BRITISH MEDICAL JOURNAL

LONDON SATURDAY DECEMBER 10 1938

PHYSIOLOGY OF THE VOCAL MECHANISM *

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The problems connected with the mechanism of voice form an interesting study which has hitherto received comparatively little attention from the laryngologist. He tends to rely upon one method of examination—that of inspection, forgetting that the larynx, like other organs, has a function which deserves investigation. The laryngoscope has become almost a fetish, and consequently in this respect laryngology has not kept pace with the sister science of otology, in which the functional examination of hearing is acknowledged to be as essential as inspection of the tympanic membrane. Surely voice production is as important as voice perception.

A Neglected Branch of Laryngology

There are other reasons for this neglect of the study of vocalization. The subject may be approached from so many angles that it is difficult to obtain a comprehensive and unbiased survey. Anatomy, physiology, phonetics, physics, music, psychology are only a few of the sciences involved in a study of voice.

Naturally enough, the literature of the subject is widely scattered. It is not easy to find a synopsis of present-day knowledge of the mechanics of voice. Paradoxical though it may seem, laryngology is strangely aphonic on vocal matters. In vain does one search the modern standard English and American textbooks of laryngology for information on the vocal mechanism and its disorders.

Before laryngology became so aggressively surgical its practitioners displayed considerable interest in speech and song. Morell Mackenzie, Semon, Lennox Browne, and others paid much attention to the problem, and their papers still deserve attention. To-day, speech and voice are again attracting general notice, and it is surely the duty of the laryngologist to make some further contribution to the subject, or at least to acquire some basic knowledge of the physics and the physiology of vocalization in order that he may render the best service to the patient who depends upon his voice for a livelihood.

The Conflict of Singing and Science

Many textbooks of physiology contain a chapter or section on the human voice, and another source of information is to be found in the writings of singers themselves, and of teachers of singing and of speech. Several small manuals have appeared in this country. But it is not easy to describe an art in terms of science. Some of those books show a lamentable lack of physiological knowledge. The best of them are the result of a collaboration of medical and vocal specialists, each contributing his share. Such co-operation is greatly to be desired, as there has long been an unfortunate conflict

between singers and scientists. The singer uses such terms as head voice, tone, register, etc., which mean nothing to the scientist; the scientist, on the other hand, may confuse the singer by concentrating too heavily upon the larynx as the vocal organ, forgetting the equally important factors of respiration and resonance.

Evolution of the Vocal Mechanism

As a unit of the vocal mechanism the larynx is highly evolved, and its performance is truly wonderful. The vocal cords are capable of delicate adjustment by means of numerous muscles, some sixty in number. Even in lowly forms of life one may find sound-producing mechanisms which are the precursors of the highly evolved human larynx.

That supreme vocalist of the insect world, the cicada, so well known in legend and fable, possesses a chitinous plate which is caused to vibrate by the rapid contractions of a powerful muscle, producing a note corresponding to a pitch of 660 cycles per second. The female cicada is dumb; only the male can sing (Baier, 1930).

Certain fishes have a vocal mechanism (Greene, 1924). In the Californian singing fish there is a swim-bladder having two compartments divided by a diaphragm with a small central aperture. On each side of the wall of the air sac is a large muscle controlled by a spinal nerve. Contraction of this muscle forces the air from one chamber to the other, and a sound is thus produced which appears to be purposive. The mechanism resembles that which enables the frog to emit his familiar croak. Birds have a highly specialized vocal organ, the syrinx, with pads at the bronchial bifurcation to act as vocal cords, while the upper larynx is also used in producing song (Haecker, 1898).

I mention these examples merely to show that the human larynx would appear to have a long ancestry so far as its vocal function is concerned.

The Development of Voice

As an introduction to the mechanics of the larynx itself and of the vocal mechanism of which it is but a part, it is necessary to say a few words regarding the development, range, and classification of the voice.

The newborn infant cries on a note approximating to 435 cycles per second, and as growth proceeds the vocal range extends until at the end of the first year it encompasses six half-tones, at the end of four years about an octave, and just before puberty about an octave and a half (Nadoleczny, 1926). A practical deduction from those facts is that the limited range of the child's voice should be more widely recognized by those who compose for children songs which are often ill adapted to their voices.

