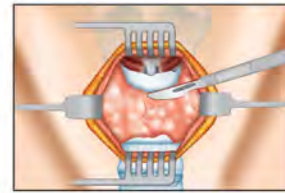
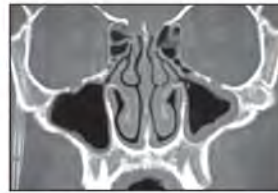


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Sataloff's Comprehensive Textbook of
Otolaryngology
Head & Neck Surgery

Laryngology

Series Editor

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Volume Editor

Michael S Benninger



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Gross Anatomy of the Larynx

Gerhard Friedrich, Georg P Hammer

INTRODUCTION

The human larynx is a complex organ composed of a skeleto-membranous framework with a series of surrounding muscles, all together with the purpose of varying the position, shape, and tension of the vocal folds during the major laryngeal functions: respiration, deglutition, and phonation. Furthermore, laryngeal closure enables an effective cough, clearing the airway passage and allowing increased abdominal pressure necessary for the Toynbee/Valsalva maneuver.

Respiration and deglutition are phylogenetically old, vital, or so-called primary functions. Phonation is an evolutionary relatively young, secondary function for the human ability of oral communication.^{1,2} Nevertheless, this new function has substantial consequences in the evolution of the unique anatomical structure of the human larynx and vocal tract compared with our mammalian relatives.

In deglutition and phonation, the sphincteric closure function of the larynx is a prerequisite, whereas in respiration a wide lumen with abducted vocal folds is required. One of the major challenges the laryngeal surgeon is confronted with is to respect those different and very often conflicting requirements and to keep a balance between the primary and secondary functions. In this chapter, we will not go into detail with all basic anatomic laryngeal structures but want to focus on functional aspects in particular for the (phono-) surgeon.

PHYLOGENETIC ASPECTS

Substantial works concerning the evolution of the whole aerodigestive tract, comparative anatomy, and the specific

role of the larynx and its precursors in pre-mammalian vertebrates were published already by Sir Victor Negus³ and Sir Donald Harrison.⁴ The larynx of air-breathing individuals is responsible for maintaining a patent air channel to and from the lungs while also blocking incursions from the digestive tract. Those functional challenges are the same in different vertebrate groups, although fundamental differences of laryngeal structure between the groups are evident. According to the laryngeal function, the prime assignment in all of these vertebrates is sphincteric to avoid aspiration. In many air-breathers, the larynx develops into a phonatory organ for sound-wave based communication.⁵ According to Laitman,⁶ the basic laryngeal features such as the skeletal framework (including cartilages homologous to those found in humans) exist in most mammalian species, though they are often substantially modified to accumulate individual requirements. The primary function of the mammalian larynx remains true to its heritage: regulating and guarding the airway as a valve. Therefore, it is not surprising that the majority of the laryngeal musculature is responsible for laryngeal closure, predominantly by vocal fold adduction.⁷ Also, the position in relation to the skull base is essential for its function. A high position in the neck enables the epiglottis to pass upward behind the soft palatal velum and lock the larynx directly into the nasopharynx. This anatomic configuration provides a direct conduit for air from the nose through the nasopharynx, larynx, and trachea into both lungs; it also permits the patency of the laryngeal airway while a stream of food is transmitted around each side of the larynx during swallowing. Some mammalian species (e.g. tooth whales) even exhibit an anatomic

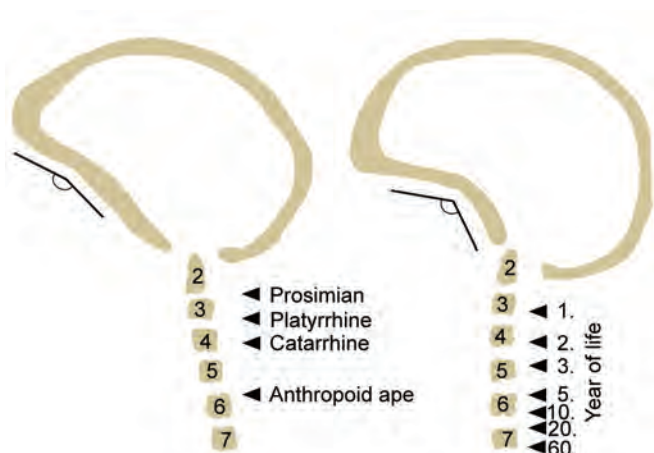


Fig. 3.1: Position of the larynx in the neck (arrows regard to the lower rim of the cricoid cartilage) and comparison of the phylogenetic⁷¹ and ontogenetic⁷² development. The different angulations of the cranial basis according to Laitman⁶ are highlighted.

connation of the epiglottic tip to parts of the basicranium, thus sealing the respiratory tract from the digestive route completely.⁶

Our closest relatives among all mammals, the non-human primates (apes, prosimians), show that their upper aerodigestive anatomy is similar to the before mentioned general mammalian pattern. The laryngeal position related to the cervical vertebrae is high in the neck with a remarkable tendency of descensus along the evolutionary ladder (Fig. 3.1). This high position protects from aspiration, but it also implies that only a small supralaryngeal portion of the pharynx exists. Consequently, the sound generated at the vocal folds resonates directly into the epipharynx and nasal cavity. This is the reason for the restricted ability of primates to produce a large variety of sounds by articulatory movements, which is a precondition of human speech. To compensate for the lack of resonatory cavities, some species have evolved modifications in pharyngeal and/or laryngeal anatomic structures, such as laryngeal air sacs, which can increase the intensity and quality of the prime laryngeal sound. Laitman's extraordinary studies of basicrania of fossil human ancestors ("hominids") established a statistically significant, direct biomechanical link between the contour of the skull base and the laryngeal position in the neck. The basic pattern that has emerged from these studies is that basicrania that are essentially flat relate to the larynx positioned high in the neck, whereas basicrania that are markedly flexed correspond to larynges and associated structures positioned much lower in the neck as compared with the vertebrae. Nonhuman primates,

including the monkeys and apes, exhibit essentially the former, whereas adult humans exhibit the latter (Fig. 3.1).⁶

In the human species, speech is the outstanding elaboration associated with the respiratory system. Human speech is characterized by rapid, precise movements of vocal tract articulators (lips, tongue, jaw, velum, larynx). The resulting changes in the shape of the supralaryngeal vocal tract lead to the dynamic pattern of formant variation that is exceptional for human vocal communication. However, recent studies show that the larynx in some nonhuman mammals (e.g. dogs and deer) is distinctively lowered during loud vocalizations as a "dynamic descent" to enhance vocal resonance.⁵

The human larynx is used for phonation continuously starting with the first cry of a newborn. The elaboration of laryngeal musculature and its subtle neural control, integrating laryngeal sound production with movements of respiratory, pharyngeal, palatal, lingual, and labial muscles during the complex articulation of speech, provides mankind with a unique ability.^{6,8}

