A Thesis
On
The Physiology
of
The Larynx

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The Physiology of the Larynx.

In order to treat of the physiology of the larynx, some account of its anatomy ought first to be given. I shall therefore give a short account of the anatomy of the parts. I shall then describe the laryngoscopic and external appearances to be observed during the production of voice; and lastly proceed to a consideration of the action of the muscles, and the functions of the various parts of the larynx in the chest and falsetto voices respectively.

And firstly as to the Anatomy. The larynx is situated immediately below the tongue and the os hyoides. It may be described as a box, the walls of which are formed of cartilaginous and membranous structures; and its cavity communicates below with the trachea and above with the cavity of the pharynx. Of its cartilages the single ones are the thyroid, cricoid, and epiglottis, and the paired ones the arytenoid, the cartilages of Wrisberg, and the cartilages of Santorini. The thyroid is made up of two lateral parts

called its alæ, which inclining forwards to the middle line, join there to form a projection, - the angle of the thyroid - the upper extremity of which is known as the pomum Adami. The alæ terminate posteriorly in free borders, and, projecting upwards & downwards from them are four cornua, the two superior and longer for articulation with the hyoid bone by means of the lateral thyro-hyoid ligaments; the inferior and shorter for articulation with the cricoid cartilage by a diarthrodial joint with movement through a transverse axis. Between the thyroid cartilage and the hyoid bone anteriorly there is the thyro-hyoid membrane; and similarly, between the thyroid and cricoid cartilages there is the crico-thyroid membrane.

The Epiglottis is a valve-like cartilage, ovate in shape, placed in front of the superior opening of the larynx, and attached inferiorly by the thyro-epiglottic ligament to the deep angular depression between the alæ of the thyroid cartilage. Its lateral borders are only partly free, being in

part concealed by the aryteno-epiglottidean folds of mucus membrane passing from them to the arytenoid cartilages, and forming the lateral boundaries of the superior orifice of the larynx. Its anterior or lingual surface is free only in the upper part of its extent where it is covered by mucus membrane. Lower down the mucus membrane is reflected from it forwards to the base of the tongue, forming one median fold and two lateral frænula - the glosso-epiglottidean folds of mucus membrane, - beneath which lies the glosso-epiglottic ligament.

The adherent portion of this surface is also connected with the posterior surface of the os hyoides by means of the hyo-epiglottic ligament. The laryngeal surface of the cartilage is entirely free & covered by mucus membrane.

The cricoid cartilage lies immediately below the thyroid. Broad behind and narrow in front its shape resembles that of a signet ring. By its external surface it articulates with the inferior cornua of the thyroid; and by its superior

border with the arytenoid cartilages by means of saddle-shaped articular facets near the summit, the front of each saddle facing that of its fellow on the opposite side. Its internal surface is smoothly lined by mucous membrane, continuous with that lining the trachea, to which its lower border is attached.

The arytenoid cartilages —: "Each of these small complicated bodies has somewhat the shape of a miniature horn, very much flattened from before backwards, in its upper two-thirds, so as to present an anterior and a posterior surface with an inner and an outer edge. The posterior surface is markedly concave from above downwards, and on it are inserted the fibres of the arytenoid muscle. On the convex anterior surface, about its middle there is a well-marked pit which gives attachment to the greater part of the fibres of the false vocal cord; and on the lower part of this surface there are also inserted some of the fibres of the thyro-arytenoid muscle.

~~On the convex anterior surface, about its middle there is a well-~~

~~marked~~

The inner edge is the part of the cartilage which is brought into apposition with the corresponding line of the opposite side when the vocal cords are approximated. It is quite smooth and covered only by mucus membrane. Inferiorly this border spreads out into a small flattened triangular surface, the anterior angle of which projects forwards in the shape of a pointed process, to which the true vocal cord is attached. The outer edge terminates inferiorly in the postero-external angle, and, together with it, forms the chief point of insertion for the muscles. To this angle are attached the tendons of the posterior and lateral crico-arytenoid muscles; whilst the fibres of the thyro-arytenoid are inserted along the edge almost as high as the apex of the cartilage. On the base the chief points to be observed are the two angles already mentioned, viz- the processus vocalis and the postero-external angle. The latter projects considerably backwards and outwards, and, scooped out

on its inferior surface is the articular facet of the arytenoid cartilage, which looks downwards and inwards upon the corresponding saddle-shaped surface of the cricoid" (Wyllie. Ed: Med: J 1866)

Passing from the back of the cricoid to the base of each arytenoid cartilage are the posterior crico-arytenoid ligaments. From a consideration of the shape of the articular surfaces of the crico-arytenoid joint, and the direction of the fibres of the muscles attached to the arytenoid cartilages, it will appear that movement takes place in the arcs of circles of which the posterior crico-arytenoid ligaments are the radii.

