Observations on the physiology of the larynx / by John Wyllie, M.D.

OBSERVATIONS

ON THE

PHYSIOLOGY OF THE LARYNX.

BY

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THE PHYSIOLOGY OF THE LARYNX.

THIS paper is intended as a contribution to the Physiology of the Larynx, and not as an exhaustive treatise on the subject. It embodies the results of a somewhat lengthened series of experiments and observations on the following topics:—

1*st*, On the descent of the epiglottis during deglutition.
2*d*, On the valvular action of the glottis.
3*d*, On the production of voice.

I.—*On the Descent of the Epiglottis.*

In former times the epiglottis was thought to be the only safeguard against the entrance of food into the windpipe, and its integrity was therefore regarded as of almost vital consequence. But more recently, cases were recorded in which it had been entirely removed by accident or destroyed by disease, and yet in these the bolus did not find its way into the larynx, for this was still effectually prevented by the closure of the *glottis*, so that the act of deglutition continued to be performed with safety, and even with ease. Magendie, also, in his experiments, repeatedly removed the epiglottis of the dog without apparently putting the animal to much inconvenience.[1] Many physiologists were therefore led to regard this valve as only of secondary importance, and merely accessory to the glottis in the performance of its function. In our own time, however, another class of cases is being observed with the aid of the laryngoscope, in which the *glottis* is permanently incapable of closure, owing in some to paralysis of the intrinsic muscles of the larynx, and in others to the presence of tumours upon the vocal cords; and yet, in the majority of these, the larynx seems, by the epiglottis alone, to be as securely guarded as it was when the parts were healthy. There are, then, at the opening of the windpipe, two

[1] Magendie's Compendium of Physiology, p. 240.

protecting valves, either of which is in itself capable of closing it when food is passing; but a double security is obtained by their simultaneous action. Of the two, perhaps the epiglottis is the more important in performing this function, for by its shape and position it seems specially fitted to roof in the larynx; and, in ordinary circumstances, it alone is actually of service, for no food comes in contact with the glottis, which, nevertheless, is closed as an additional protection.

What, then, is the mechanism by which the depression of the epiglottis is accomplished? On this subject various theories have been propounded. For example, it has been maintained that "the larynx is closed, or rather is covered, by the epiglottis depressed mechanically by the alimentary bolus,"[1]— an explanation which must have appeared improbable to any one who thought of such an arrangement protecting the larynx from fluids as well as solids. A second and much more currently accepted theory is, that during deglutition the root of the tongue is pushed downwards upon the epiglottis, which is thus in its turn depressed upon the larynx. This view is modified by some, who suppose that when the larynx is elevated, the epiglottis must be pressed upwards against the base of the tongue, which in thus effecting its closure acts the part only of a passive agent as it were. Thirdly, it is maintained that the action in question is accomplished solely by the special depressor muscles of the epiglottis, and that after the passage of the bolus the valve is raised again "by its own elasticity and that of its ligaments." This view, which was formerly promulgated by Santorini, has lately been supported by Czermak, who concludes, from his experiments with the auto-laryngoscope, that "the epiglottis is not passively depressed, for example by the base of the tongue, but this depression is actually caused by the proper muscles of the epiglottis itself."[2] A tactile examination of the epiglottis during deglutition fully confirms this statement in so far as it refers to the base of the tongue. The theory, however, that the action of its special depressor muscles is the sole agency which effects the descent of the valve, is met by a serious objection. For, the epiglottis being raised after the passage of the bolus—"by its own elasticity and that of its ligaments"—it naturally follows, if we accept this statement, that, in accomplishing its depression, the muscles must have overcome some resistance from these ligaments. One would, therefore, expect to find a development of muscle commensurate with such resistance; but a dissection of the parts shows us that these depressors of the epiglottis are mere thin bands of muscular fibre, which, if the larynx be not well developed, are too apt to escape observation altogether. Again, if we turn to the lower animals, we find in certain of the ruminantia, a strong muscle attached to the front of the epiglottis and stretching forwards, in some, into the substance of the tongue,

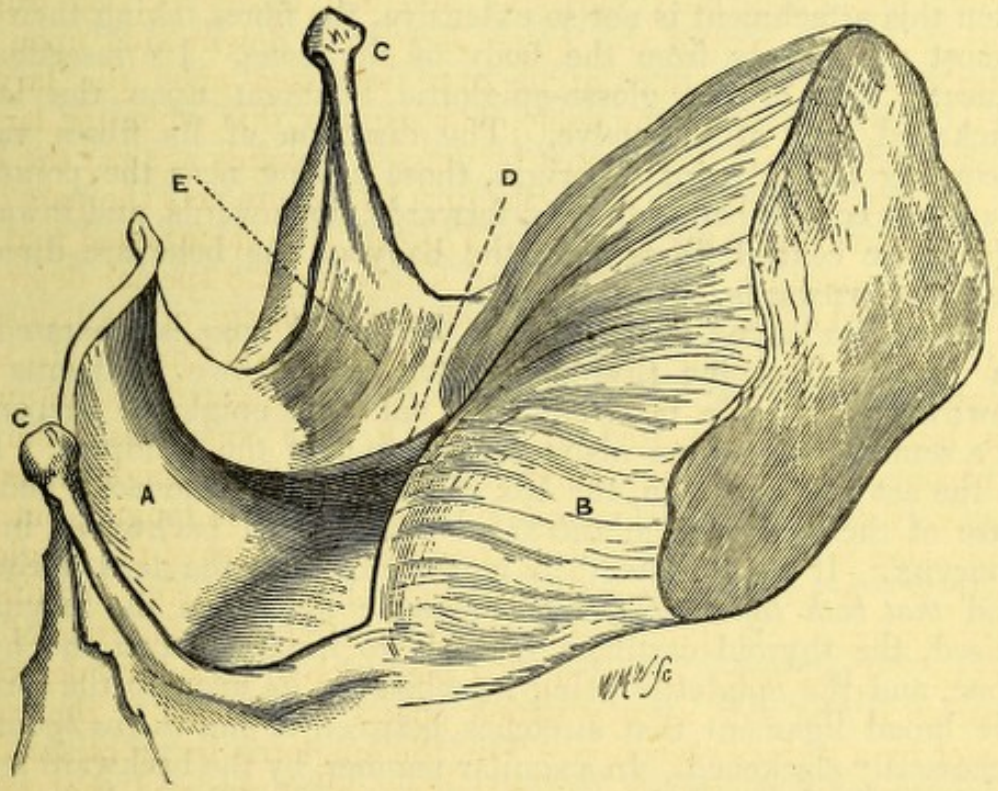
[1] M. Meyer.

[2] Czermak's Monograph, translated by the Sydm. Society.

and in others, the sheep for example, dividing in front into two processes, each of which becomes attached to one of the stylo-hyal bones, just above their articulation to the front of the os hyoides. With the existence of this strong elevator muscle we find no corresponding development of the depressors, they are here as weak and thin as in the human subject. It is, then, very improbable that, in depressing the epiglottis, they alone should be the agents employed. Let us see if, in the phenomena of deglutition, we can find anything which may render them assistance.