DEVELOPMENTAL ASPECTS

Embryology

In humans, the rudiment respiratory system arises in the fourth week as an outgrowth of the digestive tract, the so-called laryngotracheal groove. The larynx itself develops from two parts: the supraglottis from the buccopharyngeal bud (fourth arch of the branchial system) and the glottis and subglottis from the tracheobronchial bud (fifth and sixth arch); as a consequence, also the lymphatic drainage occurs on two different ways (superior and inferior), which has a major impact on oncologic treatment. An exception is the epiglottis, which appears to be a unique mammalian addition unrelated to the ancestral branchial arches. The intrinsic musculature of the larynx is derived from the branchial arch mesenchyme of the fourth through sixth arches. Accordingly, the superior and recurrent laryngeal innervation to these muscles is related to this arch system either. Congenital anomalies (e.g. webs, atresia, laryngeal clefts, or stenosis) can be the result of irregularities in this early phase of embryonic development (0–8 weeks). The positional relationships of the larynx to contiguous structures undergo dramatic changes during development. The descensus from the skull base to its position at birth happens slightly; especially, weeks 23 to 25 seem to be a critical period of development, as portions of the cranial base are intimately related to the larynx and its contiguous

musculature, cranial shape development, and laryngeal/aerodigestive tract positions may also be linked (Fig. 3.1). As previously described, characteristic of mammals in those weeks the epiglottis and soft palate overlap for the first time, providing the anatomical “interlocking” of the larynx into the nasopharynx. Remodeling and refinement of the positional anatomy of the upper aerodigestive tract including cartilaginous structures and soft tissue (such as the larynx) and bony skeletal parameters (such as skull base) begins during this period, generating the anatomical framework for the newborn’s entire respiratory and digestive region.^{6,8,9}

The Infant Larynx

The anatomy of the pediatric airway differs remarkably from that of the adult—more than can be accounted for by size alone. By comparing the ontogenetic development in humans to the situation in primates, a strong parallelism to Haeckel’s Biogenetic law—ontogeny recapitulates phylogeny—is obvious. As shown in Figure 3.1, the topographic position of the infant larynx lies much more cranial than in adults and causes an overlap of the uvula and the epiglottis. In projection to the vertebral column, the cricoid of a fetus or newborn projects lies anterior to the third to fourth cervical vertebral body, whereas the adult larynx descends over the years to the sixth cervical vertebra, and in senility it projects down to the seventh vertebral body of the neck.^{2,10–12} A normal finding in the infant larynx is an overlap of the hyoid bone and the thyroid cartilage. This situation can persist as an atavistic residuum in adults and predisposes to laryngeal dysfunction (Fig. 3.3D).^{13,14} The thyroid cartilage, which is prominent in adolescents and adults, is much more difficult to palpate in the infant neck; the hyoid bone itself can be located externally by palpation almost in the submental region. A palpating finger moving from the hyoid bone caudally falls into a depression upon arrival at the thyroid cartilage—quite in contrary to its prominence in the adult. In infants, the prominent midline ridge of the thyroid cartilage, which begins at the thyroid notch, is not present. Instead, the anterior surface is rather flat and slightly rounded. Following further inferiorly the cricothyroid space with its membrane is rather palpable as a small slit, not a depression as in older humans. This fact has to be considered when performing a cricothyroid puncture or related surgical procedures in a pediatric larynx. With the descensus of the larynx and its enlargement also the major externally palpable structures of the laryngeal framework (hyoid bone, thyroid

and cricoid cartilage) separate and distance themselves, hereby forming the preliminarily described thyrohyoid and cricothyroid membranes. Consecutively, with this laryngeal descensus also the oropharynx develops and widens up. Endolaryngeally the elevated tip and curvature of the epiglottis is striking. This curved form increases from birth until the age of 3 years and slabs constantly over the years to its typical paddle-like configuration in the adult. The folded epiglottis and the thick and short aryepiglottic folds are one reason for the frequently seen supraglottic instability or so-called laryngomalacia in newborns. The arytenoid humps are disproportionately prominent and obscure a portion of the vocal folds. At birth, the arytenoids are very large in comparison to the dimensions of the other laryngeal structures and the length of the cartilaginous glottis accounts for about two-third of the whole glottis length (Fig. 3.10). During laryngeal maturation, a proportional diminution of the arytenoids can be observed and at about an age of 2.5 years the length between the cartilaginous and membranous glottis equalizes to result in an inverse relationship of roughly two-third membranous and one-third cartilaginous after the end of the growth period.^{15–17} Adult humans have the longest membranous glottis compared with animals; this is obviously a result of the evolutionary adaptation of the larynx as a phonatory organ. Negus described in animals the arytenoids forming more than the half of the entire glottis length, especially in those that need large air volumes for running (e.g. horses): “Present day man has a choked airway: He is in the position of a powerful motor car equipped with a good engine and efficient transmission, but with a choked air inlet to the carburetor.”³

Additionally, the laryngeal aditus becomes more triangular in adolescents and adults as a consequence of the proportional diminution of the arytenoids and the lengthening of the vocal folds. Also, the angulation of the folds varies as they insert onto the posterior surface of the thyroid’s midline. In the pediatric larynx, the vocal folds tend to slope inferiorly from posterior to anterior. This glottis angulation decreases with age, and they finally lie within the axial plane at adulthood. The subglottis is a nearly rounded airspace that rapidly increases in size during the first 2 years of life (from 13 to 28 mm² in the means).^{9,16,17} The most caudal part of the upper pediatric airway, the trachea, measures approximately 0.5 cm in diameter in full-term newborns. Maximal internal diameter of the trachea in children aged less than 1 year ranges from 0.6 to 0.9 cm. The subglottis bounded completely by

the cricoid ring is the narrowest part of the infant larynx, especially because of its relatively thick mucosa.¹⁶ In conclusion, the pediatric larynx is not like an adult but more like a mammalian larynx and is primarily an organ for respiration and deglutition—it is not a “minilarynx” but a special organ.

Gender-Related Differences

Up to puberty the female and male larynges vary marginally in shape and size. Thereafter, while the female larynx grows slightly, the male larynx enlarges under the influence of testosterone and growth hormone in all dimensions with the consequence of deepening the male voice around one octave. Although the larynx and the voice are secondary sexual characteristics, and even though the sex-related distribution of laryngeal disorders and lesions is striking, the evidence of hormonal receptors in laryngeal tissue is inconclusive.^{18–22} Essential gender-related differences are particularly pronounced in the thyroid cartilage (especially in the sagittal diameters) and in the thyroid angle, forming a prominence at its upper end, the so-called Adam’s apple (Fig. 3.2).

