of lymph nodes in the level VI station, including the Delphian (or prelaryngeal) lymph node, which is located at the midline anterior to the cricothyroid membrane, can be a sign of metastasis from an AC or subglottic tumor but can also be seen with thyroid gland tumors or from direct extension of tumor to this region.[47]

THE CERVICAL TRACHEA

The trachea serves as the conduit between the larynx and bronchial tree. It typically extends from the C6 level, just below the cricoid cartilage, to the T4–T5 level, bifurcating into the mainstem bronchi at the carina.[48] The extrathoracic or cervical segment of the trachea is a relatively short portion of the trachea, measuring approximately 2 to 4 cm. The average adult trachea is approximately 11 cm in length, with a range of 10 to 13 cm[49,50] (**Fig. 20**). A segment of the cervical trachea lies superficially in the neck and is only partially covered by the infrahyoid strap muscles. It is palpable between the sternal heads of the sternocleidomastoid muscles and superior to the jugular (suprasternal) notch.[38] As the trachea courses caudally, it tracks posteriorly, and is often displaced just right of midline at the aortic arch.[51] The thyroid gland is just anterior and lateral to the trachea, with the thyroid isthmus typically located at the second or third tracheal ring. The esophagus is closely apposed to the posterior wall of the cervical trachea, usually veering along the left posterior margin of the trachea as it courses inferiorly.[39]

In infancy, the trachea is round in the axial plane. With advanced aging, the trachea may narrow in the transverse diameter and widens in the anteroposterior diameter.[39,52] This change in diameter primarily affects the intrathoracic segment of the trachea.[48]

Composition of the trachea

The trachea is composed of 18 to 22 incomplete cartilage rings that provide structural support to its anterior and lateral walls.[39,49] The trachea generally becomes intrathoracic at the level of the sixth ring.[8] Each tracheal ring is made up of hyaline cartilage and is surrounded by a perichondrium that is composed primarily of collagen with

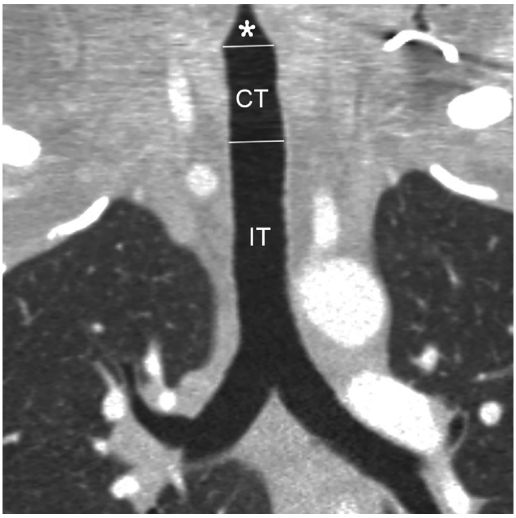

Fig. 20. Obliqued coronal CT image through the trachea. To obtain a single image showing the length of the trachea, an oblique coronal reformatted image was required because the intrathoracic trachea courses slightly posterior as it descends the mediastinum. The coronal view provides an overview of the entire length of the trachea including the cervical (CT) and intrathoracic segments (IT) and can be helpful to assess the length of stenosis or other pathologies (*asterisk* = subglottis). (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

a small component of elastin fibers. The cartilage rings are connected to each other by intercartilaginous membranes, also composed of collagen and elastin fibers.[51] The posterior wall of the trachea comprises a fibromuscular membrane. The smooth muscle in this wall is known as the trachealis and runs longitudinally along the length of the trachea.[39] The normal tracheal wall should be thin, measuring 1 to 3 mm, with the mucosa of the trachea being composed of ciliated pseudostratified columnar epithelium with an elastic lamina propria deep to the epithelial layer.[39,50,51] Goblet mucous cells and subepithelial glands are interspersed between and deep to the epithelial layer.[51]

