fatigue should be careful to be warm when eating and to partake of light food when tired. Many an attack could be avoided by such precautions.

A word on aperients. Patients who are strong, of the gouty type, and whose headaches are mainly due to hepatic insufficiency, are benefited by routine administration of calomel and saline every ten days, but for many, if not most, headache subjects strong aperients are harmful. The dose of salts which would cover a sixpenny piece or a shilling, in the early morning, is sound because it stimulates the ampulla of Vater, but no fuller dose. Castor oil in doses of 1 to 3 drachms once or even twice a week helps many, and others can take the lighter aperients like cascara or senna.

I will not stay to discuss palliative measures; each subject must find his own best—an important thing, because the rule for the headache subject is to "carry on" if possible. Any palliative must be taken at the onset. Salicylate and bromide and sal volatile suits many. Phenacetin is invaluable; pyramidon for the few; cachet Faivre has staunch supporters, but is too depressing for some.

For those prone to acidosis sodium bicarbonate is the indication. Luminal is in some cases helpful, but its effects need watchfulness, because there are some patients it does not suit; thus now and then a blueness of lips may be noted, or again, a dullness or slight perversion of mental outlook.

Skilled massage of the head and neck, and manipulation which includes gentle traction of the head from the trunk, bring great relief to some people. But enough. Headache illustrates a problem which will increasingly occupy the attention of the medical profession—namely, the keeping of man in the path of "physiological righteousness."

Note.—A list of references given by Lord Dawson will be found at the back of the JOURNAL (p. 652).

THE SURGICAL TREATMENT OF PARALYSIS OF THE VOCAL CORD AND OF PARALYSIS OF THE DIAPHRAGM.

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II.—ELECTRICAL STIMULATION OF THE RECURRENT LARYNGEAL NERVE.

WHEN the recurrent laryngeal nerve is divided previous to the anastomosis of its distal end to the phrenic or some other nerve it has been the rule to stimulate it while the vocal cords have been observed through the laryngoscope. Abduction and adduction of the vocal cord on the side on which the recurrent laryngeal nerve is being stimulated are plainly visible. If, however, the undivided recurrent laryngeal nerve is stimulated both vocal cords move equally. The movement of the opposite vocal cord is obviously induced by a sensory reflex reaching the respiratory centre from the site of stimulation. Possibly also both vocal cords are moving in obedience to the sensory reflex. The movements of the two cords appear to the eye to be synchronous, the vocal cord of the opposite side not moving later in time than the one on the same side as the stimulation. In another experiment, in which on the side opposite to the stimulation an end-to-side recurrent laryngeal-phrenic anastomosis had been done nine months previously and the vocal cord on the side of the recurrent laryngeal-phrenic anastomosis had been for three months moving rhythmically with the opposite or normal cord, the stimulation of the undivided recurrent laryngeal nerve was followed by movements of both vocal cords, but the movement of the opposite vocal cord was much more pronounced than the movement of the vocal cord on the site of stimulation.

This result brings this experiment into line with other experiments already described, and indicates that the nerve current passing through the phrenic nerve is stronger than that which passes along the recurrent laryngeal nerve

in normal circumstances. Stimulation of the appropriate area of the cerebral cortex always induces a movement of both vocal cords and never of the opposite cord alone. The above experiment shows that the same obtains from stimulation of the undivided recurrent laryngeal nerve; the reflex causing movement of both vocal cords in this case probably comes from the medullary respiratory centre and not from the cerebral cortex.

There is, however, a possible source of error in interpreting all these results of stimulation of the recurrent laryngeal nerve. It is not possible for the arytenoid muscle to contract without causing adduction of both cords, while contraction of the crico-arytenoid lateral muscle of one side will cause adduction of the corresponding cord. The general result of the stimulation of the recurrent laryngeal nerve is that when a very weak current is applied to the peripheral end of the divided recurrent laryngeal nerve adduction of the cord on that side only occurs, and it may be supposed that this movement is induced by contraction of the crico-arytenoid lateralis, but if a little stronger current is used both cords adduct, so that the arytenoid may be supposed to be contracting. These observations have been made on the monkey, the cat, and the dog. Sometimes the cord movements have been seen from above and sometimes from below.