The rapid and strong growth especially of the thyroid cartilage during maturation can lead to asymmetric developments that consequently are more frequent in men. A different development of the thyroid lamina leads to an asymmetric and tilted configuration of the endolaryngeal structures. A typical configuration can be observed: the aryepiglottic fold is situated more posteriorly on the side of the longer thyroid plate giving the clinical impression of a so-called arytenoid crossing or adduction asymmetry; the laryngeal prominence is shifted extramedian to the side of the shorter plate accordingly the interarytenoid region is tilted toward the longer side both resulting in an oblique course of the glottis. A strong growth of one thyroid plate very often leads to an inward buckling of the lamina in the anterior part moving the ventricular fold medially, mimicking a ventricular fold hyperplasia (Figs. 3.3A to D).^{23–25} Furthermore an underdevelopment of the laryngeal dimensions is not uncommon.²⁴ It could be demonstrated that in clinically diagnosed functional mutational voice disorders presenting with an abnormal high pitched phonation, a larynx hypoplasia was the underlying cause.²⁶ In general the female and male larynges differ significantly not only in nearly in all dimensions but also in several biomechanically properties, so they almost can be considered as two different organs.^{17,26–32} Interestingly, in

contrast to the absolute dimensions, the relative proportions are much more constant and are not gender-specific and therefore can be used as landmarks in laryngeal surgery (Fig. 3.4).^{17,33} Further details in gender-related differences will be provided in the corresponding chapters.

Physiologic ossification of the laryngeal cartilages in females starts at the age of 50. In males this process begins much earlier between the ages of 18 and 20, although individual differences are evident. The thyroid’s ossification is much more distinctive in men, but a fully ossified thyroid is rare before the age of 50, in females even before the age of 75; there is no relation between the age and the degree of ossification. The cricoid cartilages ossification starts in accordance with the thyroid, but it does not occur completely. The arytenoids follow a few years after the other laryngeal cartilages, but they ossify completely in senility except the vocal processes, which stay cartilaginous throughout life.

THE ADULT LARYNX

Skeletal Framework

A series of cartilages connected by fibrous membranes and ligamental structures form the laryngeal framework. Although the thyroid cartilage, the cricoid cartilage and the epiglottis are single cartilages, the arytenoid cartilages are paired. Additionally, three paired small cartilages (corniculate or Santorini’s cartilage on the apex of each arytenoid; cuneiform or Wrisberg’s cartilage within the free margin of the aryepiglottic fold; triticeal cartilage within the thyrohyoid ligament) can be variably found.^{10–12,34–40}

The thyroid, the cricoid, and the major portion of the arytenoid cartilages are composed of hyaline cartilage, whereas the vocal processes of the arytenoids, the epiglottis and the small variable cartilages (cuneiform, corniculate, triticeal) are composed of elastic fibrocartilage. From approximately the age of 25 the thyroid cartilage undergoes advanced calcification, but cases of congenital premature calcifications have been also described. Hematopoietic marrow can be present in senility. All these cartilaginous structures move in relationship to each other by forces generated by musculature external and internal to this skeletal framework and by recoil from elastic membranes and ligaments.

The hyoid bone is the only bone of the human body that is not connected to other bones by articular joints; it is a U-shaped, backwards open bone that consists of a body (corpus) and two horns (major and minor) on each side.

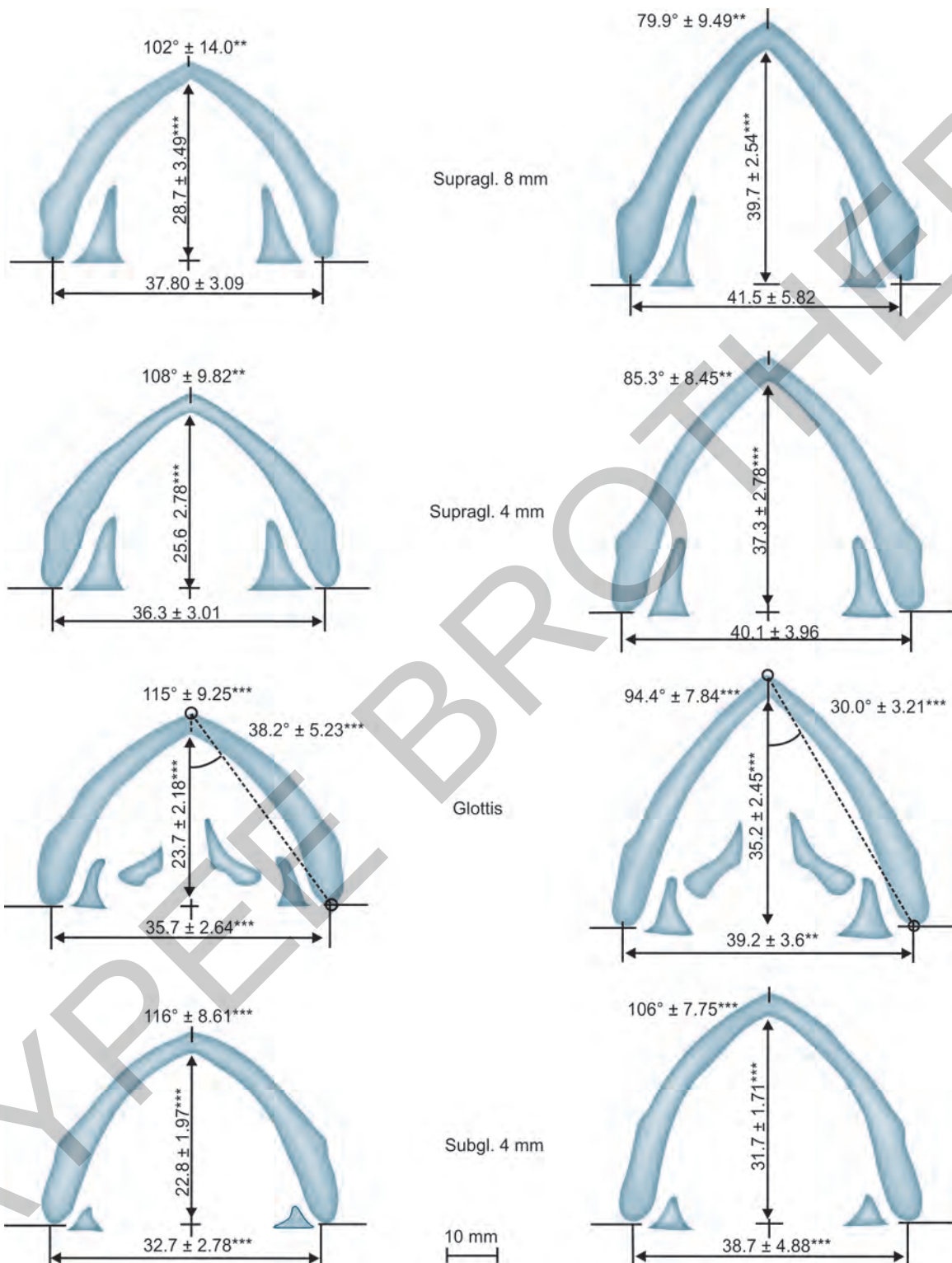
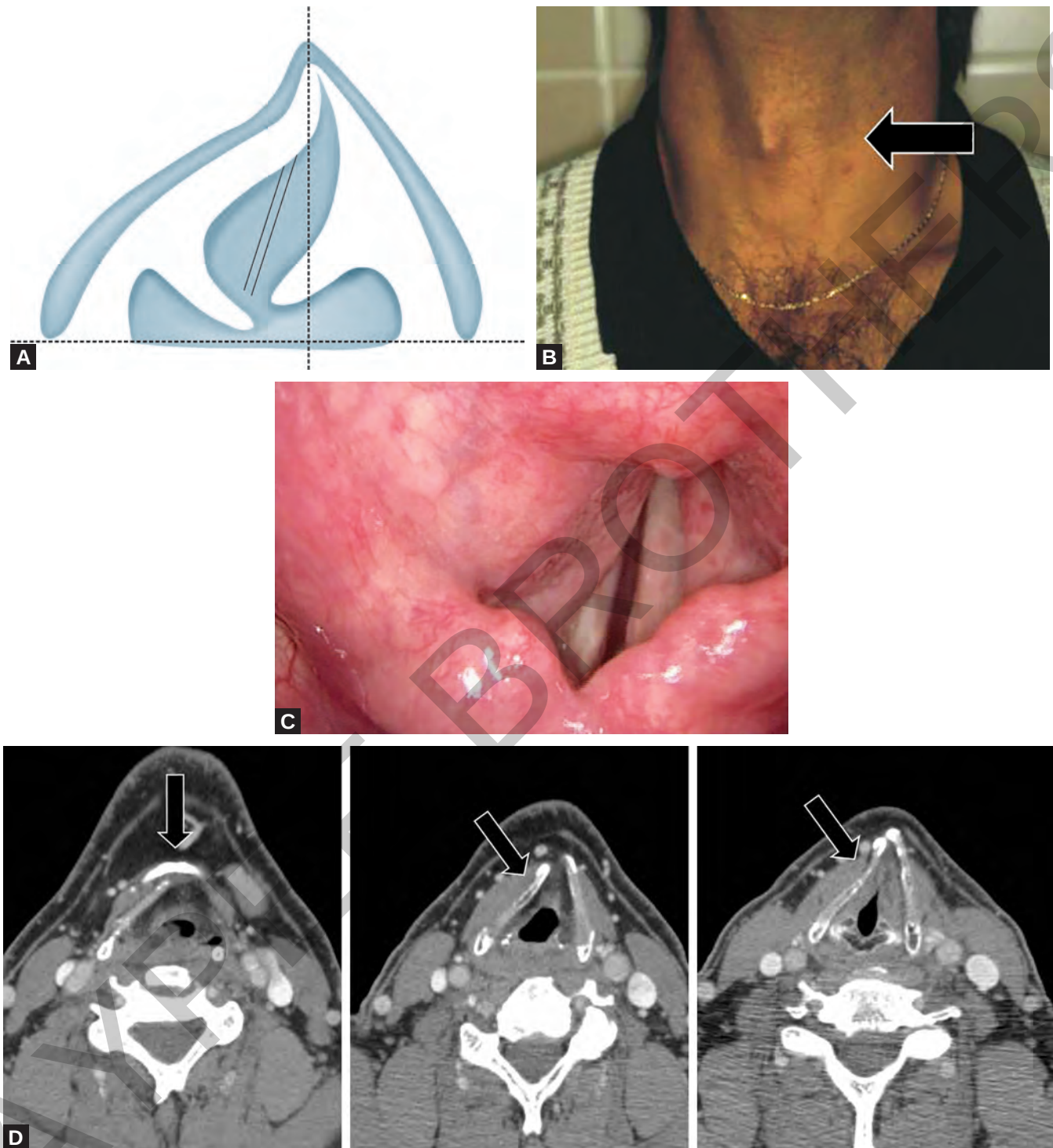


