EXPERIMENTAL RESEARCHES ON THE TENSION OF THE VOCAL BANDS.

(*a*)—THE ACTION OF THE THYRO-CRICOID MUSCLE.

(*b*)—THE ACTION OF THE EXPIRATORY BLAST OF AIR.

BY

F. H. HOOPER, M.D.

BOSTON

ASSISTANT PHYSICIAN TO THE CLINIC FOR DISEASES OF THE THROAT, MASSACHUSETTS GENERAL HOSPITAL; FELLOW OF THE AMERICAN LARYNGOLOGICAL ASSOCIATION, ETC.

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THE experiments recorded in this paper were performed in the physiological laboratory of the Harvard Medical School, in conjunction with Professor Henry P. Bowditch.

The diagrams and figures contained in the text were reproduced from the original tracings and drawings by the photo-electrotype engraving process.

(*a*).—THE ACTION OF THE THYRO-CRICOID MUSCLE.

Although the literature pertaining to the function of this important tensor—commonly but incorrectly called the crico-thyroid muscle—is not extensive, it furnishes us with every possible variety of opinion. The muscle is usually described as arising from the front and lateral part of the cricoid cartilage; its fibres pass upward and outward, diverging slightly, and are inserted into the inferior and inner border of the thyroid cartilage from near the median line in front, and as far back as the anterior border of its lower cornu. Its nervous supply comes principally from the external branch of the superior laryngeal nerve.

The observers who have directed their attention to its action may be divided into six classes:—

I. Those who hold that it tilts the thyroid cartilage downward and forward on to the cricoid. (This is the generally received theory in regard to it, and is the view expressed in such standard works of anatomy and physiology —with the exception of the ninth edition of Quain, which has only recently appeared—as Galen, Casserius, Gray, Hyrtl, Henle, Meyer, Meckel, Hartmann, Cruveilhier, Sappey, Morel et Duval, Carpenter, Huxley, Todd and Bowman, Foster, Hermann, and others; and among laryngologists, Türck, Stoerk, Mackenzie, Schrötter, and Seiler.)

II. Those who affirm that it draws the cricoid up on to the thyroid. (Cowper, 1724; Magendie, 1813; Lauth, 1835; Bishop, 1839; Longet, 1841; Cuvier, 1846; Harless, 1853; Battaille, 1861; Fournié, 1866; Jelenffy, 1873; Schech, 1873; Schmidt, 1873; Milne Edwards, 1876; Cohen, 1880; Elsberg, 1882; Quain's Anat., 9th ed.)

III. Those who maintain that it draws both cartilages together by its contraction, the predominance of movement being in the thyroid. (Vesalius, Merkel, Theile, Béclard, Harrison.)

IV. Those who assert that its action is according to the fixation of the cartilages; that when the cricoid is the point fixed, the thyroid is the one moved, and *vice versâ*. (Budge, Riegel, Mandl.)

V. Those who insist that instead of drawing the cartilages together, its function is to retain them in a fixed position when separated. (Vierordt, Luschka.)

VI. The sixth class is purely of historical interest. Brown (1683) stated that "when the muscle is contracted, it extends the cartilage cricois, or annularis, and so openeth its cleft for a more deep and greater voice or sound." Dionis (1695) considered that its action was to dilate the sides of the thyroid, thereby enlarging the glottis. Haller (1766) agreed with this view, but thought also that it approximated the two cartilages.

But one explanation can be offered to account for these conflicting theories. Except in the case of four observers (Magendie, Longet, Schech, Schmidt), the above hypotheses were not founded upon experimentation. They

are mere speculations unsupported by reliable experimental proof. And it is a significant fact that the four observers named—the only ones who substantiated their opinions by experiments upon animals—all agree concerning the action of the muscle.

Magendie in 1813 not only gave a very clear description of the distribution of the laryngeal nerves, but he was the first, by experimentation, to observe and record the true action of the thyro-cricoid muscle. He fails to tell us upon what animal he made his observation, and contents himself with saying: "Quand on enlève la peau du col, de manière à apercevoir l' intervalle crico-thyroïdien, on a lieu de se convaincre que dans la production des son aigus, et surtout à l' instant de la déglutition, le cartilage cricoïde s' élève au point que son bord supérieur s' engage sous le bord inférieur du cartilage thyroïde."

We find mentioned, however, in Cowper (1724), that the function of the muscle "is to pull up the annularis rather than to bring down the scutiformis."

