Anatomy from the Inside Out

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Introduction

The upper aerodigestive tract is one of the most complex areas of the human body due to its tripartite role in communication, deglutition, and breathing [1]. Understanding the true interplay of each process requires intimate knowledge of these dynamic physiologic processes. Therefore, laryngeal anatomy is of paramount importance when attempting to understand laryngeal physiology and pathology. However, the normal layered transcervical view by which laryngeal anatomy is described in many textbooks and atlases does not correspond to the way most clinicians encounter it in clinical practice. This can make it particularly difficult for less experienced clinicians to apply their anatomic knowledge when viewing the larynx in clinic or in the operating theater. Flexible and rigid laryngoscopy are the most common methods by which otolaryngologists examine the larynx [1]. For this reason, the modern clinician must also consider the various anatomic areas, muscles, cartilages, vascular, and neural structures from this viewpoint. We endeavor to describe laryngeal anatomy from the perspective by which most it is most frequently encountered.

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This chapter is organized systematically. First, we review the location of the bone and the six cartilage structures that make up laryngeal skeleton. Second, we identify and discuss anatomic areas used in head and neck oncology for staging purposes. Third, we discuss surface anatomy from the supraglottic view. Finally, we review vascular and neural structures. These last points are especially important when planning and performing endoscopic microlaryngeal surgery.

The Laryngeal Skeleton

Hyoid Bone

The hyoid is a horseshoe-shaped, free-floating bone that articulates with the superior horns of the thyroid cartilage and is suspended in the neck by a muscular and ligamentous sling attached to the root of the tongue [2]. The hyoid bone provides structural support for several functions related to swallowing and phonation. Beginning at the base of tongue on endoscopy, the hyoid bone can be understood as the origin of the hyoglossus and insertion of the geniohyoid muscles [2, 3]. Unseen on endoscopy are the other suprahyoid muscles—the mylohyoid, stylohyoid, and digastric muscles. Likewise, the infrahyoid muscles, which include the sternohyoid, thyrohyoid, and omohyoid muscles, are unseen on endoscopy but important in understanding the move-

P. A. Weissbrod, D. O. Francis (eds.), *Neurologic and Neurodegenerative Diseases of the Larynx*,
https://doi.org/10.1007/978-3-030-28852-5_1

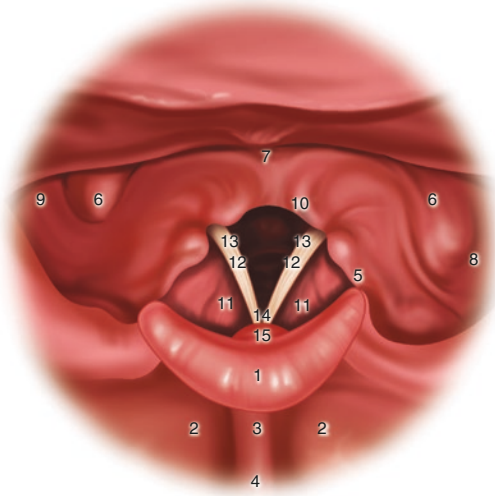

Fig. 1.1 Normal flexible laryngoscopic exam. Pertinent anatomical landmarks of the oropharynx and structures surrounding the supraglottis include: (1) epiglottis, (2) valleculae, (3) hyoepiglottic ligament, (4) base of tongue, (5) aryepiglottic folds, (6) pyriform sinus, (7) post-cricoid region, (8) greater horn of the hyoid bone, and (9) internal surface of the thyroid lamina. Laryngeal structures include: (10) arytenoid cartilages, (11) false vocal folds, (12) true vocal folds, (13) vocal processes, (14) anterior commissure, and (15) petiole of the epiglottis

ment of the larynx physiologically. The median hyoepiglottic ligament, a common finding on endoscopy, serves as an anatomic marker for locating the body of the hyoid endoscopically [1] (Fig. 1.1). The greater horns of the hyoid bone can also be identified in the lateral pharyngeal wall, especially in thin patients (Fig. 1.2).

Laryngeal Cartilages

The laryngeal skeleton is comprised of six primary cartilage structures. Each is discussed sequentially beginning with the thyroid cartilage and moving inferiorly.

