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LARYNGEAL PHYSIOLOGY*

CINEMATOGRAPHIC OBSERVATIONS

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As otolaryngologists we are intensely interested in the subject of human communications since it is our privilege to diagnose and treat the diseases of both the sound producing and sound receiving organs. However, during the past decades the main interest in our specialty has been directed toward the field of otology, resulting in many new and important discoveries in the physiology and therapy of otologic diseases. I hope you will forgive me, therefore, if I ask you to leave the lofty pinnacles and well-mapped peaks of otology, with the panoramic view over the cochlear spiral and the semi-circular canals, and join me on the uncharted waters of the larynx with their important but puzzling glottic waves.

Little more than twenty years ago, Kerridge (1938), felt obliged to record that our factual knowledge of laryngeal physiology was limited to the observation that the vocal cords vibrate, sometimes with a razor-like edge and at other times with a well-rounded surface; he was distressed that everything else seemed complication and controversy. Since then we have witnessed a veritable renaissance in laryngeal physiology, stimulated first by the monumental observations of your own Sir Victor Negus (1929), and encouraged further by the introduction of a new and highly controversial theory of phonation in France ten years ago (1950). We have read

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the interesting reports in favour of this neuro-chronaxic theory by Husson, Laget, Piquet and Decroix, and Portmann; in rebuttal, we have admired the painstaking electro-myographic investigations of Faaborg-Andersen and Nakamura, and we have followed the intricate physical experiments of van den Berg, Dunker and Schlosshauer, Smith, Isshiki, Floyd and Neal; we have observed the splendid anatomic studies of Goerttler, Rüedi, Pressman, and Sonesson, and we have witnessed the extensive roentgenographic, acoustic, stroboscopic, and spectrographic investigations in different European countries, Japan, and in the United States of America. This brief enumeration is not intended as a review of the pertinent literature or of the varied work in our sub-specialty during the past few years, but rather as an attempt to recall that many of our new technical modalities have been explored and are presently employed in this continuing research.

It would be a fitting tribute to Sir Victor Negus to discuss all these investigations in relation to his own research and to point out that all of our endeavours are built to a great extent on his own contributions in our specialty. As Professor Rüedi (1959), indicated so eloquently during his recent Semon Lecture before this very audience, it was the publication of Sir Victor's great opus *The Mechanism of the Larynx* which laid the ground work for our advance in laryngeal physiology. Unfortunately, in the interest of our time schedule, I must defer this pleasure to another day and pass on to the specific type of research which I have been invited to present at this meeting. Your President has been so gracious to permit my presentation in a rather informal style, and I would like to demonstrate our own contributions to the area of laryngeal physiology through a medium originated and developed in my own country—ultra high speed photography.

A little over twenty years ago, the Bell Laboratories (1937), produced two very interesting motion pictures which demonstrated the vibrations of the vocal cords in ultra-slow motion. These pictures were photographed at a hitherto unknown speed of approximately 2,000 frames or pictures a second and showed many new and interesting details of vibratory motion. However, after a flurry of interest this work was discontinued, and one is forced to conclude that of the early investigators only my associate Dr. Moore and Professor Luchsinger in Zürich realized the potential of this new modality for research in laryngeal physiology.

My own interest in this subject started seven or eight years ago as a direct result of dissatisfaction with the traditional technique of laryngeal examinations which has changed but little in the last century. As a clinician, I was constantly aware of the disproportion of systems and findings in the realm of laryngology. I was disturbed by my lack of ability to diagnose and treat certain types of hoarseness, which were highly distressing to my patients but which presented little or no organic change

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on gross examination with the laryngeal mirror or with the direct laryngoscope.

At this point, I was fortunate to meet Dr. Paul Moore, a well-known voice pathologist who had been interested in the subject of laryngeal photography for a number of years. This association ripened into a close affiliation and friendship, and my presentation here today reflects this mutual co-operation. While I do not wish to commit my associates on any specific issue, all of our work presents a combined effort and bears witness to Dr. Moore's ingenuity.

We initiated our project with investigations of the pathologic larynx, but after several months and several thousand feet of film, we came to the conclusion that *we* at least did not know enough about the vibratory function of the normal larynx to correctly interpret pathologic deviations. We, therefore, reversed our direction and started at the beginning—the function of the normal larynx. As our information accumulated, we were persuaded to present some of this material in the form of educational motion pictures, two of which I would like to show at this meeting.

Our first film demonstrates the function of the normal larynx during normal sound production. In order to record a clear image of the functioning larynx, without structural distortion, all of the motion pictures in this and subsequent films were obtained by indirect laryngoscopy and without the employment of any local anæsthetic agent. For the first time in laryngeal cinematography, action and sound have been synchronized to permit the simultaneous study of muscular movements and the resulting voice.

The Function of the Normal Larynx (1956, 1958)

(*Abstract of Motion Picture*)

The first in a series of educational motion pictures on "The Larynx and Voice", this film presents a brief review of the pertinent anatomy, and a clear and detailed picture of normal laryngeal physiology in voice production.