The cartilages of Santorini are minute nodules articulating with the apices of the arytenoid cartilages. The cartilages of Wrisberg are still more minute nodules lying in the aryteno-Epiglottidean folds of mucus membrane posteriorly

The true vocal cords, or inferior vocal ligaments are two bands of elastic tissue covered by mucus membrane, attached in front to about the middle of the depression between the ala of the thyroid, and behind to the elongated anterior angle of the

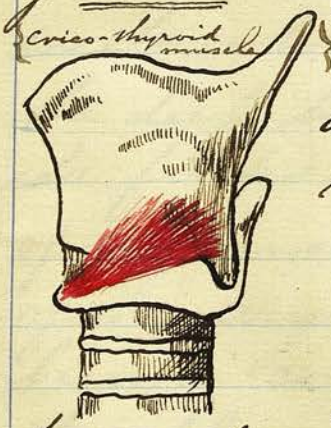
arytenoid cartilage on each side.

The interval between the true vocal cords is known as the rima glottidis

The false vocal cords or superior vocal ligaments consist of a few slight fibrous fasciculi contained within folds of mucus membrane. They are attached in front to the depression between the ala of the thyroid cartilage close to the attachment of the epiglottis, and immediately above that of the true vocal cords; and behind to the depression on the antero-external surface of each arytenoid cartilage.

The ventricles of the larynx are the spaces lying between the true and false vocal cords on each side. They extend up into pouches behind the false vocal cords called the sacculi. These culs-de-sac lead from the ventricles upwards for the space of half an inch between the superior vocal cords on the inner side and the thyroid cartilage on the outer, reaching as high as the upper border of that cartilage. The aperture between the false vocal cords, which may be called the "false glottis" is ellipsoidal from before backwards

when seen during phonation.
The intrinsic muscles of the larynx are the following -: The crico-thyroids, thyro-arytenoids, Lateral crico-arytenoids, posterior crico-arytenoids, the aryteno-epiglottidean muscles, and the arytenoideus. Of these all except the arytenoideus are paired muscles. The thyro-arytenoid, lateral crico-arytenoid, arytenoid, and aryteno-epiglottidean muscles have been described by Henle as forming a sphincter, which in this paper, will be spoken of as the sphincter glottidis. (Quain's Anatomy Vol III p 918)



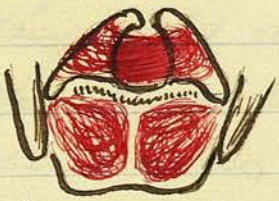
The crico-thyroid muscle arises from the lower border of the thyroid cartilage and from the anterior border of its inferior cornu, and passes forwards and downwards to be inserted into the fore part and side of the cricoid cartilage.

The thyro-arytenoid muscle runs in the direction of the vocal cord, to the deep surface of which it is intimately united. Arising in front from

the internal surface of the thyroid cartilage adjacent to the lower two-thirds of the angle, it extends almost horizontally backwards and outwards to the arytenoid cartilage to be inserted into its anterior surface and outer edge. The upper and thinner portion of the muscle lies upon the laryngeal pouch and ventricle close beneath the mucus membrane; the lower and thicker portion assists in the formation, or at least contributes to the support of the true vocal cord, lying parallel to the rima glottidis immediately on the outer side of the cord, into the deep surface of which some of its fibres are inserted. Fibres of the muscle pass round the border of the arytenoid cartilage, and become continuous with some of the oblique fibres of the arytenoid muscle.

The lateral crico-arytenoid muscle lies immediately below the thyro-arytenoid. Arising from the upper border of the cricoid, it passes backwards to be inserted into the postero-external angle of the arytenoid cartilage.