Thyroid Cartilage The thyroid cartilage, derived from the Latin word for "shield," is an aptly named cartilaginous structure providing protection and support to the vocal folds [4]. It articulates superiorly with the greater horn of the hyoid bone and is connected to the hyoid along its superior extent by the thyrohyoid membrane, which runs the length of the hyoid. The membrane has three condensations, two

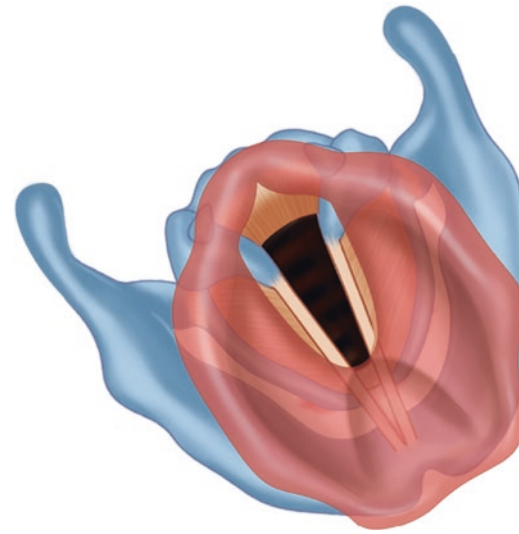

Fig. 1.2 Normal flexible laryngoscopic exam (seen in Fig. 1.1) with an anatomical rendering of the underlying cartilaginous skeleton

lateral and one medial, which are termed the medial and lateral thyrohyoid ligaments [2, 4]. Specifically, the medial ligaments connect the body of the hyoid with the superior thyroid

notch while the lateral ligaments connect the superior horn of the thyroid with the greater horn of the hyoid. Importantly, it is through this membrane that the internal branch of the superior laryngeal nerve and the superior laryngeal artery pass into the internal surface of the larynx laterally [5]. The thyroid cartilage itself is composed of two broad, flat laminae that are fused together anteriorly in the midline. The thyroid cartilage also has inferior horns which articulate with the cricoid cartilage at the cricothyroid joint, which is critical to pitch modulation [6]. The majority of the thyroid cartilage cannot be seen on endoscopy except for the internal surface of the posterior laminae, which can be seen through the anterior pyriform sinus mucosa (Fig. 1.2).

Epiglottis The epiglottis is a broad, leaf-shaped fibrocartilaginous structure which extends superiorly from a stem, or petiole [4]. The epiglottis is connected to multiple laryngeal structures including the hyoid bone, thyroid cartilage, and arytenoid cartilages via the hyoepiglottic, thyroepiglottic, and aryepiglottic ligaments, respectively [7]. Furthermore, a sheet of fibroelastic tissue termed the quadrangular membrane extends from the aryepiglottic ligament inferiorly onto the surface of the false vocal fold, creating the familiar endolaryngeal slope of the supraglottis when viewed on flexible laryngoscopy [1, 8]. It is through these interactions that the epiglottis closes over the airway during swallowing. The epiglottis is a prominent structure easily noted during laryngoscopy; often the laryngoscopist will need to carefully maneuver around the epiglottis in order to fully view the glottis, as this structure contains dense sensory fibers from the internal branch of the superior laryngeal nerve [9]. This is can be more easily accomplished by placing the patient into "sniffing position" by tilting the chin up, flexing the head forward while extending the neck [10]. This position displaces the larynx anteriorly to better align the larynx and trachea with an oral or transnasal endoscopic approach.

Arytenoid, Corniculate, and Cuneiform The prominent laryngeal cartilages of the posterior larynx—and frequently queried structures by patients—are the arytenoid cartilages. They are located in the posterior supraglottis and are oriented vertically with the muscular process located on the lateral surface (not visible on laryngoscopy) and the vocal process medially positioned and attached to the vocal ligament, serving as a prominent landmark of true vocal fold anatomy [1, 10]. The aryepiglottic folds extend from the arytenoid cartilages to the epiglottis. The corniculate and cuneiform cartilages, if present, may be visible at the superior aspect of the arytenoid cartilage or partially extending into the aryepiglottic fold [8]. The vocal process marks the beginning of the posterior one-third of the true vocal fold and is the origin of the thyroarytenoid muscle [11]. The cricoarytenoid joints are complex diarthrodial joints—filled with synovial fluid—located at the superior edge of the cricoid plate. These joints allow the arytenoid cartilage to internally and externally rotate, glide medial and lateral, as well as pitch superiorly or inferiorly in a rocking motion atop the cricoid cartilage. The overall structure is reinforced with several surrounding ligaments to prevent anterior or posterior dislocation. However, in rare cases external trauma can force the arytenoid cartilage beyond the elastic capacity of these ligaments and result in dislocation requiring transoral approach for closed reduction. Closely observing its rotational movement is essential to isolate cricoarytenoid joint and recurrent laryngeal nerve function in the setting of suspected vocal fold mobility impairment [12].