* The Annual Address delivered at the Central London Throat, Nose and Ear Hospital on October 21, 1938.

Vocal Changes at Puberty

At puberty the male larynx grows rapidly, each vocal cord increasing appreciably in length. The male voice at this stage undergoes the remarkable alteration known as "breaking," which may occupy six months to two years. The change may begin at 8 years of age or may be delayed as late as the eighteenth year.

In boys the vocal pitch falls by one-sixth at its upper limit and by an octave at its lower limit. In girls the change is much less pronounced, is more rapidly completed, and consists merely in a slight extension of the upper and lower limits. Hoarseness is common in boys, and in about 10 per cent. of cases there may be seen a slight redness and swelling of the vocal cords and laryngeal mucosa, which may lead to an erroneous diagnosis of laryngitis.

Various disorders of voice are apt to appear at puberty. For example, there is the persistent falsetto voice which is the result of an incompleting change. In other cases the vocal change is of perverse nature, and this may account for the occasional appearance of the female bass or the male soprano. No vocal change occurs in boys who have undergone early castration, an operation which was at one time largely practised in Italy.

The Classification of Voices

The adult voice is the result of the puberty change, and the voice may be classified, according to its range, as bass, baritone, or tenor in man, and as soprano, mezzo-soprano, and contralto in women. Among the races of Southern Europe there is a tendency to high male voices and low female voices; there the proportion of tenors and contraltos is greater than among Northern races, in which basses and sopranos predominate. Orientals tend to have voices of high pitch, which may account for the falsetto nature of Eastern song.

It is important for the laryngologist to ascertain the nature of his patient's voice, as a common cause of vocal troubles is the adoption of a range or tessitura unsuited to the voice. For example, one may find a baritone who believes that he is a tenor, and who is therefore subjecting his voice to the strain of singing too high a pitch range.

Range of the Human Voice

Taking into consideration all classes of voice, from the deep bass note of the Cossack choir to the shrill pipe of

FIG. 1.—The vocal range in song and speech.

the coloratura soprano, the entire compass of which the human voice is capable may extend over five or even six octaves (Fig. 1). But such extremes are rare, and an

individual voice seldom extends over three octaves, while a range of two and a half octaves is more usual.

In speaking, a range of about an octave is used, and in dramatic speech about two octaves. The average pitch for speech is situated near the lower level of the singing range. In men it is about 140 cycles per second (*d* in music), in women about 243 cycles (musical *b*). The pitch of the speaking voice may be estimated by comparison with the note of the tuning-fork made for the purpose by Edelmann of Munich.

The Three Parts of the Vocal Mechanism

The larynx is only one part of a delicately adjusted combination of organs, all of which possess functions other than that of voice production. It must never be forgotten that the vocal mechanism is a triple alliance of respiration, phonation, and articulation, the last-mentioned being intimately associated with resonance. Treatment applied to the larynx will not remedy faulty breathing or ill-balanced resonance.

No study of vocal function is complete which does not take into account each of the three units which, coupled and adjusted to each other, constitute the vocal mechanism. Before discussing the part played by the larynx in this trilogy, let me say a few words regarding the respiratory and articulatory components of the mechanism.

The Respiratory Mechanism in Vocalization

The vital apparatus of respiration supplies the motive power of the vocal machine. But normal quiet breathing is an involuntary action, and in order to produce voice a prolonged and controlled act of respiration is demanded. The best means of securing this has been a subject of controversy among teachers of singing from the earliest days of song.

The method most widely used is the whole chest or central breathing, or the old Italian method. Briefly stated, this consists in reinforcing and sustaining the upward expiratory movement of the diaphragm by contraction of the muscles of the abdominal wall. To some teachers this is known as "abdominal press."

The relative extent of costal and diaphragmatic movement may be studied by the pneumograph (Fig. 2). The excursions of tambours, connected with closed tubes encircling the thorax and abdomen, are recorded on a revolving drum. The records thus obtained vary con-

FIG. 2.—The pneumograph.

siderably. As a rule the prolonged expiration is well shown, the diaphragmatic release occurring slightly in advance of the descent of the ribs and cartilages.