When the parts concerned in the act of swallowing are carefully dissected, two ligaments are found which are specially adapted to support the epiglottis when the larynx is at rest.[1]

The Epiglottis and its Ligaments.



A, The epiglottis. B, The base of the tongue. C C, The cornua of the hyoid bone. D, The glosso-epiglottic ligament. E, The hyo-epiglottic ligament.

First, there is the *glosso-epiglottic* ligament. This has been called by some anatomists the *frœnum epiglottidis.* It seems to be the prolongation backwards of the fibrous septum of the tongue, and at its origin many of the muscular fibres of the cortex are inserted into it. Posteriorly, it crosses the hyoid bone, and

[1] These ligaments have been carefully described by Bishop in his article on the Larynx, in Todd's Cyclopædia of Anatomy and Physiology, and by other special writers on the larynx; but they are overlooked by the author of an ordinary text-book.

becomes attached to the epiglottis about its middle. It stands out prominently in the mesial line, its sharp edge being enclosed in the middle glosso-epiglottic fold of the mucous membrane. The microscope shows it to be chiefly composed of elastic fibres, but notwithstanding this fact, it is by no means easily stretched when it is isolated. This ligament is the representative, as Magendie pointed out, of the elevator muscle of the epiglottis in the ruminantia, to which I have already referred. I have, in several cases, observed muscular fibres clustering around it even at the epiglottic attachment.

The second ligament is the *hyo-epiglottic* (E), one of equal importance. This is a well-marked membranous expansion stretching from the concave edge of the hyoid bone downwards to the anterior surface of the epiglottis. Its line of origin extends in many cases backwards almost to the point of the great cornu on either side, but often this attachment is not so extensive, the fibres taking their rise almost exclusively from the body of the bone. Its insertion is beneath that of the glosso-epiglottic ligament upon the lower thickened half of the valve. The direction of its fibres varies according to the point of origin, those arising near the points of the great cornua being directed forwards, downwards, and inwards, whilst the central fibres from the body of the bone are directed simply downwards and backwards.

When the larynx is at rest, and the hyoid bone is separated by an interval from the thyroid cartilage, these two ligaments dip downwards to their insertion, and hold the epiglottis suspended in a semi-erect position above the opening of the windpipe. But, in the act of deglutition, the box of the larynx is elevated, and the base of the tongue is at the same time carried backwards in the pharynx. If we imitate their movements with the dead parts, we find *that both ligaments become relaxed;* for, when the larynx is raised, the thyroid cartilage is made to impinge upon the hyoid bone, and the epiglottis being attached by its apex to the former, the broad ligament that stretches between it and the *os hyoidis* is necessarily slackened. In a similar manner, by the backward movement of the base of the tongue, the glosso-epiglottic ligament is relaxed. The epiglottis has thus lost the support of both its sustaining ligaments, and by its own gravity it tends to droop towards the opening of the larynx,—if touched by the finger its closure is very easily completed. During deglutition, if the little depressor muscles are brought into action in these circumstances, they will meet with no resistance, and by very slight traction on their part, the roofing in of the larynx will be rendered quite secure. After the act of deglutition, the larynx once more descends, the depressor muscles cease to act, the ligaments are put gently on the stretch, and the epiglottis is restored to its original position. The return of the valve, it will thus be observed, is due, not to its elastic ligaments having recoiled after being stretched,

but, on the contrary, to their being gently tightened after a temporary relaxation.

A concluding experiment may illustrate the action of these two ligaments when they are in a state of extreme tension. In the highest notes of the voice, the larynx is raised as it is in deglutition; but there is this difference, that the os hyoides is pulled further forwards by the genio-hyoid muscles, so that the point of the pomum Adami engages itself behind the hyoid bone, instead of merely impinging upon it. The hyo-epiglottic ligament is thus put upon the stretch. In like manner the glosso-epiglottic is pulled upon by the muscles of the tongue. If, now, the finger be introduced into the pharynx when the highest note is being sung, it will be found that the epiglottis is drawn forwards upon the base of the tongue, so that its anterior surface actually touches the mucous membrane of that organ; the only part of the valve which can be pushed backwards is its free upper border, which may be bent in that direction by the finger,—its middle portion is almost immovable. If, in the same circumstances, the throat be examined with the laryngoscope, these observations will be confirmed; and it will be further seen that the natural concavity of the posterior surface of the epiglottis is considerably increased, owing to its centre being pulled forwards, whilst its lateral edges are retained somewhat in position by the aryteno-epiglottic folds. These observations, however, are more strictly concerned with the function of voice. I mention them here only to illustrate the importance of the glosso-epiglottic and hyo-epiglottic ligaments in regulating the position of the epiglottis.

II.—*The Valvular Action of the Glottis.*

The circumstances in which shutting of the glottis is observed to take place may be classed under three heads:—

1*st*, Partial closure takes place during phonation, the vocal ligaments being then approximated, so that only a narrow chink is left, through which the air escapes.

2*d*, In the act of deglutition, complete closure occurs simultaneously with the descent of the epiglottis, as we have already seen.

3*d*, Perfect closure also takes place whenever the air is compressed within the lungs and trachea, whether by a voluntary effort as in holding the breath, or involuntarily, as before each act of coughing.

I shall, in the meantime, confine my remarks to the second and third of these conditions, reserving the first for that part of the paper which treats of the production of voice.

That the glottis is shut during the act of deglutition is proved by the experiments of Magendie on dogs, and by the observation of such cases as one recorded by Mayo. A man, in an attempt to destroy himself, made a deep gash in the upper part of his throat which

extended into the pharynx. "The wound," says the narrator, "was horizontal, and passed backwards over the upper border of the thyroid cartilage, severing the epiglottis near its attachment to the latter, yet the patient, in two or three days after the injury, swallowed easily, and without the least irritation of the larynx, although so free was the opening in the throat that some of the fluid swallowed always ran out at the wound."[1] Observations such as these leave us in no doubt that the glottis is shut during the act of deglutition; but, even under the most favourable circumstances, it must be extremely difficult to observe the exact manner of its closure, and accordingly we are left very much to infer that the order of phenomena is the same in deglutition as we observe it to be in voluntary shutting of the glottis.

The mechanism of this voluntary closure has been of late years beautifully demonstrated by Czermak. "During complete and hermetic closure," says that author, "I have observed the following phenomena:—

"1*st*, The arytenoid cartilages intimately meet at their internal surfaces and processes, and bring the edges of the vocal cords in contact.

"2*d*, The superior vocal cords approach the inferior so as to obliterate the ventricles of Morgagni, at the same time they also meet in the median line.

"3*d*, The epiglottis being lowered and its cushion made more prominent still, it presses against the closed glottis, the contact taking place from before backwards. All these changes take place with such rapidity that great attention is necessary to examine them in detail."[2]

The mode of performing these experiments is, first to shut the glottis gently, and then to compress the air within the chest and trachea, by putting the muscles of expiration more and more powerfully into action.