The exact synchronization of action and sound gives an impression of realism, and decisively resolves the controversial relation of the length of the vocal cords versus their mass in the determination of pitch.

The importance of ultra high speed photography in the study of laryngeal function is demonstrated by a series of common sounds photographed at the rate of 3,000 to 5,000 frames, or pictures a second. The use of colour film at such speeds represents a new development in laryngeal photography.

New observations on normal laryngeal physiology presented in this film include a new concept of abduction, arytenoid motion, and asynchrony of vibration. Contrary to traditional teaching, in abduction the

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vocal cords often separate first, to be followed by the vocal processes of the arytenoid cartilages; the abduction is then completed by lateral movement of these cartilages. In both adduction and abduction the movement of the arytenoids is smooth and steady, without rotation around a vertical axis.

With changes in pitch, the vocal cord movements may become slightly asynchronous. This finding is not uncommon and causes no apparent change in voice. At low pitch, the slow motion pictures of the vocal cords depict a thick double lip along the free margin. The intricate motion of the loose mucous membrane in this area emphasizes the importance of this covering during phonation and contributes to a practical theory of voice production.

The complexity and diversity of laryngeal adjustments are illustrated by a cough and by a coup de glotte. These two non-linguistic phenomena are similar in appearance, with one important variation: when a cough is released, the arytenoids abduct instantly to pull the cords apart and thus open the air way. In the coup de glotte, on the other hand, the arytenoids remain together to ready the vocal cords for phonation.

Our second educational film was intended for a more advanced audience familiar with the basic anatomy and physiology of the larynx. It pictures the numerous complex adjustments of our vocal organ to the exigencies of daily life. The scenes from this motion picture were selected from some 20,000 feet of film on normal larynges in our film library.

Physiology of the Larynx under Daily Stress (1958, 1959)

(Abstract of Motion Picture)

To relate the varied physiologic changes to clinical reality the larynx is first pictured in natural colour, at ordinary speed, with synchronized sound. The details of vibratory function are then displayed by ultra-slow motion pictures, with a 200 fold magnification of the time factor. This section depicts a number of new physiologic concepts, relating to the details of the vibratory cycle, to the intensity and frequency of sound production, and to the motion of the soft tissues and cartilages of the larynx.

The traditional picture of the vibratory wave presents a rapid opening phase, a slower closure, and a brief period of approximation. The limitation of this basic physiologic principle is revealed when the intensity of the voice is changed. While the traditional observation is correct for the vibratory cycle during weak or soft voice production, a loud voice reverses the ratio of the vibratory movements. The closing phase of the vibratory wave is shorter than the opening phase, and the period of approximation increases substantially. This adjustment is the result of two interacting

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forces, the tension of muscles and ligaments in the larynx, and the pressure of the air column activating the cords.

In the production of voice different fundamental adjustments or "registers" are employed to vary the pitch and quality. In the so-called "chest" voice, the vocal cords are thick and massive, and the period of approximation is prolonged. By contrast, the so-called "head" voice shows but a momentary contact, with definite thinning of the vocal cords and an increase in the tension of the muscles and ligaments. In "falsetto" the vibrations are much faster and there is even less contact between the vocal cords; in some voices only the anterior segment of the cords appears to move at very high pitch.

Accessory waves in the anterior and posterior directions are not uncommon, and are related to pressure changes within the larynx. While all laryngeal structures are involved in ordinary sound production, this participation is particularly noticeable in such non-linguistic phenomena as laughter, clearing of the throat, and coughing. The speed of individual movements must be calculated in thousandths of a second.

The vibrations of inspiratory phonation present an entirely different picture with a massive extension of the vibratory wave laterally and an extremely long period of approximation.

For the first time, a multi-phasic pattern of vibration is presented which is characterized by the constriction of all laryngeal structures. In a steady form this pattern is associated with a harsh strident sound, variously described as "vocal fry", huskiness, or ventricular dysphonia. Because of its basic physiologic pattern we have termed this phenomenon dicrotic dysphonia.

Illustrative graphs are used to explain the new concepts and to stress the feasibility of accurate measurements. The adaptation of artificial models to the study of the vibrating mechanism is also demonstrated.

During the projection of the last film I pointed out a number of incidental findings which must be interpreted as supportive evidence for the aerodynamic theory of voice production. Since your last Semon Lecture dealt with this subject, I would like to add a brief motion picture from our own Laboratory to the impressive evidence Professor Rüedi marshalled against the neuro-chronaxic theory of voice production.

Air Pressure and Laryngeal Vibrations (1957)

(Abstract of Motion Picture)

In the summer of 1956, a fifty-three year old man had been subjected to a tracheostomy for œdema of the larynx. In the fall of the same year, after subsidence of the œdema, the larynx was photographed via indirect

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laryngoscopy at ultra-high speeds. At this time any occlusion of the tracheal canula resulted in deflection of the air stream through the larynx with apparently normal phonation, as recorded on an oscilloscope.