The posterior crico-arytenoid muscle arises by a broad origin from the posterior surface of the cricoid, and its fibres converge upwards and outwards to be inserted into the postero-external angle of the arytenoid cartilage.



{Arytenoid and Posterior Crico-Arytenoid Muscles}

The arytenoid muscle passes between the posterior surfaces of the arytenoid cartilages to the whole extent of which they are attached.

The arytæno-Epiglottidean muscles arising near the inferior and outer angles of the arytenoid cartilages, decussate with one another, and their fibres are partly attached to the upper and outer part of the opposite cartilage, partly pass forwards in the arytæno-Epiglottidean fold, and partly join the fibres of the thyro-arytenoid muscle.

According to those who believe in a longitudinal tension of the vocal cords, the intrinsic muscles of the larynx are divided into those which make tense the vocal cords, and those which relax them: and into those which ap-

proximate

proximate and separate them from one another. Thus, the crico-thyroids are said to stretch the vocal cords in an antero-posterior direction, whilst the thyro-arytenoids have an opposite action. The lateral crico-arytenoids and the arytenoid muscles are said to approximate the cords, and thus to close the glottis, whilst the posterior crico-arytenoids separate them and thus dilate the glottis

To imitate the action of some of these muscles, and chiefly of the crico-thyroids, experiments were made by Müller, Wyllie and others upon the dead larynx. Wyllie describes the method of experimentation in the Edinburgh Medical Journal for 1866. — "The first thing to be done is to fix the arytenoid cartilages by passing a needle transversely through their bases, and pulling them together by applying, on their posterior surfaces, round the projecting ends of the needle, a figure-of-8 bandage. To test the effect of weights, the larynx is suspended by its arytenoid cartilages; then another strong needle is passed

through the angle of the thyroid cartilage just opposite the attachment of the vocal cords, and to this, weights are suspended". The experiments were varied by increasing or diminishing the blast of air; and thirdly, by bringing the vocal ligaments partially into contact, so that they might vibrate only in a portion of their extent. But the stretching of the cords by means of weights was chiefly depended upon for varying the pitch of the notes to be emitted. By the second method in combination with this, the pitch could only be elevated about a fifth; and the effect of the third method, Wyllie states, was extremely doubtful (p. 234)

In describing the appearances observed externally Wyllie says- "In examining the living larynx we found that during the highest notes of the voice, the hyoid bone was pulled strongly forwards by the genio-hyoid muscles, and the thyroid cartilage at the same time was drawn upwards and forwards by the the thyro-hyoid muscles:" (p. 232) and, "as the larynx rises, the width

of the interval between the cricoid and thyroid cartilages becomes perceptibly diminished" (P. 227)

It might reasonably be asked why Wyllie should have dragged the thyroid cartilage downwards by means of weights, when he so distinctly states that it is drawn upwards as the voice rises in the scale.

In reference to the laryngoscopic appearances Beaunis says "When the person examined prepares to emit a sound, the glottis closes entirely in its whole length, or it may be only in its ligamentous part (glottis vocalis), and not in its interarytenoid part - glottis respiratorid -, or it may be simply narrowed without closing altogether.

There is thus more or less perfect occlusion due to the drawing together of the arytenoid cartilages, or their vocal processes" ---- "The larynx thus being arranged the sound is emitted, the vocal cords moving sharply the one from the other, and entering into a state of rapid vibration under the influence of the current of expired air discharged through the glottis. In the chest

voice the interarytenoid glottis is open and the ligamentous glottis presents an ellipsoidal slit or chink, very wide in the grave sounds, a little less in the medium, and very narrow in the acute sounds"... "In the production of falsetto notes, the interarytenoid glottis is completely closed. The ligamentous glottis on the contrary is open, and instead of forming as in the true voice, a linear chink, exhibits a pretty large opening which consequently allows a large outlet for the current of expired air."