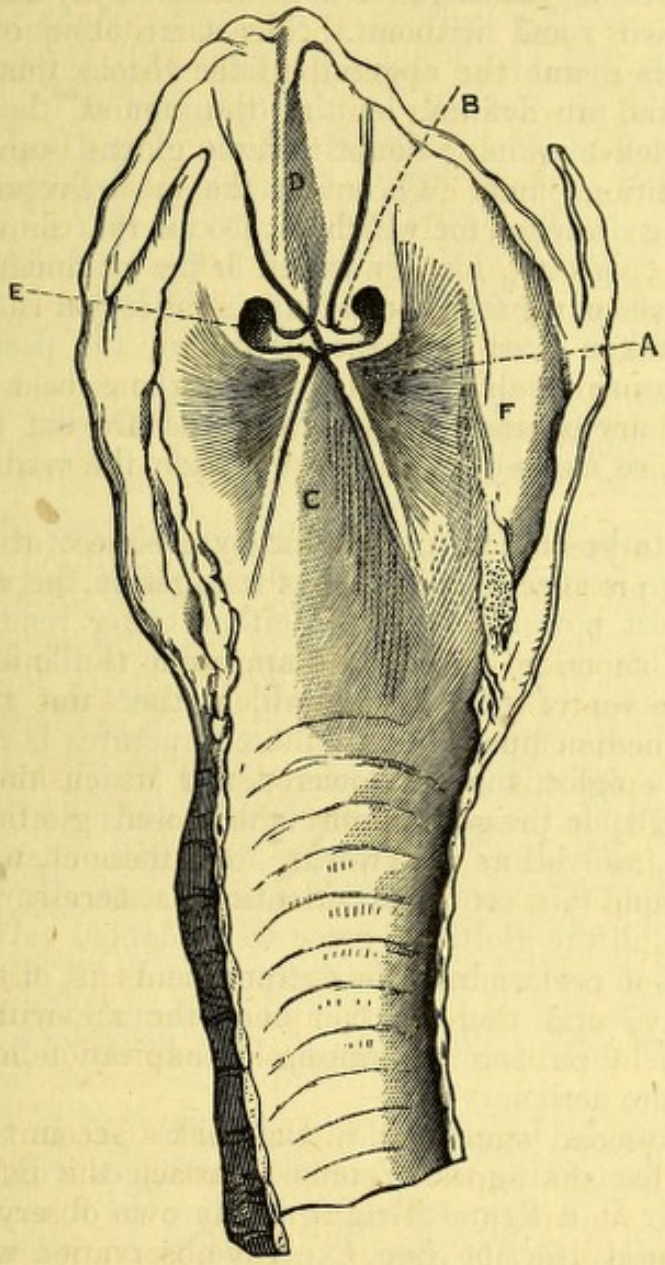
With the second statement in Czermak's account of the phenomena, viz., that the superior cords approach the inferior so as to obliterate the ventricles of Morgagni, my own observations, as will be seen presently, do not concur. Any observation with the laryngoscope, regarding the condition of these ventricles, is extremely liable to fallacy, for their oblong orifices are situated in the lateral walls of the larynx and look inwards, so that, observing them from above, it is almost impossible to tell whether they are open or closed.

The question now to be considered is, What is the use of this complexity in the shutting of the glottis? "No doubt," as Czermak remarks, "these threefold occurrences in the hermetic closure of the larynx explain the resistance which the glottis successfully opposes to the pressure of the air without the development of much force during the effort." But what is the exact importance of the false and of the true vocal cords,—what is the

[1] Mayo's Physiology, pp. 371 and 382. [2] Czermak's Monograph.

physiological purpose of the ventricles of Morgagni? These are problems which remain unsolved.

View of the Glottis from behind.



A, True vocal cord. B, False vocal cord. C, Wedge-shaped space below true cords. D, Wedge-shaped space above false cords. E, Ventricle of Morgagni. F, Ala of thyroid cartilage.

The difficulty in deciding these questions has, it appears to me, arisen in some measure from an anatomical misconception. The vocal cords are considered by many as the free edges of membranes which are flattened both above and below. But if a vertical section be made through the larynx so as to divide both false and true cords transversely, it will be found, that when these are approximated, the cavity of the larynx above the false cords as well as that of the trachea below the true, is wedge-shaped (D and C). When thus in opposition, the upper surfaces

of the true vocal ligaments present a broad flattened plane slightly hollowed out on each side, but on their tracheal aspect the mucous membrane is observed to fall away obliquely downwards and outwards, thus leaving an angle of considerable size, which forms the margin of each vocal ligament. The same obliquity is observed in the mucous membrane above the false vocal cords, whilst their lower margins are defined by the openings of the ventricles of Morgagni, well-marked pouches which extend upwards behind them about half-an-inch. These appearances are represented in the accompanying drawing, for which as also for that showing the ligaments of the epiglottis, I am indebted to the kindness of my friend Mr Ramsay, one of my fellow-residents in the Royal Infirmary. This sketch was taken from a recent dissection, the posterior wall of the trachea being removed, as also that of the cricoid cartilage with the attached arytenoids. The vocal cords are cut through about their middle, so as to exhibit in the section the ventricles of Morgagni (E).

Now it is to be borne in mind that by closure of the glottis complete stoppage is effected, not only of inspiration, but also of expiration, the most powerful efforts at either being rendered quite ineffectual. This is, no doubt, in a sense due to the action of those intrinsic muscles of the larynx which close the rima, but the strength of these comparatively minute structures is surely in itself inadequate to resist the enormous power which the air may be made to exert upon the glottis from within, during a forcible attempt at expiration, as well as its pressure from without, when we try to inspire.[1] From this consideration one is naturally led to suspect the existence in the glottis of some well-adapted valvular arrangements, suited to control both the entrance and exit of the air. With the view of ascertaining whether such arrangements exist, and, if so, what is their precise nature, I made the following experiments upon the dead larynx:—

Having brought together the true cords (A) in the vocalizing position, by transfixing the arytenoid cartilages with a needle, and applying over it a figure-of-eight ligature in a manner which I shall afterwards describe (see experiments on voice), I blew upwards through the trachea, and at the same time attempted to stop the current of air by bringing the true vocal cords accurately into contact; this being done by pressing the arytenoids firmly between the finger and thumb. After repeated trial I found that no manner of adjusting the cartilages could completely obstruct the passage of the air, for as I have already said the space in the trachea below the vocal cords is wedge-shaped (see drawing C), and the air was thus enabled to wedge itself between the vocal ligaments, producing in its escape a sound which more or less

[1] "We may wonder that muscular fasciculi so slight as those of the larynx, however advantageously placed, should be capable of counteracting the efforts of the diaphragm and other muscles of inspiration. But they are found to be no less efficient against the muscles of expiration."—*Mayo's Physiology.*

resembled the voice. Feeling satisfied that the true cords could not present any serious obstacle to the *exit* of air when the glottis is closed, I now drew air backwards through the larynx, in order to test their value as opposing its *entrance* during attempted inspiration. I found that by a very slight and easy adjustment of the arytenoid cartilages I could prevent its entrance entirely. The cords did not require to be forcibly pressed together; the circumstances most favourable for obtaining their perfect valvular action were that they should be accurately approximated but not stretched, so that when air was blown upwards through the trachea a low note was produced. In this condition by gently pressing forward the apices of the arytenoid cartilages the air was completely obstructed.