During the production of *sustained* sounds the tracheal stoma was closed intermittently, while the larynx was photographed. From repeated examinations on different days, it is evident that the vibrations of the vocal cords cease whenever the breath by-passes the larynx; the normal vibratory pattern recurs as soon as the air current again passes through the glottis. In the interim, the vocal cords remain adducted, ready for phonation.

After this demonstration, I believe you will agree with our conclusion that the passage of air under pressure is a necessary requisite for normal laryngeal vibrations and voice production.

By now you may well wonder whether this cinematographic approach has any value beyond that of satisfying our natural curiosity regarding the movements of the laryngeal cartilages and soft tissues. Doctor Moore and I are satisfied that this technique has a definite clinical application, and we are now centering our attention on the pathologic larynx. Already we have observed a number of interesting phenomena which are of value in the diagnosis and prognosis of laryngeal disorders and in the planning of indicated therapy. I refer to such varied conditions as laryngeal paralysis, contact ulcer, laryngeal œdema, and tumours of the vocal cords.

Since you insist, Mr. President, I shall present two short films on laryngeal pathologies for illustration.

Contact Ulcer of the Larynx—Etiologic and Experimental Observations (1959)

(*Abstract of Motion Picture*)

The harmful effects of faulty vocal habits on the production and persistence of contact ulcer of the larynx are well known. Cinematographic and other experimental investigations have been carried out to determine the type of vocal trauma responsible for this disabling lesion.

The anatomic and physiologic factors in the production of contact ulcer are reviewed, and the experimental evidence is supported by ultra-slow motion pictures. The clinical manifestations of a contact ulcer and its regression under indicated therapy are presented.

On the basis of these investigations, we are firmly convinced that voice rest and rehabilitation are the treatment of choice for contact ulcer of the larynx. Surgical excision of the lesion should be deferred until conservative measures have been given a fair trial, and should be reserved for cases of long standing which are characterized by diffuse scarring or extensive granulations.

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Laryngeal Physiology

Our next and last film deals with the subject of unilateral vocal cord paralysis and presents a number of interesting phenomena which startled me during my first exposure to these film strips.

Vocal Cord Paralysis—A Study in Slow Motion (1959, 1960)

(Abstract of Motion Picture)

This film presents three patients with paralysis of the left vocal cord. In the first case the paralysis was apparently the result of a toxic neuritis involving the left vagus nerve or one of its central connections; accordingly, the vocal cord was paralysed in the intermediate position. The other two cases were caused by pressure on the recurrent laryngeal nerve (cardiac hypertrophy) and malignant invasion of this nerve respectively; in these cases the paralysed cord is found in the paramedian position.

The larynges of the patients are first shown in colour at regular camera speed in order to present a realistic picture of the clinical pathology. Subsequent scenes present typical patterns of vocal cord motion, photographed at speeds up to 5,000 frames a second. These ultra-slow motion pictures afford new information regarding the movement of the laryngeal cartilages and vocal folds in cases of laryngeal paralysis.

The most striking observation is the discovery that the paralysed cord does move; at certain times the vibratory excursions of the paralysed cord may even exceed those of its normal mate. The movements of the ventricular folds are also striking and vary considerably from the normal pattern. The effect of pitch changes on the vibratory mechanism explains the associated vocal changes and suggests certain therapeutic directions.

The complex motion of the arytenoid cartilage during adduction and abduction is well demonstrated as the healthy cord is carried to the median line for phonation, and during its return to the resting position. The accumulation of mucus and the apparent difficulty in its removal explain some of the clinical manifestations.

Conclusion

This marks the end of my demonstration, and I feel sure you will be happy to see the light of day again. While these motion pictures answer many problems regarding the physiology of the larynx in health and disease, they raise other questions in their stead; these questions in turn await further investigation or confirmation. Referring briefly to the last motion picture which may still be fresh in your mind, it is apparent that the motion of the healthy arytenoid cartilage does not fit the traditional concept as it is pictured in most textbooks. It is also apparent that the normal vocal cord is not stretched for phonation as is generally assumed, but on the contrary, its length increases all the way to the resting position.

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These observations have been confirmed and explained by experimental evidence, as yet unpublished.

But what effect do these findings have on our understanding of the intrinsic muscles of the larynx? On the action of the crico-thyroid muscle? On the extrinsic muscles of the larynx? So each changing concept raises a whole battery of new questions.

The science of laryngeal physiology is still young and much remains to be learned. The door is wide open and the welcome mat is out for any laryngologist or allied scientist who would like to dwell on the foundation laid by your great British laryngologists. If our investigations in laryngeal physiology and these motion pictures stimulate interest in this area, my associates and I will feel rewarded by the thought that we have begun to repay some of the debt we owe Sir Victor Negus and other members of your Royal Society of Medicine for their stimulation and their momentous discoveries in our field.

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