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FROM THE PHYSIOLOGICAL LABORATORY OF THE HARVARD MEDICAL SCHOOL.

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THE ANATOMY AND PHYSIOLOGY OF THE RECURRENT LARYNGEAL NERVES.*

By FRANKLIN H. HOOPER, M. D., Boston,
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I. Anatomy.

NOTWITHSTANDING the centuries that have elapsed since the reputed discovery of the recurrent laryngeal nerves by Galen, it is doubtful if there be another pair of nerves in the body which have given rise to so many diverse and fanciful theories to account for the anatomical peculiarity of their course or to elucidate their physiological functions. At the present day our knowledge of the anatomy of these nerves is, for the most part, complete and exact. The reason why they are not given off by the pneumogastrics at a point opposite the larynx so as to reach that organ by the shortest route, instead of branching from the pneumogastrics low down in the neck and running a complicated and recurrent course to the larynx, is now clearly understood. Yet Magendie,† in his lectures on the nervous system, delivered at the Collège de France at so recent a date as 1836, asserted that this was a problem which anatomists were unable to solve. But several years prior to the date of Magendie's lectures two articles had appeared in a Scotch journal which, had they come under his notice, would have given him a clew to the explanation of the matter.

Stedman, in 1823, in a paper entitled "A Singular Distribution of some of the Nerves and Arteries in the Neck and the Top of the Thorax,"‡ gives a description and a drawing of his dissection

* Read before the American Laryngological Association at its ninth annual congress.

† "Lancet," July 1, 1837, p. 503.

‡ "Edin. Med. and Surg. Jour.," xix, 1823, p. 564.

of an aged female in whom he found that the right recurrent laryngeal nerve was absent. There were, however, nerves given off from the trunk of the pneumogastric, about the middle of the neck, which went direct to the larynx. He also found, in the same subject, an irregularity in the origin and course of the right subclavian artery. It arose from the arch of the aorta behind and a little to the left side of the left subclavian artery, and, forming an arch, pierced between the œsophagus and vertebral column in the region of the first vertebra of the back, and then passed over the first rib on the right side. Stedman was the first to cite an example of the connection between an irregular origin of the right subclavian artery and right recurrent laryngeal nerve—a connection which we now know is constant; but he dismissed the subject with the comment that the nerve, in his case, which went direct to the larynx from the pneumogastric probably performed the same functions as the recurrent, and that nature seemed to have been forced to have recourse to this arrangement from the singular situation of the subclavian. Three years after the appearance of Stedman's paper, Hart (1826) reported in the same journal* "A Case of Irregular Origin and Course of the Right Subclavian Artery and Right Inferior Laryngeal Nerve." The artery arose from the aorta direct, and the nerve, instead of being recurrent, went straight from the pneumogastric to the larynx. Hart speculates upon the reason why the nerve in this instance should have been straight and short, and, although his views are not strictly in accord with the teaching of modern embryologists, they show that he was aware that the secret of the circuitous course of the inferior laryngeal nerves was to be sought in the natural law of embryonic development. He says: "In the earlier periods of the existence of the fœtus the rudiment of the head appears as a small projection from the upper and anterior part of the trunk, the neck not being yet developed. The larynx at this time is placed behind the ascending portion of the arch of the aorta, while the brain, as it then exists, is situated so low as to rest on the thymus gland and front of that vessel. Hence it is that the inferior laryngeal nerves pass back to the larynx, separated by the ascending aorta, the left going round its arch, while the right goes below the *arteria innominata*. As gestation advances, the head becomes more distinct, and the neck begins to be formed after the second month, which, as it lengthens, has the effect of moving the brain upward to a greater distance, and of drawing out the larynx from the chest, in accommodation to which

* "Edin. Med. and Surg. Jour.," April, 1826, p. 286.

the nerves of the par vagum and their recurrents become elongated, and hence the circuitous route the latter are found to take afterward, forming loops in which the aorta and right subclavian artery are, as it were, suspended. . . . Had not the great blood-vessels been originally thus interposed between the brain and larynx, the inferior laryngeal nerves would not have been entangled by them, and we should find them in the adult taking the nearest route to their destination."

These early papers upon this subject are most interesting, and show that their authors were careful observers. They pointed out the right path, which, however, was not followed by all subsequent writers who expressed themselves on the question.

Swan, for instance, entertained certain theories in regard to the influence which the blood-vessels had upon the nervous system, and in "An Essay on the Connection between the Action of the Heart and Arteries and the Functions of the Nervous System," London, 1829, p. 50, he applied his views in a very curious way to explain the recurrent course of the inferior laryngeal nerves. After speaking of their encompassing the subclavian artery on the right side and the arch of the aorta on the left, and remarking that it was very singular that neither of the carotids was included, he says: "I conceive this disposition was intended for producing a more extensive sympathy between the arteries of those parts of the body which are subjected to be excited by exercise, and the glottis; for when the action and distension of the arteries are increased by exercise, the recurrent nerves become stimulated, and consequently the muscles of the glottis, the opening of which thus becomes widened, so as to admit a greater and more free supply of air into the lungs. It may be supposed that any other disposition would have sufficed, so long as the parts were properly supplied with nerves, and a case is related by Dr. Stedman where the recurrent was wanting on the right side, and its place was supplied by numerous branches of the par vagum; but in this instance 'the right subclavian artery rose from the arch of the aorta behind and a little to the left side of the left subclavian, and, forming an arch, pierced between the œsophagus and vertebral column in the region of the first vertebra of the back, and then passed over the first rib on the right side.' It must be remarked that the right subclavian was already under the influence of the left recurrent, and therefore the usual distribution was not necessary on the right side. The same unusual distribution I have also observed in a rabbit, which was very healthy, but I never saw it in exercise,

and therefore can not determine whether its respiration was affected during that state. It is a curious circumstance that the recurrents do not always include the carotids; but it seldom happens that the action of these arteries is much increased, except by the exertions of the voice, as in singing, etc., and therefore, if they had been included, the delicate and complicated actions of the glottis, which are produced during these processes, might have been too much interfered with, and I believe a compensation is made for this omission by the connection of the pharyngeal plexus with the superficial cardiac nerve. . . . The subclavian artery on the right side and the aorta on the left are almost encircled by the par vagum and its recurrent branches. This distribution, no doubt, connects the actions of these arteries with those of the glottis."

Hilton (1837), to whom we are indebted for an admirable paper * describing the distribution of the recurrent nerves, states in a footnote that he had seen a subject in his dissecting-room in which the right subclavian artery came off from the posterior part and left side of the transverse portion of the aorta. In this case, he continues, "the right recurrent nerve did not curve round the artery, but was detached from the pneumogastric at an acute angle with the descending part of the nerve, about opposite the fifth cervical vertebra." We find, moreover, in the same writer's well-known "Lectures on Rest and Pain," † the statement that he had seen examples in which the recurrent did not wind around the arch of the aorta or the subclavian artery, yet the course of the nerve was, notwithstanding, equally recurrent, thus clearly indicating that it had no necessary relation with the subclavian artery or the aorta. He then sets forth the following singular theory to explain the course of these nerves: "The nervous influence, whatever it may be, which travels by these recurrent nerves, goes from below upward. And I think it will be apparent why this nerve takes its course from below upward. It is an essential thing, to my mind, that the muscles which are acting upon the air as it escapes outward from the lungs so as to make the voice, should be acting from within outward—that is, from the lower part of the larynx to the upper. It is quite obvious that if they acted in the other way we should all be ventriloquists, talking inwardly to ourselves, as it were, and having no external voice; and it is for the purpose of determining the direction of influence from within out-

* "Guy's Hosp. Reports," vol. ii, 1837, p. 514.

† Second edition, London, 1877, p. 217.

ward that we find this nerve pursuing this singularly recurrent course."

Meckel * says the recurrent nerve is sometimes double, and, though rare, when this occurs it is always on the right side. He considers it probable "that the recurrent nerve results from the plexiform division of the trunk of the pneumogastric, and that its existence is connected with the primitive shortness of the neck, since the larynx is much nearer its origin in the early periods of life than subsequently. This hypothesis would explain its arrangement in the same manner as the high origin and long course of the spermatic vessels."