Blood supply, innervation, and lymphatics of the trachea

The arterial supply to the trachea is divided into a cervical (upper) segment and thoracic (lower) segment. The cervical trachea is supplied by the tracheoesophageal branches of the bilateral ITAs, which arise from the thyrocervical trunks of the subclavian arteries. There are several branches of the tracheoesophageal arteries, each supplying short segments of the cervical trachea with anastomoses between each segment. There is some variability to this supply but generally there are 3 major tracheoesophageal branches. Anastomoses with the STA also exist along the anterior tracheal wall, where this artery provides blood supply to the isthmus of the thyroid gland. The thoracic trachea is supplied through multiple bronchial arteries that arise directly from the aorta.[39]

Venous drainage of the trachea is through inferior thyroid veins to the brachiocephalic veins, whereas lymphatic drainage of the proximal two-thirds of the trachea is through the pretracheal and paratracheal lymph nodes of level VI, which subsequently drain to lower jugular nodes of level IV.[51,53]

The trachea is innervated by branches of the vagus nerve. Sensory fibers to the inner tracheal mucosa arise from branches of the bilateral recurrent laryngeal nerves. Parasympathetic innervation to the trachea also arises from the recurrent laryngeal nerves. Sympathetic innervation comes from both cervical ganglia and the second through fourth thoracic ganglia.[51] These autonomic nerves supply the seromucous glands, smooth muscles, and the blood vessels of the trachea.[38]

Imaging techniques for evaluating the larynx and cervical trachea

Larynx

The larynx is frequently evaluated with CT or MR imaging. Contrast-enhanced CT neck is more commonly used owing to wider availability, reproducibility, and decreased risk of motion degradation.[9] At our institution, MR imaging is primarily used to supplement CT when additional assessment is needed.

CT neck imaging with contrast is obtained in the axial plane and coronal and sagittal reconstructed series should also be generated. Because the vocal cords are often not exactly parallel to the plane of the axial images, some advocate for additional reconstructions parallel to plane of the vocal cords, which is generally well approximated by the plane of the C4–C5 or C5–C6 intervertebral disc space (**Fig. 21**). These reformatted images should typically span from 1 cm above hyoid bone to the inferior margin of the cricoid cartilage.[54]

CT imaging of the neck is primarily obtained during quiet breathing.[54,55] During normal breathing, the vocal cords are abducted and the cords and laryngeal ventricles are not always well demarcated.[9,56] This distinction may be important in assessing transglottic spread of tumors. Therefore, other imaging can be obtained with various breath hold and phonation techniques. The primary additional maneuvers include a modified Valsalva maneuver and phonation with the sound "eee."

Modified Valsalva maneuvers, which include blowing through pursed lips or nose, distend the laryngeal vestibule and piriform sinuses providing better visualization of tumors in the piriform sinus or postcricoid region; however, the true cords and FC are abducted in this maneuver so tumors of the glottic region are not well evaluated with this technique.[26,55,57] Phonation with "eee" produces adduction of the true and FC and distends the laryngeal ventricle. This can aide also in evaluation of transglottic spread of tumors.[57] Use of a high-pitched sound such as "eee" or "hee" requires the vocal cords to be thinner and allows better visualization of abnormalities along the cords. This technique can also be used for the assessment of vocal cord paralysis,[56] although, the best assessment for vocal fold motion remains clinical awake flexible fiberoptic laryngoscopy. In cases of vocal cord paralysis, on standard quiet respiration examinations, the paralyzed cord will be medialized and there will be dilation of the ipsilateral pyriform sinus and laryngeal ventricle, and thickening of the AE fold.[58] This can further be confirmed with a phonation scan, which will demonstrate incomplete adduction of the paralyzed cord and no significant change in the cord position between the quiet respiration and phonation scans.[56] There is some concern that the use of phonation techniques will increase motion artifact but it has been shown that with proper patient

