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Cricoarytenoid joint structure and function

by

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Introduction

The existence of a joint between the cricoid and arytenoid cartilages has been known since before Galen (130–201 A.D.), but until recently reports on studies of its exact anatomy and function were few.

Early this century three types of movement of the arytenoid cartilage became recognised. Morris and McMurrich (1907) suggested that the arytenoid cartilages moved by inclining forwards and backwards, gliding laterally and medially, and rotating around a vertical axis. Piersol (1907) gave a similar account, but described the rotation as a 'screw motion.'

In 1929 Negus, in his publication 'The Mechanism of the Larynx,' put forward a different concept and described how the vocal cords approximate by the rotation of the arytenoid cartilages around a vertical axis. This theory, which was endorsed by Pressman (1942), is still quoted today.

Sonneson (1959) described the cricoarytenoid joint as a cylinder joint with an oblique axis of movement that allows approximately 35° of rotation (rocking) of the arytenoid cartilage. Frable (1961) suggested that the arytenoid cartilage synchronously moves in three different planes and rotates around an oblique axis. Von Leden and Moore (1961) described it as a shallow ball and socket joint, at which three arytenoid cartilage movements, an inward and outward rocking, a lateral and medial sliding, and a 'limited pivoting' occur.

A major step forward in the understanding of these movements was made by Ardran and Kemp (1966), who studied the larynx radiographically. They showed conclusively that, on vocal cord abduction, the arytenoid cartilages incline outwards for about 45° on the cricoid facets and the vocal cords turn upwards into the laryngeal ventricles. They showed also that, on adduction of the vocal cords, the arytenoid cartilages move downwards and forwards on the cricoid facets and the vocal processes turn inferiorly through an arc of 40°.

In his monograph, Fink (1975) reaffirmed that both a sliding and a rotatory movement occur at the cricoarytenoid joint and that the arytenoid cartilages can be brought together or separated. From this he concluded that the vocal processes can swing towards or away from the midline.

Both the intrinsic and extrinsic muscles of the larynx are responsible for control of the vocal cords. At rest, all the intrinsic laryngeal muscles show a postural electrical activity (Faaborg-Andersen, 1957), which maintains the position of the arytenoid cartilage and the stability of the joint. Electomyography studies have confirmed a marked increase in activity during phonation in the cricothyroid, thyroarytenoid and

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vocalis muscles (Faaborg-Andersen, 1961; Shipp and McGlone, 1971; Gay *et al.*, 1972). The lateral cricoarytenoid muscles also contract, but less powerfully and less consistently (Gay *et al.*, 1972). Simultaneously the interarytenoid muscles contract to maintain approximation of the arytenoid cartilages posteriorly.

Reports on the behaviour of the posterior cricoarytenoid muscle are contradictory. Its resting tone is said to increase during speech, especially at high frequencies (Gay *et al.*, 1972; Kotby and Haugen, 1970a). However, Faarborg-Andersen (1961) maintained that its tone decreases in some phases of speech and increases in others, while Shipp and McGlone (1971) reported that the posterior cricoarytenoid muscles maintain a low level of tone throughout speech.

On deep inspiration active abduction of the vocal cords occurs together with slight adductor muscle activity. Kotby and Haugen (1970b) suggested that this adductor action is necessary to stiffen the vocal cords and to prevent the incoming current of inspired air causing their collapse. On expiration all these muscles relax to their resting tone, although Green and Neil (1955), working on cats, have reported an increased thyroarytenoid muscle activity during expiration.

The cricopharyngeus muscle contracts strongly during singing at low voice pitch (Zenker, 1961). This action causes the cricoid cartilage to tilt forwards and hence the tensed vocal cords to shorten, producing a lower voice register. When increase in voice pitch is necessary during singing, the sternothyroid and thyrohyoid muscles also contract, producing an anterior and caudal movement of the thyroid cartilage (Faaborg-Andersen and Sonninen, 1960; Sonninen, 1968). Significantly the difficulty in singing notes of high pitch after thyroidectomy has been related to the extent of surgical damage done to the sternothyroid muscles (Sonninen, 1956).

Because of discrepancies in standard descriptions of cricoarytenoid joint structure and movements and because of misunderstanding of the behaviour of the muscles acting upon it, a formal study of this joint was undertaken.

