LARYNGEAL BIOMECHANICS

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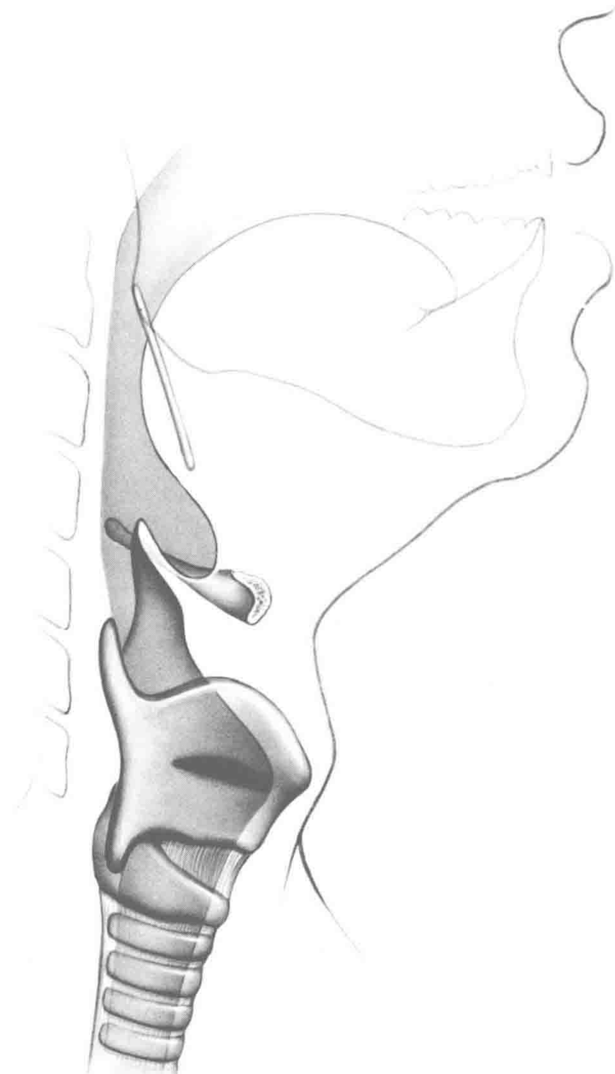

Medial sagittal section of the upper air passages.

Preface

Nature has lavished on the larynx several of its most subtle mechanical inventions. For its size the human larynx is a remarkably versatile instrument—a cavernous duct for ventilation, a vibratile slit for varied sound generation, an exit plug for gas-tight postural effort, and an entrance barrier and deflector of potential invaders.

Contrary to earlier doctrine, it is now clear that the human larynx possesses some mechanical properties that diverge more and more markedly from those of other air-breathing vertebrates as phyletic distance increases. It is true that, for want of fossil larynges, this conclusion is mainly inferred from comparative anatomy. But enough of the dynamic behavior of the organ is observable in living species to persuade one that evolution of mechanism and evolution of structure have indeed gone hand in hand. We may safely assume that the capabilities of our larynx developed slowly over the millennia, as the anatomical machinery and the brain directing it acquired increasing, matched sophistications.

The notion that the body is a machine composed of machines originated with Descartes in 1637. If, with Jeans (1943) and Hall (1969), we divide the world of nature into macromachinery (galaxies, solar system, planets), mesomachinery (animals, organs), and micromachinery (cells, organelles, molecular arrays), then the behavior of the larynx belongs in the realm of mesomechanics.

The ability to switch smoothly and rapidly from one laryngeal behavior to another and to produce finely graded respiratory airflows, vocal tones, and postural efforts is very much a part of the fiber of human existence, but its laryngeal correlates have received little notice in recent years. The refinements of the peripheral mesomachinery of the larynx have tended to be underestimated and their complex behavior imaginately oversimplified to degrees of sphincteric closure. Experience has shown that the sphincteric theory of laryngeal biomechanics has little analytic or predictive power. If, however, the larynx is viewed as a folding system, many interesting new leads open into its history and mechanics.