Daremberg, † in speaking of the recurrent nerve twisting round the subclavian artery on the right side and the arch of the aorta on the left, says: "Que la nature a disposeés comme deux bornes qui les fixent dans la carrière qu'ils ont à fournir avant de se répandre dans les muscles abaisseurs du larynx, qu'ils font mouvoir comme avec une main."

If we wish to obtain a clear idea of the reason why the recurrent nerves recur, we must leave this speculative ground and begin at the beginning of the development of the embryo. These remarkable nerves exist at a very early period of fœtal life. At a certain stage of embryonic development they have, indeed, a transverse direction, and proceed direct from the pneumogastrics to their destination, and their recurrent course is determined later solely through developmental changes in the branchial apparatus of the embryo, and to the descent of the heart into the thorax. We will briefly review these changes: In the cervical region are developed the five pairs of aortic arches—a transitory fœtal apparatus in the higher vertebrates. Of the five pairs of arches, but two are permanent at birth, namely, the fourth arch on the left side, which is represented by the arch of the aorta, and the corresponding arch on the right side, which has become the right subclavian artery. The recurrent nerves originally passed under the fifth pair of aortic arches; but as the *ductus arteriosus*—the fifth arch on the left side—is obliterated after birth, it follows that the left recurrent nerve is hooked under the first permanent arch above it, namely, the fourth, which has become the arch of the aorta; while on the right side the fifth aortic arch disappears entirely, and the right recurrent consequently passes under the fourth aortic arch, which persists as the right subclavian artery.

* "Manual of Anatomy." Translated by Doane, 1832.

† "Exposition des connaissances de Galien," etc., Thèse, Paris, 1841, p. 57.

The long course of the recurrents, like the elongation of the carotids and other anatomical features of the cervical region, is brought about by the change of position which the heart and great vessels undergo during embryonic life, and which we may best describe by borrowing Huxley's words:* "At first the heart of a mammal lies under the middle of the head, immediately behind the first branchial arches, in which the first pair of aortic arches ascend. As the other pairs of aortic arches are developed the heart moves backward, but the fourth pair of branchial arches, by the modification of one of which the persistent aorta is formed, lies, at first, no farther back than the occipital region of the skull, to which the fourth pair of branchial arches belongs. As the two pairs of cornua of the hyoid belong to the second and the third branchial arches, the larynx is probably developed within the region of the fourth and fifth branchial arches; hence the branches of the pneumogastric, with which it is supplied, must, originally, pass directly to their destination. But, as development proceeds, the aortic arches and the heart become altogether detached from the branchial arches and move back, until at length they are lodged deep in the thorax. Hence the elongation of the carotid arteries; hence also, as the larynx remains relatively stationary, the singular course in the adult of that branch of the pneumogastric, the recurrent laryngeal, which primitively passed to the laryngeal region behind the fourth branchial arch, and consequently becomes drawn out into a long loop, the middle of it being, as it were, pulled back by the retrogression of the aortic arch into the thorax."

The proof that the course of the recurrent nerves is a question of development is found in the fact that when, from any cause operating in early fœtal life, irregularities of the arch of the aorta or in the origin of its primary branches exist, the recurrent nerves have always in such instances an anomalous origin and course. There are several recorded cases of this inter-relation of these anomalies. We have already mentioned Stedman's paper, in which he described, for the first time, a case of irregular origin of the right subclavian artery associated with absence of the right recurrent nerve. In this case, undoubtedly, the fourth right aortic arch disappeared very early, and, the right subclavian arising from the descending portion of the aorta, there was nothing to carry the right recurrent down, and it consequently ran directly to the larynx. Through the kindness of Pro-

* "A Manual of the Anatomy of Vertebrated Animals," London, 1871. We take the liberty of substituting the word "branchial" for "visceral."

fessor Dwight we have had an opportunity of observing a similar case in the dissecting-room of the Harvard Medical School. Hérard* in 1846 showed a specimen at the Anatomical Society of Paris, in which the right recurrent was given off from the pneumogastric opposite the cricoid cartilage, and he suggested that we ought to be prudent in denying the existence of the recurrent if we did not find it in its proper place. The left recurrent was normal. He makes no mention of any anomaly of the blood-vessels. Reid,† in 1847, gives the correct explanation of the origin of these anomalies, and says that in those cases of monstrosity where the head and larynx are double, and the two bodies are fused together immediately below this, so that the lower part of the neck, the thorax, and thoracic extremities are single, and where consequently we have four vagi nerves in the upper part of the neck and only two at the lower part, the right recurrent of the right larynx hooks round the subclavian artery, and the left recurrent of the left larynx hooks round the arch of the aorta, while the left recurrent of the right larynx and the right recurrent of the left proceed to their destination from the pneumogastrics as they pass the larynges. Demarquay‡ (1848) was, we believe, the first one in France to record a case of irregular origin of the right subclavian artery with absence of the recurrent nerve on the same side.

Professor Turner, in his admirable paper,# cites cases where there was no innominate artery and an unusual origin of the right subclavian. In one instance the recurrent turned round the inferior thyreoid artery, and in others it passed directly inward to the larynx. He also describes cases where the aorta arched to the right side, in which the left recurrents wound round the obliterated ducti arteriosi while the right recurrents passed behind the arches of the aorta. Krause and Telgmann‖ add to the number of irregular origins of the subclavian artery and recurrent nerves, which, according to Turner, occur once in two hundred and fifty cases.

More recently, Brenner,△ in an interesting paper, describes two instances of this anomaly, and a third where the right recurrent

* "Bull. de la Soc. anat. de Paris," 1846, p. 111.

† Todd's "Cyclopædia," article "Par Vagum," 1847.

‡ "Gaz. méd. de Paris," 1848, p. 714.

"On Irregularities of the Pulmonary Artery, Arch of the Aorta, etc.," "Brit. and Foreign Med.-chirurg. Review," vol. xxx, 1862, p. 173.

‖ "Die Nervenvarietäten des Menschen," Leipsic, 1868.

△ "Ueber das Verhältniss des Nervus laryngeus inferior vagi u. s. w." "Arch. für Anat. und Entwickelungsgesch.," 1883, p. 373.

branched from the pneumogastric opposite the sixth cervical vertebra, and turned round the vertebral artery to reascend to the larynx. Here the right vertebral artery represented the fourth right aortic arch. The branches from the aorta in this case were in this order: First, a vessel that divided some two inches from its origin into the right vertebral and the right carotid; then came the left carotid, the left vertebral, the left subclavian, and finally the right subclavian from the descending aorta. He further reports two cases where the aorta passed over the right bronchus, in which the left recurrents passed under the fifth left branchial arches represented by the obliterated ducti arteriosi. The last writer who has called our attention to this subject is Chaput, whose "Note sur un rapport peu connu du recurrent gauche" may be found in the records of the "Soc. anatom. de Paris," July, 1884.

To return now to the normal relation of the recurrent nerves to the large blood-vessels, we find (Luschka) that the left recurrent leaves the pneumogastric at an acute angle in front of the arch of the aorta; it then turns round the vessel from before backward, runs up between it and the left bronchus, following the posterior surface of the aorta, which it leaves between the origin of the left common carotid artery and the subclavian to ascend to the larynx in the sulcus between the œsophagus and trachea. The right recurrent, which is shorter than the left, branches from the pneumogastric in front of the right subclavian artery. Turning under that vessel and running up behind the right common carotid, which it crosses to reach the fissure between the œsophagus and the trachea, it then proceeds to the larynx. In their course the recurrents send communicating branches to the cardiac and pulmonary nerves, and supply the œsophagus, trachea, and inferior portion of the pharynx with numerous filaments.

Rainey,* Hilton,† and Habershon,‡ from their own dissections, have described communicating filaments, running from the recurrents to the superior laryngeal nerves, while Philipeaux and Vulpian# maintain that the anastomosing fibers which are found come exclu-

* "The Recurrent Laryngeal Nerves," London "Med. Gazette," December 6, 1828.

† "Guy's Hosp. Reports," vol. ii, 1837, p. 514.

‡ "The Pathology of the Pneumogastric Nerve," "Med. Times and Gazette," vol. i, 1876.

