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The Thyroid Cartilage as a Spring

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X-rays of human subjects show that the thyroid cartilage can undergo bending in association with several functional states of the larynx. Flexibility of the laminae appears to augment the opening effect of the sternothyroid or the closing effect of the thyrohyoid muscle on the air passage, and produces spring-actuated restitution of the passage when these muscles relax. (Key words: Larynx.)

THE FUNCTION of the thyroid cartilage, as presently understood, is to gird and protect the laryngeal passage and to provide a rigid attachment for various soft-tissue elements. The shape and flexibility of the cartilage in fresh autopsy specimens suggested to me the possibility that the cartilage might also act as an auxiliary spring helping to regulate the size of the lumen. Radiographic evidence supporting this idea is presented in this report.

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Methods

Anteroposterior x-ray photographs of the neck were taken during three standard conditions: 1) eupneic expiration; 2) slow oral deep inspiration near the end of the laryngeal descent; 3) straining effort closure of the larynx. The subjects were two healthy men and one woman between the ages of 32 and 45 years. The female patient had incurred bilateral vocal-cord paralysis during thyroidectomy, and was examined both before and after recovery.

The shadows of the posterior margins of the thyroid cartilage laminae were easily identified on the films. Rulers were laid along the lateral borders of the shadows and the angle of divergence of the rulers, hereafter called the "angle of flare," determined with a protractor. Angles were measured to the nearest 0.5 degree. Independent estimates were made by the author and by two colleagues naive with respect to the investigation.

Each observer made three separate sets of measurements, and the results are expressed

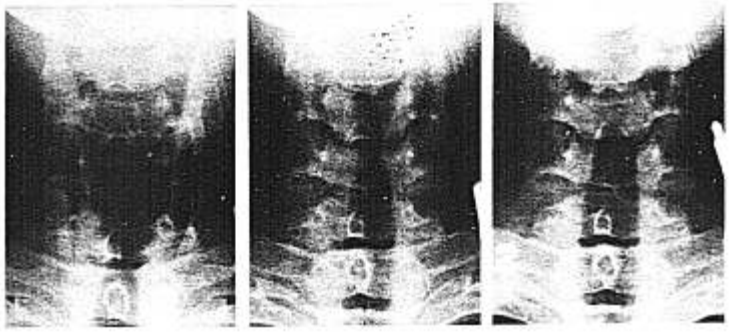

FIG. 1. Anteroposterior radiographs of the neck, Subject 2. *Left*, slow forced inspiration; *center*, eupneic expiration; *right*, straining effort. Tube film distance 72 inches, 400 ma, 72 kv, 0.1 sec. The films have been aligned to the lower border of the C_4 vertebral body.

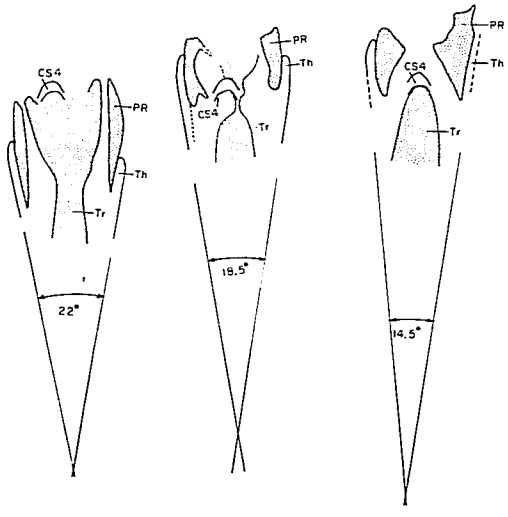

FIG. 2. Angles of flare of the thyroid cartilage laminae, Subject 2, as measured by the naive medical illustrator.

as the means and standard deviations of nine pooled measurements. The statistical significance of departures from the condition in eupneic expiration was evaluated by Student's t test for unpaired observations.

Results

The findings in Subject 2 (figs. 1 and 2) show that the angle of flare of the laminae varied with the functional state of the larynx. In eupneic expiration the larynx occupied an intermediate station in the neck and the angle of flare was 16.3 ± 1.5 degrees. In slow deep inspiration the larynx descended and the angle of flare increased to 22.2 ± 0.7 degrees. With straining effort closure the larynx ascended and the angle decreased to 13.6 ± 1.1 degrees. Qualitatively similar changes over ranges of about 9 degrees occurred in all three subjects (table 1).

Discussion

The mechanical significance of the flare of the laminae of the thyroid cartilage has hitherto escaped analysis. Although the geometry of the thyroid cartilage has been the subject of several investigations,[1-3] most recently by Maue,[4,5] none gives the angle of flare or data from which it can be calculated. However, adjustability of the flare angle is detectable in several published radiographs (ref. 6, fig. 1b and 1e; ref. 7, fig. 1a and 6a).

The evidence presented here indicates that the human thyroid cartilage in early middle age possesses function-related pliability. In-

TABLE 1. Functional Variation in the Angle of Flare of the Laminae of the Thyroid Cartilage (Degrees)

	Expiration	Inspiration	Effort Closure
Subject 1	21.5 ± 1.9	26.9 ± 1.1*	17.4 ± 1.4*
Subject 2	16.3 ± 1.5	22.2 ± 0.7*	13.6 ± 1.1†
Subject 3‡	42.5 ± 2.0	45.6 ± 2.0	35.2 ± 2.2*
Subject 3§	44.1 ± 2.6	44.2 ± 2.4	37.6 ± 2.4*

* Significant difference from expiration ($P < .001$).
† Probably significant difference from expiration ($P < .02$).
‡ Bilateral paralysis of recurrent laryngeal nerve of two weeks' duration.
§ Three months later, after recovery.