This change, or rather difference, in the appearance of the glottis may readily be observed by the laryngoscope. During the emission of a low or medium note in the chest register, there is an interval between the inner borders of the arytenoid cartilages; and on the passage into the falsetto register on the same note, the cartilages are seen to move towards each other so as to bring into very accurate apposition the arytenoid attachments of the false vocal cords, which stand prominently out as red nodules

Trans. section of Glottis showing Glottis vocalis & Glottis respiratoria

on the free inner border of each cartilage

In the higher notes this change is not so noticeable, though even here the apices of the arytenoids may be observed to turn on their axes so as to approximate the inner borders more closely. It would seem to be due to slight relaxation of the thyro-arytenoid portion of the sphincter, in relation to the true vocal cords, (which accounts for the widening of the ligamentous glottis,) and to a corresponding further contraction of the arytenoid portion (See page 25)

The essential difference between the vibrations of the true vocal cords in the two registers is ~~that~~ that in the true voice their vibration is communicated in virtue of their tension to the cartilages of the larynx and through them to the trachea and lung tissues, giving rise to the physical sign of vocal fremitus; whereas in the falsetto voice there is no such communication of vibration, because the blast only moves the fine free edges of the vocal cords in its passage, and consequently there is no physical sign known as falsetto broncho-

phony

phony in consolidation of the lung tissue from any cause.

The aperture formed by the false vocal cords may be noticed to become smaller and smaller, and to assume more of a circular form as the voice rises in either register; and also to widen slightly in the passage from the chest to the falsetto voice on the same note.

In the belief that there is no longitudinal tension of the vocal cords by muscular action during vocalization, I shall now state my argument against that view, before proceeding to consider the chest and falsetto voices. And firstly as to the muscles which are said to be concerned in the longitudinal tension of the vocal cords. Of the crico-thyroid muscles it is generally stated, that, taking as a fixed point the anterior part of the cricoid cartilage, they draw downwards and forwards the anterior part of the thyroid cartilage by rotating it about an axis passing transversely through the crico-thyroid joints, and thus stretch the

vocal cords by increasing the distance between their anterior and posterior attachments. But it has been pointed out by various observers that the anterior part of the cricoid is not fixed to enable them so to act; and also, that even if it were, in order to act in this way they must first overcome the thyro-hyoids, which are contracting at the same time, as is shown by the simultaneous diminution in the size of the thyro-hyoid and crico-thyroid intervals, as the voice rises in the scale, the thyroid cartilage being raised towards the hyoid bone. Their fixed points must therefore be their thyroid attachments. Contracting from these, they will draw up the anterior part of the cricoid to the thyroid cartilage, with the effect of tilting downwards and backwards the posterior part of the cricoid. According to this view, believers in a longitudinal tension of the vocal cords must transfer the point at which traction for the stretching is supposed to be applied, from the anterior to the

posterior extremity of the cords, through the arytenoid cartilages. Schech thus explains this action: "When the thyroid cartilage is fixed by the thyro-hyoid muscles, the crico-thyroids draw the anterior part of the cricoid cartilage up towards the thyroid, and thus effect a rotation backwards and downwards of the posterior part of the cricoid. Since the thyroid cartilage is fixed anteriorly by the thyro-hyoids, whilst the arytenoid cartilages are fixed by the arytenoid and lateral crico-arytenoid to the cricoid during vocalization, the backward inclination of the body of the cricoid, caused by the contraction of the crico-thyroids, affects also the arytenoid cartilages resting upon it; the distance between the anterior and posterior attachments of the vocal cords is thereby increased, and thus the longitudinal tension of these bands is brought about." (Zeitschrift für Biologie Band. IX 1873 p. 258)

Now, in every act of phonation there is as we have already seen, approximation of the vocal cords to one another, and at the same time

an elevation of the anterior part of the cricoid cartilage the more appreciable the higher the voice is raised. The elevation of the anterior part of the cricoid is of course due to the action of the crico-thyroid muscles alone. The approximation of the vocal cords implies movement of the arytenoid cartilages in the arcs of circles towards the middle line, and this movement will turn their antero-external surfaces and postero-external angles more forwards.

But it is to these surfaces and angles that the thyro-arytenoid & lateral crico-arytenoid portions of the sphincter glottidis are respectively attached, and both these muscles have an anterior origin. Necessarily therefore they contract to produce approximation of the cords.