I next proceeded to ascertain the effect of bringing together the *false* vocal cords (B). These are not so easily brought into contact as the true, and the means adopted were therefore rather more complicated. Still keeping the arytenoid cartilages fixed together as before, with a needle and ligature, I passed, in addition, two other needles through the anterior surface of the thyroid cartilage, one on each side of the middle line, just opposite the anterior attachments of the cords, and carefully guided their points backwards to their arytenoid extremities, so that each needle was contained within the free edge of a false ligament. The posterior attachments of the cords were then approximated by pressure between the finger and thumb, and at the same time in their whole length they were brought into close apposition by separating the heads of the needles in front of the thyroid cartilage. On attempting to blow upwards through the trachea, when the parts were so arranged, the closure of the glottis was found to be complete. The simple coaptation of the free edges of the false cords proved itself sufficient to obstruct entirely even a powerful current of air from below.

The conclusion to be derived from these experiments is obvious. There is within the larynx a double valve which is capable of controlling both the exit and entrance of air. The plan found so commonly throughout the body in such structures, in the aortic and ileo-cœcal orifices, and in the course of the veins, holds good here likewise. In the upper half the resemblance is most obvious. Comparing it with the aortic valve we find the representatives of the sinuses of Valsalva in the well-marked ventricles of Morgagni, whilst the cusps are reproduced in the two folds of mucous membrane, whose free edges are known as the false vocal cords.

The same design may be traced in the lower half of the valve. When the true vocal ligaments are brought into apposition, no deep sinus is found on either side, but their upper surfaces form together a broad flattened plane slightly hollowed out exterior to the margins of the rima glottidis, and this arrangement, owing to the greater density and mobility of the parts, is found to act as efficiently as the well-marked ventricles and cusps of the upper valve.

A laryngoscopic examination fully confirms the view which I have just stated. The following phenomena may then be observed:—

1*st*, When the glottis is simply closed, and no effort is made either to take in breath or to expire, the false cords are separated by a very narrow interval through which the edges of the true vocal ligaments may be seen in close apposition.

2*d*, When an effort is made to *inspire*, the superior cords meet in the middle line so as to leave only a very small triangular opening posteriorly, through which there still may be caught a glimmering of the pale surface of the true ligaments.

3*d*, When expiration is attempted, the false cords are immediately coaptated throughout their whole length, and if the effort made be powerful the parts above are observed "to arch or curve outwards without allowing the air to escape" (Czermak). This swelling out of the mucous membrane at the upper part of the larynx can be due to nothing but the inflation of the ventricles of Morgagni beneath.

The physiology of these ventricles and of the superior ligaments of the larynx is thus after all so beautifully simple as to render it very surprising that their action was not long since recognised. Formerly, the difficulty no doubt lay in the impossibility of displaying the parts in the living body. Even before the days of the laryngoscope, however, I find, on looking over the various treatises on the larynx, that among the numerous conjectures regarding their use, one shrewd guess has been made, which very nearly approaches the whole truth. In Mayo's Physiology there occurs the following passage:—"Mr Willis has very ingeniously conjectured that the closure of the glottis takes place through the inflation of the ventricles from below, when the ligaments have been approximated and an expiration has been attempted. An objection," he continues, "was suggested to me by Mr Wheatstone, which of itself appears fatal to Mr Willis's hypothesis;—we can close the larynx as well during inspiration as during expiration."[1] I have not yet discovered this suggestion in Mr Willis's own writings, but it is evident that he has never thought of the *true* cords as preventing the entrance of air, otherwise Mayo's criticism would not have been offered.

The characters of that peculiar brassy cough which exists so often in cases of aneurism of the aorta where the recurrent laryngeal nerve is involved, may, I think, be explained in the following manner. Each normal act of coughing may be divided into two stages. 1*st*, The complete closure of the glottis, false and true cords together, so as to enable the air to be compressed within the chest and trachea; its escape being prevented by the false cords and ventricles of Morgagni as just explained. 2*d*, The sudden and complete opening of the glottis, allowing at once the explosive

[1] Mayo's Physiology, p. 381.

escape of the compressed air. Both of these movements are performed by muscular action. But in the typical aneurismal cough the glottis is neither closed nor opened perfectly, for the pressure upon the recurrent nerve has impaired its power of transmitting a normal stimulus to the muscles, so that whilst the true cords are brought closely enough together to produce voice, the false cords —not so easily approximated—remain somewhat apart, and the air is therefore allowed to escape, so that the cough is imperfect at its commencement. Again, it is brassy or voicy, because in the second stage the opening of the glottis is not so sudden and perfect as it ought to be, the muscles being kept in a state of spasmodic contraction by the direct irritation of the nerve where it is pressed upon by the aneurismal tumour, so that in the muscles there may be said to exist a tendency to spasm, associated with a partial loss of voluntary motion, a combination not unfrequent in other nervous affections. Sometimes the spasm is so great as to give rise to crowing on inspiration, and, in a degree greater still, it is the frequent cause of death by asphyxia, for the true cords remaining in apposition shut off by their valvular action the entrance of the air.

In order to understand the action of the muscles by which the glottis is closed, one must have a correct conception of the arytenoid cartilages. Each of these small complicated bodies has somewhat the appearance of a minature 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. 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 is covered only by the mucous 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 ligament is attached. The *outer edge* terminates inferiorly in the posterior external angle, and, together with it, forms the chief point of insertion for the muscles. To the angle are attached the tendons of the posterior and lateral crico-arytenoids, 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, namely, the *processus vocalis*, and the posterior 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, and is so formed as to fit

upon the corresponding saddle-shaped surface of the cricoid. This joint is so oblique, that when the arytenoids are rotated upon it, they naturally approach each other in the middle line, so that their internal edges and vocal processes are brought into apposition. Owing to the articular surface being situated on the inferior aspect of the projecting posterior angle, the whole body of the cartilage extends forwards and assists in covering the opening of the larynx. The concave posterior surfaces being anterior to the articulations, it necessarily follows that the arytenoid muscle, to which they give attachment, must of itself be sufficient to pull the cartilages with their processus vocales together in the middle line.

The mechanism by which the true cords are approximated is thus comparatively simple. Three muscles are said to take part in the action. The arytenoid pulls the cartilages together, bringing their internal edges in contact, so as to close the so-called respiratory portion of the glottis; the thyro- and crico-arytenoids, whilst they assist the other, act more particularly by rotating the cartilages inwards, so as to bring their anterior processes into still closer apposition, and also to lower them in the cavity of the larynx. This last action must especially be accomplished by the fibres of the thyro-arytenoid, which, as already mentioned, are attached along the outer edge, almost as high as the apex of each cartilage.

It is not so easy to determine by what means the false cords are brought together. We have already seen that the point to which most of their fibres are attached posteriorly, is a pit about the middle of the anterior convex surface of each arytenoid cartilage, and, therefore, to the outer side of, and superior to, the insertion of the true ligaments. But this is not their only posterior connexion; another strong band of their fibres becomes attached to the apex of the cartilage of Wrisberg, a body which is too much overlooked by anatomists. Anteriorly, besides their thyroid attachments, they send upwards and forwards several processes to the edge of the lower thickened portion of the epiglottis. There is also to be observed, stretching between the margin of that valve and the superior border of each false ligament, in its whole length, a thin layer of muscular fibre connected with the aryteno-epiglottic muscle.