Cricoid The final cartilage to discuss is the cricoid cartilage which is located at the inferior aspect of the larynx and is connected to the trachea via the cricotracheal ligament, connecting the cricoid ring to the first tracheal ring [8]. The cricoid is the only complete cartilaginous ring in a normal airway, presenting a potential choke point of luminal narrowing. It is a signet ring-shaped structure that is short anteriorly and lengthens into a tall, flat lamina posteriorly, upon which the arytenoid cartilages sit. The anterior cricoid ring can be viewed in the anterior subglottis on flexible laryngoscopy as an offset between the cricoid and the trachea below. This natural shelf can be confused for narrowing of the airway due to an oblique viewing angle during indirect laryngoscopy and an inade-

quate view of the trachea inferiorly. The cricoid cartilage is attached anteriorly to the inferior border of the thyroid laminae by means of the cricothyroid membrane and has a condensation in the cricothyroid ligament, which is a more dense fan-shaped structure in the midline [1, 8]. This ligament (not visible on laryngoscopy) serves as a reliable landmark of midline during open laryngeal surgery.

Regional Laryngeal Anatomy and Subsites

In this section we define the regions of the oropharynx, hypopharynx, and supraglottis. We also aim to define the subsites of the larynx—the supraglottis, glottis, and subglottis—and how can they be readily identified on endoscopy. We explore these distinctions sequentially in a superior to inferior manner.

Pharyngeal Subsites The oropharynx is defined by its multiple subsites included in the American Joint Commission on Cancer (AJCC) 8th edition staging guidelines for head and neck cancer [13]. The subsites include the anterior and posterior tonsillar pillars, tonsillar fossae, valleculae, base of tongue, posterior pharyngeal wall, soft palate, and uvula [3, 13]. The boundary between the oropharynx and supraglottis is naturally developed as the lingual surface of the epiglottis, aryepiglottic folds, and the mucosa overlying the arytenoid cartilages.

The borders between the oropharynx and nasopharynx and hypopharynx are less obvious. The boundary between the nasopharynx and oropharynx is defined as an imaginary axial plane through the superior-most surface of the soft palate [14]. Delineating the hypopharynx is a bit more complex, as the boundary between the oropharynx and hypopharynx is an imaginary axial plane defined by the superior surface of the hyoid bone, which demonstrated previously is less readily identifiable, except for key endoscopic landmarks [14].

Laryngeal Subsites Finally, we must differentiate the various subsites of the larynx. The supraglottis is defined as the laryngeal structures superior to the glottis, and this boundary is usually defined as the lateral most aspect of the laryngeal ventricle, where the mucosa transitions from respiratory epithelium to stratified squamous epithelium [15]. Supraglottic structures include the epiglottis, aryepiglottic folds and quadrangular membranes, arytenoid cartilages, and the false vocal folds. The glottis is comprised of the superior and inferior surfaces of the true vocal folds and is defined to be 1 cm in vertical dimension [15]. The subglottis is defined as extending from the glottis to the inferior border of the cricoid ring. This is typically 1 cm below the vocal fold edge anteriorly and 5 mm below the vocal fold posteriorly due to the taller posterior height of the cricoid. It is important to comment on the term "infraglottis." It is not an official laryngeal subsite, but when used refers to the undersurface of the true vocal fold as they descend toward the conus elasticus and cricoid.

Supraglottic, Glottic, and Subglottic Surface Anatomy

Supraglottis The supraglottis is defined by the arytenoid cartilages posteriorly, the aryepiglottic folds laterally, and the epiglottis anteriorly [3, 15]. The aryepiglottic folds are continuous with the quadrangular membrane, which extends inferomedially to support the false vocal fold. Respiratory epithelium continues around the free edge of the false vocal fold and into the ventricle, where it transitions to stratified squamous epithelium inferiorly at the junction of the ventricle and the true vocal fold [15]. Posteriorly, a small sulcus is usually found between the arytenoid cartilages, known as the interarytenoid sulcus, which extends inferiorly until the interarytenoid muscle is encountered. The petiole of the epiglottis is encountered inferiorly in the supraglottis and articulates with the thyroid cartilage immediately superior to the anterior commissure of the glottis.