Our own experiments, performed in a different manner from any hitherto recorded, result, we think, in definitely determining the chief effect produced upon the cartilages by the contraction of the muscle. They prove the accuracy of Magendie's early observation, and force us to reject the theory, so generally accepted, that the thyroid cartilage is drawn down by its influence. The dogs used in the investigations were prepared as follows:

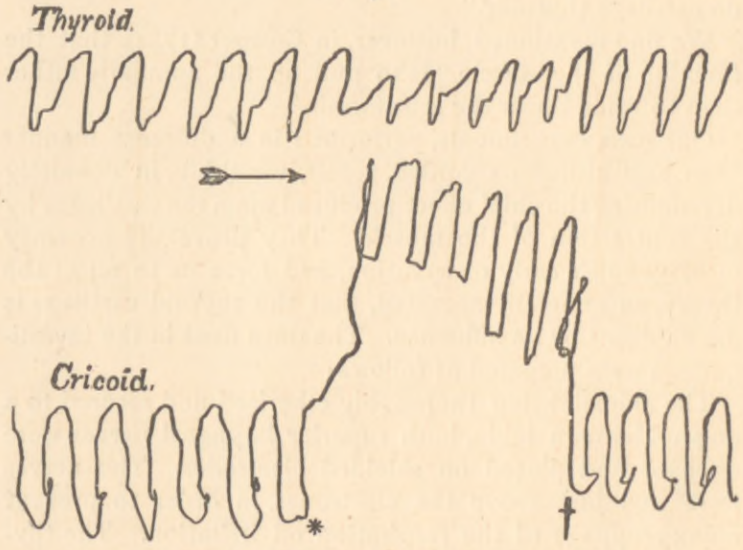
The animal being thoroughly etherized and secured to a dog-holder on a table, both superior laryngeal nerves were exposed and placed on shielded electrodes. The nerves were tied just above the electrodes, in order to prevent reflex stoppage of the respiration on irritation. The thyroid and cricoid cartilages were next exposed without disturbing any muscular attachment. Two levers, twenty-eight centimetres in length, composed of ordinary straw, and terminating at one end in a strong pin, were stuck into the centre of each cartilage. The farther end of each lever, being tipped with a delicate metallic point, was so arranged as to record graphically on a smoked paper of a revolving

cylinder the movements of the cartilages produced by irritating the superior laryngeal nerves.

Stimulation was produced by a rapid succession of induction shocks from an apparatus graduated empirically by Fick's method. The graduation was such that an intensity of 1,000 corresponded to the stimulation produced when a secondary coil of 10,260 turns of fine wire was pushed wholly over the primary coil. After repeated trials, it was determined that an intensity of fifteen was the most applicable to the purpose, and this intensity was, therefore, employed in all the experiments.

The tracings are to be read from left to right. The asterisk denotes the beginning of the stimulation, the dagger the end.

Fig 1

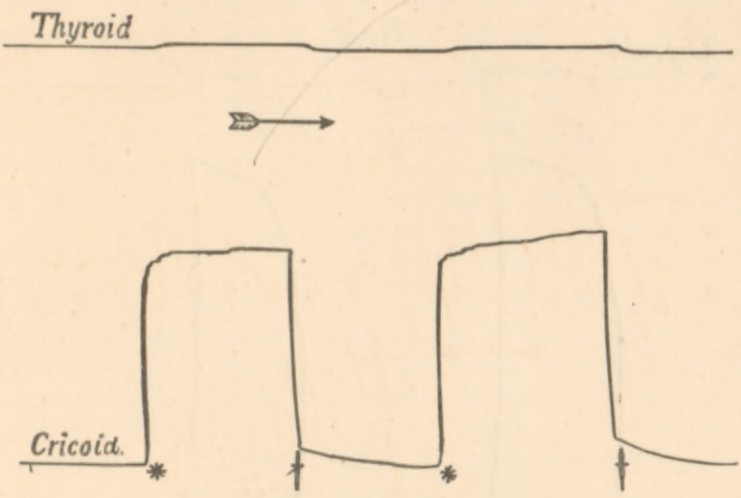


DOG ETHERIZED; SUP. LARYNGEAL NERVES TIED.

The undulations of the above tracing in fig. 1 represent the respiratory movements of the larynx. At the point of stimulation, it will be noticed that the cricoid cartilage was drawn up toward the thyroid, as indicated by the marked rise of the cricoid curve. As soon as the irritation ceased, the lever immediately fell to its previous level. No up-

ward or downward movement of the thyroid, however, can be observed. The respirations are somewhat shortened during the stimulation, but the recording pen attached to the thyroid cartilage remains on the same level throughout the experiment. The next experiment, performed after the dog had been killed by section of the medulla oblongata, yields the same result.