Fig. 3.2: Thyroid angles, transverse, and sagittal diameters of the thyroid cartilage in different horizontal planes in females and males. The thyroid angle given in each plane refers to a reference point at the anterior quarter of the median sagittal diameter. At the glottis level additionally the angle between the median sagittal line and the posterior end of the thyroid cartilage is given.¹⁷ Given are each mean with standard deviation and significant levels on comparing the corresponding gender-related values (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).



Figs. 3.3A to D: Thyroid asymmetry. (A) Typical configuration of an asymmetrically developed thyroid plate comprising a more posteriorly situated aryepiglottic fold on the side of the longer thyroid plate, shifting of the laryngeal prominence to the side of the shorter plate, tilting of the interarytenoid region toward the longer side resulting in oblique course of the glottis, and inward buckling of the lamina of the anterior part of the thyroid plate shifting the ventricular fold medially. (B-D) Examples of a patient presenting with this condition. (B) Arrow points at the extra median position of the pomum adami. (C) Laryngoscopic view presenting the features described in A. (D) CT scan of the patient demonstrating the underlying cause is the thyroid plate asymmetry (arrows pointing at the inward buckled left thyroid plate). Additionally, this patient exhibits an overlapping of the hyoid bone and the thyroid cartilage as an atavistic residuum (arrow).^{14,23-25}