The cartilages of Wrisberg are contained within the aryteno-epiglottic folds of the mucous membrane, lying immediately in front of, and parallel to the inner edge of the arytenoid cartilage on each side. They are very slender, except at their upper end, where they form in the free edge of the aryteno-epiglottic fold, a rounded eminence, which is often mistaken for the apex of the arytenoid cartilage. "It," says Ecker, "is surrounded by mucous glands, from it along the false cords a horizontal process runs forwards, which one sees radiate between the elastic fibres of these cords."[1] In front of the inner edge of each arytenoid, the position of this cartilage is marked by a slightly prominent line on the mucous

[1] Ecker's Icones Physiologicæ.

membrane, which extends downwards nearly to the level of the false ligament.

As to the means by which the false cords are approximated, the thyro- and crico-arytenoids which lie parallel with them may, when they contract, tend to bring their free edges in contact; possibly also the cartilages of Wrisberg may bear to the false cords something of the same relation which exists between the arytenoids and the true vocal ligaments, the cartilages forming movable bodies, which can be approximated by muscular action. Our knowledge of these points is very unsatisfactory; the subject requires further investigation. But be that as it may, it is evident that if the muscles which bring together the false vocal cords act also during the production of the high notes of the voice, their influence as closers of the upper part of the glottis must then be counteracted by the fibres, ligamentous and muscular, which stretch between these cords and the margin of the epiglottis. For that valve being then, as we have seen, pulled strongly forwards, these fibres will draw the false ligaments upwards and outwards, and thus keep patent the interval between them.

III.—*The Mechanism of Voice.*

The great fact that the vibrations produced at the free edges of the inferior ligaments of the larynx are the primary source of the vocal tones, has been long since recognised by physiologists. Many of the minor questions, however, which the subject includes, such as the determination of all the different agencies which may tend to raise or lower the pitch of the notes, the special action of each of the muscles, the mechanism of the falsetto voice, are still involved in a great degree of doubt and obscurity. In the following remarks I shall first note shortly a number of phenomena bearing upon these questions, which may be observed in the living body; and secondly, I shall adduce such evidence as may be afforded by a series of experiments performed upon the dead larynx.

1*st*, When the laryngoscopic mirror is placed at the back of the throat, and the individual examined is desired to sound a vocal note, "the cords are seen to come together with surprising mobility,"[1] and their edges are thrown into a state of rapid vibration. In these circumstances it is to be observed,—(*a.*) That the vibrations during a low note are distinctly visible, but as the pitch of the voice is raised they become more and more rapid and consequently less distinct, until, in the high notes, the cords appear quite motionless. (*b.*) In no part of their posterior half are the vocal cords ever seen to come into actual contact. Even the points of the vocal processes of the arytenoid cartilages are separated by a narrow interval, which continues of the same size in the high notes of the true voice as in the low; but when the sound is made to pass from the true voice into the same note of the falsetto, the vocal processes distinctly approach each other, so that the chink between them is

[1] Czermak.

diminished. The epiglottis overshadows the anterior ends of the cords so much that it is impossible with the laryngoscope to tell whether they ever come into actual contact so as to cause the vibration to cease in that part of their extent. (*c.*) As the voice rises in the scale, both false and true cords are evidently more and more stretched, the epiglottis at the same time is seen to be drawn forwards and upwards towards the tongue, as already described.

2*d*, If now an examination of the throat be made with the finger, it will be found that during the production of base notes the cavity of the pharynx is large and capacious, but in the higher treble tones its muscular walls are contracted more and more as the voice ascends, till the finger is felt to be actually grasped within them. This narrowing of the cavity may be observed to be slightly greater in the false voice than in the true, the pitch of the note remaining the same.

3*d*, The condition of the soft palate varies very much during phonation. In the production of low notes, it is raised so as to form a vaulted arch, the isthmus of the fauces is widely open, and the uvula is of its natural size, the levator palati seems the only muscle in action. In the high notes, on the other hand, the whole of the muscles seem to be violently contracted, the interval between the posterior pillars of the fauces is reduced to one-fourth of its natural size, the uvula disappears almost entirely, and the posterior edge of the palate may be felt with the finger to be quite hard and tense. The velum altogether presents an appearance somewhat like the roof of a house, its central line being much elevated, whilst its sides slope obliquely downwards, owing to the contraction of the palato-glossus and palato-pharyngeus. The elevated palate thus constitutes a fixed point from which the palato-pharyngeus may pull upon its other attachments to the wall of the pharynx and the alae of the thyroid cartilage.

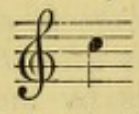
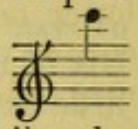
4*th*, The position of the box of the larynx varies with every note. If the finger be applied over the pomum Adami, it will be found that, during the treble tones, the hyoid bone is pulled upwards and forwards, carrying the larynx along with it; and that finally, when the voice approaches its highest pitch, the thyroid cartilage becomes still further elevated, so that its sharp projecting angle engages itself behind the body of the os hyoides. In the production of the base notes, on the other hand, the box of the larynx is pulled downwards from its position of rest, and during the lowest tones the inferior edge of the hyoid bone becomes applied to the upper border of the thyroid cartilage. The distance between the highest and the lowest point to which the pomum Adami is thus capable of reaching amounts to about one inch. As the larynx rises, the width of the interval between the cricoid and thyroid cartilages becomes perceptibly diminished. At the moment of transition between the true and the false voice, this interval, according to some observers, opens slightly, and the thyroid cartilage at the same time is some-

what lowered; these observations were first made by Mr Bishop, who regards them as affording very weighty evidence in support of his own theory of the falsetto, but I cannot say that I have been able to verify them. Another important observation to be made is, that *during the highest notes the thyroid cartilage is constricted so that its width from side to side is less than it is when the larynx is at rest.* Any one may satisfy himself of this by measuring the box of the larynx between the finger and thumb. The following little experiments may illustrate the effects which this constriction must have upon the voice.

(*a.*) When the alae of the cartilage are pressed between the finger and thumb, and a high note at the same time is sounded, it will be found that on suddenly removing the pressure, the voice involuntarily falls several notes in the musical scale. In myself, I find that this pressure renders falsetto singing easier, so that with its aid I am able to take several notes higher than I can otherwise reach. (*b.*) An opposite experiment consists in pressing backwards with the finger the point of the pomum Adami when a low note is being produced. In this case, on suddenly removing the pressure, the voice at once rises several notes. (*c.*) When, during the very lowest note of my voice, I compress the upper part of the thyroid cartilage in the manner of the first experiment, I find that, whilst the pressure continues, the voice involuntarily alternates between the natural bass tone and a high treble of a somewhat falsetto character. The only explanation of this phenomenon which I can think of is, that the vocal cords have come in contact at opposite points, so that the glottis acquires the same pitch as if it were half closed. I may state, however, that I have succeeded with this experiment only as yet upon my own larynx.