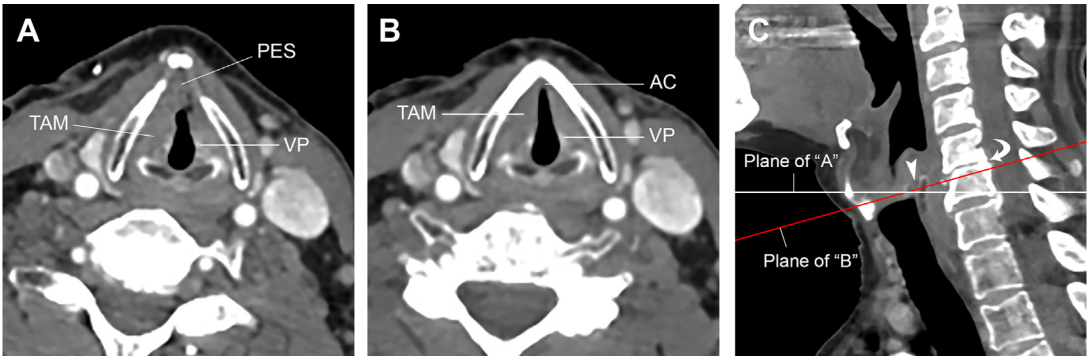

Fig. 21. Value of angled axial images for assessment of the glottis. (*A*) Straight axial CT image through the level of the vocal processes (VP) includes a portion of the PES of the supraglottis anteriorly and the thyroarytenoid muscle (TAM) of the glottis more posteriorly. The anterior extent of the true vocal cord, including the AC, is not seen in plane. (*B*) Angled axial image through the vocal processes (VP) demonstrating the length of the glottis, including the AC, which is normal in this example. (*C*) Parasagittal image through the level of the left cricoarytenoid joint (*arrowheads*) indicating the approximate location and angulation of the previous images. The white line indicates the plane for figure (A), whereas the red line indicates the plane for figure (B). Note how the red line roughly parallels the C5–C6 disc space (*curved arrow*). (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

preparation, motion artifact on phonation examinations can be minimized.[57]

MR imaging is also helpful for the evaluation of the larynx, particularly for the assessment of malignant cartilage invasion. Specifically in cases with AC involvement, MR imaging has been shown to be more accurate than CT in determining cartilage invasion (88.46% for MR imaging vs 57.69% for CT).[59] On CT, cartilage involvement can be demonstrated by cartilage sclerosis, erosion, lysis, or tumor in the extralaryngeal tissues on the other side of the cartilage.[16,17,59] However, because there is variability in ossification of the laryngeal cartilages, these changes can be difficult to distinguish from normal unossified cartilage. Some of this can be overcome with MR imaging but differentiating unossified cartilage from invaded cartilage on MR imaging can also be difficult because one of the best MR imaging markers of cartilage invasion is loss of the normal fatty marrow signal in ossified cartilage.[16–18] Another marker on MR imaging that can be used is the assessment of enhancement. Normally, the cartilage does not enhance, so if contrast enhancement is present, it can indicate invasion. This should also be interpreted with caution, however, because enhancing cartilage can also be seen in peritumoral inflammation without invasion.[16–18] An additional limitation of MR imaging is missing early invasion of just the surface of the cartilage as the rim of ossified cartilage is markedly hypointense on T1-weighted images and may mask early invasion.[18]

Dual-energy CT is a newer technique that can assist in the evaluation of cartilage invasion.[60] Briefly, 2 different series are provided, the weighted-average (WA) sequence, which seems similar to conventional CT, and an iodine overlay (IO). When there is suspected cartilage invasion on the WA, this area can be confirmed as invasion if there is bright, iodine density in the corresponding area on the IO series. If no corresponding iodine density is seen on the IO, then the region likely represents unossified cartilage. It is important to understand the limitations of dual-energy CT when interpreting a case. One of the major limitations is that bone and calcified cartilage will also seem bright on the IO series; therefore, it should not be confused with enhancing tissue. Evaluation of both the WA and IO series is required to avoid overestimating cartilage invasion.[54]

Ultrasound of the larynx is an alternative option, typically used in the clinical setting and can aid in evaluation of cord mobility; however, it requires the performing physician to have a detailed knowledge of the laryngeal anatomy and understand the limitations of sonography, typically limited by the degree of ossification of the laryngeal cartilages.[61,62]