The Method of "Rib Reserve"

My colleague, Dr. Robert Curry, and I recently took the opportunity of observing a method of breathing which, so far as we are aware, had not been investigated previously.

It consists in the use of the "abdominal press," but with the following modification. The lower part of the thorax is maintained in an expanded position during the entire act of speech. This is known as "rib reserve." The method is taught by various schools of speech and drama, and it is also recommended by certain teachers of singing. The artistic results appear to be satisfactory, and the method seems to demand no great effort from those who have practised the technique until it has become almost a reflex action. A third tambour connected with the upper part of the chest records the movements of this region, as in the accompanying tracing (Fig. 3), and demonstrates that in the upper costal region

FIG. 3.—The technique of "rib reserve." The tracings, from above downwards, record upper thoracic, lower thoracic, and abdominal movements. Lower thoracic movement is arrested during the act of speech.

movement continues, while it seems to be held in check in the lower costal region.

It was interesting to observe that one of the subjects of our experiment, a trained exponent of the method (trained as a speaker but not as a singer), did not adopt the technique for singing, and when asked to speak a passage immediately after singing, found it difficult to return to the "rib reserve" method, although she was not conscious of any such difficulty (Fig. 4).

FIG. 4.—Effect of singing upon "rib reserve." Song is recorded at A, speech at B, C, and D. Only in the third act of speech (D) was control of the lower ribs regained.

It appears probable that the elevation of the ribs (and their maintenance in a raised attitude), usually attributed to the intercostal muscles, is partly effected by the serratus magnus muscle. Sir Charles Bell (1836) indicated the importance of this muscle in respiration. It possesses a double nerve supply, from the intercostal nerves and from the long or external thoracic nerve, derived from the fifth and sixth cervical segments. Bell named this nerve the "external respiratory nerve" to distinguish it from the internal respiratory or phrenic nerve.

Our results were confirmed by radiography, but it would take too long to describe them in further detail. Suffice it to say that the breathing mechanism must be studied by the laryngologist who would treat disorders of voice. An incorrect method of breathing is perhaps the chief cause of vocal failure.

The "Resonator" Mechanism

Before discussing the mechanical action of the larynx it is necessary to refer to that most important component of the vocal mechanism which, for want of a better term,

is known as the "resonator." Certain writers on the subject of voice go so far as to say that the vocal cords serve merely to regulate air pressure, the actual sound being produced in the paranasal sinuses. The air, blowing across the ostium of each cavity, is said to produce voice. But every laryngologist knows that the ostia are very small, and hidden behind the middle turbinal away from the main air current. Moreover, there is no proof that operative destruction of the walls of the sinuses has any effect on the voice. The strongest argument against the theory is that in song or speech the air does not pass out by the nose, save in the sounds *m*, *n*, and *ng*.

It cannot be denied that such terms as "head voice," "throwing the voice forward," are useful to the singer, but they do not describe what actually happens. The nasal sinuses cannot be regarded as the source of voice, and indeed the nasopharynx and nose cannot even act as "resonators," as the sound does not pass that way. As for the palate, it has been shown that in order to function as a sounding-board it would require to be of great size.

The two resonators are (1) the mouth and (2) the pharynx, and their acoustical features have been studied in great detail by many physicists since the days of Helmholtz. Coupled to the larynx, they act as a sort of loud-speaker horn; without the resonators the laryngeal note is

FIG. 5.—The buccal and pharyngeal resonators in singing the vowel *a* at 420 cycles and the vowel *i* at 170 cycles. Oscillograph record in corner. Note that in each case the nasopharynx is closed by the velum palati; also the great difference in conformation of the cavities on comparing the two films.

weak and indefinite. Brünings observed a case of attempted suicide in which the pharynx had been cut open, the great vessels escaping. When the patient spoke as the wound was held open he made only a weak bleating sound, but when it was closed and stitched he could produce normal speech.