Following the adduction of both cords abduction occurs, but why the cord on the opposite side should abduct it is difficult to understand, except that the cords in normal circumstances always move rhythmically together. No doubt the crico-arytenoid posticus on the side of stimulation receives a stimulus to contract, but why is it that the corresponding muscle of the opposite side also contracts? The abduction excursions appear to be as active as the adduction movements.

The division of the superior laryngeal nerve does not make any difference, though it was thought before the experiment was done that the intimate anastomosis of the superior and recurrent laryngeal nerves in the larynx might enable a reflex stimulus via the superior laryngeal nerve to reach the respiratory centre. Stimulation by a weak current of the proximal end of the divided recurrent laryngeal nerve produced no movement of the vocal cords.

It is noteworthy that in a paper by H. K. Anderson⁵ on "Paradoxical pupil dilatation" in lesions of the sympathetic on both sides of the neck, the conditions that evoke the paradoxical effect are stated to be excitement, dyspnoea, anaesthesia, and death. These conditions are also associated with paradoxical movements of the vocal cords.

III.—THE PARADOXICAL MOVEMENTS OF THE VOCAL CORDS.

Haldane writes:⁶ "The respiratory centre is a small area situated in the medulla. When this area is destroyed all rhythmical respiratory movements cease. No definite anatomical group of nerve cells has been defined at the position occupied by the respiratory centre. It seems clear that it is at about the position which is sensitive to chemical respiratory stimuli. The central paths for the innervation of inspiratory and expiratory movements must be different, but in what sense the centre itself is double is still obscure."

Negus states⁷ that he and McDowell have proved in cats that the contraction of the laryngeal and diaphragmatic muscles is not synchronous. The glottis opens before inspiratory movement of the diaphragm commences and closes before expiration begins. It is clear that at the end of expiration a stimulus causes inspiration to begin, while at the end of inspiration a signal causes expiration to begin. The contraction of the diaphragmatic, intercostal, and abdominal muscles in expiration is associated with the closure of the laryngeal channel, while the relaxation of the above muscles and the contraction of other inspiratory muscles in inspiration are associated with the opening of the glottis. Evidently these events are very closely and intimately connected. They are, as John Hunter said of the lungs and heart in life, in sympathetic connexion; and any alteration in rhythm or timing must interfere with the perfection of these organic life movements. Negus adds: "The obstruction offered by the glottis to passage of air causes prolongation of the time

taken to fill or empty the lung and thereby causes suitable delay in the timing of the signals for emptying or filling of the lungs—namely, the Hering-Breuer reflex.” However this may be, and it appears to be true—and we are not now discussing the CO₂ content of the air in the lungs or blood or other chemical problems—either the diaphragm or the muscles of the vocal cords must be the factor in maintaining the respiratory rhythm. We are inclined to think that the diaphragm, the principal muscle of inspiration, must be the factor. We do not forget that the first respiratory act after birth is inspiration. The metronome in music sets the time: the question is, does the movement of the diaphragm or that of the vocal cords act as the metronome of the respiratory movements?

In our experiments the diaphragmatic contractions, as observed by Professor Elliot Smith, some months after certain anastomoses had been performed were quite normal; but in some instances, in which a double anastomosis had been carried out months previously on both sides of the neck, the vocal cords exhibited a paradoxical movement—with inspiration adduction and with expiration abduction. Before the second anastomoses were done on the left side of the neck the vocal cord on the right side of the neck was moving well with the opposite cord, but when the vocal cord on the left side began to recover from the paralysis it not only started to work in wrong time with the diaphragmatic contractions, but it prevailed on the vocal cord on the right side, which had for months been moving in a normal manner, to join it in a paradoxical movement.