"Sur l'anastomose qui existe entre le nerf laryngé supérieur et le nerf recurrent," "Arch. de physiol. norm. et path.," tome ii, 1869.

sively from the superior laryngeal nerves. Luschka * believed that in reality there was no communication between the superior and inferior laryngeal nerves, and that those filaments coming from the superior laryngeal which had this appearance were sometimes merely enveloped for a short distance in the same sheath with the inferior laryngeal, and at other times crossed it superficially at an acute angle to be distributed in the mucous membrane of the pharynx. Exner,† on the other hand, in one of the latest and most elaborate monographs on the innervation of the larynx, describes and pictures the ramus communicans, or "Galen's anastomosis." The relations of the inferior thyreoid artery and the recurrent laryngeal nerve are of practical importance in operations upon the œsophagus, and for the removal of the whole or a part of the thyreoid gland. Referring to Professor Dwight's ‡ paper on this subject, we find that Woelfler # stated that the nerve always passed before a branch of the artery. Kocher, ‖ on the other hand, describes the artery as passing behind the nerve, coming forward on its inner side and bending over it. Rotter △ made some fifteen examinations, and found the artery in one third as described by Kocher. Dr. Streckeisen ◊ reports the results of the examination of both sides of fifty-six bodies. He appears, however, to have had chiefly in mind the question whether or not the artery formed a loop around the nerve, and, if so, to what degree it surrounded it. It is not quite clear, therefore, in how many of his cases the artery passed before or behind the nerve. Dwight examined fifty-two bodies on both sides, and twenty-seven on one side. He found that on the right the artery was before the nerve thirty-three times, and behind it thirty-one. On the left the artery was before the nerve forty-nine times, and behind it fifteen. It appears, therefore, that the probabilities are equal that the right nerve or artery will be in front, and that on the left the chances are three to one that the nerve will be behind. Professor Dwight concludes that his series tend to support the practical deduction that, when it is necessary to tie the artery near the gland, the vessel should be carefully isolated.

* "Der Kehlkopf des Menschen," Tübingen, 1871.
† "Sitzungsber. d. Wiener Akademie d. W.," Bd. lxxxv, 1884.
‡ "Boston Med. and Surg. Journal."
# "Wiener med. Wochenschr.," 1879.
‖ "Arch. für. klin. Chirurgie," Bd. xxix, 1883.
△ "Archiv für klin. Chirurg.," Bd. xxxi, 1885.
◊ Virchow's "Archiv," Bd. ciii, 1886.

It has been stated that the recurrent nerves contain sensory fibers, but we are not aware of any experimental proof to support this opinion. In our judgment, this point may be determined by the following methods:

Experiment.—Anæsthetize a dog or a cat, and fix it on its back, with its lower jaw held open, so that a perfect view of its glottis can be obtained through the mouth by throwing in light by means of an ordinary head-reflector. The animal's tongue may be held out by the fingers of the left hand, and the epiglottis raised with a long forceps by the right hand. The recurrent nerve having been exposed and *cut*, the corresponding vocal band will be seen to be completely immovable, while its fellow moves rhythmically with respiration. Place an electrode on the central cut end of the recurrent, and stimulate with currents from the feeblest to the strongest intensity; no effect whatever will be produced on the glottis. But, if we now change the electrode from the cut end of the recurrent to the trunk of the pneumogastric of the same side, and stimulate it, we do obtain a decided reflex effect upon the glottis, which was impossible when its recurrent branch was irritated. But perhaps a still more delicate proof that there are no sensitive fibers in this nerve is furnished us by the absence of a rise of blood-pressure in curarized animals on stimulation of its central end after section. The observation of Ludwig and Thiry that irritation of sensitive nerves was followed by a rise of the blood-pressure occasioned by reflex contraction of the muscular coats of the arteries led us to apply this test to the recurrent, the method employed being that described by Dittmar and Miescher in their researches * on the sensitive fibers in the spinal cord.

We have used dogs and cats for this purpose without, in a single instance, being able to observe a rise of the blood-pressure when the recurrent was stimulated with weak or strong currents, which invariably followed when the internal popliteal nerve was irritated. We subjoin the details of one of the experiments, and the curves showing the difference between the action of these two nerves on the blood-pressure.

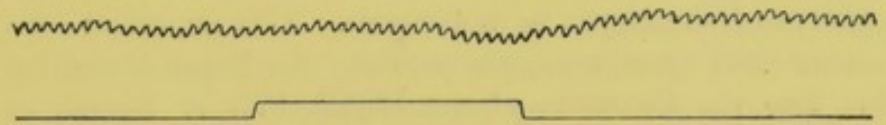
April 13, 1887.—Small black-and-tan dog. Curarized. Artificial respiration. Left recurrent and left internal popliteal nerves laid bare and cut previous to stimulation. The recording pen of a mercury manometer, which was connected with the right femoral

* "Arbeiten a. d. physiol. Anstalt," Leipsic, 1870.

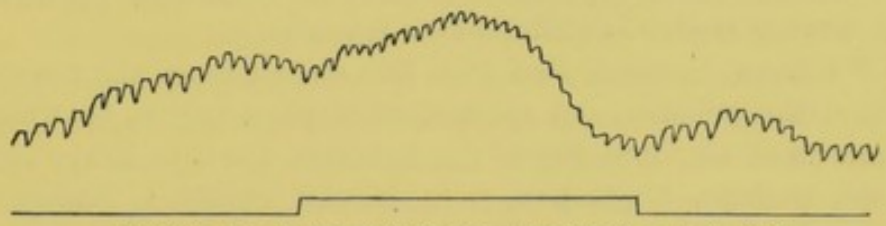
artery, recorded the blood-pressure on a long roll of paper in the usual manner.

By reading these tracings from right to left, it will be seen that irritation of the recurrent nerve with a very powerful current was not followed by any change of pressure, while, when the internal popliteal was stimulated, a marked rise was observed. We consider, therefore, that, as far as dogs and cats are concerned, the recurrents are purely motor nerves.

The recurrent nerve does not become the inferior laryngeal proper until it has reached the lower border of the cricoid cartilage. It is here about one millimetre in diameter.



Irritation of central end of left recurrent nerve. I = 200.



Irritation of central end of left internal popliteal nerve. I = 200.

Passing under the lower border of the inferior constrictor muscle of the pharynx, it enters the larynx behind the articulation of the inferior cornu of the thyreoid cartilage. It then divides into several branches, which innervate all the muscles of the larynx except the thyreo-cricoids. It is an occasional, but not a constant, phenomenon, that excitation of one of the recurrent nerves will cause a contraction of the vocal band of the opposite side, which tends to confirm the statement that there are connections between the terminal filaments of the recurrents in the laryngeal muscles. Such, then, being the course and distribution of the recurrent nerves, it remains now to investigate their rôle in carrying on the different functions of the larynx.

II. Physiology.

In looking through the mass of writings and experiments, from remote times to the present day, upon the physiology of the recurrent laryngeal nerves and the parts which they supply, we are struck, first of all, by the many discordant opinions that have been, and still are

being, recorded, and feel that the old aphorism, "experiment is fallacious and decision difficult," is as applicable to the nineteenth century as to the time when Hippocrates gave it utterance. Yet, when we consider the improvement in recent years in instruments of research, and reflect upon the advance and development of physical science, we may ask if it is not now, perhaps, the experimenter that is fallacious, and not the experiment.

It is, indeed, surprising that scarcely fifty years have passed since the first experimental study of questions pertaining to the larynx which approached completeness and was of real scientific value. We refer to a paper by John Reid (1838), of Scotland, the title of which, however, would not lead one to look for as much valuable work upon the nerves of the larynx as it contains. This important paper, to which we shall again refer, was entitled "An Experimental Investigation into the Functions of the Eighth Pair of Nerves, or the Glosso-pharyngeal, Pneumogastric, and Spinal Accessory,"* and was founded upon experiments which, as Romberg† justly says, may serve as models of philosophical inquiries.

We know, however, that from the earliest times the voice has enlisted the attention and speculation of physiologists, but the experiments of all, from Rufus the Ephesian down to Reid (1838), except, perhaps, Magendie's, were directed chiefly to finding out what influence the pneumo-gastrics or the recurrents had upon the function of phonation; whether the voice was lost after section of these nerves; and whether it could be regained when once taken away in this manner.

Rufus of Ephesus, Galen, Vesalius, and others found that the voice was lost after the pneumogastrics or the recurrents had been cut or included in a ligature, although less careful observers came to different conclusions; but we need not at present review in detail the investigations of these early writers, inasmuch, as we have just mentioned, as their researches had reference solely to the relation of these nerves to the voice.