Fig 2



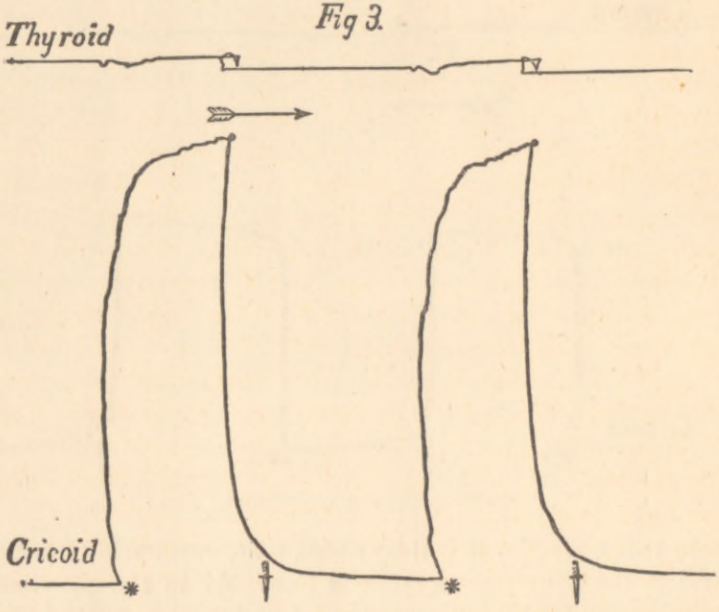
DOG; MEDULLA DESTROYED.

In this figure (2) it will be noted that, respiration having ceased, the pens trace a straight line. As in the previous experiment (fig. 1), stimulation of the nerves caused the same rise of the cricoid, while no appreciable effect was produced on the thyroid. The minute elevations in the thyroid line, at the points of irritation, were probably accidental, as will be explained hereafter. The following experiment was performed on a different animal, but under similar conditions as the preceding.

Here (fig. 3) the same effects as in the foregoing experiments are evident, only more pronounced, the rise of the cricoid being very powerful. The undulations in the thyroid line will be readily understood when we consider what an infinitely small amount of movement of the cartilage would be

sufficient to produce a change in a flexible pen at the end of a lever of the length used in these researches. Indeed, it is surprising that there is not more oscillation, for, the thyroid not being absolutely fixed, the contraction of the muscle would necessarily cause enough motion to account for the slight unevenness of the thyroid lines. But that there is no positive movement imparted to the thyroid by the action of the muscle seems beyond doubt.

Fig 3.



DOG ; MEDULLA DESTROYED.

These experiments were repeated many times, on the same and different dogs, always with confirmatory results. A dissection was made subsequently in every instance, in order to be sure that the electrodes had been on the superior laryngeal nerves,—a necessary precaution in such investigations.

We by no means submit these researches as establishing the entire function of the thyro-cricoid muscle; inasmuch as this, like all the intrinsic muscles of the larynx, has the important characteristic of being arranged or divided into bundles

of fibres. Under what conditions these bundles act, how they act, whether they can act separately or only jointly, is as yet undetermined. Nevertheless, the salient point clearly demonstrated by our experiments is, that the principal effect of the contraction of the muscle is to draw the anterior portion of the cricoid cartilage up on to the thyroid, the latter remaining practically fixed. The posterior plate of the cricoid, with every thing attached to it, being, therefore, rotated downward and backward, the bands are necessarily stretched. It would be beyond the scope of this paper, besides leading us into the field of speculation, to discuss the probable working of the different bundles of the muscle. But it is not improbable that the vocal bands, being stretched in the first place in the manner described, the oblique bundles may then, in their turn, come into play, and increase the tension by pulling the cricoid cartilage directly backward. When we bear in mind that (with the exception of a small part of the inferior constrictor) not a single extrinsic muscle is attached to the cricoid cartilage, and reflect upon the mechanical construction of the larynx, it is difficult to comprehend by what mechanism it can possibly be fixed in a sense that would permit the thyroid to be pulled down upon it. Nature, doubtless, never intended that it should be. On the contrary, its extreme mobility is one of its most striking and distinguishing characteristics. In vocalization the thyroid cartilage, steadied by the powerful extrinsic muscles inserted into it, may be regarded (as compared to the cricoid) as the passive agent, while the latter, owing to the manner in which it swings upon the short processes of the thyroid behind, and to the elasticity of the parts in front, and to a certain extent on the sides, is permitted to play upon it with every delicacy of adjustment through he agency of the intrinsic muscles of the larynx attached to it, and of another force presently to be alluded to. Indeed, were it not for this free and unrestrained movement of the cricoid cartilage on to the thyroid, the marvellous capabilities possessed by certain phenomenal voices would be impossible. For to it the stretching of the vocal bands is, in a great measure, directly due. When we are

told,[1] by J. Solis-Cohen, that a certain singer, with a compass of three octaves, was capable of effecting as many as two thousand one hundred changes of pitch, and "that the variation of tension between the tones that she could produce would represent a successive lengthening and shortening of the vibrating edges of the vocal bands in successive proportions of one seventeen-thousandth of an inch," we are simply lost in astonishment. It is therefore interesting to inquire whether muscular action is the only agent concerned in effecting such extensive as well as delicate adjustment as this.

Passing now to our second series of experiments we shall attempt to point out another, and not an unimportant, factor concerned in tightening the vocal bands, which, acting independently of all muscular innervation, exerts its influence upon the cricoid cartilage, causing a movement of it identical with that produced by the action of the tensor just considered.

(*b*) THE ACTION OF THE EXPIRATORY BLAST OF AIR.

