Anatomy and Physiology of the Larynx and Hypopharynx

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6.1 Anatomy and Physiology of the Larynx and Hypopharynx

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6.1.1 Anatomy of the Larynx

6.1.1.1 Generalities

The larynx is part of the respiratory system and is located at the upper level of the airway (Fig. 6.1.1). Because of its strategic and unique position, in relation to the crossover between the air and food passages, it is often referred to as part of the upper aerodigestive tract. It is also known as the organ of phonation, owing to special modifications of its anatomy during evolution that have rendered it able to produce voice. Indeed, from a physiologic point of view, it is essentially a valve or sphincter with a triple function: (1) that of an open valve in respiration; (2) that of a partially closed valve whose orifice can be modulated in phonation; (3) that of a closed valve, protecting the trachea and bronchial tree during deglutition.

The laryngeal cavity extends from the tip of the epiglottis down to the inferior border of the cricoid cartilage, where it continues into the trachea. It is placed in the visceral compartment of the neck, corresponding to the anterior cervical triangle delimited by the hyoid bone superiorly, the sternal notch inferiorly and the medial borders of each sternocleidomastoid muscle laterally. In the adult, it is located on the ventral side of the bodies of the fourth, the fifth and the sixth cervical vertebra (usually more cranially in women, and more caudally in men), whereas in the child it is usually positioned somewhat cranially, reaching the second cervical vertebra with its superior aspect at birth. In any case, the larynx is separated from the vertebral column by the dorsal wall of the oropharynx and hypopharynx. The position of this organ is influenced by movements of the head and neck and it also moves during deglutition and phonation. It is elevated when the head moves posteriorly (extension) and is depressed when the head is displaced anteriorly (flexion). This fact has profound clinical and surgical implications. The ideal position for every open-neck surgical procedure on the larynx, in fact, is the extended position, with the organ being stretched upward by the suprahyoid muscles, well above the sternal notch. By contrast, during microendoscopic laryngeal surgery, in the case of difficult exposure of the endolarynx (particularly when the anterior commissure must be accurately assessed or manipulated), the flexed position is of help owing to detension of the prelaryngeal strap muscles and posteroinferior drop of the whole laryngopharyngeal complex. For the passage of the rigid laryngoscope, endotracheal tube or bronchoscope, it is also essential to know the position which brings the axes of the mouth, oropharynx and laryngeal inlet into line; this is achieved by bringing the neck forward (in a flexed position) and at the same time extending the head fully at the atlanto-occipital joint (Boyce–Jackson position).

6.1.1.2 Embryology

The respiratory system arises as an outgrowth of the digestive tract. In particular, the larynx develops from a two-part anlage: the supraglottis from the buccopharyngeal bud (fourth arch of the branchial system), and the glottis and subglottis from the tracheobronchial bud (fifth and sixth arches). This fact has a major impact in oncologic practice, where the glottic plane represents an embryologic barrier between the superior and the inferior lymphatic drainage.

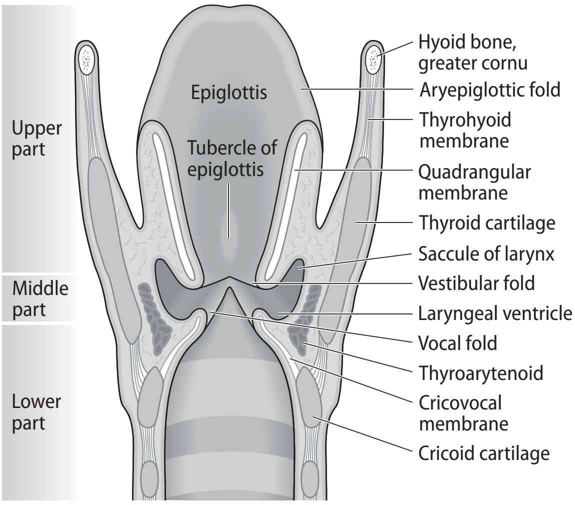

Fig. 6.1.1 Coronal section through the larynx and the cranial end of the trachea: posterior aspect

6.1.1.3 Supraglottis

The clinical term 'supraglottis' refers to that part of the larynx which lies above the glottis. It includes the laryngeal inlet, or aditus (the aperture between the larynx and the pharynx) (Fig. 6.1.2), the laryngeal ventricle (the space between the false and true vocal folds), the false vocal folds, the laryngeal (or posterior) surface of the epiglottis, the arytenoid cartilages and the laryngeal (or medial) aspects of the aryepiglottic folds.

The vestibular or false vocal folds are composed of the thickened lower border of the quadrangular membrane, covered by respiratory mucosa. The ventricle presents a fusiform, cranial recess which is called the 'saccule.' It is a pouch which ascends forwards from the ventricle, between the vestibular fold and the thyroid cartilage, and occasionally reaches the upper border of the cartilage. Laterally, the saccule is separated from the thyroid cartilage by the thyroepiglottic muscle, which compresses the saccule, expressing its secretion onto the vocal cords, which lack glands, to lubricate and protect them against desiccation and infection. Saccules occasionally protrude through the thyrohyoid membrane. Both the laryngeal ventricle and the saccule may on occasion become pathologically enlarged owing to obstruction of the ventricular aditus by inflammation, scarring or tumour. As the sealed cavity contains mucous glands, an expanding mucus-filled cyst is formed. This laryngocele may expand into the paraglottic space and extend superiorly to expand the aryepiglottic fold and reach the vallecula (internal laryngocele). Acute respiratory obstruction may result especially if the contents of the cyst become infected. The cyst may also expand through the thyrohyoid membrane at the point of entry of the internal laryngeal neurovascular bundle to appear as a lump in the neck overlying the thyrohyoid membrane (external laryngocele).