To come down to more recent periods (1734), one of the earliest papers is by Martin, entitled "The Experiment of cutting the Recurrent Nerves carried on farther than has hitherto been done."‡ We find in it, however, little to justify the title, as Martin confined himself to cutting the recurrents of a sucking pig in order to observe the

* "Edin. Med. and Surg. Journal," vol. xlix, 1838, p. 109.

† "The Sydenham Soc.," vol. ii, 1853, p. 313.

‡ "Medical Essays of Edinburgh," vol. ii, 1734, p. 114.

effect on the voice, and recorded that, after the operation, "it could never give a squeak in the ordinary manner of these animals."

A more elaborate paper, by Haighton (1792), followed Martin's, on "Experiments made on the Laryngeal and Recurrent Branches of the Eighth Pair of Nerves, etc.,"* in which he calls attention to the "contrariety of opinions" that then prevailed, and adds, significantly: "This may possibly excite astonishment, when we consider that the subject is not of very difficult investigation, requiring for its accomplishment very little more than an unprejudiced mind and a hand accustomed to dissection." He determined that the recurrents were the true vocal nerves, and showed in one experiment on a dog that the voice could, "when taken away by the division of the nerves, again return." Galen, he tells us, said also that the voice "ought to return after it had been lost by experiment," owing to the communicating branches between the superior and inferior laryngeal nerves, but Haighton believed that it depended upon the reunion of the divided nerves. Magendie (1813), who, up to his day, furnished the most noteworthy experimental work on the larynx and gave a good description of the distribution of the recurrent nerves, believed, nevertheless, that all the muscles which they supplied opened the glottis, while the superior laryngeal nerves, in going to the thyreo-cricoid and transverse muscles, had exactly the opposite function, and closed the glottis. For many years a number of writers blindly followed the teachings of this great physiologist in regard to the functions of the laryngeal nerves and muscles. Hugh Ley, among others, believed with him that the recurrents opened the glottis, and that the transverse muscle was the principal closer of the organ; and in a work of much labor on "Croup"† Ley wrote considerable that is of interest to modern laryngologists, but much also that is most extravagant.

We have mentioned elsewhere‡ that Magendie was the first who demonstrated experimentally the true action of the thyreo-cricoid muscle; and at the present day, when it is positively known that the office of this muscle in raising the cricoid cartilage on to the thyreoid is to produce longitudinal tension of the vocal bands, we can not read without a smile the reasons which Ley's fertile brain invented to account for this upward movement of the cricoid cartilage. He says

* "Mem. of the Medical Soc. of London," vol. iii, 1792, p. 422.

† "An Essay on the Laryngismus Stridulus or Croup-like Inspiration of Infants," London, 1836.

‡ "Experimental Researches on the Tension of the Vocal Bands," "Trans. of the Amer. Laryng. Assoc.," 1883.

he can trace no other purpose for it than that of throwing mucus into, and perhaps through, the chink. "This movement," he continues, "the posterior part of the ring being fixed, while the anterior is carried upward and inward, resembles that of a hoop, which will strike the shin with force when an attempt is made to raise it from its horizontal position by pressure upon its edge with the foot, or that of a basin containing fluid, treading upon the edge of which will throw its contents to a considerable height upon the limb, while the edge of the vessel itself may also strike the shin. The cricoid cartilage is thus a sort of pail, which, filled from the trachea, empties its contents into or through the glottis, and performs an office somewhat analogous to those scoops or buckets which, attached to a large wheel, help to deepen the river by drawing the earth from its bed, and, by the same revolution of the wheel, discharge their contents into an adjoining lighter for ballast or other purposes."

Here we see one of the most exquisite of the co-ordinated movements of the larynx—a movement upon which one of the fundamental laws of vocal physiology is founded—actually compared to the working of a dredging-machine and a mud-scow!

Hilton, in his "Lectures on Rest and Pain," gives a far more poetical explanation of this upward movement of the cricoid cartilage. In speaking of the motor branch of the superior laryngeal nerve, which supplies the thyreo-cricoid muscle, he says: "No matter how rapidly the nervous influence passes, it must reach the nearest point first, and that is apparently the reason why this little nerve takes so short a course to the crico-thyreoideus. It has long been my habit to regard the crico-thyreoidei as the muscles which are intended to tune the vocal instrument; and, as the instrument must be tuned before it can be played upon, so this nervous influence, first reaching the crico-thyreoidei, the vocal cords are put into a due state of tension, preparatory to the more precise and accurate influence of the other muscles acting directly and indirectly upon the vocal cords."

It was not long, however, before important light was shed upon these questions. Reid (1838), whose paper we have already mentioned, gave an accurate account of the anatomy of the recurrent nerves. He refuted Magendie's statement that these nerves moved only those muscles which opened the glottis; he confirmed experimentally Magendie's views of the action of the thyreo-cricoid muscles, and described the functions of the other intrinsic muscles, as they are now generally understood. He showed also that irritation of the recurrents of a dog closed the glottis.

Three years later (1841) Longet's* well-known paper appeared, which covered very much the same ground as Reid's, with practically the same results. Longet, moreover, agreed with Bischoff† that the internal branch of the spinal accessory was the motor nerve which presided over the tensors and the closers of the glottis, and that the dilators were innervated independently. Cl. Bernard's‡ careful experiments confirm this view. He showed that section of the spinal accessory in a kitten five weeks old was followed by aphonia, but glottic respiration remained free. Two days afterward, the kitten having remained well but voiceless, its recurrents were cut, when it instantly died asphyxiated. He concludes from this that the pneumogastric has a motor power independent of the spinal accessory which permits the animal to breathe after the latter has been cut; or, in other words, the larynx is a vocal organ when excited by the spinal accessory, and a respiratory organ when under the influence of the pneumogastric, or more probably of other motor nerves associated with it. In certain animals, as the chimpanzee, the internal branch of the spinal accessory does not blend with the pneumogastric, but goes direct as a separate nerve to the larynx.

Conclusive as were the experiments of Magendie, Reid, Longet, and others who have followed them, we find, even at the present day, differences of opinion in regard to the offices of certain of the intrinsic laryngeal muscles, about which our knowledge is apparently exact, as their function has been experimentally proved. The salient points of these questions, however, although they will always be more or less at the mercy of theorists, may be considered as tolerably well established. We know that the recurrent nerves supply those muscles which both open and shut the glottis—all of the intrinsic muscles, in fact, except the longitudinal tensors, the thyreo-cricoids; also, in part at least, those muscles which compose the ventricular bands and the ary-epiglottic folds. It is reasonably certain, too, that the internal thyreo-arytenoids, the lateral crico-arytenoids, and the transverse muscles are the closers, while the posterior crico-arytenoids are the only openers of the glottis.

In coming now to the subject-matter of this paper, we wish to express our gratification at having had the other Boston members of

* "Recherches expérimentales sur les fonctions des nerfs du larynx," etc., "Gaz. méd. de Paris," ix, 1841.

† "Nervii accessorii Willisii anat. et physiol.," Heidelberg, 1832.

‡ "Fonctions du nerf spinal," etc., "Leçons sur la physiologie et la pathologie du système nerveux," tome ii, Paris, 1858.

this association (Dr. Knight, Dr. Langmaid, and Dr. De Blois) as witnesses to some of the results herein recorded. Our thanks are especially due Dr. J. Solis-Cohen for his interest in this subject, who, with Dr. Edward Martin, of Philadelphia, was willing to submit to a long and tedious journey to pass a day of experimental investigation with us in the laboratory. It has been our object in our present series of observations, as in all our experimental work of the past five years, to multiply largely the experiments and to record only such as were typical and had been seen by other eyes besides our own. We have pursued this plan in order to eliminate, as far as possible, sources of error, and, as our work has always been undertaken without any preconceived theory to support, or care as to what might or might not happen, provided a fact could be established, we think our mistakes—if mistakes there be—will be due to some fault in our methods rather than in our observation.

