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INNERVATION OF THE LARYNX

- Introduction -

Reports on clinical cases of abductor vocal cord paralysis following thyroidectomies or acute medical conditions are not infrequently encountered in the literature, Rankin (1), Mc Nerthney (2), Hoover (3), Halsted (4), Garland and White (5), New and Childrey (6), and Smith, Lambert and Wallace (7). These case reports are published because it is of interest that the apparent pathological conditions do not offer an adequate explanation of the clinical symptoms. A thorough study of these reports indicates that the present anatomical teaching, as found in the current authoritative textbooks of Anatomy, Morris (8), Grey (9), Cunningham (10), which is, that all of the intrinsic muscles of the larynx are innervated by the inferior laryngeal nerves except the cricothyroid muscles, which are supplied by the external branches of the superior laryngeal nerves, is not entirely correct.

A study of the literature reveals the fact that since the time of Galen there have been varying opinions as to the exact innervation of the intrinsic laryngeal muscles, which further suggests that the present teaching is as much theory as fact. A search for the basis of any of the opinions advanced on this subject shows that all are either based on a few gross dissections of human larynges or experiments on dogs. In the light of these conditions and with the hope that the basic anatomy responsible for these paralyses may be uncovered, further investigation is warranted.
At this time I wish to acknowledge my profound appreciation for the opportunity to pursue original investigation under the ever-patient and guiding tutelage of Doctor Thesle T. Job, Professor of Anatomy at Loyola University School of Medicine. To Mr. Oliver I. Warren, of the Technical Laboratories, I wish to express my grateful appreciation for his invaluable technical instruction and capable assistance in the preparation of specimens. Further indebtedness is acknowledged to the late Dr. Richard Jaffe, Director of the Pathological Laboratories of the Cook County Hospital, for his ever-willingness to supply invaluable, fresh, human material.

- HISTORICAL -

Since Galen's (11) original description of the innervation of the intrinsic muscles of the larynx, which is that all are supplied by the recurrent laryngeal nerve, there has been much work done either supporting or at variance with his description. From Galen's time until Luschka in 1871, little was added of definite significance by the older anatomists such as Vesalius, Mondino, Monro or Hunter.

In 1871, Luschka (12) began what may be termed the modern era of thought by stating, after extensive experimental work, that the recurrent nerves supply all of the intrinsic muscles of the larynx except the cricothyroid muscles, and that the superior laryngeal nerves supply the cricothyroid and interarytenoid muscles. Thus he considered the interarytenoid muscles to be doubly innervated. Although this innervation was first suggested by Cruveilhier (13), it remained for Luschka to advance this idea further. After 1871 little more was done or said to strengthen
this belief until Judd, New and Mann (14) in 1918 revived it. Since then there have been other followers such as Dilworth (15), Greene (16), Berlin and Lahey (17), Nordland (18), and Ziegelman (19).

Exner (20) in 1888, stimulated by the work of Luschka, further advanced the theory first suggested by Monro secundus (21), that all of the intrinsic muscles of the larynx are doubly innervated by the recurrent and superior laryngeal nerves. Exner, supported by Mullin (22), stands alone with this idea.

Continuing with the original postulate of Galen, and adding to it, is Legallois (23) who, in 1812, after experimental work on dogs and rabbits, concluded that the superior laryngeal nerves are sensory to the larynx. Soon after Legallois, Cock (24) in 1837 added the idea that the superior laryngeal nerves are sensory to the larynx and motor to the cricothyroid muscles. Supporters of Legallois and Cock were Reid (25) in 1838 and Krause (26) in 1842. For a considerable number of years this theory was more or less disregarded until 1902 when it was revived by Onodi (27), who popularized it in the modern era. At present Lemere (28,29,30,31) is the chief experimental worker supporting this idea in conjunction with the current textbooks of Anatomy.

In 1847 Cruveilhier (13) described a lateral anastomotic branch from the internal branch of the superior to the inferior laryngeal nerve. No mention of this branch is made in the current textbooks or in the literature. Since it was very apparent in the dissections and appears to be of considerable importance, more will be said about it later.
- THE PROBLEM -

1. To study microscopically the type of nerve endings found on the terminal branches of the internal ramus of the superior laryngeal nerve in the interarytenoid muscles in the human larynx.

2. To study grossly in the human larynx the size, course, anastomosis and distribution of the internal ramus of the superior laryngeal nerve and the inferior laryngeal nerve.

3. To study grossly in detail the anatomical relationships of the cartilages, muscles and nerves of the dog larynx and compare with the anatomy of the human larynx.

