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THE SEMON LECTURE, 1958

SOME OBSERVATIONS ON THE HISTOLOGY AND FUNCTION OF THE LARYNX*

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IT IS nineteen years since my friend and teacher, Professor Felix Nager delivered the Semon Lecture. I well remember the joy which this usually reserved man showed when this singular honour was accorded him. The invitation to give the Semon Lecture today fills the recipient with the same pride, but also anxiety lest he might not measure up to the great honour as compared with his many distinguished predecessors. When Nager recommended the transethmoid approach for the treatment of intrasellar pituitary tumours, many rhinologists considered that the operation would have a very limited future in view of the rapidly developing neurosurgical techniques. These prognostications were proved correct and in the last twenty years most operations on the pituitary have been carried out by neurosurgeons. In recent years, however, Nager's Semon Lecture has come into its own again with the practice of destruction of the normal pituitary gland in the treatment of metastasizing mammary carcinoma. Most neurosurgeons agree that the transethmoid or trans-septal approach is the most suitable in these cases, and many Nose and Throat surgeons are using the operation described by Nager and others with success today.

* Semon Lecture. Delivered at the Royal Society of Medicine, London on November 6th, 1958.

Laryngology has made great strides since Morell Mackenzie's and Felix Semon's day, especially thanks to the research of British workers. There remain, nevertheless, many topics for discussion concerning the histology and neurophysiology of the larynx. We will consider some of these today.

The greater part of the larynx is lined by the characteristic respiratory ciliated cylindrical epithelium, arranged in layers. But the vocal cords, external surface of the epiglottis and the aryepiglottic folds are always covered by stratified squamous epithelium. The latter may also be present on the free border of the ventricular bands, and islets of stratified

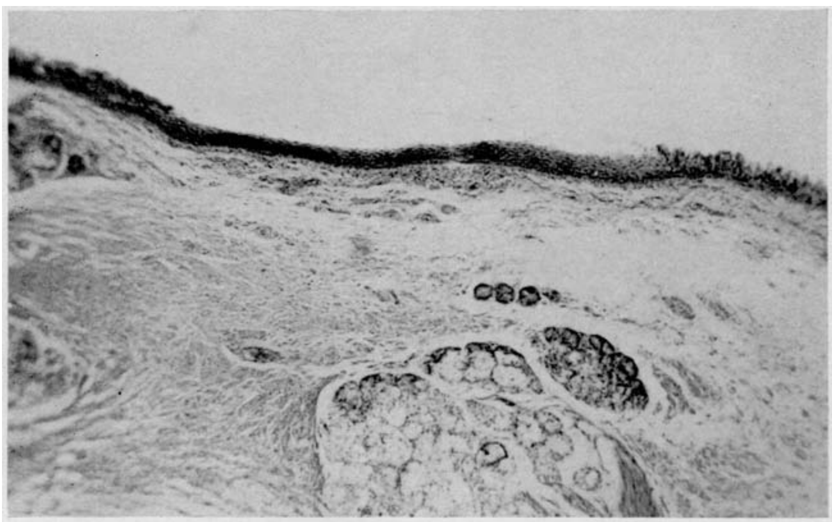

FIG. 1.
Squamous epithelial islets in the laryngeal mucosa.

squamous epithelium are commonly found in the midst of the ciliated epithelium. The distribution, limitation and relative behaviour of these two epithelial types are of clinical interest in laryngeal cancer, which occurs about twelve times more commonly in men than in women. The vocal folds are involved in 85 per cent. of the cases. Histologically 90 per cent. are squamous celled growths. We have tried Zilliacus's technique of staining with picric acid and hæmalum to determine the exact distribution of the squamous epithelium (dyed yellow) and the ciliated epithelium (dyed reddish-brown) in the region of the larynx. Unfortunately this method seldom yields reliable results when checked by microscopy, and the small islets of squamous epithelium can only be determined histologically.

The transition from squamous to ciliated epithelium in the laryngeal introitus takes place through an area of transitional epithelium where the superficial flattened cells gradually become built up into layers of taller layers of epithelium. In other situations, especially in the squamous epithelial islets (Fig. 1) and on the upper surface of the vocal cords, there is quite a sharp line ot demarcation between the two types of epithelium (Fig. 2). This abrupt demarcation only applies to the superficial layers, i.e. the ciliated and mucous cells on the one hand and the flat squames on the other. The common underlying layer of cuboidal basal cells (H. v. Hajek) resting on the basal membrane are not subject to any such separation.

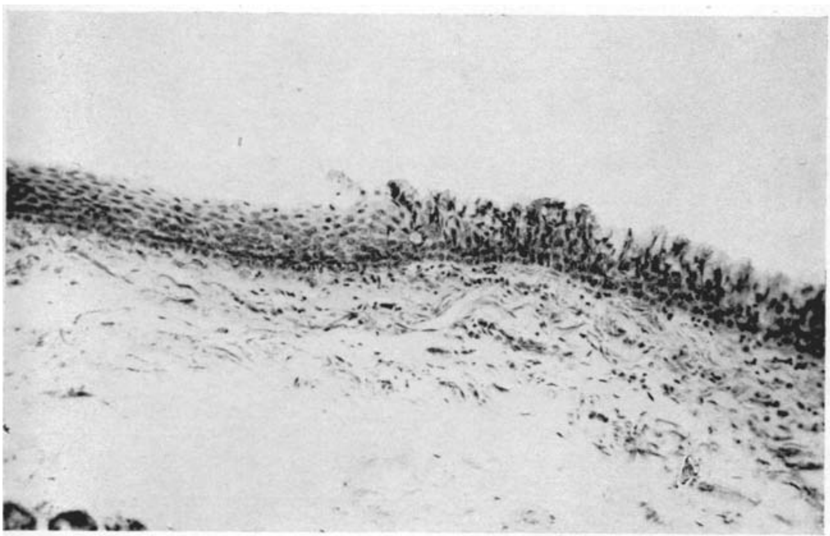

Fig. 2.