In performing experiments upon the dead larynx, I have adopted very much the plan employed by Professor Müller. The first thing to be done is to fix the arytenoid cartilages, which may be accomplished by passing a needle transversely through their bases, and pulling them together by applying, on their posterior surface, around the projecting ends of the needle, a figure-of-eight ligature. When this is done with care, the vocal cords are found to be brought accurately together in the middle line, so as to be on the same level and to possess an equal degree of tension. I found it of great advantage to use the small semicircular suture needle, since its employment obviates the necessity of notching the alae of the thyroid cartilage, which must be done when the arytenoids are transfixed by a pin or awl, as recommended by Professor Müller. In so notching the posterior borders of the thyroid, one is very apt to detach altogether their inferior cornua, and after such an accident any experiments in imitation of the action of the muscles are of no value. I have generally preserved attached, in the following experiments, the epiglottis and the hyoid bone, since I have found that voice is more easily produced when they are present, owing

probably to the support given to the vocal cords by the mucous membrane of the upper part of the larynx, which is then comparatively tense.

For convenience, the different musical notes will be indicated thus:—The note  will be marked C, and those above it up to  will be indicated like it, simply by the letters;  however, and its octave will be marked C', D', etc., whilst the octave below C will be marked B_1, A_1, etc., and that lower still as B_2, A_2, etc.

Experiment 1.—The larynx was that of a woman aged about fifty years. The cartilages were very little ossified. Attached were the hyoid bone, the epiglottis, and about three inches of the trachea. The arytenoids were fixed with a needle and a ligature in the manner just described, and a leather tube about five inches long was inserted into the opening of the windpipe. On supporting the larynx by the cricoid cartilage alone in a horizontal position, the note produced by blowing very gently through the tube was G. No difference in pitch was produced when the short tube was taken out and replaced by another a foot in length. By pressing backwards the thyroid cartilage, the note could be lowered to G_2; on the other hand, by pulling the thyroid forwards, the arytenoids being fixed, the pitch could be raised to G, so that the compass of the voice embraced two octaves. I could occasionally produce the note A, but it was of a screaming imperfect character. The effect of gently depressing the epiglottis, so as to have only a narrow opening between its margin and the arytenoid cartilages, was to lower the pitch one full tone.[1]

I next proceeded to test the effects of weights attached to the thyroid cartilage so as to stretch the vocal cords. With this object in view, I tied the free ends of the figure-of-eight ligature to a projecting piece of wood, thus suspending the larynx by its arytenoid cartilages. I then passed another strong needle through the angle of the thyroid cartilage, just opposite the attachment of the vocal cords, and to this, the larynx being held in a horizontal position, I suspended the weights with the following effects. The fundamental note being G_1, the addition of

1 oz.	raised pitch to	G_1	sharp.
2 „	„	A_1	
3 „	„	B_1	
4 „	„	B_1	
5 „	„	C	
6 „	„	C	
7 „	„	D	
8 „	„	D	
9 „	„	D	
10 oz.	raised pitch to	D	
11 „	„	E	
12 „	„	E	
13 „	„	E	
14 „	„	E	
15 „	„	E	
1 lb.	„	G	
2 „	„	A	
No further note produced.			

[1] Müller found this to produce a difference of only half a tone.

It will be observed that, as the voice rose in the scale, a greater and greater weight was required to produce each successive note. I was obliged also to increase the force in blowing almost in a similar proportion, for the gentle blast which produced the fundamental note and those near it, caused no vocal sound at all when a few additional ounces were suspended. At any time during the lower notes, the pitch could be raised by simply increasing the current of air independently of the increase of weight; but in each case, following Müller, I have marked the note produced by the gentlest possible current. With the view of showing how much the elevation in pitch is due to the weights alone, and how much to the increased force of the blast of air, I next made the following observations. Observing the note produced when a weight, for example one pound, was used, I suddenly removed it altogether, and marked the pitch to which the voice fell, the current of air remaining the same. The result was as follows:—

1 lb.	=	G	:	removed	=	C
8 oz.	=	D	:	„	=	A_1
4 „	=	C	:	„	=	A_1 flat.

2. Keeping the parts in the same position, I next suspended the weights from the hyoid bone, with results identical with those of last table, except that after passing 11 oz. which produced E as before, a greater weight was required to obtain each successive note; 25 oz. being required to produce G, instead of one pound.

3. The larynx was that of a powerful man, aged about forty. The lowest note which I could produce with it by pressing backwards the thyroid cartilage was E_2. The arytenoids being fixed with a needle as before, I now attempted to imitate by weights the action of the *crico-thyroid muscle.* This was done by passing a string through the lower border of the thyroid cartilage on each side at the middle of that muscle's line of attachment. Tying each end of the string in this position, I suspended the weights from the intervening loop, whilst the cricoid cartilage was fixed, and the larynx was held in an oblique position, so that the direction of the string was the same as that of the fibres of the muscle. The following were the results:—

Fundamental note,		E_1	
½ oz.	raised pitch to	F_1	
1 „	„	F_1	
2 „	„	F_1	sharp.
3 „	„	G_1	
4 „	„	G_1	sharp.
5 „	„	B_1	
6 „	„	C	
7 „	„	D	
8 „	„	D	
9 „	„	D	sharp.
10 oz.	raised pitch to	E	
11 „	„	F	
12 „	„	F	
13 „	„	G	
17 „	„	still G	
18 „	„	A	
22 „	„	still A	
23 „	„	B	
24 „	„	B	
2 lb. or 32 „	„	C^1	
No further note produced.			

The notes from G upwards were of a screaming imperfect character.

The following are examples as before of the effects of increased force in the current of air :—

1 lb.	=	G	: removed	=	G	
8 oz.	=	D	: „	=	F_1	
4 „	=	A_1	: „	=	E	= fundamental note.

4. With the same larynx I again applied the weight so as to imitate the action of the crico-thyroid, as in last experiment, but in this case, the string suspending the larynx was attached not to the needle transfixing the arytenoids, but to another passed for this purpose transversely through the posterior surface of the cricoid cartilage. The cricoid, therefore, and not the arytenoids, was the fixed point. Owing to the larynx having already been considerably used, the fundamental note produced on blowing very gently was now C_1, instead of E_1, as formerly.

Fundamental note, C_1	2 oz. raised pitch to D_1
1 oz. raised pitch to D_1	3 „ „ E_1

Here I was much puzzled to find that whilst when I blew with moderate force the note was E_1, the pitch rose to G_1 when I diminished the current of air, and this transition sometimes occurred even whilst the force which I employed in blowing remained the same. On examining the vocal cords, I found that the space between them became perceptibly wider and of greater length at the moment the lower note was produced. To continue the experiment :—

4 oz. raised pitch to G_1	6 oz. raised pitch to F (weak).
5 „ „ C	8 „ No note produced.