That the larynx is a folding system was one of the main positions established in a recent study by Fink (1975). Starting from that position—without repeating the evidence, but not without adding to it—we have developed the same viewpoint into a systematic account of the mesomechanical organization and function, with new ramifications in areas as diverse as the anatomy of the suspensory mechanism of the larynx, the mechanical basis of professional vocal training, the postural significance of effort closure, the mechanism of whispering, and the evolutionary rationale of such developments.

After an introductory survey of the dynamic anatomy of the larynx, the biomechanics of each of the main behaviors—

breathing, voicing, effort closure, swallow closure—is outlined. We conclude with a chapter on relevant elements of physics and mechanics. The discussion generally follows lines pioneered (for different topics) by Gans (1974). Each chapter begins with representative radiological observations from which a schema of the biomechanical behavior is derived. Diagrams define the important forces involved and lead to free-body diagrams that idealize the equilibrium at each pertinent phase of activity. Because the subject demands a liberal use of illustrations, we have attempted to make the mechanism understandable from the figures and legends alone.

Together, the text and the figures present an annotated pictorial model of the larynx as a working machine, explanatory of observed behaviors and perhaps predictive of some still unobserved (Peterson and Shoup, 1966). The model is developed primarily from photographs of the machine in life, principally from radiographs because these reveal the behavior under study without disturbing it. The portrayed attachments of the muscles and ligaments that have been added to the pictures are of course those specified by gross anatomy. We aim at fidelity to biomechanics rather than meticulous morphological accuracy and feel that our artistic structural simplifications are appropriate to the level of analysis we are undertaking. Inevitably, the model generalizes from the few to the many and will require modification in the light of additional data.

Although we did not set out to furnish a guide to clinical practice, we have provided useful background for assessing and managing mechanical malfunctions encountered in patients. For example, although available techniques in surgery and anesthesiology are equal to the demands of microsurgery of the arytenoid cartilage, such demands are still few, perhaps because progress in the field of laryngeal biomechanics has tended to lag. With a wider appreciation of the refinements of the mechanism, corresponding refinements in the diagnosis and correction of malfunctions may be expected to follow.

Our principal aim is to stimulate understanding of the adaptations by which the larynx mediates the distinctive human abilities to work and speak and whisper and sing. These pages must also surely evoke pleasure and wonder at the elegance of the machinery that produces such extraordinary effects.

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Laryngeal Biomechanics

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1
Anatomical Background

The larynx is a constrictor mechanism between the throat, or pharynx, and the windpipe, or trachea. In man it unfolds and folds cyclically for ventilation and folds episodically and in increasing degrees for voice production, physical effort, and deglutition. The framework of the apparatus (fig. 1.1) consists of hyaline cartilages—the thyroid, the two arytenoids, and the cricoid—articulated at synovial joints and suspended by muscles and ligaments from the hyoid bone and ultimately from the skull and mandible (figs. 1.2–1.4). Because the elastic suspensory ligaments are activated more continuously than the suspensory muscles (which are only activated intermittently), the suspension pattern is clearest in the arrangement of the ligaments. The suspended framework tapers from the pharynx downward to the trachea and is lined with eight folds of softer tissues whose degree of folding or unfolding determines the function performed.

At the base of the suspended system is the ringlike cricoid cartilage, from which the trachea is suspended. Posteriorly, the ring rather precariously supports the two small, mobile arytenoid cartilages, to which are attached the posterior ends of three pairs of folds, the aryepiglottic, vestibular, and vocal. Each of the arytenoid cartilages in turn supports two tiny cartilages, the corniculate and cuneiform. Externally and on each side, the ring articulates with the downward projection (inferior horn) of the thyroid cartilage, which is formed by two plates (laminae) that converge and fuse anteriorly. The paired folds end at the back of the fused region and at the margins of the epiglottic cartilage; this cartilage projects upward behind the body of the hyoid bone and is tethered to the hyoid bone and thyroid cartilage by ligaments (fig. 2.10).