The classical experiments of Müller on the excised larynx, made over 100 years ago, showed the importance of the co-operation of larynx and resonator, and quite recently Husson (1933) has indicated that various vocal defects may arise from imperfect adaptation of the resonators to the larynx. This also explains why the blowing of wind instruments has a deleterious effect on the larynx of the player. Few of those who play wind instruments have good voices, and many of them suffer from recurrent laryngitis.

The wide variations of the size and shape of the pharyngeal resonator are illustrated in the accompanying

x-ray film from Dr. Curry's work (1937), showing the comparison between the shape and size assumed in singing the vowel *a* at a pitch of 420 cycles and that for the vowel *i* at 170 cycles (Fig. 5).

The Problem of "Registers"

The term "register" has led to so much confusion that a definition is necessary. Garcia (1855) stated that a register was a consecutive series of vocal notes which the trained ear could distinguish from another series of notes, and that the quality of the voice changed in passing from one series to another. One of the problems which confront the singer is the elimination of any obvious change in passing from one register to another and the avoidance of a break in effecting the change, which is really a change of mechanism. The position of the larynx alters, as also do the tension and form of the cords. The latter change has given rise to the unfortunate terms "thick" and "thin" register. In the chest register the cords are thick, of weak tension, and the amplitude of vibration is large; in the so-called head register the cords are thin, strongly tensed, and have a small amplitude of vibration.

Three registers are usually distinguished, known as chest, middle, and head registers. The terms are in no case anatomical; they denote the sensations of the singer. He feels the notes of low pitch in his chest and those of high pitch in his head, but that does not mean that they are formed in these parts. It is purely a subjective sensation. By some authorities the head register ("Fistelstimme") has been termed falsetto, and this has led to some confusion. There is still another register for very high notes, known as the whistle register, produced only by some soprano voices. The whistle originates in a small elliptical gap in the anterior third of the glottis.

Mechanics of the Larynx

Let us now briefly consider the mechanics of the larynx itself in relation to voice. Certain adaptations of the pharynx and larynx are necessary in order to produce notes of various pitches, and those modifications are effected not only by the constrictors and other pharyngeal muscles but also by muscles causing (a) movement of the larynx as a whole and (b) movement of the laryngeal cartilages upon each other.

MOVEMENTS OF THE ENTIRE LARYNX

The act of inspiration exercises a downward pull upon the trachea and larynx, the normal tracheal tug. In expiration this pull is relaxed and the pharyngeal resonator is enlarged. This is obviously a passive movement.

The larynx is capable of movement to the extent of several centimetres in a vertical plane. It may be elevated by contraction of the thyrohyoid muscle and of those muscles which raise the hyoid bone (digastric, stylohyoid, etc.), and it may be lowered by the sternothyroid and omohyoid muscles. The downward movement is accompanied by a forward movement, and the pharynx is thus enlarged in a horizontal as well as in a vertical direction.

In the untrained singer the larynx rises as the pitch rises, and vice versa; in the trained singer this movement is reversed, and the larynx may actually descend as the pitch rises.

The descent of the larynx is intimately connected with the manoeuvre known to singers as "covering," which gives a more pleasing tone at certain pitches, owing to an increase of overtones. The downward movement of the larynx (a movement such as occurs in the initial stages of a yawn) occurs at a lower pitch in the closed vowels; that is, first

on *o* and *u*, then *e* and *i*, and finally on *a*. In other words, the larynx is lower in singing *u* than in singing *e*. As a rule the better trained the singer the less does the entire larynx move.

MOVEMENTS OF THE LARYNGEAL CARTILAGES

It is needless to describe to laryngologists the well-known action of the various laryngeal muscles, which act upon the cricothyroid and crico-arytenoid joints. The crico-arytenoid joint, with its curiously shaped articular surfaces, is capable of rotatory or sliding action, the latter being often forgotten in textbook descriptions.

Certain of the muscular actions do not concern joints. For example, the inferior constrictor of the pharynx, bestriding the wings of the thyroid cartilage, may by its contraction narrow the thyroid angle and thus assist to close the glottis. Further, the thyro-arytenoid, most important of all the laryngeal muscles, is to be regarded as an integral part of the vocal cord itself, as it can alter the form, the bulk, and the consistency of the vibrating cord, and so modify the pitch of the note. But obviously it cannot act alone. It is intimately associated with the cricothyroid muscle or external tensor.