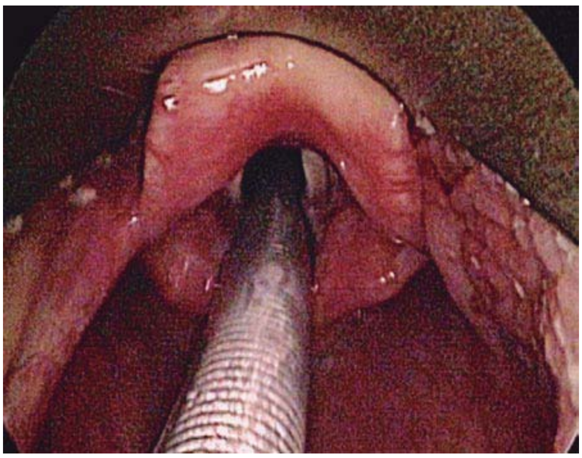

Fig. 6.1.2 Endoscopic view with a 0° rigid telescope of the laryngeal inlet, or aditus, under general anaesthesia

6.1.1.4 Glottis

The glottis includes the paired true vocal cords, the anterior and the posterior commissure, and the rima glottidis between them. The rima glottidis is the fissure between the vocal cords anteriorly and the arytenoid cartilages posteriorly. Its shape is roughly triangular during quiet breathing, widens to a pentagon with deep inspiration, and narrows to a slit during phonation and a Valsalva manoeuvre. It is bounded behind by the mucosa passing between the arytenoid cartilages at the level of the vocal cords. The rima glottidis is customarily divided into two regions: an anterior intermembranous part, which makes up about three fifths of its anteroposterior length and is formed by the underlying vocal ligament, and a posterior intercartilaginous part, which is formed by the vocal processes of the arytenoid cartilages. The average sagittal diameter of the glottis in the newborn is 0.7 cm, in the adult male is 23 mm and in the adult female is 17 mm. It is the narrowest part of the larynx and of the whole upper airway. Its width and shape vary with the movements of the vocal cords and arytenoid cartilages during respiration and phonation. During adduction (or closure) of the vocal cords, like in phonation or during a Valsalva manoeuvre, the rima glottidis becomes virtual, owing to the contact of the two vocal cords on the midline. During maximal abduction (or opening), like in deep breathing or sniffing, the rima glottidis reaches its maximum width (Fig. 6.1.3).

The free thickened upper edge of the cricovocal membrane forms the vocal ligaments. It stretches back on either side from the mid level of the thyroid angle to the vocal processes of the arytenoid cartilages. When it is covered by mucosa, it is termed the '*vocal cord*'. The vocal cords form the anterolateral edges of the rima glottidis and are concerned with sound production. The complex microanatomy of the true vocal fold allows the loose and pliable superficial mucosal layers to vibrate freely over the stiffer structural underlayers. The mucosa overlying the vocal ligament is thin and lies directly on the vocal ligament, and so the vocal cord appears pearly white in vivo. It is loosely attached to the ligaments: oedema fluid readily collects in this potential space in disease. Known as Reinke's space, it extends along the length of the free margin of the vocal ligament and a little way onto the superior surface of the cord. The site where the vocal cords meet anteriorly is known as the anterior commissure (Fig. 6.1.4). Fibres of the vocal ligament pass here through the thyroid cartilage to blend with the overlying perichondrium, forming Broyles's ligament. Each vocal ligament is composed of a band of yellow elastic tissue related laterally to vocalis muscle.

The mucous membrane is loosely attached throughout the larynx and can accommodate considerable swelling, which may compromise the airway in acute infections. At the edge of the true vocal cords the mucosal covering is tightly bound to the underlying ligament, so oedema fluid does not pass between the upper and lower compartments of the vocal cord mucosa. Any tissue swelling above the vocal cord exaggerates the potential space deep to the mucosa (Reinke's space), causing accumulation of extracellular fluid and flabby swelling of the vocal cords (Reinke's oedema). Smoking and vocal abuse may initiate such changes.

Aberrant muscle balance during phonation may cause initial contact during vocal cord apposition to occur at a point at the junction of the anterior third and the posterior two thirds of the vocal ligament. Excessive trauma at this point, for example when singing with poor technique or forcing the voice, may produce subepithelial haemorrhage or bruising, and subsequent pathologic changes such as subepithelial scarring ('singer's nodes').

6.1.1.5 Subglottis

The subglottis extends from 1 cm below the free edge of the vocal cords to the lower border of the cricoid cartilage. Its walls are lined by respiratory mucosa, and are supported by the cricothyroid ligament above and the cricoid cartilage below. Prolonged intubation, trauma or inadequate endoscopic manoeuvres can ulcerate the mucosa and submucosa of this area, exposing the underlying cricoid cartilage to the risk of chondritis, chondronecrosis and subsequent circumferential scarring. This process is the base for the formation of subglottic and/or tracheal stenoses.

6.1.1.6 Skeletal Framework

The skeletal framework of the larynx is formed by a series of cartilages interconnected by ligaments and fibrous membranes (Figs. 6.1.5, 6.1.6), and moved by a number of muscles. The cartilaginous structures which form its framework are the epiglottis, thyroid cartilage, cricoid cartilage and arytenoid cartilages. The thyroid cartilage, cricoid cartilage and epiglottis are single cartilages, whereas the arytenoid cartilages are paired.

The larynx is slung from the U-shaped hyoid bone by the *thyrohyoid membrane* (*and ligaments*) and *thyrohyoid muscles*. The hyoid bone itself (the only bone of our body not connected to other bones through articular joints) is a U-shaped bone, open backwards and attached to the mandible and tongue by the suprahyoid muscles, namely the hyoglossus, mylohyoid, geniohyoid and digastric muscles, to the styloid process by the stylohyoid ligament and muscle, and to the pharynx by the middle constrictor. Three of the four strap muscles of the neck, the omohyoid, the sternohyoid and the thyrohyoid, find attachment to it, only the sternothyroid fails to gain it.