Again, in another experiment (monkey) an end-to-side recurrent laryngeal-phrenic anastomosis was done on the right side and an end-to-end recurrent laryngeal-phrenic anastomosis on the left side. Six months after the first operation the right half of the diaphragm was contracting normally, and so was the vocal cord. On the left side the distal end of the divided phrenic nerve was not anastomosed to any other nerve, and the left half of the diaphragm remained completely paralysed. Six months after the recurrent laryngeal had been anastomosed end-to-end to the phrenic nerve the left vocal cord was moving in a normal way with the other cord. Why in this monkey is there no paradoxical movement of the vocal cords? Indeed, in this monkey there never has been any trace of stridor or difficulty of breathing. The answer seems to be that though the left half of the diaphragm is completely paralysed, the right half is working naturally through nerve influences passing down the phrenic nerve, and the suggestion is made that this half of the diaphragm is acting as a metronome of the respiratory signals.

When both halves of the diaphragm are contracting in consequence of stimuli passing through the descendens noni-phrenic anastomoses and both vocal cords are moving in obedience to signals traversing the recurrent laryngeal-phrenic anastomoses, some factor, it appears, may arise—for example, deep anaesthesia—which disturbs the normal timing of the contractions of the laryngeal and diaphragmatic muscles. No one of these groups of muscular fibres is working under normal conditions, though under such conditions their life and movement are in intimate and sympathetic connexion. There may be delay in the receipt of one or more of the appropriate signals; the longer distance which the nerve current has to traverse and the possible obstructions *en route* may have some adverse influence; or it may be, and it is probably true, that the laryngeal and diaphragmatic muscles get out of step because no one of these four groups of muscles is able, in the new and strange circumstances of their active life, to act as the metronome of the complicated respiratory movements.

IV.—THE DIAPHRAGM.

When the experiment was performed of dividing the phrenic nerve and uniting the end of the proximal segment to the divided end of the distal segment of the recurrent laryngeal nerve, the question arose how best to anastomose the distal end of the phrenic nerve to some other nerve, so as, if possible, to provide for the recovery from paralysis of the corresponding half of the diaphragm. The problem was solved by dividing the descendens noni and uniting the proximal end to the distal end of the phrenic nerve.

In the monkey experiments, when the main trunk of the phrenic nerve is mentioned, the main trunk formed by the union of the roots coming from the third and fourth cervical nerves is meant, as the root derived from the fifth cervical nerve has never been demonstrated during an experiment. In the dog, when the main trunk of the phrenic nerve is referred to, the main trunk formed by the union of the roots coming from the fifth and sixth cervical nerves is meant; the root, a considerable one, which arises from the seventh cervical nerve or brachial plexus, is placed at the upper opening of the thorax, and has never been seen during an experiment.

In the monkey, presumably as in man, the root of the phrenic from the fifth cervical nerve is variable, and when present small. In the dog, however, the root of the phrenic from the seventh cervical nerve is of fair size, and can easily be demonstrated by dissection. It is of much interest to note that in the monkey division of the phrenic trunk formed by union of the roots derived from the third and fourth cervical nerves, and in the dog division of the trunk of the phrenic nerve formed by union of the roots derived from the fifth and sixth cervical nerves, is followed in each instance by complete paralysis of the corresponding half of the diaphragm. The root of the phrenic from the fifth cervical nerve in the monkey when present probably innervates a special area of the diaphragmatic muscle. The same is probably true in the dog concerning the root of the phrenic nerve from the seventh cervical nerve. If this is correct then these special areas of the diaphragm ought to be the first to recover function—that is, if they ever really lost their power to function.

It may be suggested that if one cervical root of the phrenic nerve is divided the recovery of the contractile function of the whole of the corresponding half of the diaphragm is due to the spread of the healthy terminal filaments of the phrenic nerve to the paralysed area of the muscle. This is contrary to what is known of the recovery or continued palsy of muscular tissue in all other parts of the body. As in end-to-end anastomosis of the phrenic nerve to the recurrent laryngeal nerve there follows after a time a recovery of function of the vocal cord muscles, so in descendens noni-phrenic anastomosis it is reasonable to believe that the recovery of the diaphragmatic muscle is a direct consequence of the anastomosis. Besides, by experiment we know that in a monkey fifteen months after the division of the trunk of the phrenic nerve formed by the union of the roots from the third and fourth cervical nerves the corresponding half of the diaphragm remains completely paralysed. Further, the microscope demonstrates that the phrenic nerve distal to its anastomosis with the descendens noni nerve recovers its normal anatomical structure, just as the recurrent laryngeal nerve distal to its anastomosis with the phrenic nerve resumes its normal microscopical appearance. Electrical stimulation also of these anastomoses gives rise to the normal corresponding muscular contractions.