Glottis The true vocal folds are normally white bands of tissue located in the glottis that extend from the vocal process of the arytenoid cartilage

to the anterior commissure where the thyroarytenoid muscles insert onto the thyroid cartilage to create a V-like appearance on laryngoscopy [1, 11]. The mucosa overlying the true vocal folds is nonkeratinized stratified squamous epithelium. When viewed from above, the true vocal folds appear as two-dimensional shelves extending medially. However, the true vocal folds are composed of laminated soft tissue structures that give them their unique physiologic and biomechanical properties [16]. It should also be noted that the true vocal fold gradually continues inferiorly to the cricoid ring as the conus elasticus [16]. On the surface of the true vocal folds, blood vessels normally orient in a longitudinal fashion. Torturous or horizontal blood vessels are notable and may represent a response to an acute, chronic, or past injury.

Subglottis The view of the subglottis is somewhat limited on flexible laryngoscopy during assessment for subglottic stenosis and/or masses. However, in our experience lifting the chin can pull the epiglottis forward to obtain a better view of the glottis and tucking the chin down can better align the trachea with the larynx to obtain a view of the subglottis and often several tracheal rings. The subglottis can be more definitively explored using rigid telescopes during operative laryngoscopy.

Laryngeal Musculature

The intrinsic muscles of the larynx are divided into three basic groups: adductors, abductors, and tensors [1, 16]. While the actions of many of these muscles cannot be directly observed on laryngoscopy, a three-dimensional understanding of their actions is critical.

Adductors The thyroarytenoid (TA) muscle exists within the substance of the true vocal fold and consists of two main parts: internal and external. The external segment extends from the anterior commissure to the lateral surface of the arytenoid cartilage and principally serves to adduct the true vocal fold [1, 8, 11]. The internal segment, also known as the vocalis muscle, extends from the anterior commissure to the vocal process and acts by foreshortening and tightening the true vocal fold.

Another adductor is the lateral cricoarytenoid muscle (LCA). This muscle originates along the superior lateral border of the cricoid ring and inserts on the anterior aspect of the muscular process of the arytenoid cartilage. Contraction of the LCA muscle results in the arytenoid rotating internally and caudally, which translates into downward and medial movement of the vocal process [1].

The last major adductor is the interarytenoid (IA) muscle. This muscle consists of two defined groups: horizontal and oblique. The horizontal group inserts on the substance of the arytenoid cartilage and serves to narrow the laryngeal inlet and close the posterior glottic gap [8]. The oblique fibers insert on the apex of the arytenoid cartilage [8]. Some of the muscle fibers of the oblique group extend past the apex along the aryepiglottic fold and are known as the aryepiglottic muscle.

Abductors The posterior cricoarytenoid (PCA) muscle is the sole abductor of the true vocal folds. It extends from the broad surface of the posterior surface of the cricoid cartilage to the muscular process of the arytenoid cartilage. The paired muscles of the PCA are innervated by the abductor branch of the ipsilateral recurrent laryngeal nerve [17]. Importantly, the function of this muscle rotates the arytenoid cartilage externally and cephalad, causing the vocal process to be displaced superiorly and laterally. The PCA muscle has a medial (horizontal) and lateral (vertical) segment [17]. The medial segment serves as a true abductor while the lateral segment principally serves to elevate the vocal process and maintain the arytenoid cartilage in an upright position.

Tensors The cricothyroid muscle serves as a tensor of the true vocal folds. These paired muscles extend from the anterior aspect of the cricoid ring and insert on the thyroid laminae. This muscle is made of two separate components, the pars recta and pars obliqua [8]. The pars recta is situated more anteriorly and serves to depress the

thyroid cartilage. The pars obliqua inserts on the inferior horn of the thyroid cartilage and acts to displace the thyroid cartilage anteriorly. By performing this action, the cricothyroid muscles also serve as secondary laryngeal abductors [8].

Extrinsic Laryngeal Muscles

The extrinsic laryngeal muscles are comprised of infrahyoid and suprahyoid muscles. The infrahyoid muscles include the sternohyoid, sternothyroid, thyrohyoid, and omohyoid muscles, while the suprahyoid muscles include the digastric, mylohyoid, geniohyoid, and stylopharyngeus. The principal manner by which they affect laryngeal physiology is by changing the position of the hyoid bone and the larynx within the neck. The infrahyoid muscles can compress the laryngeal skeleton resulting in supraglottic medialization and also cause some vocal fold adduction. This can occur as a maladaptive response to a variety of laryngeal insults or compensation for incomplete glottic closure. Overuse of these paralaryngeal muscles during voice production often results in voice change, vocal strain, neck pain, and dysphagia [18, 19]. Palpation of the thyrohyoid space will often reveal exquisite tenderness as a result of chronic musculoskeletal tension.