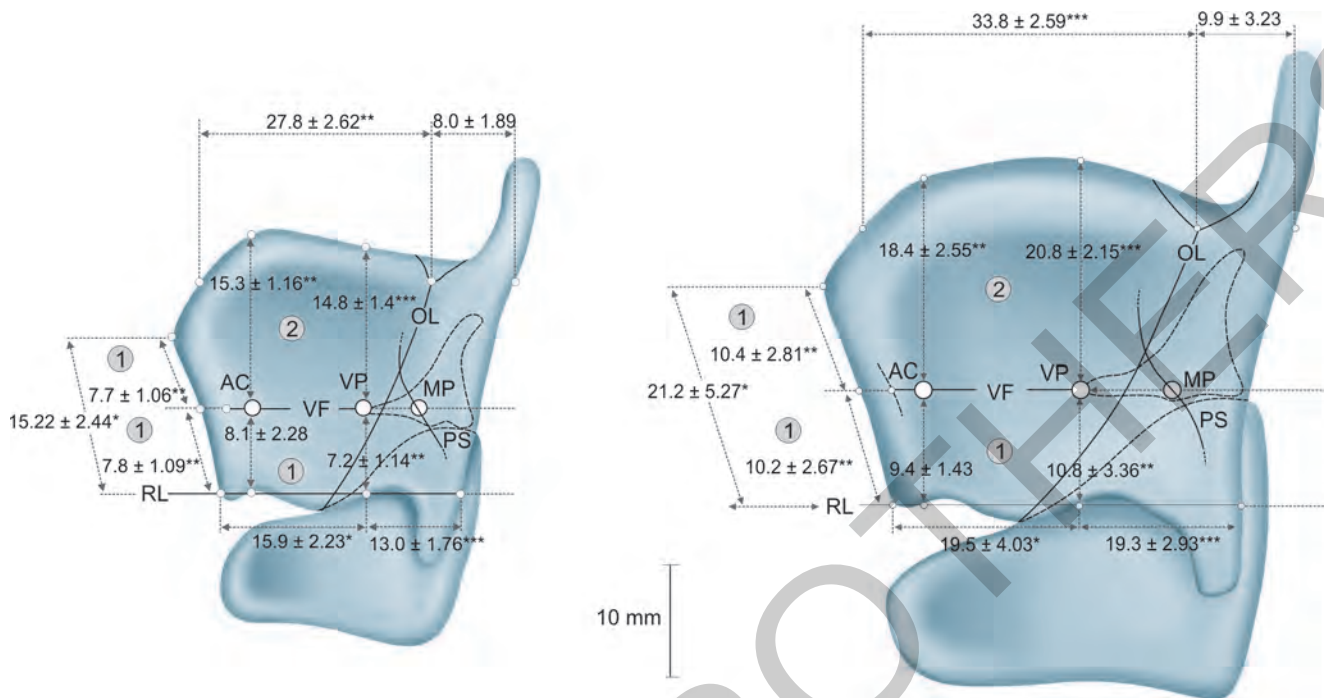


Fig. 3.4: Location of the superior and inferior thyroid tubercle and course of the oblique line (OL). Projection of the ventral extension of the piriform sinus (PS), fixation of the anterior commissure tendon (AC), free margin of the vocal fold (VF), vocal process (VP), and muscular process (MP). The free margin of the vocal fold runs parallel to a reference line (RL) at the inferior border of the thyroid cartilage, which crosses the inferior thyroid tubercle. Although nearly all absolute dimensions are statistically significant between men and women, the relative proportions are constant (1:1, 2:1).¹⁷

Attachment to the styloid process is given by the stylohyoid ligament (which can ossify over the years) and muscle; further conjunction to the mandible, the temporal bone, and the tongue is performed by the suprahyoid muscles, namely the hyoglossus, geniohyoid, mylohyoid and digastric muscles, and to the pharynx by the middle constrictor. The larynx itself is suspended to the hyoid by the thyrohyoid membrane and ligaments and the thyrohyoid muscles (parts of the four paired laryngeal extrinsic muscles or strap muscles).

The largest of the laryngeal cartilages is the thyroid cartilage that shields the opening to the airway. It consists of two quadrilateral hyaline alae (laminae) whose anterior borders fuse (after birth) along their inferior two thirds at the midline symphysis with a narrow strip of cartilage, the intrathyroid cartilage, forming the thyroid angle that in general is considered to be 90° in males and 120° in women and children. Due to measuring difficulties on the irregularly curved thyroid surface also discriminative statements can be found in literature. Based on a defined reference point at the anterior quarter of the median sagittal line a mean thyroid angle of 115° in females and 95°

in males can be found in the glottal plane.¹⁷ The angle between the posterior end of thyroid ala and the median line is particularly important for phonosurgery, especially for vocal fold medicalization by thyroplasty, and is about 40° in females and 30° in males. The thyroid angles increase from cranial to caudal (supra- to subglottal), while all diameters and dimensions decrease resulting in a funnel like shape of the thyroid cartilage (Fig. 3.2).¹⁷ Attached to the posterior rim of each thyroid's lamina are the superior and inferior horns (cornua). Although both superior cornua assist in laryngeal suspension, being connected to the hyoid bone by the thyrohyoid ligaments, the two inferior horns articulate variably with the cricoid cartilage. Just anterior to the superior horn is a cartilaginous prominence, the superior thyroid tubercle. From this point the oblique line descends to the inferior tubercle on the caudal rim. The oblique line is formed by the attachment of the strap muscles on the thyroid cartilage and is an important landmark for phonosurgery (Fig. 3.4).^{17,35,39,40} The thyroid cartilage is significantly thicker in men than in women and in general its thickness increases from anterior to posterior. The maximum thickness

is found at the oblique line, which is very prominent at the supraglottic level and decreases subglottically (Fig. 3.5).¹⁷

As the only cartilage of the entire respiratory tract the cricoid cartilage is formed as a ring, strictly speaking it is signet-ring-shaped, acting as the caudal part of the laryngeal framework, and lying horizontally with a vertical lumen (Fig. 3.6). Therefore, it can be divided anatomically into a posterior part, the lamina or “plate,” and an anterior part, also called “cricoids arch.” In adults, the mean sagittal diameter of the cricoids arch is roughly about 16 mm in both sexes, whereas the transversal diameter is about 22 mm in men and 16 mm in women.²⁷ The lamina of the cricoid is 2–3 cm in height and has a midline ridge to which the longitudinal esophageal fibers attach. On each side the cricoid cartilage articulates with the inferior horn of the thyroid via articular facets of different shape. Additionally, on the upper boarder of the lamina two planes can be found on each side for articulation with the paired arytenoids cartilages.

The two arytenoid cartilages are pyramidal and sited craniolaterally on the cricoid lamina (Fig. 3.6). In general, one arytenoid cartilage has a base, three surfaces, two processes (muscular, vocal), and one apex. The posterior surface is triangular, smooth, and concave, whereas the anterolateral surface is convex and rough; from near the apex a crest (*crista arcuata*) curves back, down and then forwards to the vocal process. The lower part of this crest separates two depressions, the upper triangular fovea (attachment for the vestibular ligament), and the lower oblong fovea (insertion of the vocalis and lateral cricoarytenoid muscles). This oblong fovea has been identified as a suited spot for special arytenoid adduction techniques.⁴¹ The medial surface is narrow, flat, smooth and covered by laryngeal mucosa; by its lower edge it forms the lateral margin of the intercartilaginous part of the glottis gap. The base is concavely formed with a smooth facet for articulation with the craniolateral rim of the cricoid lamina. The apex curves posteromedially and articulates, sometimes even fuses with the adjacent Santorini’s cartilage. The muscular process is a prominence that projects posterolaterally, serving as the insertion point for the lateral cricoarytenoid muscle in front and the posterior cricoarytenoid muscle behind. The vocal process, which is projecting horizontally forward, gives the posterior attachment of the vocal ligament (Figs. 3.6 and 3.9).¹⁸

The epiglottis is a thin, leaf-shaped, fibroelastic cartilage lying dorsally to the root of the tongue and forming the anterior wall of the laryngeal entrance. Its caudal stem, the petiole, which is round and broad, is fixed

at the median back of the thyroid (just below its notch) by the thyroepiglottic ligament. The epiglottic sides are attached to the arytenoid cartilages by the aryepiglottic folds. The intralaryngeal backside of the epiglottis is transversely concave and vertically concavo-convex; it is covered by respiratory mucosa and protruded inferiorly by the petiole bearing a convex tubercle. Also the free upper anterior surface of the epiglottis is covered by mucosa (nonkeratinized stratified squamous); here two major depressions (*valleculae*) are formed by the single median and two lateral glossoepiglottic folds. The lower anterior surface lies behind the hyoid bone and thyrohyoid membrane, from which it is separated by the pre-epiglottic adipose tissue.