Higher magnification of Fig. 1. Sharp transition from squamous to ciliated epithelium.

Regeneration of both types of epithelium takes place from undifferentiated basal layer according to the type ot stimulus, either squamous, or ciliated, and mucous cells are produced.

D. L. Wilhelm describes the healing of injured tracheal mucosa by means of flattened cells growing from the edge of the wound and from the glandular ducts. This epithelium becomes arranged in layers in a few days and differentiation into ciliated and mucous cells is complete in a few weeks. The functional behaviour of the larynx determines the type of mucosa present in various situations. The whole of the larynx is covered by a cubical epithelium in its early embryonic state. Later, those areas which come into contact during valvular action acquire a tougher and more resistant covering of stratified squamous epithelium. This applies especially to the laryngeal introitus and the vocal folds, while the basal cells in areas subject to less rigorous mechanical wear differentiate into ciliated and mucous cells.

In disease the repiratory epithelium may adapt itself in various ways. An inflammatory stimulus may result in the formation of so many mucous glands that other cellular elements are virtually crowded out. W. Messerklinger has kindly loaned me the slides illustrating a very similar mucous degeneration which he induced experimentally as a result of chronic parenteral intoxication with allyl formate. On the other hand the application of a mixture of allyl formate and vitamin B6 to the trachea of a pregnant guinea-pig has resulted in *squamous metaplasie*. According to Wolbach and Howe vitamin A and D deficiency has resulted in the ciliated epithelium in the nose, sinuses, larynx and trachea being replaced by keratinized squamous epithelium.

Our knowledge of the various factors governing the changes in the respiratory epithelium, either in the direction of the less differentiated cells or the possible regeneration of ciliated and mucous cells from squamous ones, still remains very limited.

Possibly these epithelial metaplasias play a part in the production of malignant tumours in the larynx.

It is well known that the early, superficial carcinoma circumscribed on a mobile vocal fold offers a good chance of cure. The rather poor lymphatic supply of the vocal fold renders metastasis unlikely. Sir Victor Negus has recently drawn my attention to certain specimens of the larynx at the Johns Hopkins University showing lymphatic tissue at the anterior commissure.

We have examined serial sections of fourteen larynges from young subjects in order to determine the distribution of lymphatic tissue in this situation which is so important to the cancer surgeon. But we were able to demonstrate small collections of submucous lymphoid tissue near the anterior commissure (Fig. 3) in only two of the specimens.

Furthermore we have traced the lymphatic vessels using Gerota's technique (Fig. 4). There is a lymphatic network both above and below the vocal folds, but the two do not communicate with each other. The upper lymphatic field serving the ventricle of Morgagni and the false vocal cords arises in the midline anteriorly and only has the most tenuous connections with the opposite side. The fine branching lymphatics collect into larger vessels and leave the larynx through the crico-thyroid membrane. The subglottic lymphatic system is richer and anastomoses freely with the opposite side. The vessels pass outwards through the crico-thyroid and crico-tracheal membranes. The vocal folds form a sharp barrier between the two lymphatic fields and even direct injection under the mucosa of the vocal folds themselves shows a virtual absence of lymphatic pathways there. The anterior commissure participates in this division of the two lymphatic networks. These results confirm A. Most's and P. Poirier's classical investigations.

The neuro-physiology of the larynx has been the subject of renewed interest recently. George Portmann in his Semon Lecture of 1956 presented a closely argued case against the classical tonic theory and in favour of R. Husson's new clonic theory of phonation. According to the *tonic* theory the pressure of the column of air from the lungs and trachea sets up a rhythmic opening and closure of the glottis. Thus it is the air

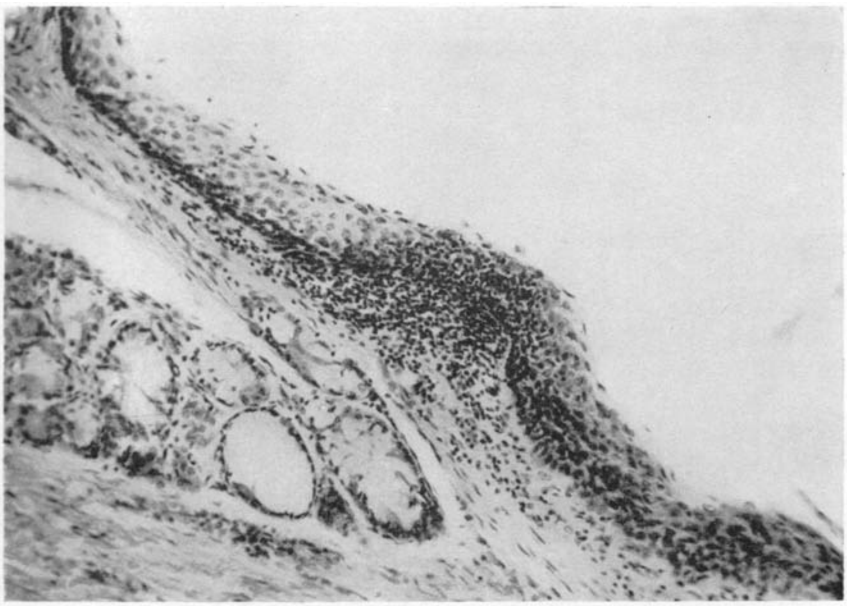

FIG. 3.
Small collections of submucous lymphoid tissue near the anterior commissure of the vocal folds.