Keith⁴ describes the origin and development of the diaphragm.

“The branchial muscles which formerly forced water through the gill slits are now transmuted into pharyngeal muscles and help to pump air into the lungs, thus acting as muscles of inspiration. The muscles of the body wall are modified to form muscles of expiration. It is worthy of notice that each half of the mammalian diaphragm is developed from two embryonic muscular sources:

“(a) A *sterno-costal portion* derived from the ventral longitudinal musculature of the embryonic neck. These muscular sheets give rise also to the rectus abdominis and the depressor muscles of the hyoid bone and larynx.

“(b) A *special or vertebral portion* arising from the bodies of the vertebrae and arcuate ligaments, and derived from the cervical part of the transversalis.

“The nerve supply of the diaphragm also points to the fact that there are two distinct muscular elements in the diaphragm. The phrenic nerve when it reaches its corresponding half of the diaphragm divides into two branches—a vertical to the right and left ventro-lateral parts (from the third and fourth cervical nerves) and a dorsal branch (from the fourth and fifth cervical nerves) to the right and left dorsal parts.”

Notwithstanding the complicated story of the evolutionary history of the muscle of the diaphragm there is no evidence that any portion of the muscle has a double nerve

supply. It is of interest to note that the depressor muscles of the hyoid bone and larynx and the rectus abdominis are so closely associated in development with the sterno-costal portion of the diaphragm, all these muscles being associated with the respiratory movements.

As in the monkey the roots of the phrenic arise from the third, fourth, and fifth cervical nerves, and in the dog from the fifth, sixth, and seventh cervical nerves, the site

FIG. 22.—Baboon. Descendens noni-hypoglossal anastomosis, end-to-side. Specimen obtained fourteen months after the operation. Stroebe stain; s, remains of suture. Complete recovery of function of sterno-hyoid, sterno-thyroid, and omo-hyoid muscles.

of section of the descendens noni nerve for the purpose of doing a descendens noni-phrenic anastomosis may be different. In the monkey the descendens noni nerve is divided above the origins of the branches to the depressor muscles of the hyoid bone and larynx, and the proximal end is united to the distal cut end of the phrenic nerve. It is then desirable to do another anastomosis—namely, to unite the distal cut end of the descendens noni nerve to the lower border of the hypoglossal nerve (end-to-side anastomosis)—so as to obviate permanent paralysis of the omo-hyoid, sterno-hyoid, and sterno-thyroid muscles. (Fig. 22.) This anastomosis has been performed in man, and in animals many times, and always with success. The distal cut end of the descendens noni nerve has in some instances been united, not to the hypoglossal nerve, but to the phrenic nerve, end-to-side, above the recurrent laryngeal-phrenic end-to-end anastomosis. In the dog the descendens noni nerve can be divided below the origins of the nerves to the omo-hyoid, sterno-hyoid, and sterno-thyroid muscles; the proximal cut end can then be united, end-to-end, to the distal cut end of the phrenic nerve. In these circumstances it does not appear necessary to provide for the anastomosis of the distal end of the descendens noni nerve with any other nerve. Whether it would be best in all circumstances to sever the descendens noni above the origins of the nerves to the depressor muscles of the larynx and hyoid bone, when the object in view is the recovery of diaphragmatic paralysis, is not clear.

In the dog recovery of the functions of the diaphragm is obtained by dividing the descendens noni nerve below its branches. The descendens noni nerve must certainly have many more nerve fibres, and nerve fibres too definitely associated with muscular action, above the origins of the nerves to the depressor muscles than below them. In the monkey the nerve below these branches is very small, but in the dog it is of fair size, and continues its course through the upper opening of the thorax. In man if it was necessary to divide the phrenic nerve there can be little doubt that it would be the right practice to divide the descendens noni nerve proximal to the place where its first branch is given off.