In arriving at an appreciation of the physiology of the recurrent laryngeal nerves, it may be well to view them in the light of our knowledge of the functions of the organ over which they preside. We can recognize three distinct functions of the larynx controlled by three distinct groups of muscles, which are all innervated by the recurrent nerves. These wonderful nerve-trunks, therefore, which, as previously stated, are but one millimetre in diameter, contain sets of nerve-fibers as distinct as the functions of the groups of muscles which they supply. Mentioned in the order of their importance to life, these muscular groups and their functions are: (*a*) Those that carry on the respiratory function of the larynx; (*b*) the sphincter group, which serve to close the lumen of the larynx to prevent the entrance of foreign bodies, and play an important part in all expulsive acts, such as coughing, sneezing, retching, vomiting, or defecation, "or in those muscular actions where it is necessary to have the thorax fixed in order to enable the muscles attached to it to act with greater advantage or greater precision" (Lauder Brunton and Cash *); and (*c*) the phonatory muscles.†

The respiratory and the phonatory muscles which are attached to the arytenoid cartilages have diametrically opposite action. The

* "The Valvular Action of the Larynx," "Journal of Anatomy and Physiology," vol. xvii.

† It must be recognized, however, that some of the fibers belonging to the group of muscles commonly described as the thyreo-arytenoids may act as sphincters under certain conditions, while at other times they serve purposes of phonation.

respiratory muscles (the posterior crico-arytenoids) hold the glottis open for the ingress and egress of air, and, on direct stimulation, they open it still wider, while the phonatory muscles, when called into play, close the glottis by approximating the vocal bands. The vocal bands are brought into apposition in the median line of the glottis for sound production by a most delicate co-ordination of automatic muscular action, and not by forcible constriction in the sense with which we apply that word to the sphincter-like working of the muscles contained in those portions of the larynx above the vocal bands —namely, in the ary-epiglottic folds and in the ventricular bands.

These functions of the larynx can be watched in the laryngoscopic mirror. If the subject under examination takes a deep inspiration, the glottis will immediately dilate under the increased respiratory stimulus; if a probe or other instrument is passed into the interior of the organ, its walls will instantly shut tightly around it, and reflex coughing or retching will be produced; if a vocal sound is emitted, it will be accompanied by an approximation of the vocal bands. Since the recurrent furnishes these groups of muscles with nerve-force, we must speak of it, like the organ over which it presides, as having three functions, its effect upon the larynx depending upon the particular set of nerve-fibers which are called into action. If the different sets of filaments contained in the trunk of the nerve could be traced to their origin, and there differentiated and separately stimulated, we might undoubtedly produce an opening or a closing of the glottis at will, according to the function of the nerve-fibers operated upon.

But when we experiment with the nerve-trunk itself we find there all the different fibers packed together in a small compass, and on applying a current of electricity to it we can not be positive that we are stimulating all of its component filaments equally and simultaneously. We have no definite knowledge of the numerical or topographical relation between the dilating and the constricting fibers. The fact that a stimulus applied to the recurrent nerve of some animals causes a dilatation of the glottis, while in others, under the same conditions, it produces a closure, and again, in the same animal, at one moment dilatation and at another moment closure, according to circumstances, shows us what a complex nerve we are dealing with, and how great are our difficulties when we attempt to apply results obtained in the lower animals to man.

The most important function of the larynx is that of respiration. The muscles which regulate this vital act are the largest of the in-

trinsic laryngeal group. They are in ceaseless activity during life, holding the glottis open to permit the passage of air to and from the lungs. Theoretically, we should expect that the nerve-fibers which innervate these muscles would be the most numerous, the most sensitive, and of greater resisting power than all the other individual filaments of the recurrent nerve; and also that any stimulus applied to the nerve would excite a contraction of these muscles, since they are the largest of the laryngeal group, and the most bountifully supplied with nerve-force; but practically we know that this is not universally the case. If, for instance, the recurrent nerves of dogs that are unnarcotized or slightly under the influence of ether, chloroform, chloral, or morphine, are stimulated with the feeblest current of electricity, the first effect noticeable upon the glottis is a vibratory movement of the vocal bands, with a tendency toward closure, which, on gradually increasing the intensity of the stimulus, becomes a firm closure of the glottis through tetanic contraction of the adductor muscles. Now, it is very remarkable that if we irritate the recurrent nerves of a cat under the same conditions, the effect upon the glottis is exactly the opposite. The cat's glottis will dilate instead of closing. Contrary to what we observe in dogs, the earliest effect of a weak stimulus applied to the recurrent nerves of the cat is to produce a vibratory movement of the vocal bands with a tendency toward dilatation, which immediately merges into a rigid dilatation as the strength of the stimulus is increased.

Dr. Douglas Powell,* of London, has drawn our attention to the fact that the same phenomena are not observed in different animals, and he has recorded that in the cat, instead of closure, powerful abduction of the vocal bands was obtained on galvanizing the recurrent nerves.

Our own observations agree with those of Dr. Powell, and we think we may affirm that in the dog the function of the recurrent nerve, under normal conditions, is to close the glottis, while in the cat, under similar conditions, it is to open the glottis. These effects take place whether stimulation be applied to the intact nerves or to their peripheral ends after section. These opposite results in the lower animals render the practical and pertinent question, "*What is the normal function of the recurrent nerve in man?*" difficult to answer until we are able to determine which animal man most resembles, or until we subject him to direct experimentation.

The results of experiments on man have not been entirely satis-

* "Med. Times and Gazette," Dec. 19, 1874, p. 701.

factory, but they all point in one direction—viz., that stimuli applied to the nerve close the glottis. We know of but one series of experiments made on man where the recurrent nerve was dissected out and irritated. Dr. W. W. Keen,* of Philadelphia, in 1875 experimented on the recurrent nerve of a criminal recently hanged, in order to determine the question whether a chiasm of the minute fibers of the nerve existed. He says that repeated faradization, both with weak and with strong currents, of the left recurrent and left vagus produced decided movements of the left vocal cord only. The character of the movements (adduction or abduction) was not mentioned, but Dr. Keen has recently informed the writer that, although he would not like, at this distance of time, to assert positively that the left cord was adducted, he is as reasonably certain that such was the fact as one can be of a remembered fact after a long interval of time.

The attempts that have been made on the living subject to excite the recurrent nerves through the skin and soft parts of the neck, and to observe the effect upon the glottis through the laryngoscopic mirror, have been crowned with a certain degree of success, and it has always been the adductor muscles that were seen to respond to the stimulation.

Gerhardt,† the earliest investigator in this direction, reached negative or doubtful conclusions. Dr. Pauly, of Posen, and Professor Quincke‡ employed this percutaneous method to reach the recurrent nerves, and observed that stimulation was followed by complete closure of the glottis. Rossbach,# Erb,‖ and Kaplan△ have each determined that it was upon the adductor muscles of the glottis that the electrical stimulation was manifested, but, as the results were not constant, and as it was uncertain whether the effects were of a reflex nature or direct upon the nerve, or perhaps upon the laryngeal muscles themselves, we can not regard these observations as throwing any very clear light upon our present inquiry. It is noteworthy, however, that an opening of the glottis has not been recorded by those who have experimented with the recurrent nerves in this man-

* "Trans. of the College of Physicians of Philadelphia," Third Series, vol. i, 1875.

† Virchow's "Archiv," vol. xxvii, 1863.

‡ Referred to by Kaplan, "Experimenteller Beitrag zur electrischen Erregbarkeit d. Glottismusculatur," etc. Inaugural Dissertation, Berlin, 1884.

"Monatsschr. für Ohrenheilkunde," etc., October, 1881, No. 10, p. 166.

‖ "Handbuch der Elektrotherapie," Leipsic, 1882, p. 472.

△ *Loc. cit.*

ner; and, from our empirical knowledge of the action of the muscles of the glottis in health and in disease, we consider it reasonably certain that any irritation of the trunk of the recurrent nerve in man would produce a spasm of the glottis and not a dilatation.

Let us now return to the lower animals. We have already said that stimulation of the recurrent nerves of the dog, under normal conditions, *closes*, while excitation of the recurrent nerves of the cat *opens*, the glottis. Yet it is in our power, under certain circumstances, to reverse this natural order of phenomena in these two animals, and to produce in the dog a dilatation and in the cat a closure. The sole condition in the dog, so far as our present experience goes, by which a dilatation of the glottis can be obtained, is through the influence of sulphuric ether, and when the animal is in profound morphine narcosis.

From some undiscovered cause ether completely abolishes the offices of the glottis-closers. It has some unknown peripheral effect upon either the laryngeal muscles or nerves, or both, so that when a dog is in profound ether narcosis his glottis no longer closes when the recurrent nerves are stimulated, but, on the contrary, is opened widely through the action of the glottis-openers, upon which ether has, apparently, no influence.