Trachea

CT is the primary modality for imaging the trachea and advancements in multidetector CT with multiplanar and three-dimensional (3D) reformations allows for a variety of visualization options.[63] Thin section reconstructions using submillimeter slice thicknesses reconstructed in multiple planes should be obtained for the assessment of stenosis of the subglottic trachea, particularly in patients with a history of shortness of breath, stridor, prolonged intubation, or a history of prior tracheostomy. When specifically evaluating the trachea, imaging is mainly obtained with a suspended inspiration; however, the cervical trachea is often seen on neck CTs, which are usually obtained with quiet respiration[9,48] (**Fig. 22**). Therefore, knowledge of the normal changes in size of the trachea during breathing is needed before assessing for pathologic condition of the trachea.

The diameter of the trachea is dynamic and changes with the phase of respiration. During inspiration, the trachea is rounded or oval shaped, with expiration the posterior wall flattens and can bow forward due to the flexibility of the posterior fibromuscular wall (**Fig. 23**). Studies have shown the anteroposterior (AP) diameter changes more significantly, up to 35% change, than the transverse diameter, up to 13% change.[48,64] In men, during inhalation, the trachea measures 13 to 25 mm in coronal diameter and 13 to 27 mm in sagittal diameter. In women, during inhalation the trachea measures 10 to 21 mm in coronal diameter and 10 to 23 mm in sagittal diameter. It is important to measure the diameter of the trachea in a true axial plane that is oriented perpendicular to the course of the trachea, which is not always the same as the axial plane of the image. Owing to the advancement of isotropic imaging with the ability to reformat images in any plane, a true axial plane of the trachea is possible and should be used if measurements are needed.[48]

Expiratory imaging can be obtained to assess for tracheomalacia.[65,66] It can also aide in the evaluation of postintubation stenosis because in the chronic state, there may only be minimal wall thickening but on expiratory imaging narrowing of the tracheal lumen can be more pronounced due to cartilage weakening, which is often located 3 to 4 cm below the cricoid cartilage.[63] Expiratory imaging is also often used to evaluate for small airway disease, which will have a mosaic pattern on the expiratory images.[48] Protocols for expiratory imaging can include static end-expiratory CT, or cine imaging during forceful exhalation or coughing.[63]

Three-dimensional images with an external volume rendering can allow easier viewing of subtle narrowing, provide a better view of the length and severity of the stenosis, as well as provide an overview of the full airway with one image.[48,66] This view can also be easier to understand for patients and provide a better anatomic roadmap for preprocedural planning.[65] Off axis coronal 2D projections are also helpful in evaluating the trachea in a single image (see **Fig. 20**).[66] Virtual bronchoscopy is an internal 3D rendering of the airway to mimic the views as seen in conventional bronchoscopy. This can be used for stenoses that will not allow passage of the bronchoscope, preplanning for transbronchial biopsies, foreign body aspiration evaluation, and tracheomalacia.[48]

Finally, the trachea can be evaluated on MR imaging but respiratory motion artifact makes it more difficult to obtain diagnostic quality imaging. MR imaging can be helpful in cases of mediastinal masses to assess for tracheal compression or invasion or in cases of vascular rings or anomalies. Because these pathologic conditions affect the intrathoracic trachea, further discussion is beyond the scope of this article. To avoid excessive exposure to ionizing radiation, MR imaging should be considered in pediatric patients that may require frequent imaging.[66]