The corniculate, cuneiform, and epiglottic cartilages, unlike the main framework, are composed of flexible elastic cartilage and form part of the laryngeal system of springs. After a folding or unfolding performance, the springs serve to return the folded or unfolded walls of the cavity automatically toward the partially folded, partially conductant configuration, seen at the end of a normal expiration. Thus, in general terms, the larynx is a suspended system of articulated cartilages lined internally by folds whose collective shape is altered by muscles and restored by springs. Each of the subunits abounds in structural refinements adapted to varied mechanical roles.

Thyroid Cartilage

The thyroid cartilage shields the open canal and supports seven of the eight folds that serve to close the passage. It is composed of two plates of hyaline cartilage that fuse and meet above at an angle of about 90 degrees in men (the angle is somewhat larger in women). The fused region, or isthmus, usually called the "angle of the cartilage," slopes downward and backward at an angle of about 60 degrees to the horizon. Its upper end forms the prominence of the larynx (prominentia laryngis). The posterior margin of each lamina bears an upward and a downward projection, or horn (cornu). The upper horn, or cornu superior, serves to suspend the thyroid cartilage from the hyoid bone; the lower, to suspend the cricoid cartilage from the thyroid cartilage. The back of the angle gives attachment to a cluster of five elastic ligaments—from above downward, the median thyroepiglottic ligament, the bilateral vestibular ligaments, and the bilateral vocal ligaments, respectively part of the median thyrohyoid fold, the vestibular folds, and the vocal folds. This ligamentous convergence constitutes a nodal point of the elastic suspensory system; it presumably prevents the development of twisting couples on the thyroid cartilage when the various ligaments are simultaneously placed under tension, as happens with inspiration.

Below the attachment of the vocal ligaments, the isthmus, or angle, is thickened and is part of the wishbone-shaped lever formed by the lower part of the thyroid cartilage. The arms of the wishbone extend along the lower part of each lamina into the inferior horn and end on each side at the cricothyroid joint, where the pivot of the lever is situated. The vocal ligaments, once their posterior end is immobilized by arytenoid adduction, are rendered tense when the lever pivots down toward the cricoid (fig. 4.5). The same effect on the ligaments, however, will be achieved if the articular surfaces of the joint slide appropriately on each other, that is, if the thyroid articular facet slides forward and partly off the cricoid facet. The flatness of the facets and the oblique direction of some of the cricothyroid muscle fibers seem well adapted to produce such sliding, or subluxation, and the elastic strength of the capsular ligaments appears ample to energize the automatic return slide. Externally, the surface of the thyroid cartilage lamina has a faint ridge called the "oblique line" (linea obliqua). The ridge is the site of attachment of powerful extrinsic muscles that move the larynx relative to its surroundings. By virtue of the flare, or divergence of the laminae, these muscles also tend to bend the lamina (fig. 2.14, 2.15). The extrinsic muscles whose fibers are directed upward away from the line tend to bend the lamina inward; those with fibers directed downward tend to bend it outward. The site of the oblique line, approximately equidistant from the prominence of the larynx and the cricothyroid joint of the same side, is probably the most advantageous site available for bending the lamina. How such bending reinforces closure or opening of the air passage is discussed in chapters 2 and 5 (figs. 2.14, 2.15, 5.7).

Cricoid Cartilage

The thyroid cartilage, which is the primary anterior support of the laryngeal folds, and the arytenoids, which are the primary posterior support, are themselves supported in part by the cricoid ring of cartilage. The ring is broad and tall at the back where it supports the arytenoids, but low anteriorly where it forms what is called the "arch of the cricoid cartilage." The rim of the ring diverges downward and forward from the lower border of the thyroid lamina to define an important angle, the cricothyroid angle, sometimes called the "visor" angle. The resting, or reference, size of this angle is that prevailing during respiration, throughout which the angle remains invariant. In fact, the angle is apparently invariant at all times except during phonation. Closing the angle rotates the top of the cricoid plate and the attached arytenoids away from the isthmus (fig. 4.11). That is, closing the cricothyroid angle increases the distance between the opposite ends of the vocal ligaments and thereby increases the tension in the ligaments, raising the pitch of the voice. The angle is restored to its prior respiratory size by elastic recoil of the ligaments but is prevented from opening more widely than this by the restraining action of the median cricothyroid ligament. This ligament bridges the front of the cricothyroid angle and suspends the arch of the cricoid from the isthmus of the thyroid cartilage.