stream which produces the vibration of the vocal folds and the waves of the issuing air stream are interpreted by the human ear as sound. According to the new *clonic* theory it is not the air stream which produces the vibration of the vocal folds. The vibrations of the vocal folds are produced by a rhythmic contraction of some tranverse fibres of the thyro-arytenoid muscle under the stimulus of a succession of nervous impulses derived from the central nervous system. The frequency of the impulses determines the frequency of the sound waves being emitted.

When Victor Negus was assembling the Onody Collection at the Royal College of Surgeons, which formed the basis of his monograph "The Mechanism of the Larynx", T. B. Layton suggested that he should study the production of voice in animals and men. Victor Negus followed this advice so faithfully that by 1929, when the work first appeared, he had already formulated everything that might be said regarding phonation today. Quotations from Negus are, therefore, ever coming to mind. "Sound production is one of the most important means of intercommunication." "In mammals and birds intercommunication has reached its greatest height." "The most elaborate and the most successful system of phonation has been elaborated in mammals. This occurrence is definitely associated with pulmonary expiration and the presence of the larynx." Victor Negus, on the other hand, repeatedly points out that the larynx basically "is a valve to protect the entrance to the pulmonary airway and that it is incorrect and misleading to speak of the larynx as

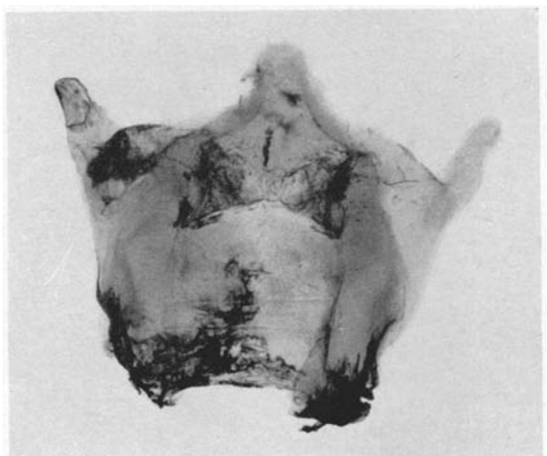

FIG. 4.
Lymphatic vessels of the laryngeal mucosa (Gerota's technique).

the organ of voice". "Birds have a primitive type of larynx and they can hiss with that larynx, but birds produce cries and songs with a special vocal organ, the syrinx, situated on the bifurcation of the trachea.

A patient who had a total laryngectomy can still make himself understood once he has learned the œsophageal speech. Such a patient swallows air and expels it under voluntary control through the mouth of the œsophagus. The impact of the air being regurgitated opens the tonically contracted pharyngeal constrictor ring which closes again at once. The escaping air thus acquires rhythmical areas of compression and decompression, which are interpreted as sound. The laryngectomized patient then articulates this sound into the gruff monotony of the œsophageal voice. In spite of the virtual absence of modulation, some of these patients achieve an astonishing vocal performance thanks to a strong will and an irrepressible urge for communication. The œsophageal voice production is achieved with a simple muscular valve mechanism, and there are no nervous impulses to set the mouth of the œsophagus rhythmically vibrating. The cerebral speech centre after laryngectomy takes over the mouth of the œsophagus, working on regurgitated air as the new, though much more primitive vocal organ.

This end organ substitution shows that speech, which is peculiar to man depends on the co-ordination of the speech and auditory centres in the human brain. Voice production may exceptionally be extralaryngeal and in those cases it is certainly not subject to direct central control by means of rhythmical contractions of the mouth of the œsophagus. In the animal world many mammals use a very powerful voice as a means of communication, and this is produced in a larynx which is structurally similar to the human organ. Nature tends to preserve successful functional systems, and under similar anatomical conditions we may assume that laryngeal voice production in man is similar to that in other mammals. The supporters of the clonic theory must therefore, to be logical, assume a centrally initiated rhythmical stimulation of the tranverse fibres of the thyro-arytenoid muscle for laryngeal sound production in animals.