In a paper* entitled "The Respiratory Function of the Human Larynx," published two years ago, we recorded this fact for the first time. From the date of that observation to the present time experimental researches have been prosecuted in the physiological laboratory of the Harvard Medical School, by others as well as by ourselves, with the view of determining the cause of this "ether-effect," and whether sulphuric ether would have analogous effects upon other nerves and upon other groups of antagonistic muscles.

While we were engaged in this direction, having established beyond doubt the *fact* of what for the sake of brevity we shall call the "ether-effect," a paper appeared in the "American Journal of the Medical Sciences," July, 1886, by Dr. F. Donaldson, Jr., wherein the writer stated that he had been unable to obtain the "ether-effect." He did, however, observe a dilatation of a dog's glottis when the animal was under ether, but inferred that the phenomenon was due to weak stimulation of the recurrent nerve instead of to the ether, inasmuch as he produced a closure of the glottis on increasing the intensity of the current.

Shortly after this paper was issued, Felix Semon, M. D., F. R. C. P.,

* "New York Medical Journal," July 4, 1885.

and Victor Horsley, B. S., F. R. S.,* published in a lucid report the results of their investigations on this subject, which fully verified our own observations. These authors also state that they were able to obtain dilatation with feeble stimuli, yet they call our attention to the fact, and it is here the practical point, that it was only in those cases in which the animal was not deeply etherized.

The dilatation, it seems to us, should be ascribed to the action of the narcotic.

The strength of the current, however, is a factor in determining whether dilatation or closure is produced, and it is undoubtedly correct that *in certain stages of etherization*, as we shall hereafter demonstrate, abduction may be called forth by a weak stimulus, while a stronger stimulus, with the same amount of ether, will produce the ordinary result of closure. But we think it is impracticable to use strong stimuli in these or other studies in experimental laryngology.

In our investigations on the "ether-effect," conducted two years ago, the intensity of the currents used was always of the feeblest, and it therefore struck us as somewhat extraordinary that others who followed us should lay so much stress upon the fact that weak stimuli should be the cause of the opening of the glottis, which, in reality, as we had proved, was due to the effect of sulphuric ether.

Considering, therefore, the confusion, although it appears to us to be more fancied than real, that has slightly befogged this question, we have felt it incumbent upon us to rehandle the subject.

It may be well here to explain more in detail than we have hitherto done the terms we use to describe the different shapes the glottis may assume in response to electrical stimulation of the recurrent nerves. By *complete dilatation* we mean that both vocal processes of the arytenoid cartilages are rotated forcibly outward, the vocal bands, in marked instances, appearing to lie flat against the walls of the larynx, this extreme opening being maintained as long as the stimulation is kept up. By *mixed movement* we mean an opening in the posterior portion of the glottis and a contraction of the ligamentous portion in front, giving to the glottis a rhomboidal shape. This shape appears to arise in two ways—either by an active opening behind accompanied by an active closure in front, or simply by a *want* of *closure* behind and an active closure in front. The

* "On an Apparently Peripheral and Differential Action of Ether upon the Laryngeal Muscles," "Brit. Med. Journal," August 23, 1886 p. 405.

large development of the cartilaginous portion of the glottis in the dog should be borne in mind in interpreting these appearances. The agency by which the mixed movement is brought about is not perfectly understood. It would seem, in some instances, as if all the intrinsic group of muscles were responding equally to the stimulation except the lateral crico-arytenoids and the transversus; hence the closure in front and the opening behind; but, the lateral and transverse muscles not acting, the lozenge-shaped glottis is the result. By *complete closure* we mean close apposition of the ligamentous and cartilaginous portions of the glottis.

When we consider what a complicated and delicate organ the larynx is, being made up of so many cartilages which are freely movable on each other by means of the numerous muscles attached to them, the fibers of which run in every possible direction, it need not cause surprise that there should be occasional variations in the appearances of the glottis in different dogs following stimulation of the recurrents which may be due to some peculiarity of the nerve distribution or to unusual strength of some of the laryngeal muscles.

But of the general results in dogs we think there is not much ground for doubt or for any difference of opinion of practical value. Errors of interpretation may be lessened and the most trustworthy results obtained by placing a shielded electrode on each nerve five to eight centimetres below the cricoid cartilage, the effect of stimulation on the glottis being watched through the mouth, when both nerves are irritated equally and simultaneously.

Small and young dogs, in our experience, are much more satisfactory for experimental purposes than old or very large ones. The breed seems to be of no consequence.

Our present series of observations have been conducted on forty-two dogs, and comprise three hundred and twelve recorded experiments. Of these animals, twelve have been devoted to a study of the effects on the glottis of stimulating the nerves when the dog was under chloral, chloroform, or morphia, eighteen to the "ether-effect," seven to the local effect of ether upon the nerve-trunk, and five to "exhaustion" experiments.

We have stated that the normal effect of irritating the recurrent nerves of dogs is to *close* the glottis. This statement is founded upon the investigations of others, who have experimented with and without anæsthetics, and upon our own observations with small amounts of different narcotics.

The following experiments with chloral may be taken as a type

of what occurs in the majority of cases when dogs are under small amounts of chloral, morphine, chloroform, or ether. These particular experiments are selected from a large number merely because some of our colleagues conducted the observations with us:

April 27, 1887.—Dr. Knight and Dr. Langmaid present. Medium-sized poodle bitch. Ether was first given until the femoral vein was exposed and a cannula tied into it, through which a 25-per-cent. solution of chloral was slowly injected. After this stage of the operation the animal had no more ether. The recurrent nerves were laid bare, and shielded electrodes placed upon them. The glottis was observed through the mouth. Stimulation of the nerves with the feeblest current was followed by a vibratory motion of the vocal bands, which, on increasing the intensity of the stimulus, passed into complete closure. Nothing resembling a dilatation or the mixed movement could be called forth in this dog.

Dr. Knight was present on another occasion, when a very small terrier bitch was the subject of experiment under similar conditions, and the results were identical in all respects. In no instance, in a chloralized dog, have we been able to elicit a complete dilatation, but the mixed movement has been seen in two cases. In one of these, Dr. Knight, Dr. Langmaid, and Dr. De Blois assisting, the dog was a very powerful animal, and, although the first few effects of stimulation were followed by closure, the mixed movement only was afterward called forth with all intensities. It would seem that this mixed movement was produced through a failure of the lateral crico-arytenoid muscles to respond to electrical stimulation, the other muscles acting equally. It may be that, as narcosis comes on, the lateral adductor is the first to lose its contractility, and, as the narcosis becomes more profound, the functions of the other adductors are also arrested, while the dilators hold out to the last.

Although we have not been able to produce complete dilatation with chloral or chloroform, it is not unlikely that, by pushing these drugs to extreme limits, we might, in certain cases, elicit such an effect. It is difficult to believe that sulphuric ether should be the only drug capable of calling forth abduction. We have succeeded in obtaining complete dilatation in a dog under an enormous dose (2–5 grammes) of morphine; but the condition of the dog under these circumstances can hardly be compared with that of the animal when a harmless dose of ether has been administered. It was with much surprise that, in the spring of 1885, we saw, for the first time, the glottis dilate under the effect of an irritation applied to the

recurrent nerve; but we immediately surmised the reason, which subsequent researches by ourselves and others have shown to be correct. It may render this study clearer if we briefly review the circumstances of our first observation, and how we were led to what appeared to us the only possible conclusion, that the dilatation was brought about through the influence of sulphuric ether. Our experiments, which had already been quite numerous, were generally performed on dogs chloralized by intravenous injection. This means of producing anæsthesia was almost invariably employed for prolonged experiments. Ether, however, was given in the first stage of the operation. The dog in which we first observed a dilatation was etherized for the purpose of passing a thread through the recurrent nerve, after which the incision in the neck was to be sewed up, and the animal returned to his kennel for a few days before further observation. On looking for the nerve, it was not found in its proper anatomical situation; but two small nerves were discovered near by. As it was doubtful what these two branches were, it was considered prudent to irritate them, and, if the glottis contracted, we could then be certain we had the nerve we were in search of, and proceed with the operation. But, when the nerves were stimulated, we were greatly surprised to see a forcible dilatation, instead of the customary closure. The assistant in physiology, Dr. Warren, was requested to come and witness this unusual sight. The ether sponge had been removed from the dog since the beginning of the experiment, and by the time Dr. Warren was ready to look at the glottis the animal was somewhat out of its influence. At all events, on stimulating the nerve a second time, closure was manifested, instead of the dilatation so evident a few moments before. Here we had in the same dog, at a short interval, both a dilatation and a closure of the glottis. As all the conditions were the same, with the exception of the depth of the narcosis, the natural inference was that the amount of ether in the animal must be the cause of the dilatation. A large quantity of ether was again administered, and the abduction again clearly demonstrated.