Hitherto the action of the air-blast as a tensor of the vocal bands has been recognized as producing its effect (as any current of air might stretch an elastic membrane) merely by its force in coming in contact with them. But it is the purpose of the subjoined experiments to establish the fact, that in addition to the general rise of the whole larynx, as in singing high notes, the pressure of air causes an excessive and independent upward movement of the cricoid cartilage on to the thyroid, of which no mention, to our knowledge, has heretofore been made.

The method adopted in arranging the dogs was as follows:

Having been thoroughly etherized during the early part of the operation, the animal was subsequently killed by bleeding and section of the medulla oblongata. The thyroid and cricoid cartilages were first exposed by a careful dissection in order that the normal position of the external muscles of the larynx might be disturbed as little as pos-

[1] "The Throat and the Voice," p. 105.

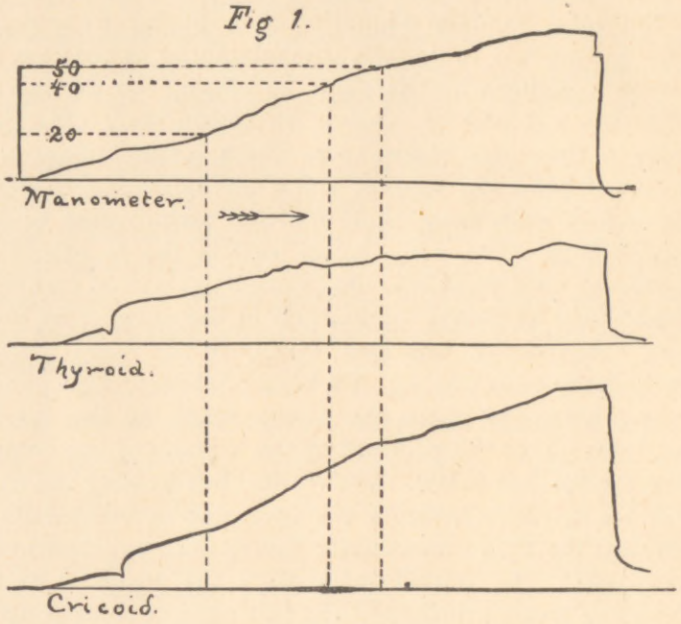
sible. The sternum being removed, a T-shaped canula was firmly tied into the trachea very near the base of the lung. One arm of the canula communicated with a Fick's manometer which registered the pressure of the air blown into the trachea through the other arm by the experimenter. The larynx being nearly closed during life by the approximation of the vocal bands in phonation or in singing it was necessary in some way to imitate, as satisfactorily as possible, the natural condition of the parts by closing up the larynx. This was effected by a pad of cotton-wool, extending down to the vocal bands, upon which a small quantity of plaster of Paris was poured, which on hardening rendered the larynx sufficiently tight for the performance of the experiments. The same levers used in the foregoing experiments were stuck into the thyroid and cricoid cartilages respectively at points represented in the drawing by black dots. Advantage was also taken of the same graphic method, the pens tracing, on a horizontal revolving cylinder bearing a smoked paper, the curves made by the moving cartilages under the pressure of the column of air coming from the trachea below. The vertical line bearing the numbers 20, 40, 50 represents the pressures in millimetres of mercury, the Fick's manometer having been experimentally graduated. The dotted lines show the positions of the ascending levers attached to the cartilages at corresponding pressures.

The arrow indicates the direction in which the curves are to be read.

The tracings in this figure (1) were obtained by inflation of the trachea when the extrinsic muscles of the larynx were intact. A glance at the diagram shows that at equal pressures the rise of the cricoid curve above its zero line exceeds that of the thyroid. By measurement we have at a pressure of 20 mm. Hg., an ascent of the cricoid lever of 8 millimetres, while that of the thyroid at the same pressure is 7. As the force of the blast of air is increased, the difference is more marked. At a pressure of 40 mm. Hg., the cricoid moves up 16 mm., the thyroid 10.5 mm. At a pressure of 50 mm. Hg., the

increase is still greater. Under this pressure the cricoid goes up 19.5 mm. to 12 mm. of the thyroid. At all pressures, therefore, in this experiment, we have an excess of movement of the cricoid cartilage over that of the thyroid.

Fig 1.

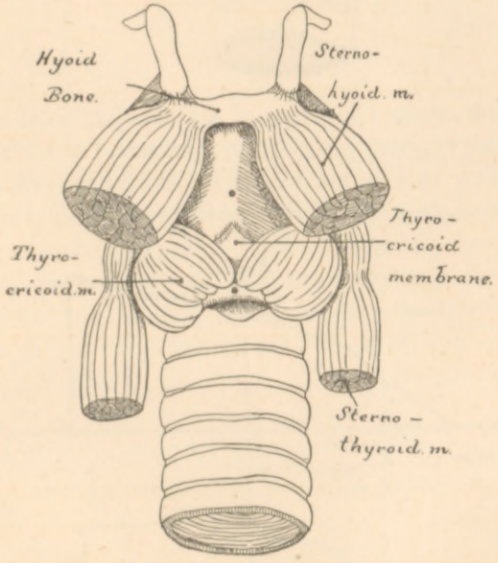


MUSCLES INTACT.