These results are very different from those of last experiment. The curious alternation in the pitch which occurred when three ounces were suspended, and also to a less extent during the other notes, I attributed to the apices of the arytenoids being pulled forwards by the tightening of the false vocal cords, and of the mucous membrane. The slight traction of these parts, I supposed, might imitate to some extent the action of the thyro-arytenoid muscles, to be afterwards described, rotating the cartilages slightly inwards, and at the same time, depressing the points of the vocal processes so that the cords were tightened as well as approximated; on the current of air being increased, these effects were undone, the vocal processes were raised from below, and the cords were separated to the same extent as before. This is the only example of sudden and unexpected alternation between two perfect notes that I met with in all my experiments upon the dead larynx. Müller, who seems to have met with it frequently, speaks of it thus :—"If a slight tension of the ligaments is maintained, it depends upon the manner of blowing whether the note be of the ordinary tone or falsetto (the falsetto note being most easily produced by blowing very gently),

and the two different notes thus produced may be very distant from each other in the musical scale, even so much as an octave." [1] In his experiments, Müller always fixed the arytenoid cartilages to a wooden board.

5. 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 behind it by the thyro-hyoid muscles. The object of the following experiment is to ascertain what effects the traction of these muscles, exercised in this direction, will have upon the voice. The larynx being once more suspended by the arytenoid cartilages, as in all the experiments except the last, it was held in an oblique position with its superior opening looking downwards. A string was then fixed to each side of the thyroid cartilage about the middle of the oblique line. To this the weights were suspended, the obliquity of the cartilage being such that the string, depending vertically, crossed its superior margin several lines posterior to the point of the *pomum Adami*. This I conceive to be the general direction of the muscular fibres when they are thus strongly contracted :—

Fundamental note = D_1		8 oz.	raised pitch to B_1 flat.
½ oz.	raised pitch to E_1 flat.	9 „	„ C
2 „	„ E_1	10 „	„ D
3 „	„ F_1	13 „	„ E flat.
4 „	„ G_1	19 „	„ F
6 „	„ G_1 sharp.	24 „	„ G
7 „	„ A_1	2 lb.	„ G

It must always be borne in mind that in this experiment the arytenoid and cricoid cartilages were fixed and immovable, so that the weights exercised their whole force in pulling forward the thyroid cartilage, whereas, in the living body the muscles raise the larynx *en masse*. But making due allowance for this difference, it will still be admitted that the thyro-hyoid muscles in thus acting upon the larynx must tend in some degree to separate the upper part of the thyroid from the arytenoid cartilages, thus stretching the vocal ligaments, and consequently raising the pitch of the voice.

6. In any larynx prepared for vocalization when the apices of the arytenoid cartilages are simply pressed forward with the point of the finger, the effect is to raise the voice in a very remarkable manner. By this simple means I could frequently produce the note G, the highest in last table; and it may be remarked that the vocal sounds thus obtained were always very powerful, though of a somewhat *punchinello* character. By resting weights upon the posterior surface of the cartilages, I attempted to estimate the amount of force required in this experiment, and found that—

Fundamental note being C_1	4 oz. raised pitch to E_1
1 oz. raised pitch to D_1	8 „ „ F_1

[1] Müller, Physiology, vol. ii. p. 1013.

There was, however, great difficulty experienced in applying these weights accurately; and it was found that by properly directed pressure with the finger, more striking results could be obtained, even when much less force was employed. The cartilages on being pressed forward were observed to rotate slightly inwards upon their articulations, so that the vocal processes became more closely applied to each other, whilst at the same time they were slightly depressed within the cavity of the larynx. The vocal cords were thus actually stretched from before backwards as well as approximated, and owing to their being brought into actual contact posteriorly, the length of the chink through which the air passed was diminished.

7. Exactly the same effects were produced upon the voice by pressing the arytenoids together between the finger and thumb.

8. Simple lateral compression of the thyroid cartilage was also productive of the same effects, but the notes in this case were soft and weak, instead of being loud and shrill as in the last two experiments. In one larynx I could by this means elevate the pitch to C^1. In this experiment, as in the two preceding, the glottis was observed to be constricted, so that the cords vibrated only in part of their extent. The space between the alæ of the thyroid being wedge-shaped, another effect of their compression was to force backwards the cricoid cartilage, so that the vocal ligaments were tightened.

9. The larynx was that of a man aged about thirty years. In this case the hyoid bone and epiglottis were removed. I also dissected away those muscular fibres of the thyro-arytenoid which lie parallel to the direction of the vocal cord, and within the angle of its free edge, my object being to observe the effect of isolating the cords as much as possible. The result was that extreme difficulty was experienced in producing any vocal sounds at all. When, however, I supplied the place of the muscular fibres just mentioned by small soft rolls of wet paper, the musical tones were produced with almost as much ease as in the other experiments. This observation points out, I think, one function of the thyro-arytenoid muscle, namely, that of supporting the vocal ligaments when their free edges are in a state of vibration.

10. A tube about fifteen inches long furnished with perforations like that of a clarionet was affixed to the upper part of the larynx in such a manner that the connexion between them was air-tight. On producing the voice in these circumstances a difference only of one full tone was observed between the note sounded when all the perforations on the side of the tube were left open, and that obtained when they were all closed with the fingers. This is in accordance with the experience of Müller, and in opposition to the theory of Bishop—the vocal-tube theory.

11. The effect of simply increasing the current of air from the gentlest to the strongest blast that could produce a note was to elevate the pitch generally one-fifth, rarely one-sixth, and

sometimes only one-fôurth. This also accords with Müller's observations.

12. Before concluding the experiments from which I have thus given a selection, I had acquired a command over the dead larynx sufficient to enable me to perform upon it a variety of slow airs, not very correctly, but still in such a manner that they could easily be recognised by my audience. In doing this I could employ at pleasure one of four different methods of raising the pitch :—

1*st*, By pulling forward the thyroid cartilage, as in the first experiment;

2*d*, By pushing forwards with the point of the finger the arytenoid cartilages, as in the sixth experiment;

3*d*, By pressing the arytenoids together between the finger and thumb, as in the seventh experiment;

4*th*, By compressing the thyroid cartilage laterally, as in the eighth experiment.

I always at the same time regulated the current of air so as to blow gently in the low notes, and more powerfully when I required to rise in the scale. The lowest base tones were invariably produced by pressing gently backwards the thyroid cartilage.

I now proceed to inquire if from these experiments any light is thrown on the many difficult problems connected with the production of voice. We have seen that in the dead parts there are three distinct methods by which the pitch of the voice may be elevated :—

1*st*, By tightening the cords;

2*d*, By increasing the current of air;

3*d*, By bringing the vocal ligaments partially into contact, so that they vibrate only in a portion of their extent.

In the living body it is universally admitted that the first of these is the chief means employed in raising the pitch of the notes. It is exceedingly probable that the second acts as an assisting agent, for we are conscious of using a greater effort in singing the high notes than the low, just as in the dead body we required to increase the current of air as the notes rose in the scale. As to the third method we are left in greater doubt. On the one hand the laryngoscope shows us that during phonation the vocal cords never come into actual contact in the posterior half or three-fourths of their extent, but owing to the projection of the epiglottis we are as yet uncertain of what may take place at their anterior extremities. On the other hand we find among Magendie's observations the following :—"I laid bare the glottis of a noisy dog by cutting between the thyroid cartilage and the os hyoides, and I saw that when the sounds are grave the ligaments of the glottis vibrate in their whole extent, and that the expired air passes out in the whole length of the glottis. In acute sounds the ligaments do not vibrate in their anterior part, but only in their posterior; the opening is therefore diminished."[1]

[1] Magendie's Compendium of Physiology, p. 137.