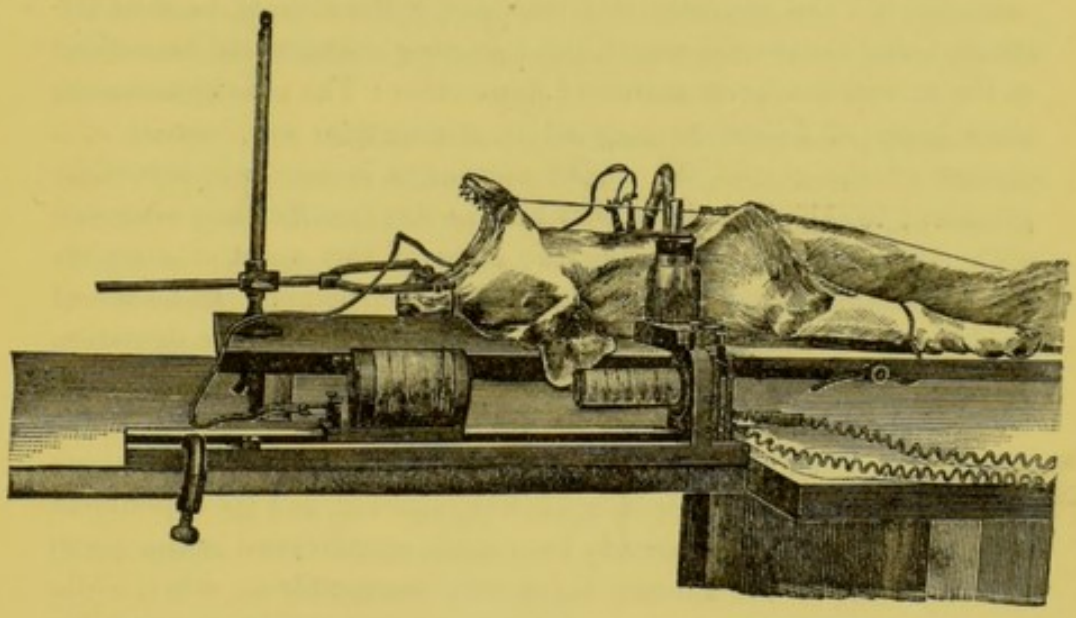
Our first idea was that the "ether-effect" was central. To test this hypothesis the recurrent was divided, and the irritation applied to its peripheral end. The glottis dilated after section of the nerves as well as before.

With regard to the fact of the "ether-effect" in dogs we have little to add. Our previous experiments were based on so many confirmatory observations on different dogs that the fact was clearly

established. The facility with which a dilatation may be elicited depends upon the susceptibility of the dog to the drug, the intensity of the irritation, and the amount given. It differs in different dogs. In the majority complete dilatation may be elicited; in other instances the mixed movement only is obtainable. In two dogs, in our experience, the effect has been negative; in these cases there was neither contraction nor dilatation on stimulation of the recurrent nerves, even in the most profound stage of etherization, but with slight anæsthesia closure took place.

"*Ether-Effect*" *Method.*—The accompanying figure will make our method clear.

The dog is here arranged in what we consider the most satisfactory manner to demonstrate the "ether-effect" in its different aspects.



It will be seen that the animal is fixed on his back, with his upper jaw tied to a dog-holder, while the lower jaw is held open by a cord fastened to the lower end of the board. A perfect view of the glottis is now made easy by holding the tongue forward in one hand and lifting the tip of the epiglottis by a long forceps with the other. Tracheotomy has been performed, and the tracheal cannula is connected with a bottle containing ether by a short piece of rubber tubing, which can readily be adjusted to or removed from the cannula. A shielded electrode is upon each recurrent nerve; the electrodes are connected with each other, and in communication with an induction apparatus, which is supplied from one Grove cell in a bat-

tery closet. The secondary coil of the apparatus is on a slide, so that it can be moved to and fro at will, according to the intensity desired. It is our custom to begin an experiment with the secondary coil so far removed from the primary that no effect is manifest on the glottis by opening the short-circuit key connected with the secondary coil, and then to slowly approach the secondary coil toward the primary until some effect on the vocal bands is produced. When a dog is very slightly etherized, the first movement noticed of the vocal bands is of a vibratory character, which changes into a closure of the glottis as the intensity of the current is increased. Now, having determined on a given dog the feeblest stimulation that will provoke a closure of the glottis with the smallest amount of ether, let us attach the ether-bottle to the tracheal cannula, and watch the evolution of the "ether-effect" through the mouth. By irritating the recurrent nerves at intervals of a few moments (the intensity of the current, be it understood, being always the same), the following changes will be noticed as the animal consumes more and more ether: The constrictors soon show signs of failure to respond to stimulation, and, instead of a closure of the glottis, the mixed movement is seen, which in time gives way to complete dilatation when the dog is sufficiently saturated with ether. By now removing the ether at this point of complete dilatation, the reverse picture of the above phenomena can be traced as the animal emerges from profound ether narcosis. The dilatation will soon give way to the mixed movement; this mixed appearance will gradually become less and less until, finally, complete constriction supervenes, when we have returned to the starting-point of the experiment. The ether may now be again administered, and the experiment repeated. Mention has already been made of individual canine peculiarities, some of the animals being very susceptible to ether, while in others the mixed movement only can be demonstrated, no matter how much of the anæsthetic is given. In presenting detailed experiments, we shall select from our note-books the most typical cases, which may be taken as representative of the average dog. The following experiment shows the time it may take to complete the circle of the "ether-effect" when the intensity of the stimulation remains the same as just described.

December 22, 1886.—Smooth-haired mongrel bitch, ten to eleven months old. Arranged for observation as previously described. Intensity of stimulation = 5, which was the feeblest current possible to produce a decided effect upon the vocal bands.

TABLE I.

	Time, A. M.	Result.
Ether applied.	10.15	Contraction.
	10.16	Mixed movement beginning.
	10.17	Mixed movement more marked.
Ether removed.	10.18½	Complete dilatation.
	10.20	Mixed movement.
	10.22	Almost complete contraction.
	10.23	Complete contraction.

It will be noticed that in this particular dog eight minutes were sufficient to exhibit the "ether-effect" in all its stages.

All our animals, we need hardly say, were etherized while being prepared for experimentation, which generally occupied from a half to three quarters of an hour. During that time the dog was given merely enough ether to keep him quiet and free from pain. Some dogs pass very quickly and quietly under the influence of ether, and come out of it with surprising rapidity, while others are very bad etherizers.

We may add another experiment here, like the one just detailed, solely for the sake of comparison, on an older dog than the last and one not quite as susceptible, but the variations are within narrow limits, as has been the case in all similar observations.

December 19, 1886.—Rough-haired terrier bitch, about two years old. Intensity of stimulation = 6, which was the weakest we were able to use, as a feebler current caused merely a vibratory movement of the vocal bands.

TABLE II.

	Time, A. M.	Result.
Ether applied.	11.13	Contraction.
	11.15	Mixed movement.
Ether removed.	11.18	Complete dilatation.
	11.19	Dilatation.
	11.20	Dilatation.
	11.21	Dilatation accompanied by slight vibration.
	11.22	Dilatation less marked; tendency toward mixed movement.
	11.23	Mixed movement.
	11.25	Almost complete contraction; on increasing the intensity of the stimulation at this point very slightly, a complete and vigorous contraction took place.