- METHODS AND MATERIALS -

1. Seven fresh human larynges were obtained as occasion permitted from the Pathology Laboratories of the Cook County Hospital. These were immersed immediately in a normal saline solution and taken to the Anatomical Research Laboratories of Loyola University School of Medicine for technical treatment.

Gross dissections of the internal branch of the superior laryngeal nerve were made. Special attention was accorded the branches penetrating the interarytenoid muscles which were dissected to their point of entrance into these muscles. At this point, a low-power Zeiss dissecting binocular head-band microscope was used to trace the finer fibers into the muscle substance. Small cubes of muscle averaging 2 to 3 millimeters in size were then removed with the dissected nerve fiber intact.

The preparation of the microscopic material, under the direc-
tion of Mr. Oliver I. Warren, was as follows:

1. Place the specimens in fresh 4% citric acid for 30 minutes.
2. Rinse twice in distilled water.
3. Place in fresh 1% gold chloride solution for 30 minutes in a light-proof cabinet.
4. Place directly into fresh 33% formic acid solution for 48 hours in the dark cabinet.
5. Thoroughly rinse in distilled water.
6. Place in glycerin for 4 to 8 days in the dark cabinet.

Upon removal of the muscle-nerve preparations from the glycerin they were placed under a low-power dissecting microscope and dissected with teasing needles. The aim of this procedure was to remove as much excess muscle as possible and to leave only a small piece averaging a millimeter or two in size at the end of the nerve fiber. This was then placed on a standard glass slide, immersed in a drop of glycerin, and covered with a 7/8 inch standard cover slip. Slight pressure was applied to the cover slip to further flatten the preparation and render it more suitable for examination under the microscope.

2. Through the courtesy of Dr. Thesle T. Job, 96 human larynges were removed in toto from laboratory cadaver specimens. In order that no significant structure might be excluded, the incisions in all cases were made superior to the hyoid bone, inferior to the thyroid gland, posterior to the esophagus and laryngeal pharynx, and lateral
to the thyroid cartilage, and in many instances lateral to, and inclu-
ding with the specimen, the carotid sheath structures.

Bilateral, gross dissections were then made on each specimen in an attempt to reveal the exact course, relations and terminations of the internal branch of the superior laryngeal nerve and the inferior laryngeal nerve. In all instances the dissecting head-band binocular was employed to trace the smaller branches of the nerve fibers as nearly as possible to their terminations.

3. Eighteen dog larynges were prepared for study in the usual manner. Detailed gross dissections were made with the aim being to determine the relationships existing between the cartilages, muscles and nerves in order that a reasonable comparison might be made with corresponding structures in the human larynx.

- CRITICAL ANALYSIS OF TECHNIQUE -

1. The ease of preparing fresh tissues is always influenced by the state of preservation of the material, as is well known. The fact that a few of the specimens obtained unquestionably came from bodies which had been held 3 or 4 days before necropsy, was evidenced by the obvious signs of post-mortem autolysis. In the handling of some of the tissues, this worked to a distinct disadvantage as the material tended to separate and fall apart.

A few of the microscopic preparations did not respond to the gold impregnation as selectively as was desired. Since the principle of the technique is the reduction by the formic acid of the selectively absorbed gold chloride in the nervous elements, the presence
of organic acids from the post-mortem autolysis caused many areas of diffuse impregnation of gold to appear due to generalized reduction of the gold salt. Although this over-staining of some areas of tissue reduces the number of fields available for examination, it does not interfere with properly stained fields.

The mounting of the specimens in glycerin, which is imperative for immediate microscopic examination, causes them to soften. Thus, within a period of a few weeks, marked separation of nerves and muscle fibers is noted. This fact prevents permanent mounting of the tissues.

2. Although the dissection of gross, fixed material primarily depends upon the skill and dexterity employed, the results have always been subjected to the over-zealousness of the investigator. The complete, positive separation and identification of minute, uninjected arteries, veins and nerves from fascial septae and connective tissue bands is not always possible. Thus, due allowance for this fact must be made in interpreting the results obtained.

3. In the gross dissection of the dig larynges the same may be said as is stated in #2.

- RESULTS -

1. Microscopic examination of the interarytenoid muscles from the 7 fresh human larynges in which the nerves were impregnated with gold chloride revealed in every specimen the presence of motor end plates on fibers.
of the internal branches of the superior laryngeal nerves associated with the cells of the transverse arytenoid muscle. PLATES I, II, III, IV, V, VI.