Moreover, we found that of the three means by which this constriction of the glottis may be artificially produced in the dead larynx (Experiments 6, 7, and 8), the only one which we could also employ in the living was the lateral compression of the thyroid cartilage, and in both cases this was observed to produce the same effect upon the voice. This lateral compression occurs naturally during the highest treble tones. It is therefore very probable, though it cannot be said to be absolutely proved, that in certain conditions the pitch of the voice is raised by a shortening of the vibrating portion of the vocal cords, owing to their anterior extremities having come in contact.

When compression of the thyroid cartilage occurs during the production of high notes, it must, I think, be due to the action of the palato-pharyngeus and the middle constrictor of the pharynx, the attachments of which are such that both of them, when contracted as they are in these circumstances, must pull the upper parts of the alæ towards the middle line; this action is favoured by the box of the larynx at the same time being carried forwards along with the hyoid bone.

The *falsetto voice* has been explained by supposing that during its production the vibrating portion of the cords is shortened in the manner just alluded to. This is the opinion of Bishop, Willis, and others; and the supposition seems a very feasible one. It is also favoured by some of the facts which I have observed. It was noticed for example that during the transition from the false voice to the same note of the true, the vocal processes became somewhat more closely approximated. In the same circumstances the muscles of the pharynx were more strongly contracted. If this contraction be really the cause of the lateral constriction of the thyroid cartilage, as just explained, we see at once the means by which the vocal cords are thus partially brought into contact. I hesitate, however, to conclude from these limited data that the cause of the falsetto voice is the lateral constriction of the thyroid cartilage, the more especially as I find Müller ascribing to it in his experiments upon the dead larynx exactly an opposite effect. "The deepest note," he says, "which I could produce in one of my experiments by relaxing the vocal cords was the middle C of the base clef; by exercising slight tension on the cords, and blowing with greater force I could produce the octave above this (C^1), but I could in that way raise the notes no higher. By compressing the larynx laterally, however, about the situation of the vocal cords and below them, I was able to produce a series of higher notes to the extent of another octave (C^2), without any falsetto tone, although under other conditions falsetto notes could be produced from the A sharp, below the second C (C^1). The prevention of the falsetto notes, which was here attained by the lateral compression of the larynx, seems during life to be effected by the action of the thyro-arytenoid muscles."[1]

It astonishes me to find Müller speaking so confidently of dis-

[1] Müller's Physiology, page 1015.

tinguishing the true and false tones in the voice of the dead larynx. In my own experiments I never succeded in doing so; I even found that very little difference could be observed between the sound of the male and of the female larynx, further than the fact that the voice of the former was set several notes lower than that of the latter. The absence of the peculiar characteristics in both cases I ascribed to the removal of the pharynx and the other parts of the "vocal tube." From the observations which I have just mentioned, and from the fact that by artificially compressing my own larynx, I am enabled to add to my falsetto register several notes which I cannot otherwise reach, I have been led to adopt the opinion of Bishop and Willis, namely, that the falsetto voice is produced by a shortening of the vibrating edges of the vocal cords, owing to their having come into actual contact anteriorly; and this I believe to be due in part at least to the constriction of the thyroid cartilage by the palato-pharyngeus and the middle constrictor of the pharynx. This theory accounts for the height of the notes which we are able to produce in the falsetto voice without any great muscular effort, whereas, their soft throat character is probably due to the sounds having been made to pass through the greatly contracted pharyngeal cavity.

With reference to *the action of the thyro-arytenoid muscle*, this is a question much disputed by physiologists. On the one hand it is maintained by Mr Willis, and most other English writers, that by its agency the low notes are produced, whilst, on the other, the opposite action has been ascribed to it by some of the German authors, namely, that of elevating the pitch of the voice. Now, in my experiments upon the dead larynx, it was remarked that,

1*st*, Pressing forward the arytenoid cartilages has always a most marked influence in raising the pitch. Exper. 6.

2*d*, Pressing backward the thyroid operates with equal certainty in lowering the notes.

As the muscle therefore stretches between the thyroid and arytenoid cartilages, the effect of its contraction upon the voice will depend entirely upon which of these is the fixed point. A little experiment upon one's own larynx will show at once that it is an easy matter to press back the thyroid cartilage during the production of low notes, so that if the muscle acts in these circumstances it can have little difficulty in approximating the upper part of the thyroid cartilage to the arytenoids. Its action, however, cannot be altogether favourable to the lowering of the vocal pitch, for in their contraction, those fibres contained within the fold of the vocal ligament near its free margin, must render somewhat tense the edges of the cords, thus destroying the laxity which is necessary for the production of bass notes; at the same time, the forward traction of the arytenoids with the consequent depression of their vocal processes must tend, so far as they go, to raise the pitch of the voice. It is therefore evident that if the thyro-arytenoid muscle is in-

tended to produce low notes, it must act under most unfavourable circumstances.

On the other hand, let us suppose that its agency is employed in elevating the pitch of the voice. As the vocal tones rise in the scale, we observe that the larynx is pulled upwards and forwards by the thyro-hyoid muscle, and at the same time the lower border of the thyroid cartilage is pulled downwards by the crico-thyroid. *Between these two muscles the thyroid cartilage is thoroughly fixed*, and the thyro-arytenoid must, therefore, in contracting, produce its effects solely upon its arytenoid attachments; pulling them forwards, it must exercise the same powerful influence in raising the notes, as we observed was produced by pushing the cartilages from behind in the sixth experiment. Those of its fibres also contained within the folds of the vocal ligament will act by rendering the edges of these cords more tense, and at the same time by supporting them during their vibration.

There can be no doubt then that the thyro-arytenoid is one of the muscles which tighten the cords and raise the pitch of the voice. Ecker has thus expressed the German view regarding it. "When these muscles contract, their fibres lose their slightly wavy direction, thereby the free margins of the vocal cords approach each other; seeing that the *processus vocales* are drawn forwards, inwards and downwards, even to touching, so that only a small linear split remains. As the thyro-arytenoid muscles fill the fold of the vocal ligament nearly to its free margin, necessarily, on the contraction of the muscle, the free margin of the fold becomes sharpened. In this position the vocal cords are drawn as much as possible into the lumen of the air passage. Probably, they vibrate in their whole extent, and the chest-notes are produced."

We have as yet, I believe, no satisfactory explanation of the manner in which the lowest notes are produced. We know that the vocal cords are relaxed by the upper part of the thyroid cartilage moving backwards, but we are still in doubt as to the cause upon which this movement depends.

I cannot bring this paper to a conclusion without expressing my sincere thanks to Dr Grainger Stewart, and also to Dr Sanders, for their kind advice and assistance, and for the interest they have all along taken in the investigation of these very complex questions.

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