The difference in the height of the curves at the several pressures being 1, 5.5, 7.5, represents in millimetres the approximation of the cricoid pen to that of the thyroid, and a consequent stretching of the vocal bands. The amount of stretching may be computed by dividing this difference by the ratio of the length of the lever (28 cm) to the distance from the vocal process to the crico-thyroid articulation (16 mm.). This ratio being 17.5 to 1 we obtain a lengthening of the vocal bands of about .06 mm., at a pressure of 20 mm. Hg., .31 mm. at 40 mm. Hg., and .43 mm. at 50 mm. Hg.

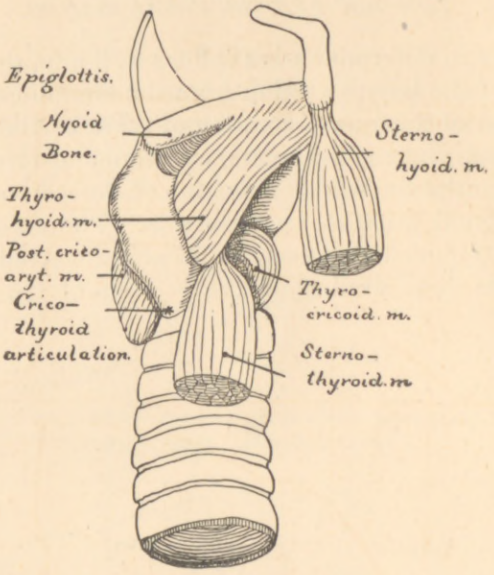
In order to determine what influence, if any, the extrinsic muscles of the larynx coming from the sternum and attached in front of the axis of rotation of these cartilages, would exert upon their movements, experiments were made of blowing up the trachea after section of the sterno-hyoid and sterno-thyroid muscles on each side. The accompanying diagrams (reduced about one third) of a dissected larynx of one of the dogs used, show the relation of the parts very clearly.

LARYNX OF DOG. FRONT VIEW.



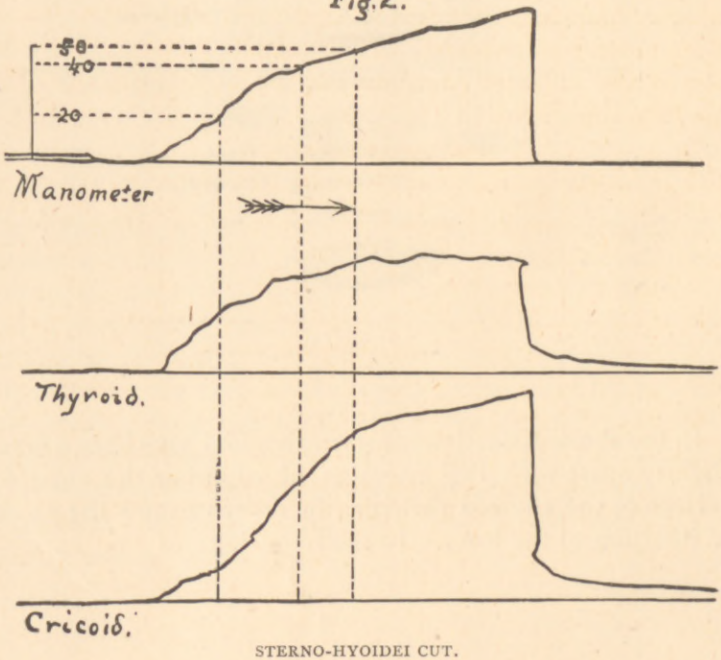
In the above dissection the sterno-hyoidei have been drawn slightly apart with the intention of exposing the anterior surface of the thyroid cartilage, in order to show the point of insertion of the lever. In the following

SIDE VIEW



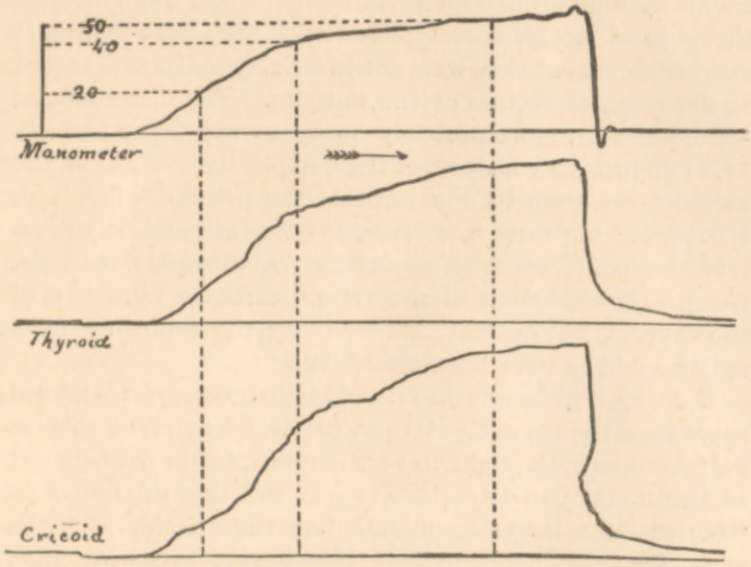
the asterisk marks the point of articulation of the two cartilages. The supposition that the powerful muscles attached anteriorly to this pivot might effect the movements of the cartilages, was sustained by the following experiments.