The *epiglottis* is a feather-shaped fibroelastic cartilage lying behind the root of the tongue. It is attached ante-

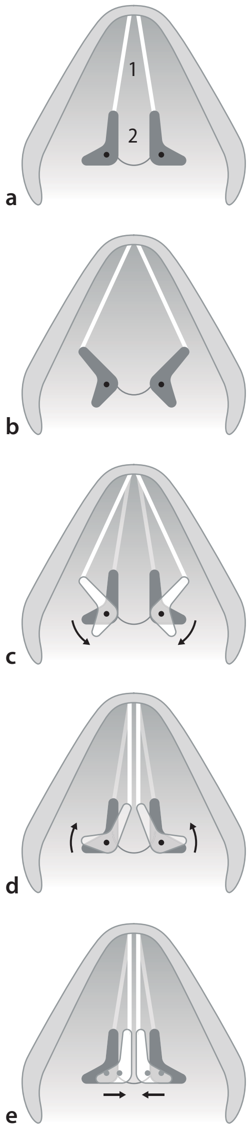

Fig. 6.1.3a–e Relation between the vocal cords and the arytenoid cartilages. **a** The position of the rima glottidis in quiet respiration. The intermembranous part of the rima glottidis seems triangular and the intercartilaginous part rectangular. **b** Forced inspiration. Both parts of the rima glottidis seem triangular. **c** Abduction of the vocal cords. The *arrows* show the movement of the abducted, retracted and laterally rotated arytenoid cartilages. Both parts of the rima glottidis seem triangular. **d** Adduction of the vocal cords. The *arrows* show the movement of the medially rotated arytenoid cartilages induced by the cricoarytenoid muscles. **e** Closure of the rima glottidis. The *arrows* show the movement induced by the transverse arytenoid muscles, without rotation of the arytenoid cartilages

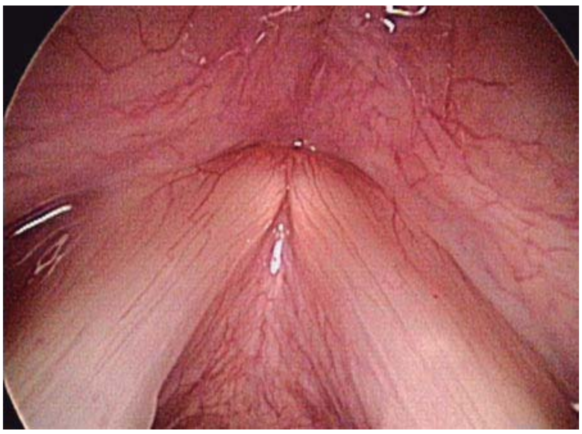

Fig. 6.1.4 Endoscopic view with a 70° rigid telescope of the anterior commissure under general anaesthesia

riorly to the body of the hyoid by the hyoepiglottic ligament and below to the back of the thyroid cartilage by the thyroepiglottic ligament, immediately above the vocal cords. Its sides are attached to the arytenoid cartilage by the aryepiglottic folds (containing the aryepiglottic muscle) which run backwards to form the margins of the vestibule, or *aditus*, of the larynx. Its free upper anterior surface projects above the hyoid bone (suprahyoid epiglottis) and is covered by mucosa (the epithelium is non-keratinized, stratified, squamous), which is reflected onto the base of the tongue and the lateral pharyngeal walls as a median glossoepiglottic and two lateral glossoepiglottic folds. The depression on either side between these folds is the *glossoepiglottic vallecula*. The inferior half of the epiglottis (infrahyoid epiglottis) is the posterior boundary of the pre-epiglottic space, a fat-filled visceral space of the larynx, comprising the hyoepiglottic ligament above, the thyrohyoid ligament and upper half of the thyroid cartilage anteriorly, and the epiglottis itself with its thyroepiglottic ligament posteroinferiorly. In the sagittal plane the pre-epiglottic space is triangular in shape, whereas in the axial plane it has a U shape open backwards. Posterolaterally, the pre-epiglottic space communicates with the lateral paraglottic space, a fat-filled laryngeal visceral space that, on each side, comprises the thyroid ala and the vocal muscle at the glottic plane, and the quadrangular membrane at the level of the false vocal fold. Even though some subtle connective membranes have been microscopically observed at the junction between the pre-epiglottic and the lateral paraglottic spaces, some authors consider these as a unique anatomical entity. The major function of the epiglottis is to help prevent aspiration during swallowing. The epiglottis is displaced posteriorly by the tongue base retropulsion and laryngeal elevation. This causes the superior free edge of the epiglottis to fall over the laryngeal inlet, which, in conjunction with sphincteric closure of the larynx at the supraglottic and glottic levels, closes off the laryngeal vestibule. The epiglottis is not essential for swallowing, which occurs with minimal aspiration even if this cartilage is destroyed by disease or removed by a surgical procedure as for supraglottic cancer excision, nor it is essential for respiration or phonation.

The *thyroid cartilage* is the largest of the laryngeal cartilages. It consists of two quadrilateral laminae whose anterior borders fuse along their inferior two thirds at a median angle (of approximately 90° in adult males, and 120° in women and children), forming the subcutaneous laryngeal prominence (Adam's apple). This projection is most distinct at its upper end, and is well marked in postpubertal men but is scarcely visible in children and women. Attached to each lamina posteriorly are the superior and inferior cornua. The superior cornua are attached to the greater horns of the hyoid bone by the thyrohyoid ligaments, found in the context of the thyrohyoid membrane. The inferior cornua form a synovial joint with the cricoid cartilage (the cricothyroid joint). At the junction of each superior cornu with its respective thyroid ala is a cartilaginous prominence, the superior tubercle. The superior tubercle is of significance because it marks the point 1 cm below which the superior laryngeal artery and nerve cross over the lamina to pierce the lateral aspect of the thyrohyoid membrane. The relationship of the internal laryngeal structures to the surface anatomy of the thyroid cartilage is important in surgical planning, for example when planning the placement of the window for thyroplasty or before cutting the thyroid cartilage transversally during open-neck horizontal supraglottic laryngectomy. The level of the vocal fold lies a