Blood and Lymph

The laryngeal blood supply is of particular relevance to otolaryngologists that perform microlaryngeal surgery. Our discussion will identify the usually paired arteries and veins of the larynx from superior to inferior. Finally, we discuss laryngeal lymphatic structure and drainage patterns from each subregion, which normally cannot be identified on endoscopy or gross examination.

Blood Supply

The principal blood supplies to the endolarynx are the superior and inferior laryngeal arteries, which are branches of the superior and inferior thyroid arteries (arising from the external carotid and subclavian artery, respectively) [8, 19]. The superior laryngeal artery normally branches from the superior thyroid artery at approximately the level of the hyoid bone in the neck, from which it courses medially with the internal branch of the superior laryngeal nerve [19]. These structures then pierce the thyrohyoid membrane approximately 1 cm anterior and superior to the superior horn of the thyroid cartilage. The superior laryngeal artery has three commonly noted branches: the epiglottic artery which courses through the aryepiglottic fold to the epiglottis and a common trunk which gives rise to the anteroinferior and posteroinferior arteries, which course over the internal surface of the thyroid cartilage to supply the supraglottis and glottis [19]. Multiple anastomotic networks exist between these arteries as well as between these arteries and branches of the inferior laryngeal artery (Fig. 1.3).

By contrast, the inferior laryngeal artery branches from the inferior thyroid artery and

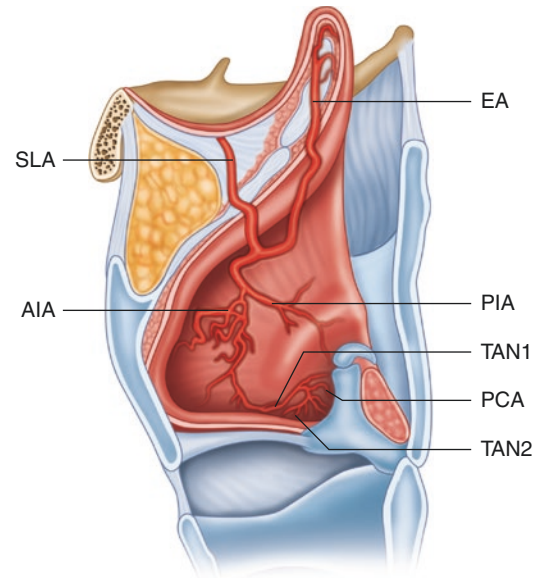

Fig. 1.3 Drawing of a right hemilarynx with tissue removed to reveal the branching of the superior laryngeal artery into the (1) epiglottic artery (EA), (2) anteroinferior artery (AIA), and (3) posteroinferior artery (PIA). The anteroinferior branch also gives off the thyroarytenoid branches (TAN1, TAN2) and the posterior cricoarytenoid branches (PCA)

courses superiorly with the recurrent laryngeal nerve [8, 19]. It has multiple branches that run deep to the inferior constrictor muscle into the larynx that then anastomose with the branches of the superior laryngeal artery. The cricothyroid artery is also a branch of the inferior laryngeal artery, which courses along the superior external surface of the cricothyroid membrane, supplying the cricothyroid muscle. This artery is noted in cadaveric studies to pierce the cricothyroid membrane approximately 2–3 mm from the midline and anastomose with branches of the anteroinferior branch of the superior laryngeal artery [19]. In all areas, the venous blood supply mirrors the arterial supply.

Lymphatics

Lymphatic drainage of the supraglottis is complex, but primarily drains to jugular nodes and deep cervical lymph nodes. The glottis itself has relatively little lymphatic drainage due to the isolation provided by the thyroid cartilage. In the rare case that metastasis occurs from a glottic cancer, it generally tends to involve prelaryngeal, pretracheal, and paratracheal lymph nodes in addition to the deep cervical chains (levels II-IV) [15]. The subglottis normally drains into paratracheal and inferior deep cervical lymph nodes [15].

Innervation

Both sensation and motor innervation of the larynx derive from the vagus nerve. In the neck, the vagus nerve descends in the carotid sheath after exiting the skull via the pars nervosa of the jugular foramen. The vagus nerve has three principal branches in the neck: a pharyngeal branch, the superior laryngeal nerve, and the recurrent laryngeal nerve (Fig. 1.4) [20].