2. Bilateral, gross dissections of 96 human larynges revealed:

   a. The presence of a bilateral posterior anastomotic branch between the superior and inferior laryngeal nerve in 94 larynges. Of the 2 remaining larynges 1 was pathologic, #4 in the series, and in the other, if present the nerves could not be demonstrated, #3 in the series.

   b. The presence of a bilateral deep muscular branch from the inferior laryngeal nerve to the transverse portion of the interarytenoid muscles in 95 larynges. In larynx #1 of the series, it could not be demonstrated if present. This branch leaves the inferior laryngeal nerve at the posterior-lateral aspect of the larynx to disappear under the posterior cricoarytenoid muscle. Beneath this muscle the nerve, passes superiorly between the muscle and the cricoid cartilage to penetrate the interarytenoid muscles at their inferior border.

   c. The presence of a lateral anastomotic branch, in most instances bilateral, between the superior laryngeal nerve and the inferior laryngeal nerve in 31 larynges and suggested in a few others. This branch first recognized and described by Cruveilhier (13) has been overlooked in modern teaching.

   d. The presence in all larynges of 3 to 8 bilateral muscular twigs from the internal branches of the superior laryngeal nerve to the interarytenoid muscles. The larger branches were distributed
mainly to the transverse portion of this muscle, while the finer twigs penetrated the oblique arytenoid and aryepiglottic muscles.

3. The results of the gross dissection of the 18 dog larynges is embodied in the discussion.

- DISCUSSION -

1. The functional significance of a motor component in the internal branch of the superior laryngeal nerve is somewhat beyond the field of anatomy. Nevertheless, a few facts in this regard are worthy of further consideration.

The present concept of the innervation of the larynx by the inferior laryngeal nerve is in no way changed by these findings. Functionally, the role of this nerve would become more complex, however, since the influences of the superior laryngeal nerves would have to be integrated with it.

Recalling the basic question, namely: Why do the cords assume a cadaveric position with loss of voice but without interference with the respiratory function in some cases of abductor cord paralysis, while in others the cords assume a spastic mid-line position with a loss of both phonation and respiration? In the light of this research one is still without a complete answer.

In the severest form of abductor vocal cord paralysis, with spastic adducted cords, an explanation based on this newly discovered motor component would require both a consideration of the function of the recurrent and superior laryngeal nerves. Thus assuming a case with the release of the abductor force of the cords through the loss
of recurrent nerve function, the result would be unopposed cords in in spastic adduction. This is not, however, the final word, for in just such a case as this, Imperatori (32) found that injection of the superior laryngeal nerve with cocaine relieved the adductor spasm, while Hoover (3) reported that section of the same nerve in a similar case had no effect.

The demonstration of a motor component in the internal branch of the superior laryngeal nerve to the transverse arytenoid muscle is just the beginning of a new approach to the study of the innervation of the larynx. So similar in origin, function and gross innervation are the oblique arytenoids and aryepiglottic muscles that there is a tantalizing desire to forecast their innervation by this same nerve at this time. Again, the technique employed in this work may reveal startling facts when applied to the recurrent nerve fibers within the larynx.

2. Gross dissection of the nerves of the human larynx reveals nothing which has not been previously described at some time or another. However, certain facts which have been previously neglected need stressing at this time.

The presence of the lateral anastomotic branch in 30% of the specimens examined is certainly worthy of note, especially since this nerve is practically neglected at the present time (Cruvielhier). If this branch carries motor fibers, as is certainly possible, it undoubtedly innervates the lateral cricothyroid and thyroarytenoid muscles as it terminates in their substance with the recurrent laryngeal
nerve. This being the case, the theory of double innervation of the laryngeal musculature, as first advanced by Exner (20), would be supported. In contra-distinction the nerve may contain only sensory fibers from the laryngeal mucosa in spite of the fact that this would be a rather round about path to take. Either instance being the case, this nerve is certainly worthy of careful study.

Careful consideration of the relations of the muscular branches of the superior laryngeal nerve must be given in all cases of pathology of the larynx. Of special importance are not only the branches to the transverse arytenoid muscle, which branches have been proven definitely to be motor, but also the branches to the oblique arytenoid and aryepiglottic muscles. The question of the size of these branches is not a factor, but their constant presence certainly serves as the most reasonable explanation of hoarseness and aphonia in a larynx whose only pathology is a small gumma, tubercle or neoplasm.