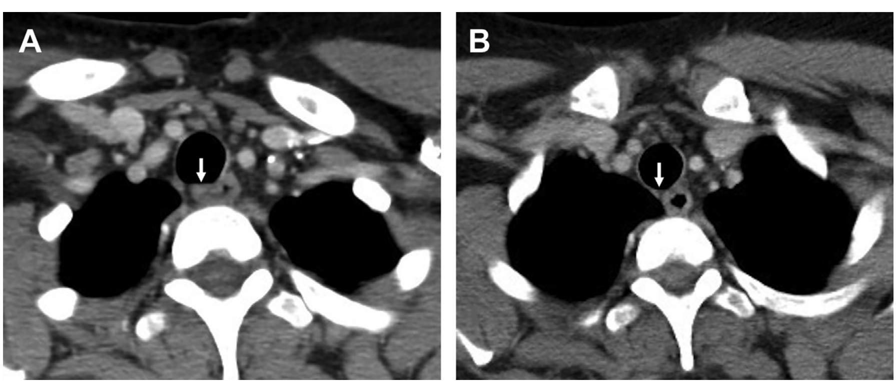

Fig. 22. Normal CT images demonstrating the variation in the shape of the trachea using different breathing techniques. Figure A obtained from a neck CT during quiet respiration showing flattening of the posterior wall of the trachea (*arrow*). Figure B obtained immediately after Figure A from a chest CT from the same patient during end-inspiratory breath hold showing the posterior wall is now convex (*arrow*) and gives the trachea a rounded appearance. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

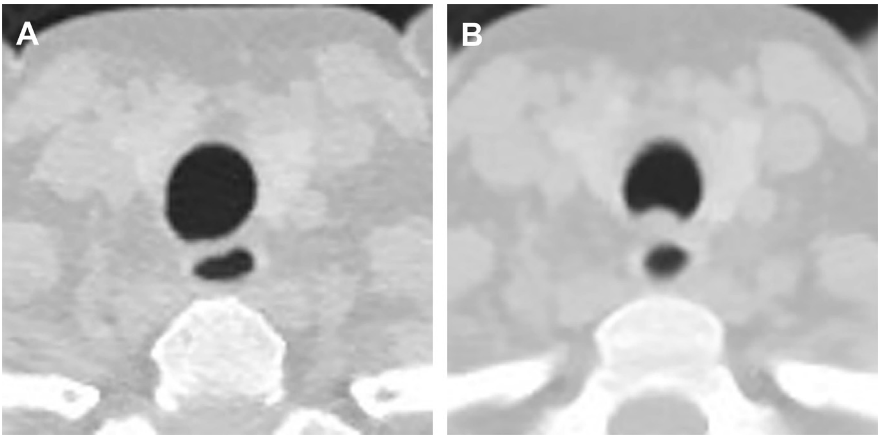

Fig. 23. Axial chest CT images through the cervical segment of the trachea in a lung window. Figure A was obtained during end-inspiratory breath hold and figure B was obtained during end-expiratory breath hold. This shows the normal change of the posterior fibromuscular wall and normal overall reduction in the tracheal diameter in the expiratory phase. At end-expiration the normal inward bowing of the posterior fibromuscular wall (*B*) could be mistaken for pathologic condition if not aware of this normal dynamic change. On these images, the esophagus is also visualized as the air-filled structure located just posterior to the trachea; more commonly the esophagus is collapsed. (*Courtesy of* University of North Carolina, Chapel Hill, NC.)

CLINICS CARE POINTS

- Involvement of the preepiglottic and paraglottic spaces may not be clinically suspected in patients with laryngeal cancers but when present could potentially increase the tumor category (to at least T3) and AJCC prognostic stage (at least stage III).
- Tumors involving the anterior commissure (AC) are associated with early invasion of the adjacent thyroid cartilage, subglottic extension, and early extralaryngeal extension, so this region should be closely scrutinized in patients with laryngeal cancers. The normal AC should measure no more than 2 mm in thickness.
- Subglottic tumor extension precludes most types of partial laryngectomy, leaving only total laryngectomy or near total laryngectomy as the only surgical option.
- Imaging protocols for vocal cord paralysis should cover the entire course of the cervical vagus and recurrent laryngeal nerves from the skull base through the aortic arch because lesions at any site along this course may cause vocal cord weakness.
- In patients potentially undergoing thyroidectomy, it is important to recognize the presence of an aberrant subclavian artery because this anatomic variant is associated with a nonrecurrent course of the inferior laryngeal nerve, which places the nerve at increased risk for injury during surgery.

DISCLOSURE

The authors have nothing to disclose.

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