The lumen of the cricoid ring is elongated anteroposteriorly and tapers downward but, nevertheless, is larger than that of the trachea. The elongation and taper probably minimize any tendency of the ring to bend during tensor activity of the cricothyroid muscle.

Cricoarytenoid Articulation

Just how well the architecture of the cricoarytenoid joint is adapted to the suspensory biomechanics of the air passage will become apparent in chapter 2. Anatomically, the cricoid facet for the arytenoid cartilage is oblong and convex and is located at the posterolateral extremity of the cricoid rim. The long axis of the facet follows the inclination of the rim downward, outward, and forward (fig. 1.1), a direction that should be carefully noted because of its importance in regulating arytenoid movement during respiration. This facet forms the track on which the arytenoid cartilage slides. The lateral limit of the slide track is directly above the middle of the nearly circular facet for the thyroid inferior horn. In other words, the outward slide of the arytenoid comes to a halt when the arytenoid articular facet reaches the plane of transmission of thrust from the thyroid cartilage.

A great part of the mass of the cricoid cartilage is concentrated in its posterior plate; this has the interesting result of placing the transverse axis of balance of the cartilage at or very close to the axis transfixing the two cricothyroid joints. It has been suggested that this minimizes the incidence of disadvantageous inertial moments of the cricoid during the mechanical regulation of pitch (fig. 4.11).

The outstanding mechanical property of the arytenoid cartilage is the smallness of its mass and of its moment of inertia. In the role of posterior support of the laryngeal folds, each arytenoid has to be accelerated medially and laterally with virtually every respiratory cycle, every phonation, every effort, and every swallow. The importance of small mass is underlined by the fact that in the course of articulated speech, adduction or abduction of the arytenoids is performed in less than 0.1 second (Netsell, 1973). Accordingly, the arytenoid cartilage is mechanically equivalent to an upside-down T-bar, whose anteroposterior horizontal segment transports the vocal ligament and vocal fold and slides on the cricoid facet and whose vertical segment transports the vestibular ligament and fold and the aryepiglottic fold. Furthermore, the vertical segment at its apex bears the corniculate cartilage. This conical piece of elastic cartilage projects backward and medially and, when compressed against its fellow of the opposite side, functions as a spring whose recoil aids in pushing the adducted arytenoids apart and restores the respiratory conductance of the larynx.

The epiglottic cartilage is a leaf-shaped lamella whose narrow end (stem, or petiole) is intralaryngeal and bears an elongated, median convexity called the "epiglottic tubercle," which projects backward into the laryngeal cavity. The broad upper end of the epiglottic cartilage projects into the pharynx behind the tongue. This part, the epiglottis proper, is concave facing backward, and the transition between its curvature and the reverse curvature of the epiglottic tubercle endows the epiglottic cartilage with the remarkable property of folding over backward automatically with deglutition (see chapter 5).

Folding System—The Eight-Fold Way

The folds of soft tissue, which by their configuration determine the condition of the laryngeal cavity (fig. 1.2), constitute a folding system. The tautology is deliberate and serves to underline the nonsphincteric character of the arrangements and the desirability of using the anatomical terms, *vocal folds* and *vestibular folds,* in preference to the colloquial equivalents, *vocal cords* and *false vocal cords*. The term *folds* was introduced in 1745 by E. J. Bertin but has hitherto failed to supplant its predecessor *cords,* even though internationally agreed on in 1895. In present anatomical usage, a laryngeal fold is simply a reduplication of mucous membrane; however, we have extended the usage to include the subjacent enfolded tissues as well. Our object is to unify anatomy with biomechanics and complete the description of the folding system—classically restricted to the bilateral vocal, vestibular, and aryepiglottic folds—by identifying and naming two additional, unpaired folds. One, the interarytenoid fold (Testut, 1949), separates the paired folds posteriorly; the other, the median thyrohyoid fold, separates the aryepiglottic folds anteriorly.