The thyro-arytenoid muscle forms the anatomical sheet anchor of the new clonic theory. According to the text books the thyro-arytenoid muscle arises from the vocal process of the arytenoid cartilage and runs parallel to the vocal fold to be inserted into the thyroid cartilage. K. Goerttler's histological work has led him to the conclusion that the thyro-arytenoid muscle does not exist in this form but consists of a complicated system of fibres which cross each other. K. Goerttler separates two muscle bundles. One, called the *thyreo-vocalis*, arises above and ventrally on the inner surface of the thyroid cartilage and radiates down dorsally to insert obliquely into the vocal fold. The fibres of Goerttler's second bundle, called *ary-vocalis*, arise from the arytenoid cartilage and are inserted above ventrally and likewise obliquely into the ligamentum vocale. Both muscle bundles are bound together through a central tendon and certainly act as antagonists. According to Goerttler the muscle fibres inserted into the vocal fold act as abductors and at the same time as elevators and depressors of the vocal folds. The clonic theory maintains that these muscle fibres running obliquely to the vocal fold contract rhythmically as a result of central impulses reaching the larynx through the recurrent nerves. The active pull of the oblique muscle fibres will thus abduct the vocal fold while the elastic recoil of the ligamentum vocale will set up horizontal vibrations of the vocal folds corresponding to the frequency of the nervous impulses. The arrangement of the thyreo-vocalis muscle as described in the human larynx by Goerttler has to our knowledge never been demonstrated in animals. Victor Negus has described muscle fibres arising from the arytenoid cartilage and inserted obliquely into the vocal fold in certain mammals, especially in the dog tribe. However, the majority of mammals, including monkeys, have no such oblique muscle fibres. In spite of this, many of these animals are able to produce a very loud voice. Thus the necessary anatomical basis for the clonic theory is absent in the majority of mammals. Goerttler's findings have, however, not been confirmed by others investigating human laryngeal muscles. Admittedly Koelliker, Ludwig, Jacobson and others have described fibres of the vocalis muscle arising from the arytenoid cartilage and being inserted into the ligamentum vocale. The function of these fibres is, however, debatable, as they are rather inconstant and F. Wustrow has reported on a human larynx showing absence of the portio ary-vocalis, where the patient had a normal voice before death. These oblique fibres according to Victor Negus may play a part in the production of the higher tones by widening the conus elasticus and thus reducing the area of vocal folds in contact. F. Wustrow's observations, which have been confirmed by K. H. Vosteen, Elze, Oltersdorf, J. W. van den Bergh, J. Moll and H. Mayet, show that the thyro-arytenoid muscle consists of two bundles. In the abducted position of the fold the portio thyreo-vocalis runs directly backwards from the thyroid to the vocal process of the arytenoid. The second muscle bundle arises centrally and more deeply from the inner surface of the thyroid cartilage and crosses under to insert into the muscular process of the arytenoid. This is the portio thyreo-muscularis. In the adducted position, as a result of rotation of the arytenoid cartilage, both portions of thyro-arytenoid muscle run parallel to each other and parallel to the surface of the vocal fold. Wustrow's findings thus confirm the old established views of the longitudinal course of the thyro-arytenoid muscle. Goerttler's assumption of so-called vocalis system with oblique muscle fibres to the ligamentum vocale is attributed by Wustrow to misinterpretation of oblique histological sections of the vocal folds.

In order to settle this dispute concerning the direction of the muscle fibres, we have paid particular attention to the structure of the ligamentum vocale. The term "ligamentum vocale" is used to describe the free border of the vocal fold. This border is formed by a connective and elastic tissue strut in the upper part of the conus elasticus. The ligamentum vocale arises in the second month of embryonic life by a condensation of cells in the mesenchyme forming the chordal nodula. Strands of cells run from the latter to the thyroid, cricoid and arytenoid cartilages. The ligamentum vocale is difficult to separate from the underlying muscle. Certain authors conclude that this strong adherence is due to the insertion of numerous muscle fibres into the ligamentum. A *frontal section* through the vocal folds (Fig. 5) however, shows that it is not the muscle fibres that bind down the vocal fold, but on the contrary it is the connective tissue of the ligamentum that radiates in among the thyro-arytenoid muscle fibres and blends with their perimysium(!). Thus a firm union is effected between many longitudinal fibres of the thyro-arytenoid muscle and the free border of the vocal fold being formed of connective and elastic tissue. This internal union between the muscle fibres and the ligamentum vocale explains the great pliability of the vocal folds as observed during the production of different tonal qualities. During voice production the free border of the vocal fold consisting largely of connective tissue responds most readily to the mechanical effects of the horizontal

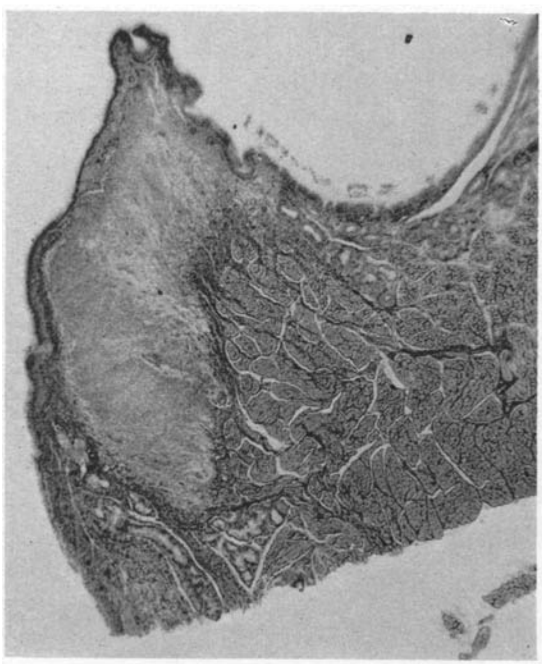

FIG. 5.
Frontal section through a vocal fold.

vibrations of the vocal fold. Wherever a collagenous fibre system immediately responds to neighbouring muscular tensions, the collagenous and elastic fibres are predominantly arranged in the direction of the muscle pull. If the transverse vibrations of the vocal folds are caused, as postulated by Husson, by the active contractions of some muscle fibres which should be inserted at right angles to the ligamentum vocale, then one would expect the collagenous and elastic fibres to be similarly disposed in the line of the muscle pull.