The two synergic muscles are shown in the accompanying engraving from Müller's *Physiology*, published in 1832 (Fig. 6).

Fig. 6.—The cricothyroid and thyro-arytenoid muscles, so-called external and internal tensors of the vocal cords.

The cricothyroid muscle approximates the two cartilages by pulling the cricoid upwards, and thus the cords are tensed. It also assists to close the glottis, but only with the assistance of the posterior crico-arytenoid and interarytenoid muscles. The glottis can be closed only if a side-slipping of the arytenoid is prevented by the arytenoid muscle and if the arytenoid is braced back by the posterior crico-arytenoid muscle.

The lateral crico-arytenoid muscle can act either as an abductor or an adductor, depending upon which of the other muscles are in action and upon whether it causes the arytenoid to rotate or to slide. In using the words "tensor" and "tension" as applied to the vocal cords it must be distinctly understood that no idea of stretching is implied. The cords alter very slightly in length if at all during phonation.

The most important fact to remember regarding the muscles of the larynx is that, while they are grouped and paired, each pair does not act as an isolated unit, but always in conjunction with other laryngeal muscles.

Vibratory Movement of the Vocal Cords

The laryngeal muscles do not produce the vocal note. Phonation is an aerodynamic, not a muscular, phenomenon. The muscles merely adjust and hold the cords in a certain position, at a certain tension, and with a certain shape, and the expiratory air current from the lungs does the rest.

Many vague and ill-considered opinions have been expressed on the all-important question of vocal cord vibration. All sorts of curious theories have been advanced. One school of observers affirmed that sound was produced by the "cyclonic" air currents within the laryngeal ventricles. Others stated that the cords vibrated in a vertical plane. Although our knowledge is still far from complete it is easy to refute such obsolete notions. We now know, for example, that

vocal cord vibration is mainly transverse, and only to a very slight extent vertical.

From time to time the larynx has been compared to various types of musical instrument. It can in no wise be likened to a stringed instrument, as alterations of pitch do not depend upon changes in the length of the cords. To some extent the larynx resembles a reed or a siren, but the resemblance is not very accurate. What actually happens is that the vocal cords forming the glottic margins are approximated and hardened by muscular action; then, by the increasing pressure of air from the lungs, the glottis is opened and some air escapes. By reason of the elasticity of its margin the glottis again closes, and by the rapid succession of these movements of opening and closing a note is produced, the pitch of which depends upon the number of glottic movements a second. The simile of the siren holds good in that the sound is the result of a rapid series of puffs of air. But the number of movements a second depends, in the larynx, upon the rigidity, thickness, and tension of the vocal cord rather than upon the air pressure. The mechanism for altering the vibrating mass such as one finds in the larynx is not present in any musical instrument. Sir Richard Paget has aptly compared the vocal cords to the lips of a trumpeter.

Working Models of the Larynx

Ewald (1913) constructed a number of models to illustrate the mechanics of the larynx which are probably as accurate as any model can be. The accompanying diagram (Fig. 7) illustrates the principle. The elastic edges

FIG. 7.—Ewald's models, to illustrate the mechanism of vocal cord vibration. In model A the parts representing the cords may be caused to vibrate by a blast of air from below. In model B vibration may also be caused by a downward blast.

are set in motion by the upward air current, but in the second model a note may be produced on inspiration as well as expiration. We know that this occurs in the human larynx in humming, crying, laughing, etc., and even during speech the inspiratory voice is used by children and very talkative persons, while certain animals, such as the cat and donkey, can phonate on inspiration.

Perhaps the most accurate model is that which Harless (1853) constructed from two parallel strips of fresh frog's muscle, stretched across the linear opening of a tube so that they might be set in vibration by a blast of air. When the muscles were electrically stimulated to contract the pitch of the note was raised. The experiment has been repeated by Ewald and more recently by Negus, and it illustrates very well the mechanism of the larynx. The pitch of the note is raised by increased tension of the cords, the loudness by increase of air pressure.