Functionally, the laryngeal folds segregate into two groups, separated by the sinus of the larynx (also called the "sinus laryngis," "ventricle," or "sinus of Morgagni"): (1) a group of six folds above the sinus, forming a ring around the cavity of the larynx and (2) a group of two folds below the sinus, consisting simply of the left and right vocal folds. The lower group, the vocal folds, when dragged to the median line by the arytenoids, form a curtain that closes the glottis except for a narrow median slit called the "rima glottidis" (literally, the "crack of the glottis"). The substance of the vocal fold consists principally of the stout elastic vocal ligament (fig. 1.3) in the free median edge of the fold and the vocal muscle (M. vocalis) elsewhere. The vocal ligament is continuous below with a submucosal elastic membrane, the cricovocal membrane, which ends at the rim of the cricoid cartilage.

The rima glottidis faces downward into the subglottic space and upward into the sinus laryngis (or ventricle) and beyond that into the vestibule and entrance (aditus) of the laryngeal cavity. The supraglottic part of the passage is surrounded by the upper group of six folds: on either side, the vestibular folds continued above into the aryepiglottic folds; in front, the median thyrohyoid fold; behind, the interarytenoid fold.

The vestibular fold is a wedgelike shelf of tissue, broad posteriorly at the arytenoid, and tapering forward to the ligamentous confluence at the isthmus of the thyroid cartilage. It contains the elastic quadrangular membrane (membrana quadrangularis), which terminates at the lower border of the fold as the vestibular ligament. Anterolaterally, the fold receives an extension of the sinus called the "saccule"; posteriorly, the vestibular fold contains a rod of elastic cartilage called the "cuneiform cartilage," which is attached to the anterolateral facies of the arytenoid cartilage. The rod and its attachment form a spring that retains the vestibular fold laterally except when the fold is forced medially by contraction of the thyroarytenoid muscle external to it. Lateral to the quadrangular membrane, the tissue of the vestibular fold consists partly of mucous glands, many of which empty into the saccule and distribute lubricating mucus to the surfaces of the laryngeal folds. More laterally still, as just indicated, the external thyroarytenoid muscle sweeps from near the angle of the thyroid cartilage backward and upward to the arytenoid cartilage (figs. 1.5, 3.3). When this muscle shortens, it pushes the substance of the vestibular fold medially and also a little downward, closing that part of the vestibule and sinus. Because of its attachment to the arytenoid cartilage a short distance above and lateral to the vocal process, the vestibular fold is a satellite of the vocal fold, following it part way to the median line when the arytenoid is adducted.

The aryepiglottic fold is a thinner upward continuation of the vestibular fold and occupies the triangle between the vestibular fold and the lateral margin of the median thyrohyoid fold. Its upper free edge contains the aryepiglottic muscle, which is attached to the external surface of the quadrangular membrane. When contracted, the muscle raises the edge of the aryepiglottic fold into a ridge and indirectly lifts the vestibular fold. The aryepiglottic fold also contains some submucosal muscle fibers, called the "thyroepiglottic muscle," that probably control the overlying mucosa.

The elastic quadrangular membrane (fig. 1.3) in the vestibular fold is continued upward in the aryepiglottic fold all the way to the entrance of the larynx. Its upper boundary is the free edge of the aryepiglottic fold, at the entrance to the laryngeal cavity; its lower boundary, the vestibular ligament, is the thickened lower edge of the membrane and borders on the sinus or ventricle. In front, the quadrangular membrane extends to the lateral border of the epiglottic cartilage down to the ligamentous confluence. Because the cartilage is part of the median thyrohyoid fold, this border marks the junction of the aryepiglottic and median thyrohyoid folds. Finally, posteriorly, the back boundary of the membrane is formed by the attachment of the membrane to the arytenoid cartilage. The quadrangular membrane and vestibular ligament do for the aryepiglottic and vestibular folds what the cricovocal membrane and vocal ligament do for the vocal fold: they supply elastic deformability and support.