Methods and Findings

This report considers the structure of the joint, its movements, and the muscles that act upon it. Forty-five cadaver larynxes (90 cricoarytenoid joints), six fresh post-laryngectomy and 17 preserved larynxes were used. The exact methods of their examination have previously been reported (Sellars and Keen, 1978; Sellars, 1978; Sellars, 1979).

Anatomy

On detailed examination of the arytenoid cartilages (Fig. 1) all the articular facets were found to be small concavities on the undersurface of the cartilages' muscular process and body. They were all very similar in shape and symmetry. The short axis of the arytenoid facet was parallel to the long axis of the cricoid facet and in all of them was shorter than the length of the cricoid facet with which it articulated (Fig. 2). The average difference between the lengths of these two axes was about 2 mm. and the largest difference was 2.5 mm. (Sellars and Keen, 1978). At rest the long axis of the arytenoid facet was at right angles to the long axis of the cricoid facet (Fig. 2).

The cricoid facet was more or less oval in shape and each was present on either side of the posteriorly placed cricoid lamina. Each of the 90 facets was convex on its short axis and usually convex on its long axis. Furthermore 60 of these facets were accurately measured and it was found that in 43 the medial part of the facet was significantly more sharply curved than the lateral part. In seven facets the lateral curvature was more marked and in the remaining ten specimens the medial and lateral curvatures were very similar. The mean medial curvature (2.1 mm. radius) was significantly smaller than the lateral curvature (2.6 mm. radius).

Asymmetry was evident between the cricoid facet axes of different larynxes and often between the two cricoid facets of

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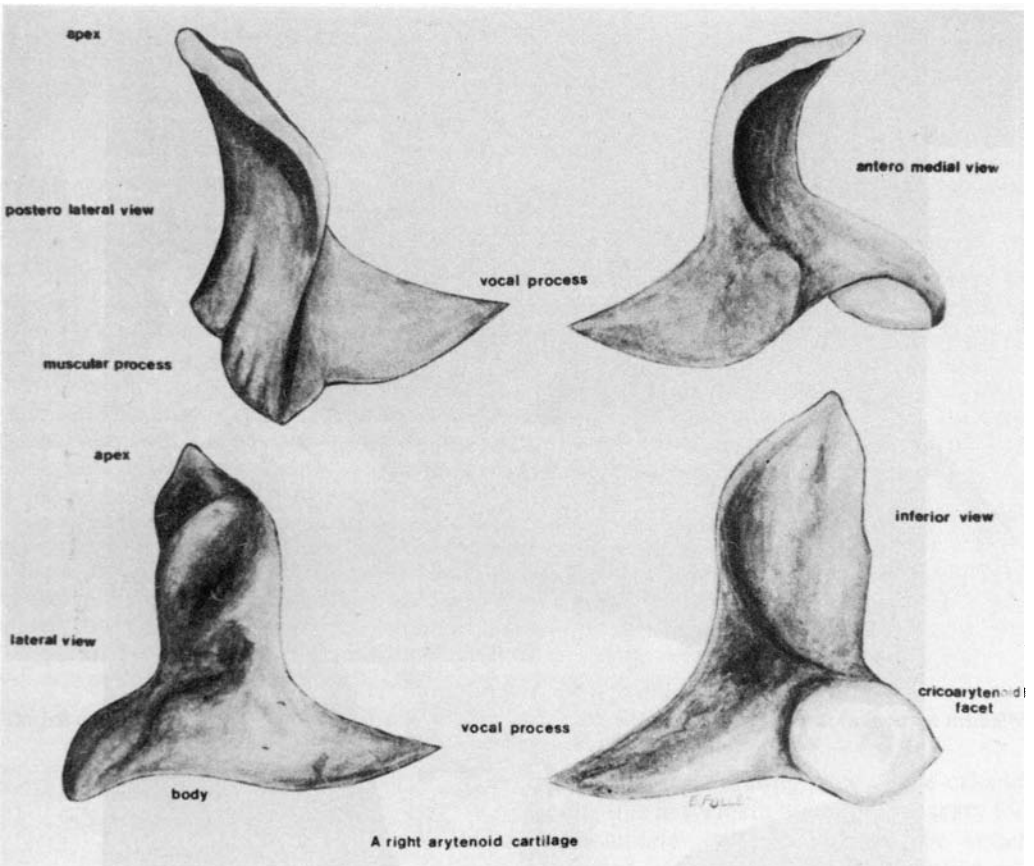