It is generally taught that during phonation the arytenoid cartilages are firmly opposed, the cords alone vibrating. In view of investigations by Némai (1916) and of the cinematograph record of Pressman it would appear that this is not so. In the production of low notes the arytenoid edges vibrate along with the cords. Like the laryngoscope, cinematography at the rate of sixteen images per second can only give a picture of the major

phase, although an ultra-rapid technique, giving several thousands of pictures per second, has recently been tried, and would appear to be an ideal means of investigation, though naturally very expensive.

The exact mechanism of vocal cord vibration is best studied by the stroboscope.

The Principle of the Stroboscope

The principle of the stroboscope was applied to the larynx for the first time by Töpler in 1866. Since then it has been used by numerous workers, and their results form a large bibliography, although in this country stroboscopy has not received the attention it deserves. Even those who have had experience of the method are not agreed as to its usefulness. While some regard the stroboscope as merely an interesting toy, others call it the microscope of the larynx, and regard it as the best means of demonstrating the finer movements. As usual, the truth lies between the two extremes.

Stroboscopy consists in the inspection of the larynx by a periodically interrupted beam of light, the number of interruptions per second coinciding or nearly coinciding with the number of vibrations of the vocal cords. A blast of air passing through the slots in the revolving disk gives (after the manner of a siren) a note of a pitch corresponding in frequency to the number of interruptions of the light, and the subject is asked to imitate this note. If, for example, he emits a note of a pitch corresponding to 128 double vibrations per second while the larynx is viewed by a beam of light interrupted 128 times per second the vocal cords appear to be immobile. Then, if the revolving disk is very slightly retarded so that the light is interrupted, say, 127 times per second, the cords are seen to move at the rate of one vibration per second; in other words, the observer views the vocal cords in "slow motion," each interruption contributing a small fraction (1/127) of the composite view presented each second. But if the number of light interruptions be slowed down considerably, say to 115 per second, the laryngeal note remaining at 128 cycles, one will no longer see each individual vibration. The less the variation between the interruptions of the light and the vibration of the cords, the more clearly is the movement of the cords demonstrated. By varying the speed of the disk and the pitch of the note produced one may analyse the vibratory movement of the vocal cords.

A stroboscope has been recently introduced in which the source of light is a neon lamp which may be directly controlled by the voice pitch transmitted by a microphone connected to the lamp.

Results of Stroboscopic Examination

It cannot be denied that the stroboscope has added to our knowledge of the physiology of the larynx. By its aid one may study the closure of the glottis, the amplitude of the vibration, the direction of movement, and the form of the cords at the various pitches which the voice may produce.

By means of the stroboscope one may clearly distinguish between a paralysed vocal cord and a cord which is fixed by crico-arytenoid ankylosis. One may diagnose a paresis of the adductor muscles which escapes notice in the ordinary laryngoscopic view. One may note incoordination on various pitches (islands of defective phonation); one may discover a difference in the rates of vibration of the two cords (a phenomenon not yet fully elucidated); and one may study abnormal mechanisms such as ventricular band voice.

Vibratory movement in the vertical plane is characteristic of a paralysed cord, the normal movement being horizontal. The duration of contact of the cords varies

according to the pitch. In 1832 Lehfeldt suggested that there were two vocal cord mechanisms—the normal and the falsetto—and he stated that in the high note of the so-called falsetto register the glottis remained open while the edges of the cords vibrated. Müller confirmed this view, and at a later date Katzenstein (1909) sought to prove that the thyro-arytenoid was the active muscle in the lower register, while in falsetto the cricothyroid took over the work of maintaining the tension of the cords.

Quite recently Tarneaud (Husson and Tarneaud, 1932), using the stroboscope, observed that in the falsetto register the cords did actually make contact, but that the duration of such contact occupied so small a part of the cycle that it escaped notice under ordinary laryngoscopy. Tarneaud's diagram, here reproduced (Fig. 8), illustrates how, in

FIG. 8.—Tarneaud's diagram showing the open and closed phases of vocal cord vibration as revealed by the stroboscope. On the left are sections of the vibrating mass (thyro-arytenoid muscle) during the closed phase from a low-pitched note at 1 to a high note at 4; at 1 and 2 the thyro-arytenoid muscle is contracted; at 3 and 4 the cord mass is smaller and tension is maintained by the cricothyroid muscle.