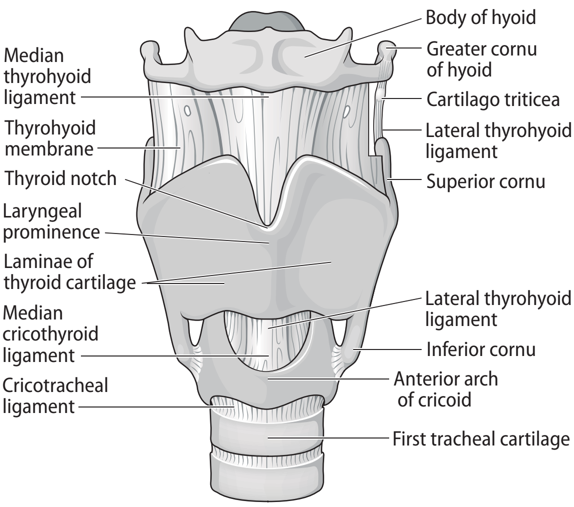

Fig. 6.1.5 Anterolateral view of the laryngeal cartilages and ligaments

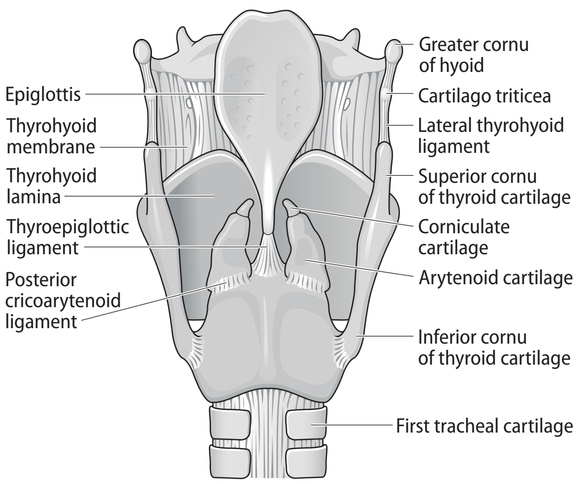

Fig. 6.1.6 Posterior view of the laryngeal cartilages and ligaments

little bit closer to the lower border of the thyroid cartilage lamina than to the upper border, more than at its exact midpoint.

The *cricoid cartilage* is attached inferiorly by the *cricotracheal membrane* to the trachea, and articulates with the thyroid cartilage and the two arytenoid cartilages by synovial joints. It is the only complete ring of cartilage throughout the respiratory tract. It is signet-ring-shaped, deepest behind. Its posterior part, also called 'cricoid plate', is covered by the posterior cricoarytenoid muscles and by the hypopharyngeal mucosa of the postcricoid area. The upper oesophageal sphincter is located at this level. The anterior portion of the cricoid cartilage, also called 'cricoid arch', is covered by the cricothyroid muscles. It represents the most important surgical landmark when emergency cricothyroidotomy is performed. The cricothyroid membrane represents the most superficial portion of the airway and the easiest point in it to gain access to it during an airway emergency, even without adequate surgical instrumentation and assistance. Owing to the anatomy of the airway, a congenital malformation of the cricoid cartilage may result in severe narrowing of the subglottic airway and respiratory obstruction.

The paired pyramidal *arytenoid cartilages* sit one on each side of the posterior 'signet' (or plate) of the cricoid cartilage. They have an upper projection covered by the corniculate cartilage, an anterior one called 'vocal process', made of elastic cartilage on which the vocal ligament and thyroarytenoid muscle are attached, and a posterolateral muscular process which allows insertion of the posterior and lateral cricoarytenoid muscles. Movements of the arytenoid cartilages on the underlying cricoid plate (made possible by the intrinsic laryngeal muscles and the cricoarytenoid joint) are reflected as movements of the vocal cords (essentially, adduction or closure and abduction or opening).

In addition to the above-mentioned major laryngeal cartilages, there are two paired cartilaginous nodules at the inlet of the larynx: the *corniculate cartilage*, lying at the apex of the arytenoid cartilage, and the *cuneiform cartilage*, a flake of cartilage within the margin of the aryepiglottic fold. These likely serve to provide additional structural support to the aryepiglottic folds.

The thyroid cartilage, cricoid cartilage and most of the arytenoid cartilages consist of hyaline cartilage and may therefore become calcified. This is a postpubertal process which initially involves the lower and posterior part of the thyroid cartilage, and subsequently spreads to involve the remaining cartilages. Calcification of the arytenoid cartilage starts at the base. The degree and frequency of calcification of the thyroid and cricoid cartilages appear to be less in females, in which the ossification process usually starts later in life. There is some evidence to suggest that a predilection for tumour invasion may be enhanced by calcification of the laryngeal cartilages. By contrast, the vocal processes of the arytenoid cartilage and the epiglottis are made of fibroelastic cartilage and never ossify during life.

6.1.1.7 Laryngeal Joints

The most important joints of the larynx are the cricoarytenoid and the cricothyroid. They are both diarthrodial joints with a capsule, a synovial lining and extracapsular ligaments. The cricoarytenoid joint is the primary moving structure of the intrinsic larynx. The arytenoid cartilages articulate with the cricoid cartilage, forming multiaxial joints (making possible at least three distinct arytenoid movements: sliding from posterior to anterior, rocking from lateral to medial, and twisting or rotation along a vertical axis perpendicular to the articular facet). The action of movement at the cricoarytenoid joints changes the distance between the vocal processes of the two arytenoid cartilages and between each vocal process and the anterior commissure. The combined action of the intrinsic laryngeal muscles on the arytenoid cartilages alters the position and shape of the vocal folds. Each cricoarytenoid joint sits at a 45° angle with the horizontal plane on the cricoid cartilage. Subluxation or frank luxation of this joint after laryngotracheal trauma or postintubation damage can cause ipsilateral vocal fold fixation, to be taken into account in the differential diagnosis of recurrent nerve palsy.

The cricothyroid joint is formed from the articulation of the inferior cornua of the thyroid cartilage with facets on the cricoid lamina. The two major actions at this joint are anteroposterior sliding and rotation of the inferior thyroid cornu upon the cricoid cartilage. Cricothyroid muscle contraction pulls the thyroid alae anteriorly with respect to the cricoid cartilage and closes the anterior visor angle between the thyroid and the cricoid arch. This motion increases the distance between the anterior commissure and the vocal processes of the arytenoid cartilages and serves to lengthen and tense the vocal folds. This joint can be manipulated to assist in pitch control in cases of paralytic dysphonia and to provide vocal fold tightening like in changing the voice in case of male to female transsexuals.

6.1.1.8 Soft Tissues

The skeletal framework of the larynx is interconnected by ligaments and fibrous membranes, of which the thyrohyoid, cricothyroid, cricotracheal, quadrangular and cricovocal (or conus elasticus) membranes are the most significant. The thyrohyoid, cricothyroid and cricotracheal membranes are external to the larynx, whereas the paired quadrangular and cricovocal membranes are internal. Inside the larynx are also found two ligaments: the hyoepiglottic and thyroepiglottic.