Complementary to these paired, roughly anteroposterior lateral folds and completing the folding system are two unpaired transverse folds. The anterior one, the median thyrohyoid fold (fig. 1.2), includes and is supported posteriorly by the lower part of the epiglottic cartilage. The upper part of this cartilage, the epiglottis proper, is a mucosa-covered projection of the fold. Although the epiglottic cartilage is elastic, it is almost inextensible; the fold as a whole, however, is quite extensible because elastic ligaments attach the epiglottic cartilage to its upper and lower supports: the hyoepiglottic ligament attaches to the body of the hyoid bone; the thyroepiglottic ligament, to the angle of the thyroid cartilage. Between these, anterior to the epiglottic cartilage, there is fatty tissue and, finally, another elastic ligament, the anterior thyrohyoid ligament. This construction converts the median thyrohyoid fold into an elastic wedge—broad end upward, against the hyoepiglottic ligament; thin end downward, against the angle. Because of its construction, the wedge is able to function both as a tension spring and as a compression spring, depending on which way it is stressed.

Finally, the posterior median fold, the interarytenoid fold (fig. 1.2), containing the arytenoid muscle and covering mucosa, attains an extreme of foldability. It folds its internal mucosa forward into the cavity and its muscle and posterior mucosa backward into the hypopharynx when the arytenoids are adducted (fig. 3.3). It gains a certain elasticity from the corniculate cartilages and a flimsy Y-shaped cricopharyngeal ligament that is thought to constrain the corniculates downward and medially toward the cricoid cartilage; this ligament is often difficult to find.

Suspensory System

The suspensory system binds the supports and the folds of the larynx into a working unit. Its elastic ligaments and membranes divide into a main suspensory system, supporting the hyoid bone and the thyroid and cricoid cartilages, and a subsidiary suspensory system, supporting the arytenoid cartilages.

The principal suspensory system (figs. 1.4, 2.1, 2.2) commences with the stylohyoid ligaments, which suspend the hyoid bone from the cranium, and continues with the structures that suspend the thyroid cartilage from the hyoid bone, principally the lateral and median thyrohyoid ligaments. The median thyrohyoid ligament has already been noted as forming part of the median thyrohyoid fold. This fold does duty both as part of the suspensory mechanism and as part of the closing mechanism referred to in chapter 3. The suspensory system continues below the thyroid cartilage with the ligaments that suspend the cricoid cartilage: laterally, the cricothyroid articular ligaments (the ceratocricoid, or lateral cricothyroid, ligaments) and anteromedially, the anterior cricothyroid ligament.

The suspension of the hyoid bone allows it considerable mobility. The bone is a median structure suspended principally at the junction of the hyoid body and the minor and major horns (cornua). The stylohyoid ligament is attached to the cornu minor, and the pulley of the digastric muscle is attached to the side of the junctional area. Together, these define a transverse axis around which the hyoid bone is able to tilt in response to stresses from various sources (figs. 1.4, 2.3), while still retaining free mobility in anteroposterior, lateral, and vertical directions. Continuing downward, the ligamentous suspension of the thyroid cartilage from the hyoid bone may be regarded as a three-point suspension, less extensible than the two-point hyoid suspension but still allowing moderate movement in all planes between the hyoid bone and the thyroid cartilage. Below this, however, the three-point suspension of the cricoid from the thyroid cartilage provides only a limited amount of movement between the two cartilages, and lower still, between the cricoid and the trachea and between the tracheal rings, the mobility is minimal.

Mechanically, the main ligamentous suspension transfers to the large cartilages (the cricoid and thyroid cartilages) the brunt of the cyclic stresses generated by the vertical respiratory excursion of the larynx. The subsidiary suspension is thus left free to regulate the delicate excursion of the arytenoid cartilages.