FIG. 1
The gross anatomy of the right arytenoid cartilage.

the same larynx. As well, it was found that the signet ring-shaped cricoid cartilage frequently did not show right-left symmetry. The positions, therefore, of the two arytenoid vocal processes can be asymmetrical. Despite this the ultimate movement of each arytenoid cartilage ensures correct and synchronous opening and closing of the glottis. However, because of the differing anatomy, the exact muscle action and the type of movement produced is specific to each joint.

Each particular capsule of the 90 cricoarytenoid joints was also examined and was found to be firmly attached to the rim of the articular facets of the arytenoid and cricoid cartilages. In all specimens this fibro-elastic ligamentous sleeve was extremely lax. It was found to be supported medially by a thick and obliquely placed ligament, the posterior cricoarytenoid ligament (Fig. 3), which in several specimens was bilaminar. It was attached inferiorly to the upper border of the cricoid lamina, medial to the cricoid facet, and stretching upwards and obliquely forwards was attached to the medial surface of the arytenoid cartilage midway between the vocal process in front and the muscular process behind.

Movements

On manipulation the arytenoid cartilages could be taken through three planes of

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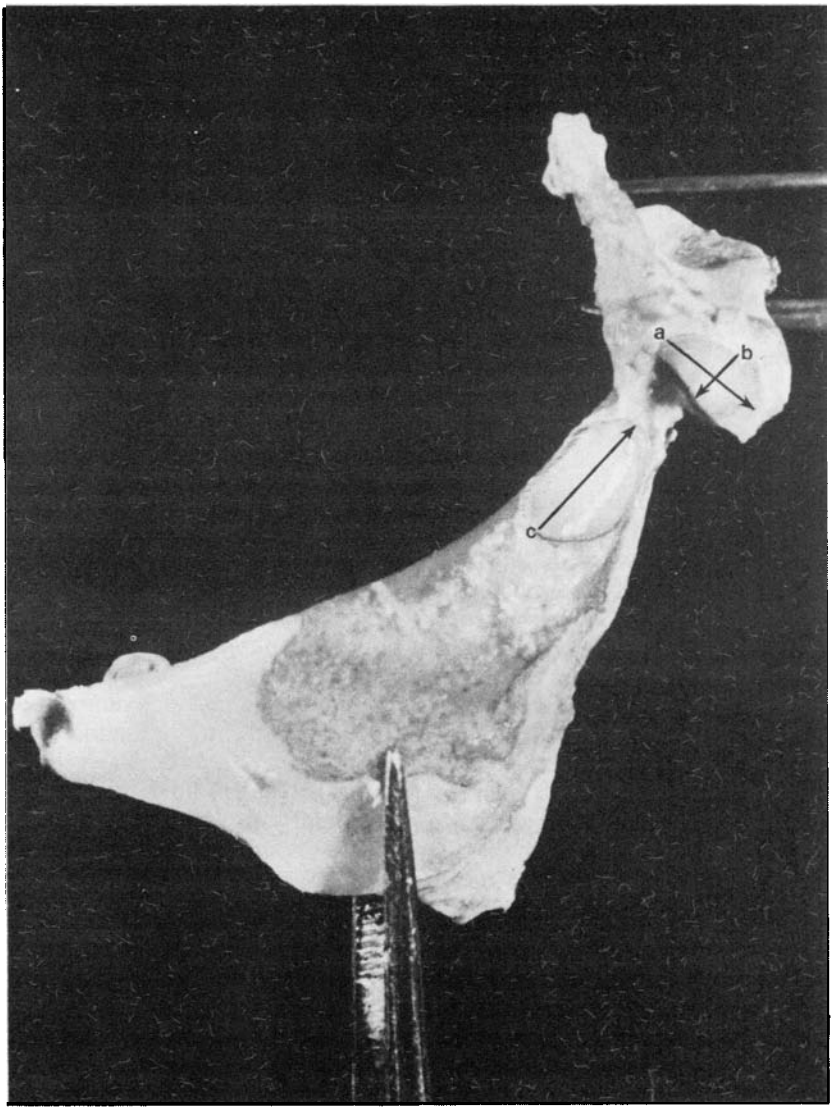