The projection of the endolaryngeal structures onto the thyroid surface is especially important for phonosurgery. Although significant gender-related differences can be found in the absolute dimensions, the relative proportions are more constant. The fixation of Broyles’ tendon divides the distance between the superior and the inferior thyroid notch in a ratio of 1:1. Starting at this point the free edge of the vocal fold runs parallel to the lower margin of the thyroid and divides the thyroid plate in a ratio of 2:1. As the inferior thyroid margin does not run straight, this reference line crosses the thyroid tubercle (Fig. 3.4).^{17,33} The oblique line is an important landmark. A few millimeters anterior to it, the tip of the vocal process is seen in the lateral projection and nearly at the same level a few millimeters posteriorly the muscular process of the arytenoid projects, which roughly also corresponds to the posterior wall of the glottis (Figs. 3.4 and 3.5).

A potentially endangered structure in laryngeal surgery is the piriform sinus. It extends far ventrally at the supraglottic level and flattens subglottically so that a surgical approach, e.g. to the muscular process in arytenoid adduction, should start inferiorly. The ventral extension of the piriform sinus takes an opposite course compared with the oblique line and crosses this line a few millimeters above the level of the glottic plane.¹⁷ At the glottic level the ventral extension of the piriform sinus is about 6 mm in females and 6.5 mm in males without statistically significant difference. This corresponds nearly exactly to the location of the muscular process and the posterior wall of the glottis (Figs. 3.4 and 3.5).⁴¹

Membranous Structures and Ligaments

The laryngeal skeletal framework is interconnected and suspended in the neck by various elastic structures, such

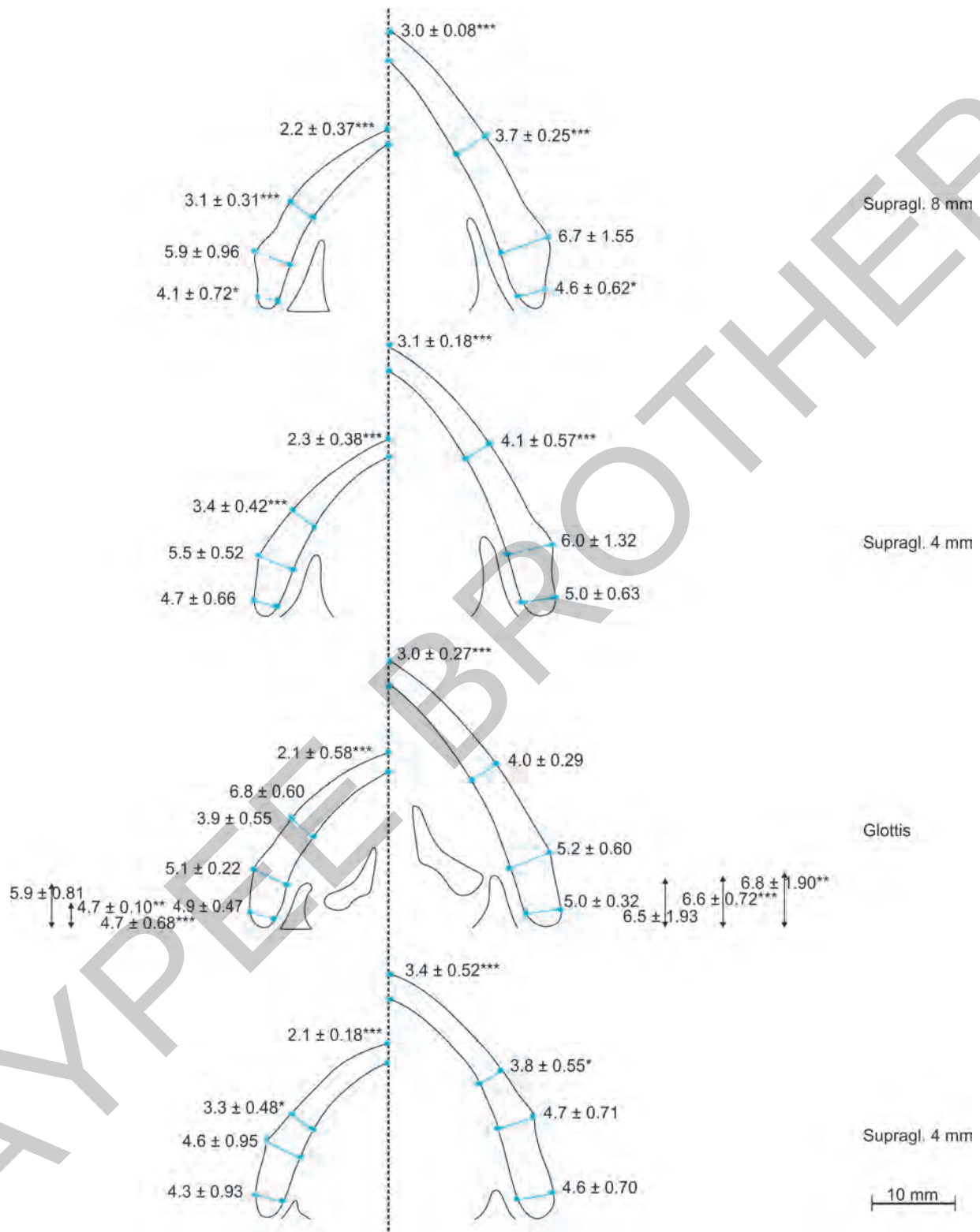


Fig. 3.5: Thickness of the thyroid cartilage on different positions and in different levels in males and females. At the glottis level, it can be seen that the posterior wall of the glottis, the muscular process, and the ventral extension of the piriform sinus are located nearly at the same level.¹⁷

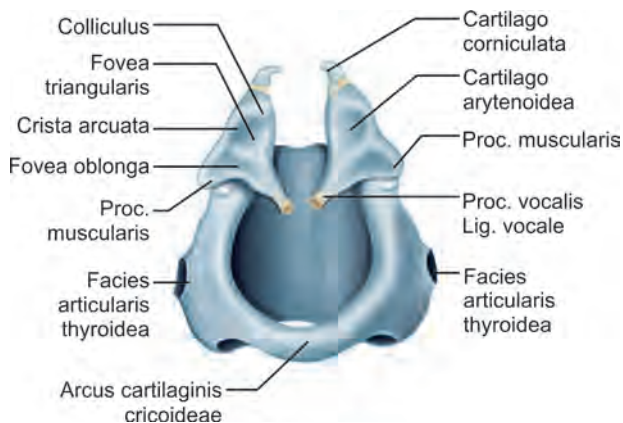


Fig. 3.6: Cricoid and arytenoid cartilages from above.⁷³

as fibrous membranes and ligaments. The thyrohyoid, cricothyroid, and cricotracheal membranes are the most significant membranous structures external to the larynx, whereas the paired cricovocal (or conus elasticus) and quadrangular membranes are internal.