We have examined serial sections of numerous vocal folds of all age groups, stained for elastic tissue (Fig. 6). The elastic fibres of the ligamentum vocale run consistently parallel to the long axis of the vocal fold. It is only deep to the ligamentum vocale that this strict order of arrangement alters in the lacework of fibrils forming the conus elasticus. There are also many small muscle bundles criss-crossing in all directions from the thyroid and cricoid cartilages to be inserted into the conus elasticus.

The histological findings in the region of the ligamentum vocale confirm Wustrow's observations. Apart from very occasional oblique muscle fibres of the ary-vocalis type, the thyro-arytenoid muscle consists of bundles running longitudinally from the inner surface of the thyroid cartilage, parallel to the surface of the vocal fold, to the arytenoid cartilage. Thus in human vocal folds there is no evidence of the tranverse fibres which form the anatomical basis of the new clonic theory of phonation.

FIG. 6.
Horizontal section through a vocal fold, stained for elastic tissue.

The vocal folds at birth (Fig. 7) are very short and the ligamentum vocale is almost as thick as the underlying mass of the thyro-arytenoid muscle. It is, therefore, very hard to explain how the rhythmic contractions of the thyro-arytenoid can produce transverse vibrations of the thick ligamentum vocale. Nevertheless, the larynx in the new-born is capable of an astonishing vocal output. When the foetal circulation is interrupted at birth, the infant's blood CO_2 rises rapidly. This stimulates the respiratory centre. The first inspiration opens the hitherto narrow glottis, which closes again after the first expiration. This is the moment of the first cry. The closing glottis is forced open again by the rising expiratory force so that the plump vocal folds are subjected to rhythmic vibrations. During the ensuing several minutes or even hours this forced expiration leads to the loud and penetrating cry of the new-born. We have prepared a tape recording of the new-born infant's vocal efforts at birth and would now give you an example of the first exercise in human voice production (sound recording tape).

The vocal records of 13 new-born babies were analysed for frequency. A well known fact was confirmed, namely that in the voice of all these different infants the relative distribution of loudness to sound frequency (Fig. 8) was practically identical with a maximal difference of 7 db. This remarkable uniformity of pitch in the infants is clearly connected with

FIG. 7.
The vocal folds at birth.

the similar size and shape of their glottis. I do not know how the vocal performance of the new-born can be explained on the basis of the clonic theory. How is the rhythm of the nervous impulses so uniformly laid down in the brain of the new-born? Is it possible that from the moment of birth the striped muscle fibres of the thyro-arytenoideus respond to these impulses by way of completely co-ordinated excursions or vibrations?

Both clonic and tonic theories recognize that the other intrinsic and extrinsic laryngeal muscles take part in voice production in addition to the disputed thyro-arytenoid. The position of the arytenoid cartilage in relation to the cricoid must be repeatedly fixed or altered against the pull of the muscles of the vocal folds. The fixation or the changes in position of the arytenoid cartilage are effected by the crico-arytenoideus posticus, the inter-arytenoid and the lateral crico-arytenoid muscles in varying degrees. Simultaneously the crico-thyroid muscles regulate the position of the cricoid and thyroid cartilages and thus affect the tension of the vocal folds. These various muscular activities take place through a highly differentiated increase or decrease in muscle tone.

The new theory of phonation attributes the function of clonic contractions to the thyro-arytenoideus only. On this assumption one would expect the muscle to have its own special and rich nerve supply. Remarkably enough the thyro-arytenoid muscle is not supplied by a special large branch of the recurrent nerve (Fig. 9), but it receives two twigs which also innervate the inter-arytenoideus and lateral crico-arytenoideus

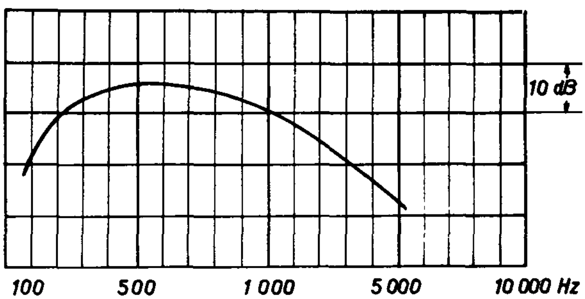

FIG. 8.

Relative distribution of loudness to sound frequency in the voice of 13 new-born infants.

on the same side. S. Sunderland and W. E. Swaney have found that the branches of the recurrent laryngeal nerves reaching the larynx are not divided according to the individual muscles to be supplied. Even in the main recurrent nerves the fibres do not run in an orderly and parallel manner. They branch and unite repeatedly and the fibres become well mixed. Separate nerve bundles destined for certain muscle groups could not be traced.

J. Piquet, M. Hoffmann and R. Husson have investigated the motor unit and end-plates in the thyro-arytenoideus. Most muscle motor units consisted of 2-3 and never more than 8 myofibrils.

We have repeated these investigations of the thyro-arytenoideus and have also examined the crico-arytenoideus posterior and crico-arytenoideus lateralis for comparison. The structure of these three small laryngeal muscles is identical (Fig. 10). We have found that the crico-arytenoideus posterior also mostly shows only 2-3 myofibrils per motor unit. Comparison of the muscle end-plates—you see in Fig. 11 an end-plate in the thyro-arytenoideus—also shows no difference in the three small laryngeal muscles. The end-plates in the crico-arytenoideus posterior (Fig. 12), and lateralis occur in similar numbers per section as in the thyro-arytenoideus and there is no difference in construction of the motor end-plates in the three muscles. There are 4-8 neuro-fibrils per end-plate.