The descendens noni nerve, like the facial artery, has a tortuous course, as it lies among structures which are always in movement and constantly altering their length and position; hence when the nerve is dissected out it is of sufficient length so that it can be made to extend to any desired place.

In some instances one of the roots of the phrenic nerve was divided (instead of dividing the main trunk of the phrenic nerve), the proximal cut end of the root being

united end-to-end with the distal cut end of the recurrent laryngeal nerve, while the distal cut end of the root of the phrenic nerve was anastomosed end-to-end with the proximal cut end of the descendens noni nerve. If the descendens noni nerve had been divided above the origins of the nerves to the depressor muscles then, as described above, a further anastomosis of the distal end of the descendens noni would be carried out.

In one instance an end-to-side anastomosis was performed, the end of the recurrent laryngeal nerve being united to a root of the phrenic nerve; the result being a partial paralysis for some months of that portion of the diaphragm supplied by the nerve fibres of the injured root.

It does not appear that there is any advantage in choosing a root, instead of the main trunk, of the phrenic for anastomosis with the recurrent laryngeal nerve; indeed, in one experiment the final recovery of the function of the diaphragm appeared to be delayed by the employment of this plan of anastomosis.

EXPERIMENT XII.—Baboon.

In this instance when the main trunk of the phrenic nerve on the left side had been divided and its proximal end sutured, end-to-end, to the divided recurrent laryngeal nerve, it was noticed that a large nerve was arising from the fourth cervical nerve close to the origin of the root of the phrenic nerve from the fourth cervical nerve. This large nerve received also a smaller root of origin from the third cervical nerve and passed down the neck for some distance near the phrenic nerve. It was the descending superficial cervical nerve which afterwards divided into suprasternal, supraclavicular, and supra-acromial branches. The trunk of this nerve was divided and its proximal end was sutured end-to-end to the distal cut end of the phrenic. (Fig. 23.) This union of the phrenic nerve with a sensory nerve seemed to be justified by the surprising results obtained by union of the lingual, glosso-pharyngeal, and cervical sympathetic nerves with the facial nerve. It would seem that the actual pathway of a nervous impulse is not of such moment as has been hitherto generally believed, as long as the nerve cells from whence issue the nerve impulses (in this case the nerve cells of the respiratory centre) and the nerve fibre endings (in this case in the muscle elements of the diaphragm) are intact. Sir David Ferrier was present at this operation.

A week after the operation some anaesthesia in the region of the distribution of suprasternal, supraclavicular, and supra-acromial nerve branches was demonstrated. Five months after the operation no anaesthesia of the skin in the region of distribution of these nerves could be made out, but the monkey was difficult to examine and the examination was not very satisfactory. Eight months after the operation the left vocal cord was moving in tranquil respiration rhythmically with the vocal cord of the opposite side and to an equal extent.

The Diaphragm.—Dr. Eidinow, with his radiographic screen at the Hampstead Research Institute, reported that the left half of the diaphragm was contracting well; in fact, there was no difference in the contraction movements of the two sides of the diaphragm.

This experiment remains a single one and therefore must not be too much relied upon. Unfortunately a week after Dr. Eidinow's examination the baboon became ill and had to be destroyed.

In other instances the cut end of the recurrent laryngeal nerve was united, end-to-side, to the main trunk of the

FIG. 23.—Baboon (Experiment XII). Recurrent laryngeal-phrenic end-to-end anastomosis. Descending superficial cervical-phrenic end-to-end anastomosis.

phrenic nerve, either to a small lateral incision made in the side of the phrenic nerve, or to a small median incision made in the middle of the phrenic nerve. In these cases no further anastomosis was necessary. An immediate partial paralysis of the corresponding half of the diaphragm results, and in all probability after a few days the cellular invasion at the site of anastomosis causes an anatomical division of the trunk of the phrenic nerve, so that complete paralysis of the corresponding half of the diaphragm ensues. But this paralysis is evanescent and passes off in three or four months.