The subsidiary ligamentous suspension, consisting essentially of the highly elastic and extensible membrana quadrangularis, suspends the arytenoid from the margin of the epiglottic cartilage. The epiglottic cartilage is part of the median thyrohyoid fold and, thus, is part of the anterior main suspension. The arytenoid cartilage slides on the cricoid facet, which ends directly above the cricothyroid joint in the lateral subdivision of the main suspension; thus, it is apparent that the subsidiary suspension slings the arytenoid cartilage between the anterior and lateral subdivisions of the main suspension. The subsidiary suspension is neither sufficiently substantial nor appropriately oriented in space to support the full weight of the arytenoid and its attached folds, but two small muscles, the posterior and lateral cricoarytenoid muscles, provide critical added support and link the cricoid to the arytenoid cartilage and stabilize the posture of the latter. The suspension does perform the equally critical function of converting vertical momentum of the larynx into transverse momentum of the arytenoid cartilage and, according to our model, is therefore indispensable to abduction of the arytenoid. Suspension of the thyroid and cricoid cartilages by the main suspension is in operation at all times. Suspension of the arytenoid cartilage by the subsidiary train prevails during respiration but is overridden whenever the arytenoids are adducted and apposed to each other. Apposition, as shown in chapter 4, clamps the arytenoids to the cricoid.

Muscles

The muscles of the larynx are customarily divided into two groups: (1) intrinsic muscles, which connect different parts of the larynx with one another (fig. 1.5), and (2) extrinsic muscles, which attach the larynx to outside structures (figs. 2.14, 2.15). Our interest in the muscles relates to their role in the folding operations of the larynx; the details of where the muscles are and what they do will be more readily understandable after the nature of the foldings has been considered.

In man certain intrinsic muscles act in agonist-antagonist pairs to stabilize posture at the laryngeal joints. The lateral and posterior cricoarytenoid muscles stabilize the posture of the arytenoids at the cricoarytenoid joint when the cartilages are unadducted. (When adducted, the arytenoids are clamped to each other and to the cricoid by the adducting muscle, the M. arytenoideus.) The two oblique or crossed arytenoid bundles conjointly reinforce the adductor action of the transverse arytenoid fibers; individually, one oblique bundle exerts an approximately axial force at one cricoarytenoid joint and an approximately normal force at the other. The cricothyroid and vocal muscles stabilize the posture at the cricothyroid joint.

The basic reflex for the regulation of posture is the stretch reflex. Stretching a muscle stretches and stimulates the muscle spindles, the specialized sensory organs that lie among and parallel to the muscle fibers. A stimulated spindle sends afferent impulses up the sensory fibers of the muscular nerve to the region of the motor neurons, causing the motor cells to excite the skeletal muscle to contract. This reflex serves to maintain body posture, and, in the case of the cricoarytenoid muscles, our model postulates that it serves to maintain the posture of the arytenoid cartilages.

Postural reflexes are also triggered by sensory endings in tendons, but the extent of stretch necessary to evoke a response from the Golgi tendon organ is greater than for the annulospiral ending of the muscle spindle (Best and Taylor, 1973). How far this may be relevant to the intrinsic laryngeal muscles is uncertain. The cricoarytenoids have tendinous insertions on the arytenoid muscular process. The other laryngeal muscles are atendinous.

The intrinsic muscles are all supplied by the tenth cranial nerve, and, with one exception, by a single branch of that nerve—the recurrent laryngeal branch (for the effects of paralysis, see chapter 4 and fig. 4.3). However, the cricothyroid muscle receives its supply from the external division of the superior laryngeal branch. This muscle is phylogenetically a latecomer and is found only in mammals.

The nerve supply of the extrinsic muscles is diverse; it includes the glossopharyngeal nerve (M. stylopharyngeus), the pharyngeal plexus of the vagus (M. constrictor pharnygis inferior), and the cervical plexus (M. sternothyroideus and M. thyrohyoideus).

The sensory supply of the larynx down to the level of the vocal folds is derived from the internal branch of the superior laryngeal; below this level, from the recurrent laryngeal. There is also a sympathetic innervation.

The arteries of the larynx are laryngeal branches of the superior and inferior thyroid arteries. Of special note is a transverse arterial branch along the upper border of the cricothyroid membrane, which is liable to be injured and cause troublesome hemorrhage in an emergency cricothyrotomy. The patterns of the veins and lymphatics follow those of the arteries.