Thus neither the histology of the recurrent nerve and its laryngeal branches, nor details of the structure of the muscular elements and motor-end-plates of the intrinsic laryngeal muscles can be used in support of the clonic theory of phonation. No special features of muscular structure or of special innervation of the thyro-arytenoid muscle could be discovered.

As we have not carried out any electro-physiological investigations, we have had to content ourselves with a review of the work carried out so far by other authors.

P. Laget and J. L. Robin have applied electronic stimuli of very short duration and with frequencies varying from 10-1,000 c./s. to the recurrent

FIG. 9.

Innervation of the thyro-arytenoid muscle, the inter-arytenoideus and lateral crico-arytenoideus by different twigs of the same branch of the recurrent nerve.

laryngeal nerve of the dog. They recorded the excursions of the vocal folds electromyographically using a Bronk's electrode. Up to 250 c./s. action potentials appeared synchronously with the stimuli and were of corresponding amplitude. Above 500 c./s. the response was greatly reduced and of inconstant amplitude. Above 600 c./s. the response became so weak and inconstant that it could not be recorded by electromyography. These findings of Laget and Robin are not confirmed by the work of Floyd, Negus and Neil on the cat. "At frequencies of 50 and 100 c./s. a large response followed each stimulus and at rates as high as 250 c./s. occasional response was found in the muscle. At higher frequencies, however, there was no obvious relationship between the electromyographic potentials and the stimulation frequency." B. Schlosshauer also stimulated the recurrent nerve in the dog at frequencies of 100 c./s. and was unable to observe any synchronous movement of the vocal folds with the stroboscope. The same author collaborating with Dunker stimulated the central branch of the recurrent laryngeal nerve in the dog with currents of different frequencies. Movements of the vocal folds were recorded with a high speed camera. Up to 30 c./s. the movements were synchronous with stimuli. Above 30 c./s. there was a gross shortening of the vocal folds.

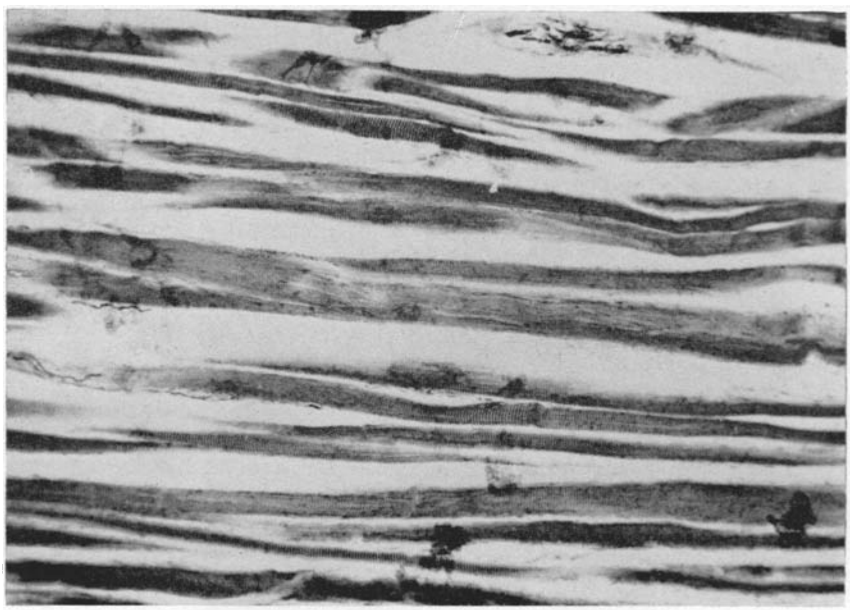

FIG. 10.
Myofibrils of the crico-arytenoideus posterior.

Finally A. Fessard's and B. Vallancien's work, refuting Laget and Robin's results, was confirmed. By applying currents over 60 c./s. to the recurrent laryngeal nerve in the dog a titanic contraction of the vocal fold muscles was obtained.

Of the electro-physiological investigations on the human larynx Moulonguet's experiment is frequently quoted by the supporters of the clonic theory. In the course of a laryngectomy he asked the patient to sing two notes. He recorded this tone as being of 140 and 190 c./s. and simultaneously measured the action potentials in the recurrent laryngeal nerve. The strictly homorhythmic swings in potential often occurred a few hundredths of a second before vocalization. In contrast to Moulonguet, K. Faaborg-Andersen examined the human larynx electromyographically and found the maximal frequency discharge during phonation to be only 20-30 c./s. of a single motor unit. Furthermore this author found the action potentials to be qualitatively the same in cases of vocal fold paralysis as in those with normal mobile folds. The electro-physiological investigations of the human larynx by G. F. Greiner, E. Isch and J. Cl. Lafon and the confirmatory work of A. Spoor and van Dishoeck are of special importance. Greiner and his collaborators performed electromyography of the normal larynx during phonation by inserting a Bronk electrode into the conus elasticus. Spoor and van Dishoeck examined the