Fig. 2.



STERNO-HYOIDEI CUT.

Fig. 3.



STERNO-HYOIDEI AND STERNO-THYROIDEI CUT.

Inspection of these curves (figs. 2 and 3) suffices to show the increase in their height on inflation, after the depressor muscles had been divided, as compared with fig. 1 when those muscles were intact. Their relative distances in numbers at the different pressures may be best appreciated by the following table.

FIG. 1.—MUSCLES INTACT.

Am't. of pressure in mm. Hg.	Movem't of cricoid pen.	Movem't of thyroid pen.	Difference, representing approximation of the cricoid cartilage to the thyroid.	Amt. of stretching of the vocal bands in mm. (about)
20	8.	7.	1.	.06
40	16.	10.5	5.5	.31
50	19.5	12.	7.5	.43

FIG. 2.—STERNO-HYOIDEI CUT.

20	4.	7.	—3.	—.17
40	16.	12.5	3.5	.20
50	22.	15.	7.	.40

FIG. 3.—STERNO-HYOIDEI AND STERNO-THYROIDEI CUT.

20	4.5	4.	.5	.03
40	17.	15.	2.	.11
50	27.	21.	6.	.34

Ninety-two experiments of this character were recorded, which were performed on nine different dogs, and although the general results corresponded with the above figures, it must be admitted they were not invariably uniform in regard to the effect of section of the muscles. The discrepancies were, however, more probably owing to the many and obvious difficulties which beset the complicated nature of the experiments, than to any error in the principles involved. Not presenting them, therefore, as being scientifically accurate, the point we wish especially to emphasize, namely, the greater excursion of the cricoid cartilage over that of the thyroid, was evident, and we think the following facts may be said to have been established:

I. At high pressures the cricoid cartilage *invariably* moved more than the thyroid. It may safely be asserted that at *all* pressures such ought to be the result, for in only six out of the ninety-two experiments was the thyroid found to have made a larger excursion than the cricoid. This, in each instance, happened at the lowest pressure; due, perchance, to some minute obstacle on the revolving cylinder which impeded the immediate rise of the pen, or to some such accidental cause. In fig. 2, at the low pressure, it will be observed that this anomalous movement took place.

II. At high pressures, after section of the muscles, both cartilages move up more freely. But inasmuch as the thyroid rises more, in proportion to the cricoid, than when the muscles are intact, the difference between the curves, it will be noted, is less, and consequently also the stretching of the bands. That the uncut muscles, therefore, which are attached anteriorly to the axis of rotation of these cartilages should restrain their motions, to some degree, especially that of the thyroid, seems probable.

It is evident, then, from these researches, that the air escaping from the lungs produces a decided upward movement of the cricoid cartilage, in addition to the general rise of the larynx, which movement increases in proportion to the force with which the air is expelled from the chest.

This movement may be readily observed by taking an excised human larynx or that of one of the lower animals, dog or cat, and arranging it in this manner. Suspend the larynx to an ordinary iron holder by a clamp attached to the hyoid bone. Plug the glottis with cotton-wool and plaster. Inflation of the trachea causes the front part of the cricoid cartilage to rise on to the thyroid. Easy as it is to demonstrate this phenomenon, we meet with a difficult problem in proceeding to explain the cause of it. It seems fair to infer that from the anatomical construction of the larynx the ascent of the cricoid must be an active, and the descent a passive movement. For when the parts are at rest physiologically, the attachment of the cricoid to the trachea and the strength of the thyro-cricoid ligament would prevent any downward movement of the cricoid cartilage *per se*; if any such movement did take place, it would have to be shared also by the thyroid cartilage and the trachea. It was at first thought that the trachea itself, stretched and expanded by inflation, would push the cricoid upward, and thus approximate it to the thyroid. But we were compelled to abandon this view, as it was found that, after cutting the trachea off close to the cricoid, leaving only enough (two rings) to attach the canula, the phenomenon took place as before.

It was then suggested that the force arising from the communication of motion of the current of air passing from the trachea into the laryngeal cavity might communicate its onward motion to the cricoid, and thus raise it on to the thyroid. The non-resisting and elastic crico-thyroid membrane offering no obstacle to such a movement of the cricoid cartilage, while the ascent of the thyroid would be checked by the resistance arising from the approximation of the bands inside, and the influence of the extrinsic muscles outside. Not being thoroughly satisfied, however, that this explanation solved the problem, we surmised that the expansion of the larynx itself, *when inflated*, might play an important part in producing the phenomenon.