The diagram on the right shows how the closed phase predominates at 2, and on laryngoscopic examination the cords appear to meet. At 4 the open phase predominates and the cords appear to remain apart. The real extent of movement can be determined only by stroboscopy.

singing up the scale, the open and closed phases of the vibration vary in duration, and how, in falsetto, the closed phase is very brief in comparison with the time occupied by opening and closing of the glottic aperture. It is generally agreed, however, that in the highest notes of the whistle register there does remain a small opening near the anterior part of the glottis during the entire vibration, and this note is produced only by the rush of air through the hole.

Pressman's film (1938), which was shown this year at the Royal Society of Medicine, while of course it did not analyse each vibration as does the stroboscope, showed clearly that on the low notes the posterior part of the glottis, including the arytenoid margins, is vibrating, on the middle notes the edges of the entire cords vibrate, and on the high notes the anterior part of the cords vibrates. The film also shows how the cords were kept moist by a continuous flow of mucus from the laryngeal ventricle, this being probably one of the chief functions of the ventricle. The ventricle also enables the ventricular bands to act as an outlet valve, preventing the escape of air and thus ensuring fixation of the thorax during movements of the upper limbs. This function was first described by Professor John Wyllie (1866) of Edinburgh seventy years ago.

Treatment of Voice Disorders

The physiological facts which I have so roughly outlined are of no mere academic importance. They form an essential background to the diagnosis and treatment of voice disorders. Just as orthopaedics has budded from general surgery, so may orthophonics become a useful branch of laryngology. The laryngologist is often consulted by the singer or speaker who complains that the voice is weaker than usual or becomes easily fatigued or is apt to "crack" at certain pitches. There may be symptoms of local irritation or soreness, of constant clearing of the throat or recurrent hoarseness. On examination one may find the dilated vessels and lymphoid nodules which are sometimes described as the signs of "clergyman's sore throat" but which, if pathological at all, are the result rather than the cause of the trouble. The tonsils may be present and the nasal septum may be deflected, but as a rule some previously consulted colleague has dealt with those structures. Most often local examination reveals no abnormality, and the laryngologist is content with the diagnosis of a "functional disorder" and sends the patient to a singing teacher or to a speech therapist. Such a diagnosis is correct: it is indeed a functional disorder—phonasthenia, if we choose to name it so—and the treatment also is sound, as a good speech therapist knows how to deal with the case. But one ought to go further and endeavour to ascertain what part of the vocal mechanism is at fault. Is it the method of breathing? Is it the vocal range? Did the trouble originate from overstrain of the voice or from use of the voice in the course of a cold or after an illness? The laryngologist must not regard his patient as a larynx surrounded by a body, and he must even inquire into the environment of the body with a view to discovering any feature which has an influence upon the voice. The prescription of a spray is not enough, though it may be of great psychological value. Orthophonic treatment must be directed towards the correction of disordered function, and must necessarily be on a physical basis.

Conclusion

And so I conclude this address as I began it, with a plea for a closer study of the problems of speech and of voice, and for a fuller recognition that the vocal mechanism—using the term in the widest sense—still offers a great field of study for the laryngologist. One often hears it said that laryngology is a narrow specialty and that it must needs constantly invade other anatomical territory. What more interesting research could be found than that which concerns vocal function? In pursuing such a study the

laryngologist is in the very centre of his own domain, but even here there is a territory which has too long been left unexplored.

I desire to record my indebtedness to the superintendent, Royal College of Physicians Laboratory, and to Professor Drever, Department of Psychology, University of Edinburgh, for their kindness in providing facilities for histological and experimental work.

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VI AGGLUTINATION IN THE DIAGNOSIS OF TYPHOID FEVER AND THE TYPHOID CARRIER CONDITION

BY

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Our conception of the diagnostic significance of a Widal reaction has materially altered since it became known that the typhoid-paratyphoid group of organisms are possessed of more than one antigenic component—notably the flagellar H antigens and the somatic O antigens, which produce their serum counterparts on human infection. Since the great war a complicating factor in the serological diagnosis of the enteric group of fevers has been introduced by the widespread use of T.A.B. inoculation.