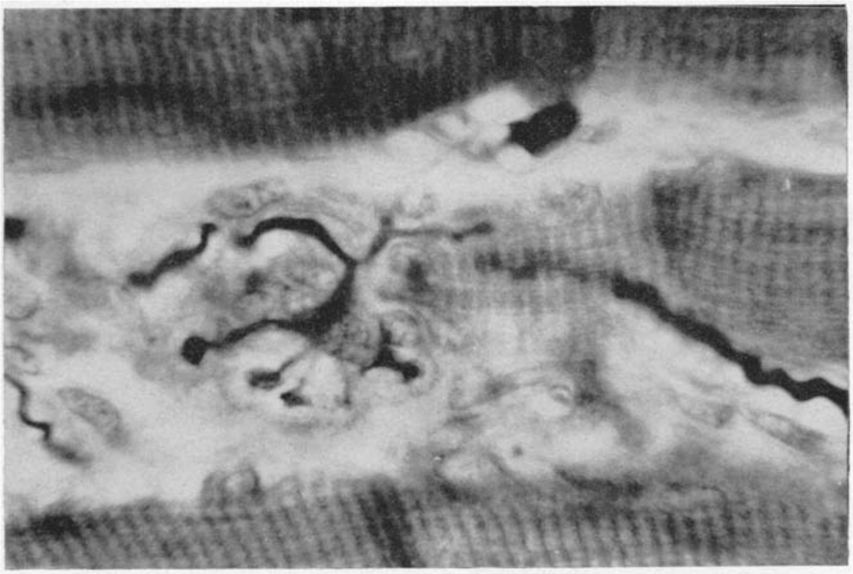

FIG. 11.
Muscle end-plate in the thyro-arytenoideus.

vocal folds by electromyography through a subglottic stoma. The results of both methods show a satisfactory degree of agreement. At least two types of electrical activity must be differentiated. Firstly aperiodic action potentials appear in the larynx $\frac{1}{4}$ second before voice production. Even silent speech accompanying thought without any airstream produces these action potentials. A homorhythm between these action potentials and the singing of a note was not however observed. Apart from this a microphone effect always appears as soon as the tone begins, corresponds exactly to the frequency of the tone, and disappears as soon as the air stream ceases. This microphone effect has nothing to do with muscular activity. It appears wherever sound is conducted through the tissues. During humming a Bronk needle electrode inserted into a nasal polyp will also pick up the homorhythmic microphone effect.

Apart from Moulonguet, the majority of electromyographic investigations of the human larynx by Faaborg-Andersen, Greiner and collaborators, Spoor and van Dishoeck, speak against the clonic theory of phonation. Especially the last two papers have shown up certain technical difficulties which must be reckoned with in the electro-physiological investigations of the larynx.

In order to avoid these pitfalls other workers prefer direct or indirect observation of the laryngeal function with and without air supply by means of stroboscopy and more recently the high speed camera. But even

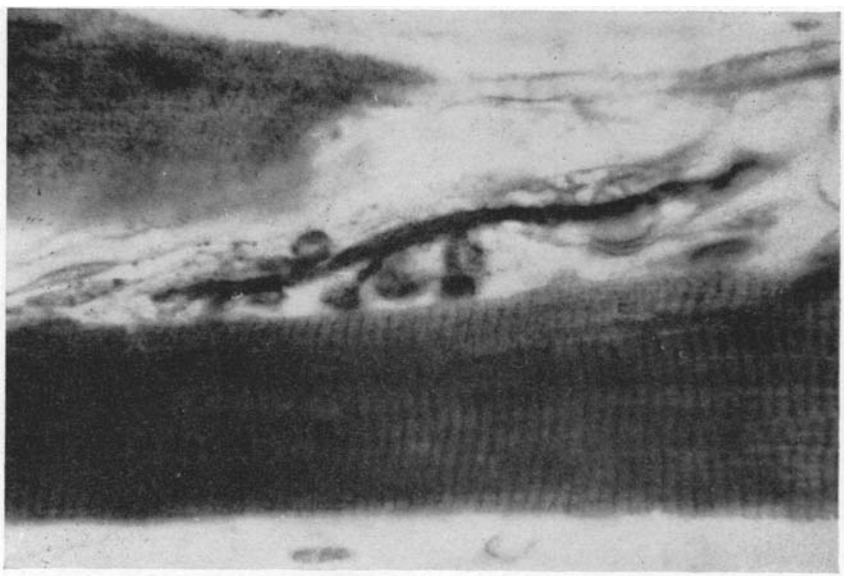

FIG. 12.
Muscle end-plate crico-arytenoideus posterior.

these physiological methods of investigations have not yielded uniform results.

J. Piquet and G. Decroix asked a patient to sing a certain note after the establishment of a pharyngostome during a horizontal laryngectomy, which was being performed under local anæsthesia. The movements of the vocal folds were recorded on a high speed film. A tracheostomy was then performed and the subglottic space closed with a cuffed tube. The patient was asked to sing the same note again, and during this "silent song" a normal adduction of the vocal folds occurred. Also vibrations of the vocal folds continued although no sound could be heard, "tout au moins en dehors d'un espèce de petit râle très court". (i.e. apart from a little short wheeze). The movements of the vocal folds as recorded on the film are fully comparable with those taken before the trachea was occluded.