The cricovocal membrane connects the thyroid, cricoid and arytenoid cartilages. Its upper edge is attached anteriorly to the posterior surface of the thyroid cartilage and behind to the vocal process of the arytenoid cartilage. Between these two structures, the upper edge of the membrane is thickened slightly to form the *vocal ligament*. Anteriorly, the membrane thickens, as the *cricothyroid membrane*, easily felt subcutaneously at palpation.

The muscles of the larynx may be divided into intrinsic and extrinsic muscles. The intrinsic muscles are responsible for altering the length, tension, shape and spatial position of the vocal folds by changing the orientation of the muscular and vocal processes of the arytenoid cartilages with the fixed anterior commissure. As a result of these movements, the glottis is opened during inspiration, closed during phonation and closed with supraglottic reinforcement during deglutition. The intrinsic muscles are the cricothyroid, posterior and lateral cricoarytenoid, transverse and oblique interarytenoid, aryepiglottic, thyroarytenoid and its subsidiary part, vocalis, and thyroepiglottic muscles. The intrinsic laryngeal muscles may be placed in three groups according to their main actions: three major vocal fold adductors (thyroarytenoid, lateral cricoarytenoid, and interarytenoid muscles), one abductor (posterior cricoarytenoid muscles), and one tensor (cricothyroid muscle). The posterior and lateral cricoarytenoid muscles and oblique and transverse interarytenoid muscles vary the dimensions of the rima glottidis. The cricothyroid, posterior cricoarytenoid, thyroarytenoid and vocalis muscles regulate the tension of the vocal ligaments. The oblique interarytenoid, aryepiglottic and thyroepiglottic muscles modify the laryngeal inlet. Bilateral pairs of muscles usually act in concert with each other. The posterior cricoarytenoid muscle anatomy serves as a key landmark for arytenoid adduction surgery aimed at the closure of the posterior glottal chink after standard medialization thyroplasty.

The cricothyroid muscle is the only intrinsic laryngeal muscle of the larynx supplied by the external branch of the superior laryngeal nerve. The recurrent laryngeal nerve innervates all the other intrinsic muscles. All these muscles (both adductors and tensor) have a sphincter action; the only exception is represented by the abductor muscle, the posterior cricoarytenoid muscle, which, by rotating the arytenoid cartilages outwards, separates the vocal cords (Fig. 6.1.7).

The extrinsic muscles connect the larynx to neighbouring structures and are responsible for moving it vertically during phonation and swallowing. They include the infrahyoid strap muscles, i.e. thyrohyoid, sternothyroid, sternohyoid and omohyoid muscles, and the inferior constrictor muscle of the pharynx. The role of the extrinsic muscles during respiration appears variable. The larynx has been seen to rise, descend or barely move during inspiration. The extrinsic muscles can affect the tone and pitch of the voice by raising or lowering the larynx, and the geniohyoid muscle (together with the suprahyoid muscles, generally considered as part of the floor of the mouth) elevates and anteriorly displaces the larynx, particularly during deglutition.

6.1.1.9 Vascular Supply

The blood supply of the larynx is derived mainly from the superior and inferior laryngeal arteries arising, respectively, from the superior thyroid artery (branch of the external carotid artery) and the inferior thyroid artery (branch of the thyrocervical trunk, from the subclavian artery). The venous drainage passes superiorly via the superior thyroid vein to the internal jugular vein and inferiorly via the inferior thyroid vein to the brachiocephalic vein.

6.1.1.10 Lymphatic Drainage

The supraglottis has a rich, partly multilayered capillary lymphatic network, converging on the anterior insertion of the aryepiglottic fold and leaving the larynx in a small collections of vessels along the superior neurovascular pedicle of the larynx. Submucous and pre-epiglottic horizontal anastomoses have been found in the midline of the larynx and are responsible for bilateral and/or contralateral lymph node metastases, frequently observed in supraglottic carcinoma. The supraglottis drains to the upper deep cervical lymph nodes (levels IIA–III) and then to

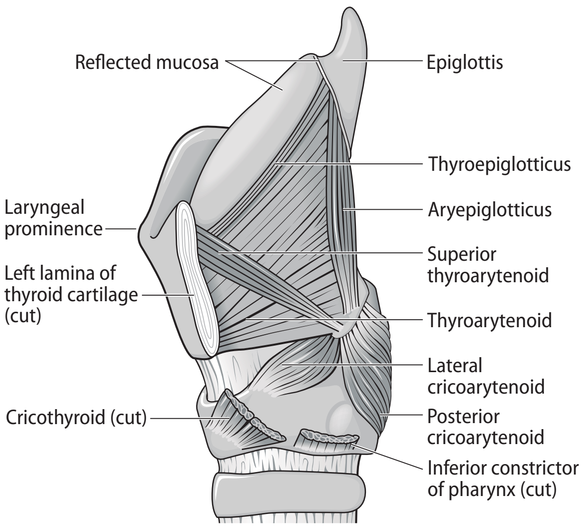

Fig. 6.1.7 Left lateral aspect of the muscles of the larynx

the mediastinal lymph nodes (level VI), some lymphatics passing via small nodes lying on the thyrohyoid membrane. Below the cords, drainage is to the lower deep cervical nodes (levels III–IV), partially via nodes on the front of the larynx and trachea (level VI), one of them rather constant and called the Delphian node, located in front of the cricothyroid or cricotracheal membranes. The vocal cords themselves act as a complete barrier separating the two lymphatic areas, even though posteriorly there is free communication between them. A laryngeal carcinoma may thus seed throughout the whole lymphatic drainage area of the larynx. The upper deep cervical lymph nodes act as pathways for spread of malignant tumours of the supraglottic larynx: up to 40% of these tumours will have undergone such spread at the time of clinical presentation. The glottis is very poorly endowed with lymphatic vessels, which means that 95% of malignant tumours confined to the glottis will cause a change in voice or airway obstruction but will not show clinical signs of spread to adjacent lymph nodes at presentation. The subglottic capillary network is not as dense as the supraglottic one, but its density is more than that observed at the level of the glottic plane. Tumours of the subglottic larynx will often spread to the chain of paratracheal and recurrent lymph nodes (level VI) prior to clinical presentation. Even in this laryngeal subsite, bilateral and contralateral metastatic spread are frequently encountered in the case of malignant tumours.