FIG. 2

The disarticulated cricoarytenoid joint articular facets showing the concave axis of the arytenoid facet (a), the concave short axis of the arytenoid facet (b), and the convex long axis of the cricoid facet (c).

movement, inward and outward rocking (Fig. 4), medial and lateral sliding, and rotation.

When passively rocked backwards, the arytenoid cartilage also slid laterally and swung (rotated) outwards on the flatter lateral part of the cricoid facet, producing abduction of the vocal cord up to maximum glottic opening. When the arytenoid cartilage was rocked forwards it also slid medially, producing adduction of the vocal cord.

Medial rotation of the arytenoid cartilage could also be produced passively and,

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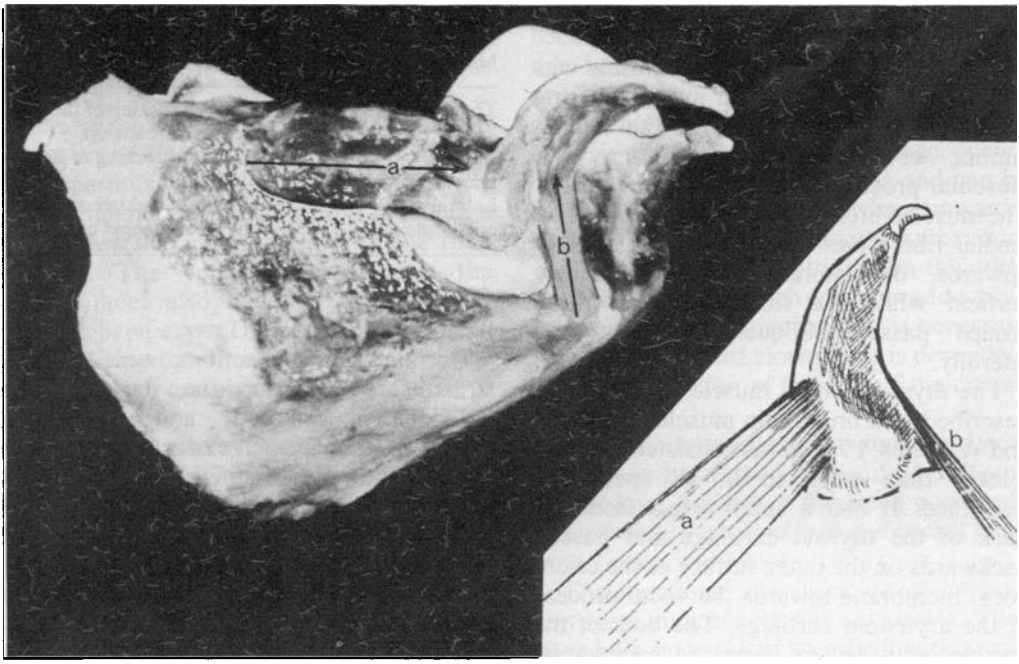


FIG. 3

The left cricoarytenoid joint with capsule removed showing the lateral cricoarytenoid muscle (a) and the medially placed posterior cricoarytenoid ligament (b).

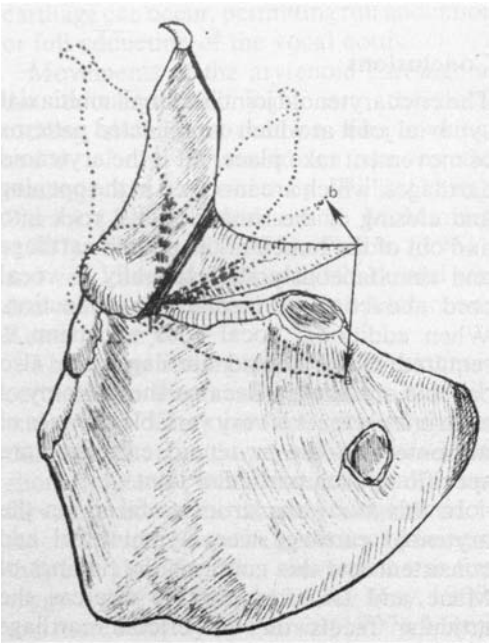


FIG. 4

The rocking action of the arytenoid cartilage in the adducted position (a) and the abducted postition (b).