The construction of the larynx is so complicated, it is not at first sight clear why such a movement as we have

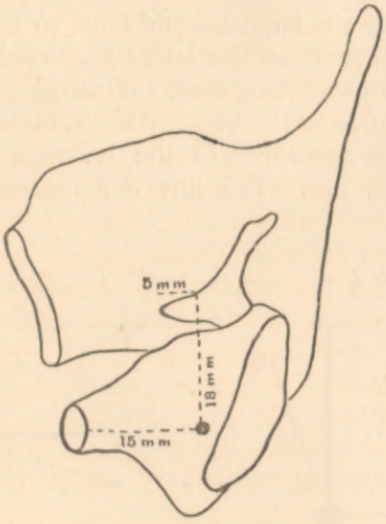
described should be caused by inflation, for when the cricoid cartilage is pulled up on to the thyroid (as by the action of the thyro-cricoid muscle) the vertical dimensions of the larynx are diminished, while the antero-posterior dimensions are increased. Whether the capacity of the larynx is increased or diminished by this movement cannot well be determined *a priori*. Therefore the following experiment was made in order to ascertain whether an upward movement of the cricoid cartilage was necessarily associated with an increased capacity of the larynx.

EXPERIMENT.

Small dog. Curarized. Artificial respiration. Pharynx plugged with cotton-wool; a cord strongly tied around the head and jaw in front of the ears, to compress the cotton and the passages leading upward. Trachea divided between second and third rings. A tubulated cork secured in the upper end, connected by a rubber tube with a delicate Marey's drum, whose lever indicates for every millimetre of excursion a certain fraction of a cubic centimetre of change of volume (1 mm. of curve = 0.01 cc. of volume). Irritation of the thyro-cricoid muscle on one side caused a descent of the lever of 10 mm., indicating an increase of the capacity of the larynx of one tenth of a cubic centimetre. When both thyro-cricoid muscles were simultaneously stimulated the lever went down 15 mm., showing, as might be expected, a still greater increase of the capacity of the larynx, as both of the muscles working together would naturally produce a more forcible rise of the cricoid than one alone.

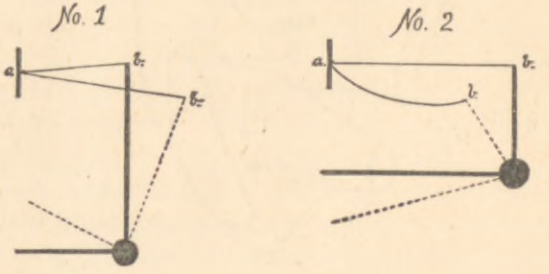
It may be questioned, certainly, how far an experiment of this nature can be applied to the living human larynx, or with what logical justice we can draw conclusions from it. We believe, nevertheless, and we shall append additional proof to sustain our opinion, that the lumen of the larynx is enlarged by an upward movement of the cricoid cartilage, and therefore in violent phonic efforts the cricoid, owing to the expansion of the larynx, must move upon the thyroid in such a way as to stretch the bands, since by so doing it increases the capacity of the larynx.

Inspection of the dissected human larynx enables us to see that the distance from the vocal process of the arytenoid cartilage to the crico-thyroid articulation is greater than the distance from this point to the anterior edge of the cricoid cartilage. The pivot then being at the articulation, the long arm of the lever is above, the short arm in front of the fulcrum. The diagram herewith presented, drawn from exact measurements, and representing the inside of the right lateral half of a human larynx from which the soft parts have been removed, shows us at a glance the relative proportions of the unequal arms of the lever. The fulcrum, denoted by the black dot, is directly opposite the crico-thyroid articulation.



Now here are two artificial larynges roughly constructed to illustrate the points of the present inquiry. The models are composed of a skeleton of wood, enclosed in a piece of thin rubber tubing, which renders them air-tight, with the exception of a small opening in the top, into which a glass tube is inserted. For convenience of description they may be designated as Nos. 1 and 2. No. 1 is articulated on the principle of the human larynx, namely, with the short arm

of the lever in front of the fulcrum. Connecting this by means of the rubber tube with the Marey's drum, and imitating the action of the thyro-cricoid muscle, by pushing the cricoid upward, we notice a fall of the lever denoting an increase in the capacity of the model. No. 2, on the other hand, is articulated in such a manner that the long arm of the lever is in front of the pivot. It will be seen in this case that, in making the same movement, the lever attached to the drum will ascend. Now, if the human larynx were constructed on this principle, it is evident that a blast of air would, by increasing the capacity of the larynx, relax the vocal bands. The relaxation being due in such a case to the fact that, as the horizontal arm of the lever is longer, and offers a larger area than the vertical arm, the pressure of the air inside the larynx would tend to force the former downward rather than the latter backward. The dotted lines in the following two cuts, indicating the manner the lever would move in the two instances, make our reasoning clear. No. 1 is according to the leverage of the human larynx; No. 2, not. The line *a b* represents the vocal band.