6.1.1.11 Nerve Supply

The nerve supply of the larynx is of great practical importance and comprises the superior and recurrent laryngeal nerves, branches of the vagus nerve (cranial nerve X).

The *superior laryngeal nerve* exits the vagus just below the nodose ganglion, and passes deep to the internal and external carotid arteries, where it divides. Its internal (sensory) branch pierces the thyrohyoid membrane together with the superior laryngeal vessels to supply the mucosa of the larynx down to the vocal cords. The external (motor) branch passes deep to the superior thyroid artery to supply the cricothyroid muscle. During thyroidectomy, ligation of the superior pedicle of the thyroid gland may pose at risk for the anatomical integrity of the external branch of the superior laryngeal nerve, thus causing some weakness of phonation owing to the loss of the tightening effect of the cricothyroid muscle on the cord. Selective ligation of every branch of the superior thyroid vessels when they enter the upper pole of the thyroid lobe allows avoidance of undue lesion to this nerve.

The *recurrent laryngeal nerves* have a different course on each side. The right nerve arises from the vagus as this crosses the front of the subclavian artery, passes deep to and behind this vessel then ascends behind the common carotid to lie in the tracheo-oesophageal groove accompanied by the inferior laryngeal vessels. The nerve then passes deep to the inferior constrictor muscle of the pharynx to enter the larynx behind the cricothyroid articulation. The left nerve arises on the arch of the aorta, winds below it, deep to the ligamentum arteriosum, and ascends to the trachea. It then lies in the tracheo-oesophageal groove and is distributed as on the right side. The recurrent laryngeal nerves supply all the ipsilateral intrinsic laryngeal muscles, apart from the cricothyroid muscle (supplied by the external branch of the superior laryngeal nerve), and the mucosa below the vocal cords (Fig. 6.1.8). The recurrent laryngeal nerves, at the level of the tracheo-oesophageal groove, are usually behind the terminal branches of the inferior thyroid artery. Occasionally, however, the nerve lies in front of these vessels or passes between them. Careful dissection (possibly with the aid of magnification by surgical loops) of the distal branches of the inferior thyroid artery, with attention paid to the preservation of the superior and inferior parathyroid vascularization (entirely depending on the inferior thyroid artery), allows identification of the recurrent laryngeal nerve. Proximal ligation of the inferior thyroid artery (as it emerges behind the common carotid artery) is technically easier, usually preserves the recurrent laryngeal nerve, but can cause permanent iatrogenic hypoparathyroidism. The left recurrent laryngeal nerve, in its thoracic course, may become involved in a bronchial or oesophageal carcinoma, or in a mass of enlarged mediastinal nodes, or may become stretched over

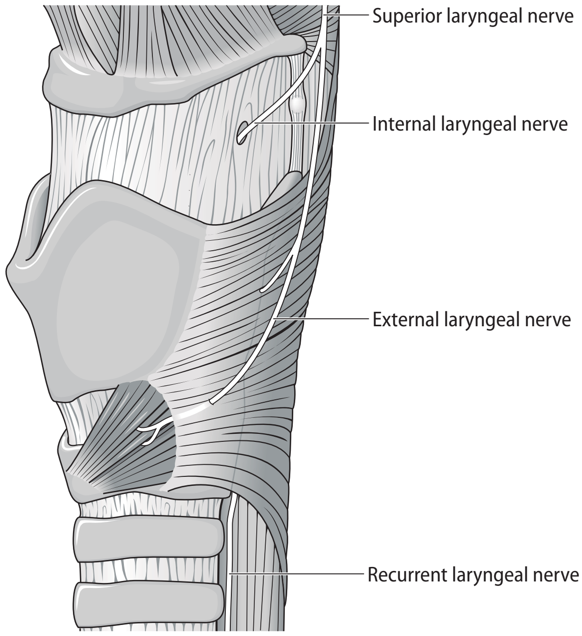

Fig. 6.1.8 Nerve supply to the larynx

an aneurysm of the aortic arch. The enlarged left atrium in advanced mitral stenosis may produce a recurrent laryngeal palsy by pushing up the left pulmonary artery, which compresses the nerve against the aortic arch. Either nerve, in the neck, may be damaged by an advanced thyroid carcinoma or malignant lymph nodes. For these reasons, loss of voice due to unilateral recurrent palsy must be always regarded as an ominous symptom requiring careful investigation of the entire course of the vagus and recurrent laryngeal nerves.

Unilateral complete palsy of the recurrent laryngeal nerve (more commonly on the left side owing to its increased length) leads to paralysis of all the laryngeal muscles on the affected side with the exception of the cricothyroid. The patient may be asymptomatic or have a hoarse, breathy voice. The hoarseness may be permanent or may become less severe with time as the opposite cord develops the ability to hyperadduct and appose the paralysed cord and thus close the glottis during phonation and coughing. Clinically, the position of the vocal cord in the acute phase after section of the recurrent laryngeal nerve is very variable. Stridor is more common after bilateral lesions but by no means does it represent the rule; indeed the cords may be sufficiently abducted for there to be little problem with airway obstruction. With great surprise for beginners, bilateral vocal cord palsy is usually associated with a better quality of voice than unilateral vocal cord dysfunction, owing to the tendency of the vocal cords to assume an adducted position which allows a relatively good (but static) glottic closure. Even food inhalation and liquid inhalation are exceptional after bilateral vocal cord palsy, but are sometimes observed in unilateral paralysis (particularly in the presence of a vagal lesion with simultaneous impairment of the superior and inferior laryngeal nerves).