Lastly, related to, but apart from the larynx, are those lesions which are extralaryngeal. As is well known, the control-center of phonation is located in the cerebral cortex while that for respiratory oscillation of the vocal cords is medullary. According to the neurological classification of lesions there are those of upper motor neurones resulting in a spastic paralysis, and those of the lower motor neurones resulting in a flaccid paralysis in cases of interruption of the nerve, and spastic paralysis in cases of purely irritating lesions. Thus the location as well as the type of the lesion requires a full appreciation of the basic anatomy.
Immediately upon examination of the stripped, cartilagenous framework of the dog larynx, one is impressed by the dissimilarity encountered in respect to the general appearance, topography and relation between the dog and the human specimens. A detailed examination reveals the presence of an interarytenoid cartilage; the longer, more transversely placed corniculate cartilages; the larger, more firmly attached cuneiform cartilages, and the more laterally placed, and anterio-inferiorly inclined, arytenoid cartilages.

In the human larynx the arytenoid cartilages are mounted on the lateral superior aspect of the lamina of the cricoid cartilage, with the larger apices directed superiorly and the shorter vocal and muscular processes projecting at right angles to each other in the transverse plane. Thus, axial rotation will move the tips of the vocal processes in the transverse plane and concomitantly, in the absence of other adjusting movements, lengthen or shorten the vocal cords as they are abducted or adducted respectively. A second type of motion of the human arytenoid cartilage is a gliding movement which may result in either medial approximation of the two arytenoid cartilages or movement in an anterior or posterior direction, with the vocal processes remaining at all times in the transverse plane. The apparent results are primarily two-fold. Firstly, the complete readjustment of muscular tensions in the larynx, and secondly, a lengthening or shortening of the vocal cords without axial rotation. On the other hand, the dog arytenoid cartilages are mounted laterally on the lamina of the cricoid in an angular and relatively fixed position. This
fixation is due to the presence of the interarytenoid cartilage and the angularity to the greatly modified corniculate cartilages. The much shorter spines of the arytenoid are directed superiorly and forward at approximately a thirty degree angle, while the vocal processes extend laterally in the transverse plane. With such an arrangement axial rotation will move the tips of the vocal process outside of the transverse plane and will not only result in abduction or adduction of the cords, but will also elevate or depress them. The human type of gliding motion is negligibly seen. The active laryngeal factors encountered in the phonation mechanism are the length, thickness and tension of the vocal cords and the size of the glottic chink. The detail of the complex integration of these factors is common knowledge to students of phonation, but to conclude that added anatomical facts render this integration any the less complex or precludes the manifold combinations of these factors in the same or different species in order to produce the same end result is a false assumption.

The interarytenoid cartilage found in dog and not in man is of great significance in understanding the phonation mechanism of the dog due to its position, immobility, and muscle relationships. Situated on the superior crest of the lamina of the cricoid in the mid-line, and bridging the gap between the two arytenoid cartilages, it primarily serves to prevent approximation of the medial surfaces of the arytenoid cartilages, which action can be accomplished in the human larynx.

Arising from the interarytenoid cartilage at its lateral extrem-
ities are the bilateral, transverse, arytenoid muscles, which, by virtue of the fixed position of the interarytenoid cartilage possess a fixed origin in contra-distinction to the movable origin of the interarytenoid muscle in man. Attached more medially to the interarytenoid cartilage and extending along its body in the mid-line is the origin of the large and well-developed bilateral ventricular muscles which are either absent or so slightly developed in man that they are worthy of no further consideration.

The corniculate cartilages of the human larynx are small, varying from 1 to 3 mm. in length and extend superiorly and posteriorly from the arytenoid apices with which they alone articulate. In the dog, however, the longer and notably larger corniculates extend posteriorly from their arytenoid and cuneiform articulations over the interarytenoid cartilage to reach the anterior wall of the laryngeal pharynx. As has been suggested by Negus (33), this additional length and added articulation is required in animals swallowing large boli of food, since it helps in elevating the pharyngeal wall over the bolus as well as pushing the arytenoid and cuneiform cartilages anteriorly out of the path of the bolus. It is to be noted that this contact of the free end of the corniculate cartilage with the pharyngeal wall will, in addition to the elevating action, exert a constant, steady pressure forward, tending to maintain the axis of the arytenoid cartilages in their anteriorly directed inclination at all times.

The generally conceded function of the small, cylinder shaped, non-articulating cuneiform cartilages of the human larynx is to main-
tain the integrity of the aryepiglottic folds. The dog cuneiform cartilages are larger than in the human. They are flat, irregularly triangular in shape, and articulate with the corniculate cartilages. This increase in the complexity of the cartilages easily accounts for their three-fold function, namely, support of the aryepiglottic folds, support of the lateral glottic walls, and the site of attachment of the well-developed ventricular muscles.

Although the differences in the arrangement and development of the laryngeal musculature between the dog and man are few, there are some details worthy of consideration.