The cricovocal membrane on each side connects the thyroid, cricoid, and arytenoid cartilages. Its upper edge is thickened slightly to form the elastic vocal ligament, which is attached anteriorly to the median back of the thyroid cartilage (at the so-called anterior commissure) and behind to the vocal process of the arytenoid cartilage. The connective tissue between the noduli elastici anterior of the vocal ligament and the posterior surface of the thyroid cartilage is frequently called Broyles' tendon.⁴² This is a very special anatomical region with great implications for the spreading characteristics of vocal fold carcinomas. The length of Broyles' tendon, from the inner border of the thyroid cartilage to the mucosa of the anterior commissure, is significantly different between both sexes and measures on average 1.8 mm in females and 2.9 mm in males.^{17,39}

Extending from the vocal ligaments caudally to the cricoid arch, this layer of elastic tissue forms the conus elasticus. The quadrangular membrane composes the luminal aspect of the supraglottic space. On each side, it extends from its inferior margin, the vestibular ligament, to the free margin of the aryepiglottic fold. The vestibular ligament is the thickened lower border of the quadrangular membrane and extends from the isthmus of the thyroid cartilage anteriorly to the arytenoids cartilage posteriorly. Thus, it forms the inferior border of the wedge-shaped vestibular or false vocal fold, which extends anterolaterally into the laryngeal ventricle or saccule of the laryngeal sinus of Morgagni.

Ligamental structures strengthen the suspension of the larynx to its neighboring tissue and to the skull base. The stylohyoid ligaments descend bilaterally from the styloid process of the temporal bone to the lesser horn of the hyoid bone. In turn, the hyoid provides attachment for the thyrohyoid membrane, which is thickened laterally on each side by the lateral thyrohyoid ligaments; these connect the superior horns of the thyroid to the greater horns of the hyoid bone. Fibers of an unpaired median thyrohyoid ligament additionally tighten the connection between the hyoid body and the thyroid notch.

The epiglottis is attached anteriorly to the body of the hyoid by the unpaired hyoepiglottic ligament and below, immediately above the vocal cords, to the back of the thyroid cartilage by the unpaired thyroepiglottic ligament. Its sides are connected as mentioned before with the arytenoid cartilages by the aryepiglottic muscles forming the aryepiglottic folds as the lateral border of the *aditus laryngis*. From its free upper anterior surface a median glossoepiglottic and two lateral glossoepiglottic folds run to the base of the tongue and to the lateral pharyngeal wall, respectively. The depressions between these folds are the paired glossoepiglottic valleculae.^{8,10,43}

The Joints of the Larynx

Moving interaction between the single parts of the skeletal framework is preserved by two paired major articulations. The cricothyroid and the cricoarytenoid joints of the larynx are both diarthrodial joints, mostly with a capsule, a synovial lining and extracapsular ligamental structures.

The cricothyroid joint is formed by the articulation of the inferior cornua of the thyroid cartilage with facets on the cricoid lamina. The articular surfaces of this joint are noticeably variable in size, shape, configuration, and presence. Three major types can be distinguished: (A) well-defined facet with a tight capsule and ligaments (~60%), (B) no definable facet and solely soft tissue connection (~25%), and (C) soft tissue facets, flat cartilage surfaces or tiny protuberances with thin capsular connection (~15%). The capsule of the cricothyroid joint in Type A is tight and strengthened by three ceratocricoid ligaments (anterior, posterior, lateral), thus preventing gliding movement of the sagittal adjusted facets. In the other two articulation types (B, C), those ligamental structures are only rudamentarily pronounced, which causes a significantly higher gliding mobility. Interestingly, in about one-third, both in males and females, the types of joints are different on each side of the larynx. The functional consequences of these

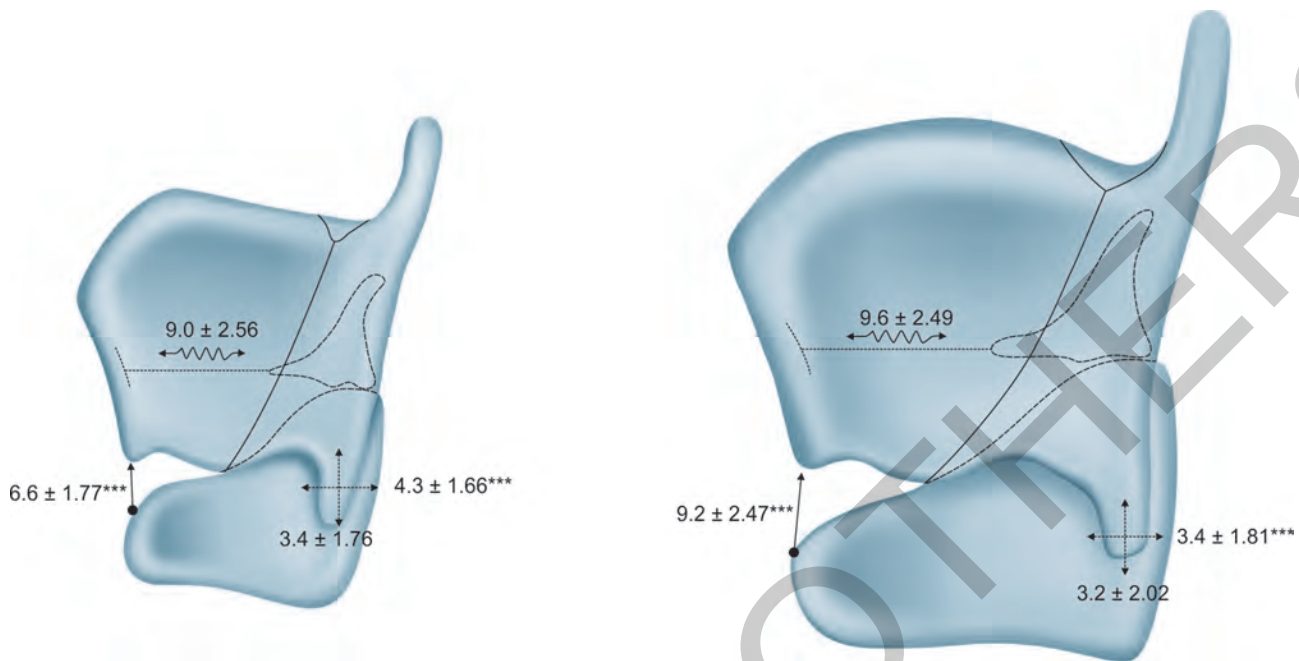


Fig. 3.7: Movements in the cricothyroid joint. Given are the mean movements in mm. The visor mechanism enables a significantly greater movement in males, whereas the resulting length changes of the vocal folds (sinuous line arrows) are not significantly different. The horizontal gliding movements are significantly larger in females, whereas the vertical gliding capabilities are not different.^{28,29}

side-different biomechanical properties for pitch regulation of the voice are not clear.^{27,28} Depending on its different types, the cricothyroid joint allows, besides its main function as a pivoting joint—rotation around an axis that crosses the top of both inferior horns of the thyroid – also horizontal and vertical gliding movements. It could be demonstrated by vector analysis that the anatomic structure of the cricothyroid joint that determines the freedom of gliding movements influences directly the position of the effective rotation axis and consequently the degree of elongation of the vocal folds. Interestingly, the gliding mobility of this joint is significantly higher in females (Fig. 3.7).^{28,29} The functional consequences of these findings have to be determined yet, but they may also have an impact on the results of cricothyroid approximation surgery.³¹ The main action of the cricothyroid joint rotation as a visor mechanism again exhibits significant gender differences in its biomechanical properties. Although the narrowing of the cricothyroid space is significantly greater in males, the resulting vocal fold elongation is not significantly different as compared with females (Fig. 3.7).^{28,29}