The relative importance of the two types of antibody (O and H) in the diagnosis of typhoid fever, and of other enteric infections, in the inoculated and the uninoculated individual, first demonstrated by Felix (1924), has been the subject of a large number of studies, the literature being fully summarized by Topley and Wilson (1936). As a result it is being realized that in the interpretation of serological tests such diverse factors as the natural level of O and H agglutinins, the state of the subject in relation to previous inoculation, the agglutinin curves, the individual titres of the antibodies, and the possibility of non-specific stimulation of antibody formation, have to be taken into consideration.

In the laboratories of the Army in India Widal reactions are carried out as a routine every fourth day throughout the course of a continued fever, against standard O and H suspensions supplied by a central enteric laboratory at Kasauli. From personal experience and from a study of the carefully kept records of cases of typhoid fever for the past five years, it was observed that in a typhoid infection in the inoculated the trouble taken in estimating the O and the H agglutinins could not be justified when the value of the results obtained was assessed. In a large

majority of cases the rise in the titre of these agglutinins offered no tangible evidence from which alone a positive diagnosis could be arrived at. Reliance had therefore to be placed on the isolation of the infecting organism from the blood, the urine, or the faeces. Where this failed, one was commonly confronted with a positive clinical picture and doubtful serological findings. The results proved to be so disappointing that the practice of carrying out tests for the detection of H agglutinins has recently been entirely discontinued in the Army in India.

It is now generally recognized that, apart from the O and the H antigen, the great majority of strains of *Bact. typhosum* possess a third antigen—the Vi antigen—described and designated as such by Felix and his co-workers. A number of strains alleged to be free from Vi antigen were collected by us and grown on a medium consisting of mutton digest agar (2 per cent.) to which 1 per cent. saccharose was added. They all showed the presence of this antigen and gave rise to Vi antibody on animal inoculation.

Serological analysis of sera over the past three years from patients suspected to be suffering from typhoid fever suggested the possibility that Vi agglutination may prove to be a more reliable method of serological diagnosis of typhoid infection than the time-honoured O and H types of agglutination. This view was further strengthened by the observation that in the examination of thousands of sera from both inoculated and uninoculated persons no Vi antibody could be detected. The explanation why this antibody is not produced in spite of the inclusion of a Vi-containing typhoid strain in a T.A.B. vaccine has already been given (Felix and Bhatnagar, 1935; Bhatnagar *et al.*, 1937). Thus no interference was anticipated in the interpretation of serological tests from Vi antibody which could be accounted for either as a natural or as an inoculation agglutinin.

The present communication deals with the demonstration of Vi antibody in 134 cases of bacteriologically proved typhoid fever. The material was collected from both the inoculated and the uninoculated. In addition, information obtained on the bearing of Vi agglutination on the typhoid carrier condition is included.

Detection of Vi Antigen in a Typhoid Organism and of Vi Antibody in a Serum

When an organism with the morphology and the biochemical reactions of *Bact. typhosum* is found to agglutinate with a typhoid O serum much below the established titre of the serum the presence of Vi antigen in the culture is to be suspected. This is confirmed if it gives a positive reaction in agglutination with a pure Vi serum—that is, a serum prepared against a highly virulent strain of *Bact. typhosum* and from which the O and the H antibodies have been completely removed by absorption.

While the detection of Vi antigen can thus be carried out comparatively easily, the titration of Vi antibody in a serum, on the other hand, is complicated by the simultaneous presence in it of O and H agglutinins. Two methods are usually employed to overcome this difficulty: (a) Complete absorption of O and H antibodies from the serum by the use of a strain devoid of Vi antigen. In our experience very few strains indeed are completely devoid of Vi antigen; moreover, this method is a laborious process, hardly of practical applicability to an investigation which involves the serological analysis of a large number of samples. (b) Agglutination against selected strains or their chemically treated suspensions sensitive to one type of antibody only. While alcoholized