6.1.1.12 Histology

The laryngeal epithelium is mainly a ciliated, pseudostratified respiratory epithelium where it covers the inner aspects of the larynx, including the posterior surface of the epiglottis, and it provides a ciliary clearance mechanism shared with most of the respiratory tract. However, the vocal cords are covered by non-keratinized, stratified squamous epithelium, an important variation which protects the tissue from the effects of the considerable mechanical stresses acting on the surfaces of the vocal cords during phonation, deglutition and coughing. The highly specialized functions of the vocal cords explain their peculiar anatomical microstructure. Deep to the epithelium, a stratified arrangement of connective tissue allows the mucosa to vibrate upon the underlying vocal ligament and muscle. Below the epithelial basal membrane, the superficial layer of the lamina propria (the so-called Reinke space) is loosely arranged with collagen and elastic fibres that allows a uniform and optimal sharing of the forces produced during epithelium vibration, thus reducing to a minimum the impedance to vibration. The intermediate and deep layers of the lamina propria are denser and more compact, formed by highly concentrated and thicker collagen bundles. The intermediate and deep layers of the lamina propria together constitute the vocal ligament. The vocal ligament and the underlying vocal muscle form the body of the vocal cord, whereas the epithelium represents the cover (body-cover theory). The cover vibrates on the underlying body thanks to the presence of Reinke's space. Moreover, an elastic gradient is provided to the vocal cords even in the anterior–posterior direction. In fact, lamina propria is thickened at the two ends of the membranous vocal cord, forming the anterior and posterior maculae flavae. These structures are mainly formed by elastic fibres. They cushion the vocal folds and provide extra strength at regions of maximal stress, those of connection of the vocal ligament to the anterior commissure of the thyroid cartilage anteriorly and to the vocal process of the arytenoid cartilage posteriorly. Moreover, maculae flavae generate connective tissue such as collagen and elastin in the lamina propria.

The exterior surfaces of the larynx which merge with the hypopharynx and oropharynx (including the anterior surface of the epiglottis) are also subject to the abrasive effects of swallowed food, and are therefore covered by non-keratinized stratified squamous epithelium. The laryngeal mucosa has numerous mucous glands, especially over the epiglottis, where they pit the cartilage, and along the margins of the aryepiglottic folds anterior to the arytenoid cartilages, where they are known as the arytenoid glands. Many large glands in the saccules of the larynx secrete periodically over the vocal cords during phonation. The free edges of these folds are devoid of glands and their stratified epithelium is vulnerable to drying, thus requiring the secretions of neighbouring glands. Hoarseness due to excessive speaking is due to partial temporary failure of this secretion. Taste buds, like those in the tongue, occur on the posterior epiglottic surface, aryepiglottic folds and less often in other laryngeal regions.

6.1.2 Anatomy of the Hypopharynx

6.1.2.1 Generalities

The hypopharynx (or laryngopharynx) is the lowermost portion of the pharynx and, in the craniocaudal direction, it follows the rhinopharynx and the oropharynx. It is part of the digestive tract, but it has strict anatomical, functional and pathologic relationships with the larynx. The hypopharynx is a 5-cm-long cone-shaped tube, wide superiorly (about 4 cm) and rapidly narrowing in the postcricoid and cervical oesophagus area (1.5 cm). It extends from the tip of the epiglottis superiorly to the inferior edge of the cricoid cartilage. Anteriorly it communicates with the larynx which, in fact, is posterolaterally surrounded by the two funnel-shaped piriform sinuses and by the postcricoid area. The hypopharynx is anteriorly limited by the marginal structures of the laryngeal inlet and the posterior surface of the larynx; superiorly it is continuous with the oropharynx. Laterally it is separated from the common carotid artery, the internal jugular vein and the vagus nerve by the inferior constrictor muscles and the piriform sinus (bounded medially by the aryepiglottic fold and laterally by the internal surface of the thyroid ala and the thyrohyoid membrane), a pair of spaces with the shape of upside-down pears, with the apex (or stem of the pear) located inferiorly, at the level of the inferior limit of the cricoid cartilage, and the superior border corresponding to the pharyngoepiglottic fold (Fig. 6.1.9). Posteriorly the constrictor muscles separate the hypopharynx from the prevertebral fascia and the bodies of the third to the sixth cervical vertebra. Inferiorly the hypopharynx opens into the oesophagus at the level of the upper oesophageal sphincter. The piriform sinuses on each side, the posterior pharyngeal wall and the postcricoid region form the three designated anatomical sites within the hypopharynx. Their boundaries, however, overlap and their demarcation is somewhat arbitrary.

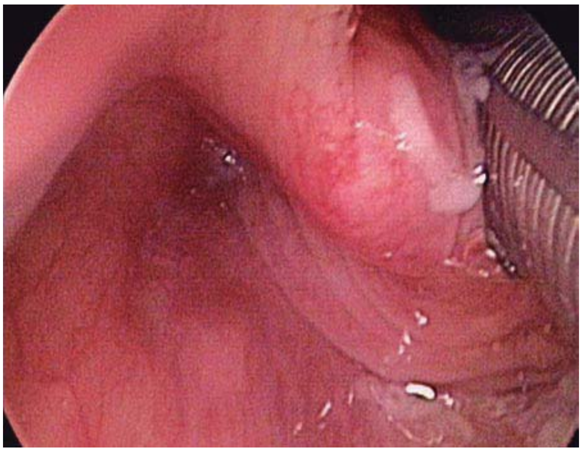

Fig. 6.1.9 Endoscopic view with a 70° rigid telescope of the left piriform sinus under general anaesthesia

6.1.2.2 Soft Tissues

The hypopharynx is essentially a muscular tube (whose epithelial lining consists of non-keratinized stratified squamous epithelium, whereas the lamina propria of mucosa contains scattered lymphoid aggregates and mucoserous glands) with strict relationships with some of the components of the cartilaginous laryngeal framework previously described, particularly the thyroid and cricoid cartilages. The funnel-shaped muscular segments forming the entire pharyngeal tube are overlapped at their lower end by the segment below, even though all segments are inserted posteriorly into a tendinous median raphe. The inferior constrictor muscle is divided into a superior thyropharyngeal part (inserting on the thyroid lamina at the level of the oblique line) and an inferior cricopharyngeal one (inserted at the junction between the cricoid arch and plate). The cricopharyngeus muscle encircles the hypopharynx more or less in an axial plane, in contradistinction to the angulated course of the fibres of the other constrictors. It does not have a posterior midline raphe, therefore being continuous from its left to right sides. The cricopharyngeus muscle is the major component of the upper oesophageal constrictor and, with its tonic contraction, maintains a constant level of closing pressure, approximating the pharynx to the cricoid plate. During swallowing, the cricopharyngeus muscle relaxes, thus permitting passage of the bolus from the hypopharynx to the cervical oesophagus. On the posterior midline of the inferior end of the hypopharynx, a triangular dehiscence (known as Killian's triangle) comprises the superior oblique muscle fibres of the thyropharyngeal muscle and the inferior horizontal ones of the cricopharyngeus muscle. A pharyngoesophageal pouch (or Zenker's diverticulum) may develop at this weak point owing to abnormal pressure during swallowing for altered function of the upper oesophageal sphincter.