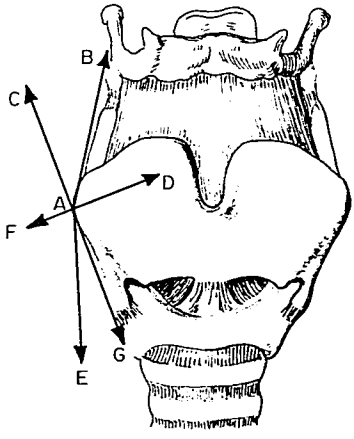

FIG. 3. Diagram to show theoretical forces exerted at the linea obliqua. *AB*, thyrohyoid; *AE*, sternothyroid; *AC*, *AG*, components parallel to the plane of the thyroid lamina; *AD*, *AF*, components perpendicular to the lamina. *AD* is the effective compressive force exerted by the thyrohyoid. *AF* is the effective opening force exerted by the sternothyroid.

crease in the angle of flare accompanies opening of the larynx in deep inspiration and decrease in the angle occurs in effort closure (figs. 1 and 2, table 1).

Since the changes observed in the angle of flare accompany vertical movements of the larynx they are probably attributable chiefly to the action of muscles producing such movements, notably the sternothyroid and thyrohyoid muscles. These muscles exert components of force normal to their attachment to the oblique line of the thyroid cartilage (fig. 3), tending respectively to separate (fig. 3, *AF*) and to approximate (fig. 3, *AD*) the laminae. Such normal forces reinforce the effect of the vertical excursion on the lumen.

On one hand, a passive downward excursion of the larynx stretches the walls of the passage and enlarges it in all directions;[8] the sternothyroid muscles will accelerate this action and accentuate the opening effect by pulling the laminae apart. This interpretation is in agreement with Kotby and Haugen's[9] observation that stimulation of the sternothyroid muscle consistently leads to dilatation of the laryngeal inlet and widening of the glottis.

On the other hand, upward excursion of the larynx (relative to the hyoid bone) in effort closure compresses the walls of the passage and narrows the passage in all directions;[10-11] in producing this action the thyrohyoid muscles crossing the rim of the thyroid cartilage will tend to push the laminae toward each other, thereby reinforcing the closing effect.

During general anesthesia effort closure is manifested as tight laryngeal spasm, and anesthesiologists who have tried intubating a larynx in spasm can vouch for a considerably narrowed state of the inlet in this condition, possibly intensified by inward bending of the superior horns of the thyroid cartilage (fig. 4). It is probably significant that the inferior constrictor of the pharynx also gains attachment to the linea obliqua, since attachment to this line maximizes the muscle's ability to reduce the angle of flare and reinforce the closure of the larynx during swallowing. This is so because the linea obliqua (fig. 5) constitutes a locus of points approximately equidistant from the crico-

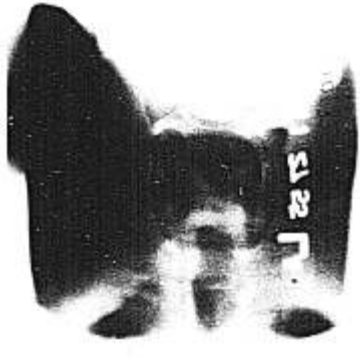

FIG. 4. Tomogram from Subject 1 during effort closure while the cheeks were distended with air. Tube film distance 30 inches, plane 2.5 cm posterior to thyroid notch, 50 ma, 75 kv, 3 sec.

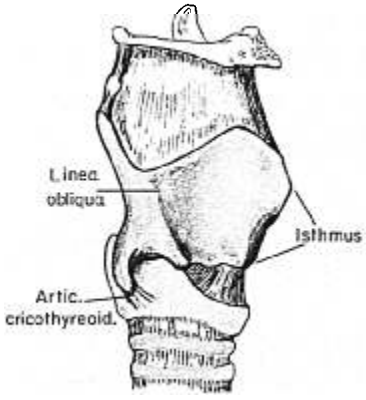

FIG. 5. Side view of the larynx to show approximate equidistance of linea obliqua to the isthmus and to the cricoarytenoid joint.

thyroid joint and the isthmus, two relatively fixed areas of the thyroid cartilage. Other things being equal, this location represents the zone of greatest flexibility of the lamina and the zone of greatest bending effect by attached muscles.

The elasticity of hyaline cartilage[12] enables it to resume its pre-existing configuration after being bent, although flexibility probably varies with age and the extent of calcification of the cartilage. In the thyroid cartilage, as in the rib cartilages and elsewhere, such passive restitutory spring action[13] is automatic and perfectly timed. The spring "stores" energy derived from the agonist muscles, releases it when agonist contraction ceases, and thus reduces or eliminates the call on restorative antagonist muscle activity.

The relative importance of this factor in governing the laryngeal lumen is still unclear, but measurements in Subject 3 suggest that thyroid cartilage spring action can persist essentially intact in the presence of paralysis of most of the intrinsic small muscles. Flexibility of the thyroid cartilage may explain why bilateral paramedian paralysis of the vocal folds can be tolerated by some patients for many years if it begins in early life. Flexibility of the thyroid cartilage also helps to explain why a unilateral, midline, paralyzed vocal fold may not produce dyspnea on exertion in early adult life, whereas dyspnea frequently does occur after 50 years of age, when advanced calcification is likely to be present.

NOTE ADDED IN PROOF

A tomogram by W. Zenker (Research Potentials in Voice Physiology, edited by D. W. Brewer, State University of New York, 1964, page 23) demonstrates approximation of the laminae of the thyroid cartilage during high-pitch phonation.

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