So that the simultaneous movements of elevation of the anterior part of the cricoid ~~cricoid~~ cartilage, and approximation of the vocal cords, imply simultaneous action of the crico-thyroid, lateral crico-arytenoid, and thyro-arytenoid muscles.

Now, if the crico-thyroid muscles stretch the vocal cords longitudinally

through their arytenoid attachments they must necessarily also stretch the thyro-arytenoid muscles, for they are intimately united to the vocal cords, and have the same attachments, viz: the thyroid angle and the arytenoid cartilages. But the thyro-arytenoid muscles are contracting at the same time. To admit therefore a longitudinal tension of the vocal cords by the crico-thyroid muscles is to admit an anomaly in the phenomena of muscular action, in the shape of an increase in the length of a muscle during its contraction.

The larynx has generally been considered to act as a reed instrument in the emission of chest notes; but as to its action in the production of the falsetto voice physiologists are still in doubt. Müller regarded the organ of voice as a reed instrument with a double membranous tongue, and made a series of experiments with tongued instruments. He concludes that "it would be of the greatest importance to know the respective influences of the tube prefixed to the tongue

and of that affixed to it, for in the organ of voice the larynx and bronchi represent a prefixed tube to the membranous tongue, and the cavity in front of the inferior ligaments of the larynx, a tube affixed: but this is one of the most difficult problems in the science of acoustics, and I have not succeeded in arriving at any result which approximates to a law". Each of the three elements of the true vocal cords, has, by one observer or another been regarded as the true vibrating surface.

Thus Bishop says "The true vibrating surface of the glottis is the mucus membrane. The vocal cords confer on it tension, resistance, position, and probably other conditions necessary for vibration".

Kuss thinks that "the ligament does not exhibit the necessary conditions for constituting the vibrating cord, as is generally supposed. It is composed of elastic tissue i.e. of fibres which are not rectilinear but entangled in every direction, so that whichever way it is drawn the tension produced is extremely slight". And again "The muscular

tissue constitutes the true vocal cord in a physiological point of view, for what is more vibratory than a contracted muscle?" (Physiology - Russ.)

Beaunis says - "The whole, mucus membrane, elastic tissue & muscle constitutes a small vibrating system inseparable and solid, the tension of which is immediately dependent upon the contraction of the muscle"

I attach more importance to the ligamentous portion, although I agree with Beaunis in reference to its tension. In the lowest notes the whole width and length of the vocal cords is set in vibration; but as the sphincter glottidis contracts for the production of higher notes, a less width will be available for vibration, on account of their deeper portions being rendered tense by their close proximity to, and intimate union with, the adjacent fibres of the thyro-arytenoid portion of the sphincter, which are becoming more and more tightly contracted; and a less length, on account of their close approximation anteriorly.

Of the falsetto voice many theories have been put forward. Thus. "By a shortening of the vibrating

portions of the lower vocal ligaments."
(Willis)
"By the vibration of the inner borders of the vocal cords only" (Müller)
"A greater breadth of the vocal cords vibrates than in the true voice" (Garcia)
"The aperture of the glottis assumes the contour of the embouchure of a flute, and this voice is produced by the vibrations of the air through it"
(Petrequin & Diday)
"The superior vocal cords vibrate to produce it" (Segond)
"Suppose the same sound to be produced by the ordinary voice and the falsetto. The ligaments of the glottis vibrating in the same manner in both cases, the difference may be this. For the ordinary sound the column of air in the trachea may vibrate entire; for the falsetto the column of air may assume an harmonic subdivision" (Wheatstone)
"The falsetto tones are produced by a nodal division of the column of air together with the vocal tube into separate vibrating lengths" (Bishop)

Dodart attempted to prove that it is a supralaryngeal function & that the nose becomes the principal

tube of sound instead of the cavity of the mouth.