Piquet and Decroix accept this film as proof of the clonic theory of phonation, where the vocal folds vibrate in the absence of an air stream, and conclude that they must therefore be controlled by centrally induced muscular contractions. J. W. van den Berg has performed a similar experiment on a patient with a large tracheotomy without a cannula. On stroboscopic examination all movements of the vocal folds ceased when the tracheostomy was opened. This author also points out that when a tracheal cannula is inserted some air always escapes past it into the larynx, even when the cannula is wide open. The little râle noted by Piquet is evidence of a similarly incomplete exclusion of the larynx. In order to test this source of error K. Mündnich has performed a horizontal laryngectomy in the same way as Piquet, but he applied a rubber cuff to the tracheostomy tube. The high speed film showed similar excursions of the vocal folds during attempts at phonation which again produced no audible voice. The film also showed a small bubble of mucus in the larynx, which quickly burst. Thus in spite of the steps taken to block up the trachea, air nevertheless passed between the vocal cords. Mündnich explains that the enclosed subglottic space becomes narrowed during adduction of the vocal folds and the air contained in the space is expelled through the glottis. In a further experiment Mündnich therefore used the cuffed tracheostomy tube and in addition he drained the space above the cuff with a second cannula. In this way all the vibrations of the vocal folds stopped irrespective of attempted phonation. Dunker and Schlosshauer reached a similar conclusion on stroboscopic examination of a patient with a tracheostomy tube. Finally B. Vallancien and his collaborators have prepared a high speed film of the movements of the vocal folds with a simultaneous oscillographic record of the emitted tone. When the subject was asked to hum or produce "silent speech", the vocal folds came together and no vibrations occurred. As no tone is being produced the oscillograph traces a straight line during this time.

Apart from Piquet no investigator was able to observe any movements of the vocal folds after the air stream had been effectively diverted from the larynx.

We have repeated these experiments on three patients in order to form our own opinion. Two patients had large pharyngostomes after excision of pharyngeal carcinoma. The third case was one of recurrent laryngeal papillomata who had worn a tracheostomy tube for years. The laryngeal function was recorded with a high speed camera from a mirror examination *viâ* the pharyngostomes. The third case was examined by conventional indirect laryngoscopy with the tracheostomy open and closed, without warning to the patient. The rough voice was tape-recorded in one case and played back to the patient through ear-phones during phonation in order to eliminate possible acoustic reflexes. This was not repeated in the other experiments because the high speed camera is so noisy that the deafened patient is not aware of his own voice or the sudden absence of it. In our three cases all movements of the vocal fold stopped the moment the air stream was diverted from the larynx. The sudden stilling of the vocal folds, which remain in the position of phonation during rhythmical brief opening of the tracheostomy, was particularly impressive. Many cinematographic recordings of laryngeal movements have been prepared by various workers, both with and without the glottic air stream. Apart from Piquet they all support the classical *tonic* theory of phonation. A short film will illustrate the points mentioned above.

Summary of the film:

(1) Shows the normal vibrations of the vocal folds in a singer while she is singing a note of constant frequency, with increasing and decreasing intensity.

(2) I would now like to express my thanks to Professor J. Berendes of Marburg for kindly allowing me to show the film of his experiments. This shows a specimen of human larynx subjected to blasts of air. The resulting vibrations of the vocal folds correspond very closely to those observed in the living larynx.

(3) Shows one of our patients with a pharyngostoma and a tracheostomy investigated with a high speed camera. On each occasion the movements of the vocal folds stop whenever the tracheal air stream is diverted away from the larynx.

(4) Shows high speed camera pictures of very high tone production (2048 c./s.) taken by Professor R. Luchsinger. The glottis is incompletely closed. It is remarkable that vibrations of the vocal folds are distinctly slower than the light reflex from the laryngeal mucosa, which is vibrating at the same frequency as the tone being sung.

The comparison between the movements of the vocal folds in life and in the specimen of the larynx shown in the film requires no comment. The experimental, brief, rhythmic opening of the tracheostomy during phonation shows very clearly that the vibrations of the vocal folds depend on a stream of air passing through the larynx. The incomplete closure of the glottis during the production of high notes is noteworthy. The remarkable fact that with very high tones the visible vibrations of the vocal folds are of a lower frequency than the audible note has not yet been explained. At the same time the light reflex from the moist mucosal surface vibrates at the higher, audible frequency. Possibly these frequencies are produced secondarily in a resonator as in the okarina, and so the lower vibration frequency becomes augmented.

There are certainly still many aspects of the function of the vocal folds to be studied also on the basis of the tonic theory. Recently R. Timcke, H. von Leden and P. Moore have shown that the vibratory pattern of human vocal folds does not resemble a rhomboid or a sinusoidal wave. The process of abduction differs from that of adduction. The components of the vibratory cycle may be further analysed by means of a speed quotient and an open quotient.

Finally Victor Negus points out that even on the basis of the tonic theory the production of pure tones, the extremely rapid variations in pitch, volume and quality of the sound are only possible thanks to an extraordinarily complicated apparatus. This calls for the co-operation of numerous muscles controlling the air pressure in the pulmonary system, and the resonance in the cavities of the mouth, throat and nose. At the same time the intrinsic and extrinsic laryngeal muscles govern and constantly adjust the elasticity, shape and position of the vocal folds. All the finer points of voice production, which are only possible thanks to these complicated tonic changes in the laryngeal muscles, the high degree of differentiation of the human speech centre and the complexity of the nervous control are only used in their infinite variety by the vocally talented actors and singers. Negus considers that for ordinary everyday use a much more simply constructed larynx would be sufficient instead of the highly complex apparatus. "The range of voice for the vast majority of human beings is extraordinarily limited. As the average individual certainly indulges in conversations but almost in a monotone."

It is not by chance that these observations on the histology and function of the larynx close with a quotation typical of the Englishman, Sir Victor Negus. It is inherent in the subject matter that the name of this author must ever come to the fore. And so this Semon Lecture has almost naturally developed into an appraisal of the scientific work of Victor Negus. It is thanks to his achievements that British laryngology still remains in the forefront of the profession.

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