The craniocaudal movements of the hypopharynx are made possible by the presence of three paired muscles (stylopharyngeus, salpingopharyngeus and palatopharyngeus) radiating into the pharyngeal wall from outside at the level of the oropharynx. Even the stylohyoid and styloglossus muscles are responsible for pharyngeal elevation during swallowing. On the other hand, a true intrinsic longitudinal muscle in the hypopharynx does not exist and only begins at the level of the upper oesophageal sphincter. Surrounding the hypopharynx, the parapharyngeal and retropharyngeal spaces, filled with loose areolar connective tissue, allows this organ to freely move with respect to the fascia overlying the prevertebral muscles, vertebral column and adjacent tissues.

6.1.2.3 Vascular Supply

The hypopharynx receives arterial branches from the ascending pharyngeal artery (branch of the external carotid artery) and the superior and inferior thyroid arteries. The venous drainage is accomplished by a number of small venous vessels forming a submucosal plexus and draining into the mid and distal portion of the internal jugular vein.

6.1.2.4 Lymphatic Drainage

The hypopharynx has a quite rich mucosal and submucosal lymphatic capillary network, explaining the high propensity of tumours of this organ to precociously metastatize to adjacent lymph nodes. This is either via an inconstant retropharyngeal lymph node (Rouvier's node) and then to the deep middle and lower jugular lymph nodes (levels III–IV) or directly to the latter group. The piriform sinuses and postcricoid area also drain to the recurrent or paratracheal lymph nodes (level VI), thus gaining a connection to the lymphatic system of the thoracic cavity.

6.1.2.5 Nerve Supply

A number of branches leave the vagus nerve in the midportion of the neck, cranially to the emergence of the superior laryngeal nerve, to innervate the pharyngeal musculature. These branches arborize and intercommunicate with branches of the glossopaharyngeal nerve to form a plexus enveloping the constrictor musculature of the pharynx. This plexus, along with additional contributions from the vagus nerve, continues along the oesophagus and into the remainder of the alimentary tract. Disruption of this plexus or its contribution from the vagus nerve has a deleterious effect on the constrictor activity and sensation of the pharyngeal musculature and mucosa, with ensuing deterioration of the swallowing function.

6.1.3 Physiology of the Larynx and Hypopharynx

During respiration at rest, the laryngeal valve is open (abducted position of the vocal cords) and the air comes in and out through its lumen without an active participation of the larynx in the process itself. During high-volume respiration, the glottis is actively abducted and tensed thanks to the contraction of the posterior cricoarytenoid and cricothyroid muscles. In this way, the cross-sectional area of the glottic plane is considerably widened and the resistance to the airflow reduced.

The human larynx, when acting as a sphincter or closed valve, does a lot more than protect the airway. It comprises several important reflexes for protection of the airway against external stimuli and foreign bodies (glottic closure reflex). These reflex mechanisms are relayed by the mucosal (sensory afferent), myotatic and articular receptors of the larynx via both the superior and the recurrent laryngeal nerves. The strongest of the laryngeal reflexes is that of laryngospasm (a response to mechanical stimulation). Other reflexes include those producing cough, apnoea, bradycardia and hypotension. The glottic closure reflex is one of the most crucial events during swallowing. It is reinforced by supraglottic closure of the epiglottis (thanks to retropulsion of the base of the tongue and laryngohypopharyngeal elevation), and adduction of the false vocal folds and aryepiglottic folds. Simultaneous mediolateral and craniocaudal squeezing of the hypopharyngeal muscular tube allows a bolus to enter the postcricoid area. The relaxation of the cricopharyngeus muscle transmits the bolus to the cervical oesophagus. After its passage, the cricopharyngeus muscle comes back to its tonic closure, thus avoiding retrograde regurgitation of the bolus. At this time, the vocal cords are abducted again. An effective glottic closure is also needed to produce an adequate Valsalva manoeuvre, essential in a number of different physiologic functions such as defecation, urination, parturition, coughing, weight lifting and jumping.

Sound production requires that several mechanical properties be met. There must be adequate breath support to produce sufficient subglottic pressure. There must also be adequate control of the laryngeal musculature to produce not only glottic closure, but also the proper length and tension of the vocal folds. Finally, there must be favourable pliability and vibratory capacity of the tissues of the vocal folds. Once these conditions are met, sound is generated from vocal fold vibration. The detailed contribution, timing and recruitment of each of the above-described laryngeal muscles in the production of sound have been studied. The intrinsic laryngeal muscles are not only highly specialized for their particular vector of action, but they are also controlled for the timing of the onset of contraction, and the degree of recruitment and fade during phonation. Actual phonation is a complex and specialized process that involves not only brainstem reflexes and the muscular actions described above, but high-level cortical control as well. Accessory effects such as lung capacity, chest wall compliance, pharyngeal, nasal, and oral anatomy and subsequent mental status also play a role. The process begins with inhalation and subsequent glottal closure. An increase in subglottic pressure follows until the pressure overcomes the glottal closure force and air is allowed to escape between the vocal folds. Once air passes between the vocal folds, the body-cover concept of phonation takes effect. The body-cover theory describes the wavelike motion of the loose mucosa of the vocal folds over the stiffer, more densely organized vocal ligament and vocalis muscle. This motion is known as the mucosal wave. The wave begins infraglottically and is propagated upward to the free edge of the vocal fold and then laterally over the superior surface. Eventually, the inferior edges become reapproximated owing to both a drop in pressure at the open glottis and the elastic recoil of the tissues themselves. The closure phase is also propagated rostrally. With the vocal folds fully approximated, subglottic pressure may again build and the cycle is repeated.

Suggested Reading

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