I regard the falsetto voice as being produced in a manner analogous to that of whistling by the mouth. Bounded below by the true vocal cords and above by the false, and extending laterally up into the laryngeal sacculi is a cavity which may be called the "laryngeal cavity" This cavity I believe to be used with the false vocal cords, for the production of the falsetto voice in the same way as the mouth and lips are used in whistling. Whistling I understand to be due to the generation of pulses in the air by the more or less forcible and exact direction of a blast against the opening between the approximated lips; the size of the cavity of the mouth being regulated by the buccinator muscles and tongue, and that of the oral aperture proportionately widened or narrowed by the sphincter oris, according as the buccal cavity is larger or smaller and the note therefore to be emitted lower or higher in pitch. And

See Quain Vol ij p 913 & Model No 7

similarly in the larynx we have the laryngeal cavity, regulated by the sphincter glottidis which envelops it, and the aperture between the false vocal cords widened or narrowed by the action of the higher fibres of the sphincter.

In the passage from a chest to a falsetto note of the same pitch the cricoid cartilage may be noticed to drop so as to widen the crico-thyroid space. This occurrence is to be explained by the fact that in the production of falsetto notes of the same pitch there is less powerful contraction of the thyro-arytenoid portion of the sphincter, and consequently a less powerful contraction of the crico-thyroid muscles is needed to resist its antero-posterior traction upon the arytenoid cartilages (see pages 15 & 27)

In the true or chest voice and more especially in those of piano intensity, there can be detected the pure or falsetto tone, and by practice it becomes easy to pass from one register to the other on the same note. This would indicate that their modes

of production are fundamentally similar. The chest voice I believe to be produced by bringing into action the true vocal cords, to roughen by their vibration the pure or falsetto voice produced by the "laryngeal cavity" and false vocal cords.

As in the falsetto so in the chest voice I regard the laryngeal cavity as the sole regulator of pitch.

The true vocal cords may be made to vibrate without setting in action the laryngeal cavity, but only in the act of inspiration. We have an instance of this in the purring of cats.

The laryngeal muscles I look upon as being five in number, viz: the sphincter glottidis, a pair of crico-thyroids, and a pair of posterior crico-arytenoids.

The sphincter and crico-thyroids alone are concerned in vocalization; the posterior crico-arytenoids in respiration. By the sphincter glottidis, I mean the mass of muscle which extends from the margins of the ary-teno-epiglottidean folds to the upper border of the

cricoid cartilage, and embraces the arytenoid cartilages posteriorly; including thus the ary-teno-epiglottidean, thyro-arytenoid, lateral crico-arytenoid, and arytenoid muscles, between all of which there exists a more or less distinct continuity of muscular fibre. When the sphincter is put in action for phonation it will tend not only to approximate the arytenoid cartilages (and necessarily therefore also the vocal cords) but also to draw them bodily forwards towards its anterior fixed attachment. Here the crico-thyroids come into play. Acting simultaneously with the sphincter they will hold back the posterior part of the cricoid cartilage, thus acting upon the arytenoid cartilages through the posterior crico-arytenoid ligaments to prevent their being drawn forwards bodily, by the antero-posterior traction of the sphincter. The crico-thyroids may thus be regarded as centre-pin-fixers, by firmly holding the cricoid attachments of the crico-arytenoid ligaments, whilst the sphincter &

posterior crico-arytenoid muscles move the arytenoid cartilages in the arcs of circles of which those ligaments are the radii.

According to this view of voice-production, a man's voice differs from a woman's chiefly because he has a larger laryngeal cavity. The fact that his vocal cords are longer and wider is of secondary importance only.

In illustration of my views on the "laryngeal cavity" and false vocal cords I send eight models of plaster of Paris.

Of these Nos. 1, 2 & 3 give a clear "whistling" sound on blowing gently and accurately across the lower opening, with the lips closely applied to the surface to prevent any escape of air on either side. This will be in imitation of expiration through the glottis with the larynx prepared for phonation.

In No. 4. the relation between the cavity and orifices is not so accurate, and hence the sound emitted is less distinct

Nos. 5 & 6 have the true and "false" glottides arranged correctly for the emission of a falsetto note during

inspiration. To imitate inspiration the blast should be directed through the superior orifice of the model.

The note produced by expiration through the inferior orifice is not good.

No. 7 represents a vertical transverse section of the true and "false" glottides and "laryngeal cavity" as shown in Quain's Anatomy Vol: ij p. 913. This model is made after the same fashion as the rest.

No 8. Shows the process of modelling in clay and plaster.

Some of the models are pieced together by plaster, others by white wax.

Kendal
April 26th 1880