As is well known, the interarytenoid muscle of the human larynx is a mid-line muscle composed of a single transverse and paired oblique portions, attached at either end to the lateral posterior surface of the arytenoid cartilages, and extending directly between them. Functionally, it approximates the medial surfaces of the arytenoid cartilages, thus adducting the vocal cords. Furthermore, since it possesses no extra-arytenoid attachments, it is required to move passively with the arytenoid cartilages when they are acted upon by other muscles. In the dog, bilateral transverse arytenoid muscles are encountered arising medially from the interarytenoid cartilage near the mid-line, but not crossing it, and inserting laterally on the muscular process of the arytenoid cartilages of the same side. The true significance of this difference lies in the field of physiology but on the anatomical basis alone, unilateral peripheral lesions would seemingly not be functionally alike in man and dog.
The regressive ventricular muscle in man, as has been previously mentioned, is either exceedingly small or absent in contra-distinction to the dog where it is found to be well developed. It arises from the interarytenoid and arytenoid cartilages dorsally, passes ventrally in the lateral glottic wall, to be inserted upon the ventral process of the cuneiform cartilage of the same side. Phylogenetically, as well as functionally, the ventricular muscle appears to belong to the sphincteric group of laryngeal musculature (Negus). Its presence, alone, is not only a wide departure from the conditions found in man, but also a decided factor in the resulting functional arrangement among the laryngeal muscles as a whole.

A comparative study of the thyroarytenoid muscle reveals it to be a pure sphincteric muscle in the lower forms, being attached to the muscular process of the arytenoid cartilages but not to the vocal process. In higher forms, an internal division is referred to, which has migrated medially becoming attached to the vocal process, while the lateral or external portion still remains inserted on the muscular process (Negus). The dog thyroarytenoid muscle seemingly corresponds to this type, showing the well-developed external division separable from, but overlapping on the lateral surface, the equally well-developed internal division which lies more medially and is inserting upon the vocal process. The human larynx reveals an even higher stage in this medial migration of the thyroarytenoid muscle fibers, with the apparent regressive external division appearing as a thin, less well-developed sheet of muscle attached to the anterior surface of the body.
of the arytenoid cartilage and the base of the muscular process, whereas the better-developed internal or vocal portion passes more medially to attach to the base and ramus of the vocal process, extending outward as far as the tip.

Special attention has been accorded the course, relation and distribution of the recurrent and superior laryngeal nerves of dog and man in recent years, in an attempt to establish a more exact anatomical basis for the interpretation of experimental and clinical findings, notably among which is the detailed study by Lemere (28) on the innervation of the dog larynx.

A comparative, gross study of the relative sizes of the laryngeal nerves of dog and man reveals the fact that the superior laryngeal nerve is noticeably smaller in dogs whereas the recurrents are, relatively, approximately of equal size. The constantly appearing posterior anastomotic nerve in the dog always assumes the proportion of a sizeable nerve in marked distinction to the human anastomotic branch which, though always present, is small in size and delicate in structure. Furthermore, the presence of the frequently occurring lateral anastomotic branch in the human larynx, which, if present in dogs, has as yet not revealed itself in our eighteen detailed dog dissections, only serves to further emphasize the difference in corresponding anatomical structure to be taken into consideration.

- CONCLUSION -

1. The internal branch of the superior laryngeal nerve has a motor component.
2. The posterior anastomotic nerve is constantly present in the human larynx.

3. A deep muscular branch from the recurrent nerve to the transverse arytenoid muscle is constantly present in the human larynx.

4. The lateral anastomotic nerve is present in approximately 30% of human larynges.

5. The internal ramus of the superior laryngeal nerve in the human larynx constantly supplies 3 to 8 muscular twigs to the interarytenoid muscles.

6. The anatomy of the dog larynx differs so markedly from the anatomy of the human larynx that conclusions obtained from laboratory experimentation upon the dog are not applicable to the human larynx.

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HUMAN INTERARYTENOID MUSCLE

Human interarytenoid muscle fibers and terminal filaments of the internal branch of the superior laryngeal nerve with motor end plates. X73.
PLATE II

HUMAN INTERARYTENOID MUSCLE

Same as PLATE I, Indicated field X225.
HUMAN INTERARYTENOID MUSCLE

Human interarytenoid muscle fibers and terminal filaments of the internal branch of the superior laryngeal nerve with motor end plates. X73.
HUMAN INTERARYTENOID MUSCLE

Same as PLATE III, Indicated field X225.
HUMAN INTERARYTENOID MUSCLE

Human interarytenoid muscle fibers and terminal filaments of the internal branch of the superior laryngeal nerve with motor end plates. X73.
PLATE VI

HUMAN INTERARYTENOID MUSCLE

Same as PLATE V, Indicated field X225.