The cricoarytenoid joint is the primary moving structure of the intrinsic larynx. The arytenoid cartilages mount on the articular facet of the cricoid's lamina (at a 45° angle with the horizontal plane).^{8,9,45} The articular surface of the

cricoid cartilage has a longitudinal extension of 7–8 mm and a transverse extension of is 3–4 mm in males. At the arytenoid the longitudinal extension of the articular surface is about 4 mm and the transverse extension is about 5 mm. In females, all of those extensions are roughly about 1 mm smaller.^{27,32} This anatomical constitution enables a special multiaxial movement of the arytenoid cartilages on the cricoids: sliding from posterior to anterior along the longitudinal joint axis, rocking from lateral to medial around the longitudinal joint axis, and rotating along a vertical axis that runs perpendicular to the articular facets (Fig. 3.8).³² In regard to the rocking and rotating component of the arytenoid movement, there is little difference between men and women. The sliding movement, however, is more extended in men, which correlates with the longer articular surface of the male cricoid. In reality, the movements of the arytenoid cartilage are a complex combination of the aforementioned components, all together changing the position, shape and tension of the vocal folds. This is the basis of the exceptional vocal variability in men.^{32,45–47}

LARYNGEAL MUSCULATURE

Laryngeal function and movement is caused by two groups of muscles. The extrinsic muscles connect the larynx to

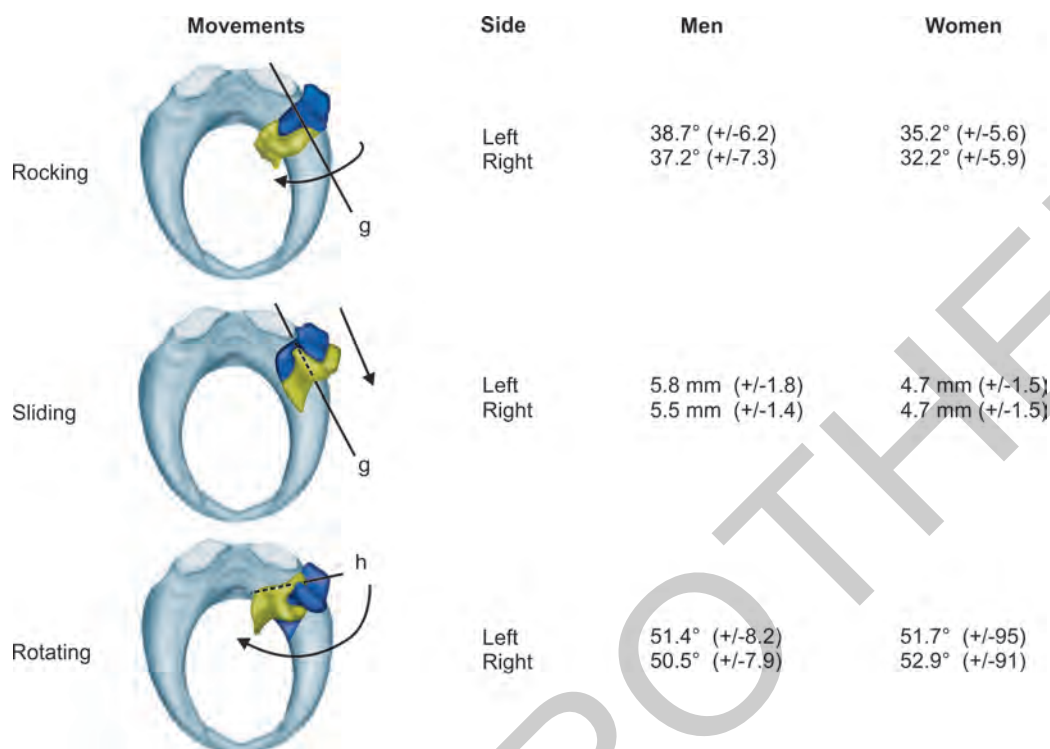


Fig. 3.8: Compound movement of the arytenoid cartilage: Top view of the cricoid cartilage with the left arytenoid cartilage in the “respiratory” position (blue) and in the “phonatory” position (yellow). Demonstration of different movements around/along the joint axis g and h; differences between both sides and between both sexes are shown in rocking angle (degree), sliding movement (mm), and rotating angle (degree).³²

surrounding structures and move it as a unit vertically during phonation and swallowing. The intrinsic muscles modify motion of different parts of the larynx, altering vocal cord tension as well as varying in the size and shape of the laryngeal inlet.

The Extrinsic Muscles

This group of muscles includes the infrahyoid strap muscles such as sternohyoid, omohyoid, sternothyroid, and thyrohyoid muscles, as well as the inferior constrictor muscle of the pharynx. The thin and narrow-strapped sternohyoid muscle arises from the posterior surface of the manubrium sterni, the posterior sternoclavicular ligament, and the posterior aspect of the medial end of the clavicle; it ascends medially and inserts at the lower border of the hyoid bone. The sternothyroid muscle lies deeper and partly medial to the sternohyoid muscle. It is attached inferiorly to the posterior rim of the first costal cartilage and to the back of the manubrium sterni below to the sternohyoid. On each side it ascends anterolateral to the lobe of thyroid gland above to the oblique line of the thyroid

cartilage’s lamina. Originating from that oblique line, the thyrohyoid muscle appears as an upward continuation of the sternothyroid muscle. This flat, quadrilateral muscle extends to the lower rim of the major horn and adjacent hyoid body. The omohyoid muscle arises from the upper border of the scapula (near the scapular notch) and incidentally from the superior transverse scapular ligament. Its insertion point is at the lower border of the hyoid body, lateral to the sternohyoid’s attachment. This muscle has two bellies united at an angle by an intermediate tendon, which is fixed at the middle cervical fascia.^{11,12} Although the inferior belly inclines forwards and slightly up across the lower neck to pass deep to the sternocleidomastoid muscle as the intermediate tendon, the superior belly ascends almost vertically from this tendon.

Except for the thyrohyoid muscle that approximates the thyroid cartilage and the hyoid bone, all of these muscles are depressors of the larynx; as antagonists of the suprahyoid muscles, they depress the hyoid bone but may act as fixators or cooperate in cyclic hyoid movements. In contrast, the suprahyoid muscles, which include the stylohyoid, digastric, geniohyoid and stylopharyngeal

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