This method of anastomosis — recurrent laryngeal-phrenic anastomosis, end-to-side — appears to be the method of choice for operations on man, as has been said in the previous remarks on the vocal cords. It simplifies the operation; it avoids the making of more than one anastomosis; it is satisfactory in that it promises recovery of the movement of the vocal cord, and in that it promotes recovery of the function of the diaphragm by regeneration of the phrenic nerve itself.

On one occasion, when the descendens noni and hypoglossal nerves were exposed, the hypoglossal nerve was stimulated. The thyro-hyoid muscle contracted and the depressor muscles relaxed; thus a typical Sherringtonian phenomenon was observed of contraction and relaxation of opposing muscles. The reverse experiment, of stimulation of the descendens noni nerve, which caused contraction of the omo-hyoid, sterno-thyroid, and sterno-hyoid muscles, should have been associated with relaxation of the thyro-hyoid muscle, but this could not be determined with certainty because of the overlying structures.

It is not possible to determine with accuracy whether half the diaphragm is in part or completely paralysed by observing or palpating the movements of the abdominal wall and costal arches. Dr. Eidinow kindly made some examinations at the Hampstead Institute for Research by means of the radiographic screen, and the results were also observed by Sir David Ferrier, the late Sir Frederick Mott, and Professor Leonard Hill. It was believed in each instance that the previously paralysed diaphragm was contracting again.

It was then decided to take some of the animals to the radiographic department of the Anatomical Institute of University College, Professor Elliot Smith having kindly promised to examine and report on the condition of the diaphragms in these animals. Dr. Beattie and Mr. Melville also observed the contractions of the diaphragmatic muscle through the radiographic screen. It will be seen from the reports of experiments that recovery of the muscular contraction of the diaphragm had taken place in each case.

V.—THE METHOD EMPLOYED FOR FILMING THE CORDS. (See Figs. 24 and 25.)

We are much indebted to the British Instructional Film Company for the painstaking effort which they made to film the vocal cords. The following are the chief points of the method employed:

1. A special high and solid table was made so that when the animal was anaesthetized and placed on it the eye of the observer, when standing, was on a level with the vocal cords.

2. A powerful beam of light from an arc lamp, A, was directed on and reflected from a small mirror through a

special laryngoscopic tube, X. In length this tube was 5 inches along the upper border and 4 inches along the lower. The beam of light, before it reached the mirror, was caused to pass through a film of water, B. In this way the heat rays were cut off.

3. The inner extremity of the laryngoscope was a little larger than would ordinarily be employed for examination considering the size of the animal. It measured three-

quarters of an inch from side to side and a millimetre more than half an inch in the vertical direction. The whole tube was oval in shape, and gradually increased in size till at the outer extremity it measured 2 inches from side to side and 1½ inches in the vertical direction. The oval shape facilitated the passage of the beam of light, F, down the tube to the region of the vocal cords. The tube itself was blackened inside so as to prevent any reflection of light except from the vocal cords. A black oval screen, Z, was fitted around the outer extremity of the laryngoscope. It projected 1½ inches on either side of the outer extremity of the laryngoscope, and in the vertical direction the screen extended 1½ inches above the opening of the tube and three-eighths of an inch below.

4. The laryngoscope was fixed to the ordinary suspension apparatus of Killian, E, by a metal rod. Thus unnecessary movement was avoided. In this rod was a hinge, Y, which could be fixed. The hinge allowed of the inner extremity of the laryngoscope being tilted a little upwards and downwards so as to facilitate the best exposure of the vocal cords.

5. The reflector, D, was attached close to the lens of the cinematograph camera, so that the light was reflected down the laryngoscope as nearly parallel as possible to the optical axis of the camera, C.

6. The anaesthetized animal was fixed approximately in position with a number of small sandbags. Then fine adjustments were made by means of the vertical and horizontal movements of the suspension apparatus and the hinge already referred to situated close to the laryngoscope.

7. One of us (L. C.) found it easy to manipulate the apparatus.

FIG. 24.

FIG. 25.

6. The anaesthetized animal was fixed approximately in position with a number of small sandbags. Then fine adjustments were made by means of the vertical and horizontal movements of the suspension apparatus and the hinge already referred to situated close to the laryngoscope.

7. One of us (L. C.) found it easy to manipulate the apparatus.

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