because of the differing axes of the cricoid facets, this movement appears necessary for the complete approximation of the vocal processes in full adduction. Rotation of the arytenoid cartilage has also been demonstrated in a biomechanical study on five postmortem specimens (Sellars and Vaughan, 1981).

Muscles

The anatomy and functions of the posterior and lateral cricoarytenoid and the thyroarytenoid muscles were studied in detail (Sellars, 1979). These muscles are responsible for active vocal cord movements, but their exact actions are controversial. Indeed, that of the lateral cricoarytenoid muscle has been largely misinterpreted. The position, size, direction of fibres and exact attachments of each of these muscles were assessed in 17 preserved larynxes. In an additional nine fresh larynxes, removed by laryngectomy, these muscles were

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stimulated electrically and the results directly observed.

The posterior cricoarytenoid muscle was seen to be a large triangular muscle passing from the posterior surface of the cricoid lamina, converging to insert into the muscular process of the arytenoid cartilage. The muscle fibres lay in three directions. The medial fibres passed laterally and slightly upwards, the lateral fibres were nearly vertical while the fibres between these groups passed obliquely upwards and laterally.

The thyroarytenoid muscle, traditionally described as a broad thin muscle (Warwick and Williams, 1973), was consistently much thicker than expected in all specimens examined. It had a small origin from the back of the thyroid cartilage and passed backwards on the outer surface of the cricovocal membrane towards the vocal process of the arytenoid cartilage. The bulk of the muscle increased as it passed backwards, with the addition of obliquely directed fibres originating from the outer surface of the cricovocal membrane. The muscle is functionally divided into two, while anatomically its fibres were seen to lie in three directions. These were medial horizontal fibres (vocalis muscle), oblique fibres from the cricovocal membrane, and lateral fibres which spread outwards to meet the insertion of the lateral cricoarytenoid (Sellars, 1978).

It has been traditionally accepted that the lateral cricoarytenoid muscle takes origin from the rim of the upper border of the cricoid arch. However, it was found that it also arises from the outer surface of the arch (Fig. 3). In only one specimen with an abnormally broad cricoid did it originate from the upper rim alone. The muscle was found to be attached to the arytenoid cartilage directly opposite to the attachment of the medially placed posterior cricoarytenoid ligament (Fig. 3). As the arytenoid cartilage rides in and out of the cricoid lumen in both adduction and abduction, it is balanced between the attachments of the lateral cricoarytenoid muscle and the posterior cricoarytenoid ligament (Sellars, 1981).

TABLE I

Muscle	Action on Stimulation
Thyoarytenoid	Inward rocking of the arytenoid cartilage
Posterior cricoarytenoid	Outward rocking of the arytenoid
Lateral cricoarytenoid	Forward and lateral sliding of the arytenoid cartilage

Certain specific actions were demonstrated as each of the muscles was individually isolated and stimulated (Table I). On further examination, simultaneous stimulation of the lateral and posterior cricoarytenoid muscles produced abduction and simultaneous stimulation of the lateral cricoarytenoid and thyroarytenoid muscles produced adduction of the vocal cord. This would seem to confirm that the lateral cricoarytenoid muscle, with its limited power, does not alter the basic abductor or adductor action of the other two muscles, but enhances it.

Conclusions

The cricoarytenoid joint is a small multiaxial synovial joint at which complicated patterns of movement take place. At it the arytenoid cartilages, which are involved in the opening and closing of the rima glottidis, rock into and out of the lumen of the cricoid cartilage and simultaneously slide laterally in vocal cord abduction or medially in adduction. When additional vocal cord excursion is required the arytenoid cartilages are also capable of rotation. Because the anatomy of each cricoid facet is very variable the axes of movement of the arytenoid cartilages are specific to each particular joint.