The superior laryngeal nerve emerges from the carotid sheath and divides into an internal and external branch. The internal branch courses with the superior laryngeal artery through the thyrohy-

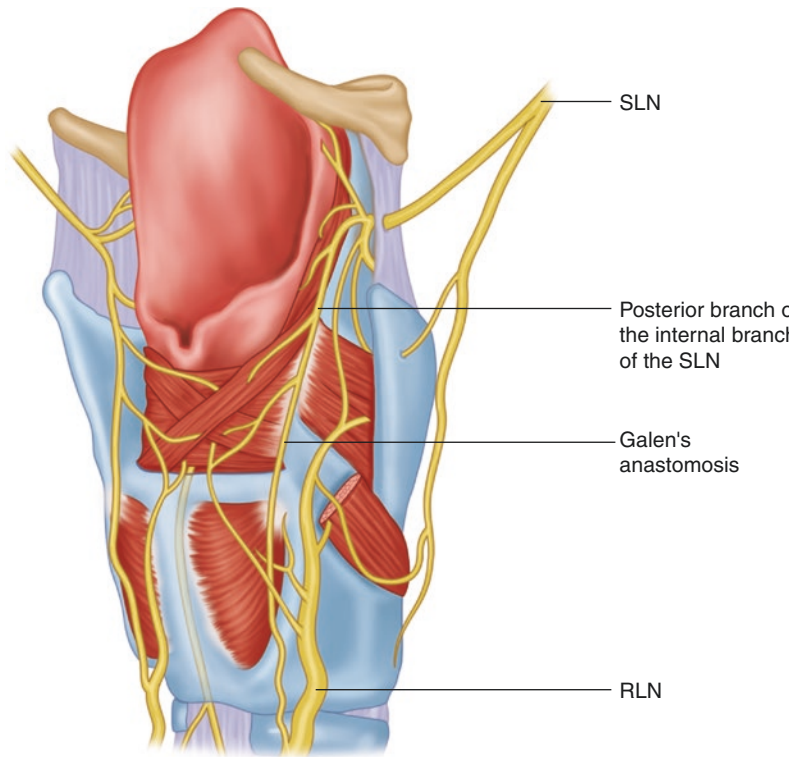

Fig. 1.4 Artist rendering of the larynx with mucosa removed. Noted structures include (1) superior laryngeal nerve, (2) posterior branch of the superior laryngeal nerve, (3) recurrent laryngeal nerve, (4) posterior branch of the recurrent laryngeal nerve, and (5) Galen's anastomosis

oid membrane, as discussed previously, to provide sensory innervation to the supraglottis and the superior portion of the glottis. Importantly, it is known that the internal branch of the superior laryngeal nerve and the endolaryngeal portion of the recurrent laryngeal nerve have a sensory anastomosis [21]. The external branch of the superior laryngeal nerve courses over the external surface of the larynx in close proximity to the superior lobe of the thyroid to innervate the cricothyroid muscle [22].

The recurrent laryngeal nerve emerges from the vagus nerve in the chest and loops from anterior to posterior around the aorta (left) or the right subclavian artery (right) before ascending to the larynx within the tracheoesophageal groove. Rarely (0.7% of the time), the right RLN does not descend, usually secondary to the presence of a retroesophageal (aberrant) right subclavian artery. This anatomic variant leads to the nonrecurrent laryngeal nerve (NRLN) entering the larynx horizontally and places it at great risk during thyroid surgery [23]. The paired nerves course into the endolarynx at the cricothyroid joint to provide sensory innervation to the subglottis and inferior glottis as well as motor innovation to all intrinsic laryngeal muscles except the cricothyroid muscle. It should be noted that motor anastomoses between the RLN and the SLN occur including Galen's anastomosis between the posterior branches of the internal branch of the superior laryngeal nerve and the recurrent laryngeal nerve [24]. Galen's anastomosis normally was found on the posterior surface of the interarytenoid or posterior cricoarytenoid muscles [24].

Conclusion

The anatomy of the pharynx and larynx is particularly complex but provides the basis for our understanding of the complex physiology of the upper aerodigestive tract. The discussed anatomy is from the perspective of the laryngoscopist, which is how most practicing clinicians in the modern age examine the larynx. This applicable anatomy provides the basis for a deeper study of the physiology of the upper aerodigestive tract with regard to airway protection, swallowing, and phonation as well as a greater understanding of the effects of laryngeal pathology on these important functions.

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