These researches may, perhaps, offer a suggestive clue in elucidating certain pathological conditions.[1] For instance, the fact that the singing voice can be relied upon, while, in the same individual, conversation is impossible, may, perchance, in a measure, be explained by this action of the air-blast as a tensor at high pressures. We know that the

[1] See case reported by Solis-Cohen: "Diseases of Throat," p. 642. Ed., 1880.

famous singer, Malibran, was always at constant war with her rebellious voice. She would never admit that it could resist her; it was something to be conquered. And it is only necessary to refer to the interesting pages by M. Legouvé upon this remarkable woman to learn the power of a strong will and powerful lungs to overcome vocal difficulties, and how she, with her characteristic saying, "I will force it to obey me," was able, in spite of severe pharyngeal inflammation, to electrify an audience solely by the violence of her efforts. It is insufficient to ascribe such vocal feats to "inspiration" so-called. There can be no vocal effects produced without definite physical causes. There may be many which are not demonstrable, for the working of the intrinsic muscles of the larynx is so complex that it is doubtful if we can devise any means of investigation sufficiently delicate to determine accurately all the laws which regulate their marvellous adjustments. Experimentation on one's self, after the fashion of certain writers, by pushing the cartilages with the fingers this way and that, presumably imitating the action of some muscle, is too gross a method to apply to such a delicate apparatus as the larynx; and theories founded on such manipulations, however interesting, cannot be accepted as reliable. To insure accuracy, the nerve supplying the muscle, or muscular bundles, ought to be exposed and irritated, and the working of the fibres graphically registered in some such manner as we have attempted. We think the facts demonstrated by these researches justify the following conclusions:

I. The cricoid cartilage is the most movable part of the laryngo-tracheal tract.

II. The thyro-cricoid muscle, according to its physiological action, should be described as *arising* from the thyroid cartilage, and *inserted* into, and giving motion to, the cricoid.

III. The air-blast, in virtue of the mechanism herein set forth, is a direct and important longitudinal tensor of the vocal bands.

BIBLIOGRAPHY.

GALEN: "Oeuvres Anatomiques, Physiologiques et Médicales." Traduites par le Dr. Ch. Daremberg.

VESALIUS: "De Corporis Humani Fabrica," 1545. (Ed. of Albinus, 1725.)

CASSERIUS: "De Vocis Auditusque Organis," 1601.

BROWN: "A Compleat Treatise of the Muscles," 1683.

DIONIS: "Nouvelle Anatomie de l' Homme," 1695.

COWPER: "Myotomia Reformata," 1724.

HALLER: "Elementa Physiologiæ," 1766.

MAGENDIE: "Mémoire sur l' usage de l' Épiglotte dans la Déglutition," Paris, 1813.

WILLIS: Mechanism of the Larynx. Trans. of the Camb. Philosoph. Soc., x, iv, 1829.

LAUTH: Remarques sur la Structure du Larynx, etc. Mémoires de l' Académie Royale de Médecine de Paris, Tome iv, 1835.

LONGET: Recherches Expérimentales sur les Nerfs des Muscles du Larynx, etc. *Gazette Médicale de Paris*, 1841.

THEILE: "Traité de Myologie et d'Angéiologie," 1843.

BISHOP: Anatomy of Larynx, in Todd's "Cyclopædia of Anat. and Phys.," 1839–1847.

CUVIER: "Anatomie Comparée," Tome viii, 1846.

HARLESS: Stimme in Wagner's "Handwörterbuch d. Physiologie," Bd. iv, 1853.

BATTAILLE: "Nouvelles Recherches sur la Phonation," 1861.

BUDGE: "Lehrbuch d. speciellen Phys. des Menschen," 1862.

RIEGEL: Lähmung Einzelner Kehlkopfmuskeln, *Deut. Arch. f. klin. Med.*, Bd. vii, 1870.

JELENFFY: Der Musculus crico-thyreoideus, *Arch. f. d. Ges. Physiol.*, vii, 1873.

SCHECH: Experimentelle Untersuchungen über die Funktionen der Nerven und Muskeln des Kehlkopfs, *Ztschr. f. Biologie*, ix, 1873.

SCHMIDT: "Die Laryngoscopie au Thieren," 1873.

RÜHLMANN: Sitzungsb. d. Wiener Acad. Mathernnaturw., Classe lxix, 1874.

MICHAEL: *Berlin. klin. Wochenschr.*, 1876.

GRÜTZNER: In Hermann's "Handbuch d. Physiol.," 1879.

MEYER: "Unsere Sprachwerkzeuge," 1880.

ELSBERG: Paral. of mus. of larynx. *Arch. of Laryngology*, vol. iii, No. 3, 1882.

See also the various standard text-books of anatomy and physiology; special works on diseases of the throat and physiology of the voice.

Press of
G. P. Putnam's Sons
New York