In this study the articular facets on the arytenoid cartilage were symmetrical and consistent and this confirms the findings of Maue and Dickson (1971), whereas the articular facets on the cricoid cartilage showed such asymmetry that the axes were different in every joint examined. This is supported by the work of Frable (1961), who

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found that the angle between the median sagittal plane and the long axis of the cricoid facets of ten larynxes varied by as much as 20° to 45°.

The shape of the cricoid facet has been shown to be flatter laterally than medially. This permits easier lateral rotation of the arytenoid cartilage in full abduction and allows maximum opening of the rima glottidis. The variable anatomy of the cricoid facet also explains the difficulty that has been experienced in analysing and standardising the various laryngeal muscle actions, which can also differ from larynx to larynx.

The importance of the medially placed fibrous thickening of the joint capsule, known as the 'posterior cricoarytenoid ligament,' has been previously overlooked. The medial positioning of this ligament has been described by Sonesson (1959), Maue and Dickson (1971) and Sellars and Keen (1978) and its name therefore is confusing since it does not lie behind the joint. In its medial position it acts as a fulcrum around which rocking and rotation of the arytenoid cartilage can occur, permitting full abduction or full adduction of the vocal cords.

Movements of the arytenoid cartilage at the cricoarytenoid joint are threefold: rocking, sliding and rotation. The 'rocking' action of the arytenoid on the cricoid cartilage was described by Willis (1829), Piersol (1907), Morris and McMurrich (1907), Sonesson (1959), Frable (1961), and von Leden and Moore (1961), and was demonstrated conclusively by Ardran and Kemp (1966).

The lateral sliding action of the arytenoid cartilage on the cricoid cartilage is easily understood. The joint facets are so shaped that, in abduction, the arytenoid facet with its shorter lateral axis slides laterally and forwards down the sloping longer cricoid facet. This increases the posterior opening of the rima glottidis. This movement was first suggested by Galen in 165 A.D. (May, 1968) and more recently by Piersol (1907), Morris and McMurrich (1907), Sonesson (1959), von Leden and Moore (1961) and many others. There are, however, those who believe that this movement does not occur, because the muscle action responsible for this lateral slide has not previously been explained.

The third type of movement, the rotation or twisting of the arytenoid cartilage, occurs on abduction of the vocal folds and can be seen as the vocal process swings upwards, backwards and outwards, causing maximum opening of the rima glottidis. On the other hand the rotation, which occurs in adduction, is a corrective mechanism that is necessary for total vocal cord closure and is dependent upon the direction of the axis of the cricoid facet.

The cricoarytenoid joint is thus multiaxial and could be termed a modified ball and socket joint. Indeed, it has been previously described as a 'shallow ball and socket joint' (von Leden and Moore, 1961).

The functional classification of intrinsic laryngeal muscle action is not simple. They have both interrelated specific functions and constant resting tone. The posterior cricoarytenoid muscles are the prime abductors of the vocal cords. They are assisted in this by the lateral cricoarytenoid muscles, which are responsible for the lateral slide of the arytenoid cartilage on the cricoid cartilage, an action previously overlooked. The thyroarytenoid muscles, assisted by the interarytenoid muscles, are the adductors. If medial rotation of the arytenoid cartilages is necessary for full adduction, this is produced by the laterally directed fibres of the thyroarytenoid muscles and the upper fibres of the lateral cricoarytenoid muscles (Sellars, 1981).

The lateral cricoarytenoid muscle shows an electrical activity which varies in intensity during different phases of glottic movement (Gay *et al.*, 1972). The laterally directed force of this muscle stabilises the arytenoid cartilage and maintains it in the optimum position for all vocal cord movements. The lateral cricoarytenoid muscle is therefore an important synergist to both the abductors and adductors of the vocal cords.

In these investigations the cricothyroid muscle was not examined and its action, like that of the vocalis muscle, as a vocal cord

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tensor is not disputed. When necessary the extrinsic laryngeal muscles also increase vocal cord tension. Sonninen (1956) demonstrated loss of high-pitched voice following thyroidectomy, which he stated was caused by surgical trauma to the sternothyroid muscles. From his study it can be concluded that this trauma, and not superior laryngeal nerve injury, is the reason for voice changes that can temporarily follow thyroidectomy.

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