Leaving the question of the phenomena consequent upon the same stimulus in different stages of etherization, we will pass to a consideration of the effect of weak and strong stimuli rapidly applied in succession to the recurrent nerves, according to the depth of the

ether narcosis. For this purpose, let us start with a dog in the most profound state of etherization, at a point where stimulation with currents, from the weakest to the most powerful that it is reasonable to use, will fail to produce a closure of the glottis. When this condition is determined, remove the ether and proceed in the following manner until the experiment is completed: Place the secondary coil so far from the primary that there will be practically no current; then, leaving the short-circuit key open, move the secondary toward the primary coil at stated intervals, noting the different effects upon the glottis, according to the intensity of the stimulation, as the animal comes out of the ether. It will be found, under these circumstances, that dilatation or the mixed movement with *all* intensities soon gives way to dilatation or the mixed movement with weak stimuli only, and contraction with stronger; and that contraction is called forth by stimuli less and less strong as the dog becomes less and less etherized, until finally contraction only is produced by even the feeblest irritation. We submit the following table, showing in minutes the time it usually takes to demonstrate these phenomena.

November 28, 1886.—Well-bred collie bitch, six to seven months old. Arranged for observation as already described. Profoundly etherized. Ether removed at beginning of experiment, 10.39 A. M. (*a*). The intensity of the irritation necessary to produce the results indicated at the head of each column is shown by the numerals below.

TABLE III.

Time, A. M.	Vibration.	Dilatation.	Mixed.	Closure.
a. 10.39.....	2	5	22	....
b. 10.40.....	2	....	9·5	....
c. 10.41..	2	....	4·8	....
d. 10.41½..... ...	1·5	....	4·8	22
e. 10.42.....	1·5	....	4·8	9
f. 10.42½.....	1·5	....	....	4·8
g. 10.43½.....	1·5	....	....	3

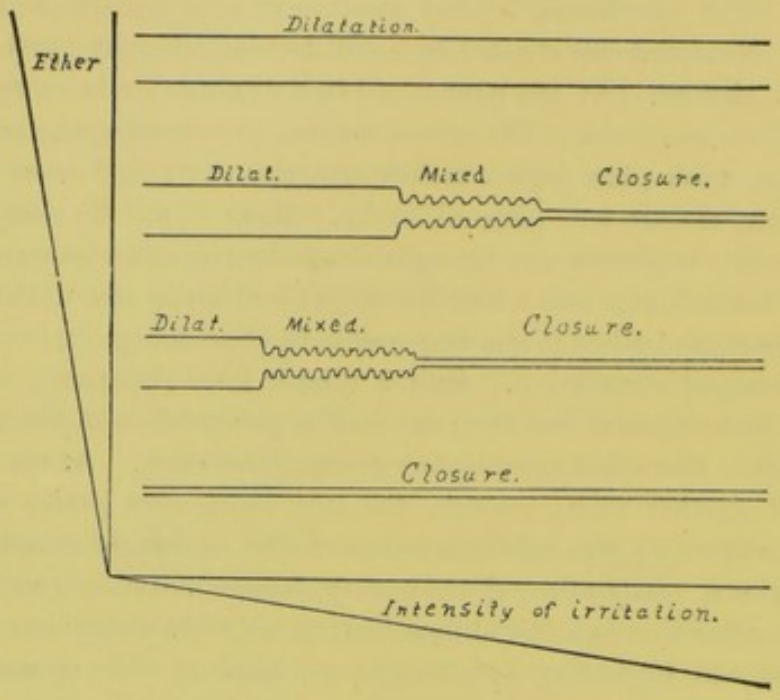
An analysis of this table shows that at the beginning of the experiment (*a*), when the dog was thoroughly saturated with ether, vibrations of the vocal bands were called forth by the excessively weak stimulus of 2; as the secondary coil was moved toward the primary, complete dilatation was manifested at 5, which persisted until the comparatively powerful intensity of 22 was reached, when the mixed movement supervened. No closure of the glottis could be

obtained in this stage of etherization, even by the strongest stimulation. One minute later (*b*), the secondary coil being again started at the farthermost point from the primary, vibrations were noticed at the same intensity as before, but dilatation was no longer obtainable, although the ether had been removed but one minute. The mixed movement, however, was seen to occur with a much feebler irritation (9·5). Still no closure. After another minute had elapsed (*c*) the mixed movement was elicited by a still feebler intensity (4·8); otherwise no change. At the next trial (*d*), half a minute later, a marked change was observed. The mixed movement remained the same, but vibration took place with a feebler stimulus (1·5), and now, for the first time, closure was effected at 22. Here it will be noticed that closure of the glottis was brought about by the same intensity (22), which two minutes and a half before (*a*) had given rise to the mixed movement, and when it was impossible to close the glottis even with the strongest stimulation. Half a minute later (*e*) closure was produced by a stimulus less than one half as powerful as in the previous trial (*d*). The other conditions remained the same. At the expiration of another thirty seconds, the dog being now pretty well out of his ether (*f*), the mixed movement was no longer manifest, and closure was easily effected by a very feeble irritation (4·8). One minute after this (*g*), the animal having so little ether left in him that he was beginning to struggle, a complete closure was called forth by an intensity of 3. At this point ether was again administered. The duration of the experiment was four minutes and a half from the time (*a*) when a closure was impossible with the strongest stimulus to (*g*) when closure took place with an excessively weak stimulus.

The foregoing method of watching the "ether-effect" is very conclusive. The experiment may be repeated on the same dog several times with almost mathematical precision, and it has been a source of surprise to us that there should be so little variation in the transitional stages of the phenomena, even in the same dog; but it is quite natural that there should be differences in different dogs. The differences, however, are only in the *length of time* necessary to bring out the phenomena with ether, not in the character of the phenomena themselves. We have devoted eighteen separate dogs to the study of this particular question of the effects of intensity of varying strengths, according to the amount of ether in the animal, and the results on a susceptible dog are identical—namely, dilatation of the glottis is obtained with *all* intensities when the dog is pro-

foundly etherized; but as there is less and less ether in the animal, dilatation is obtained *pari passu* by weaker and weaker stimuli and closure by stronger, until the normal closure is effected by *all* intensities when the dog is very slightly under the influence of the drug.

The "ether-effect" may be represented diagrammatically as follows:



The converging lines on the left represent the amount of ether, which diminishes from above downward. The diverging lines at the bottom of the diagram, as read from left to right, indicate the increase in the intensity of the irritation. Starting now at the bottom of the diagram with a very small amount of ether, the two parallel lines close together indicate a closure of the glottis with all intensities. Going a trifle higher, we find with a larger amount of ether dilatation takes place with weak stimuli, which changes into the mixed movement as the intensity of irritation is increased and finally closure supervenes. The same general effect noted directly above is observed with a larger amount of ether, only the dilatation and the mixed movement do not give way so early to complete closure as the intensity is increased. Finally, with a full amount of ether, dilatation is elicited with all intensities.

Shortly after our first observations were published (autumn of 1885 and spring of 1886) Mr. J. W. Perkins, interne at the Children's Hospital, Boston, and Dr. F. W. Ellis undertook a series of

investigations on the sciatic nerve of the frog in order to decide whether similar peripheral "ether-effects" could be elicited from this nerve, which, like the recurrent laryngeal, supplies groups of antagonistic muscles. The results of these observers have been embodied in a paper by Professor Bowditch, entitled "The Action of Sulphuric Ether on the Peripheral Nervous System," which may be found in the "American Journal of the Medical Sciences" for April, 1887. We must refer those interested in this question to the original paper for the details of the results of the experiments, for we shall quote here only such portions as are of importance in connection with our present study of the recurrent nerves, and which led to fresh experiments on our part. Perkins and Ellis found that stimulation of the sciatic nerve of the frog, treated by various methods with ether, produced opposite effects from those without ether. It was determined also that similar to the experiments on the recurrent nerve, the "ether-effect" was at the periphery, and from a study of the question, whether it was upon the nerve-trunks, the nerve terminations, or the muscular fibers, Professor Bowditch concludes that, as far as the sciatic nerve of the frog is concerned, the "ether-effect" is a phenomenon dependent upon the action of the drug upon the nerve-trunk, and that it exercises an elective and paralyzing action upon certain of the nerve-fibers. This explanation, however, of the "ether-effect" being a partial paralysis of the nerve-fibers, although justified from the studies on the sciatic nerve of the frog, is not applicable to the action of the drug on the recurrent nerves of the dog. Perkins and Ellis observed the "ether-effect" in the frog by applying the drug locally to the sciatic nerve. We determined, therefore, to pursue the same line of research in the dog. For this purpose chloralized dogs were used. Now, if the cause of the "ether-effect" resided in the nerve-fibers themselves, we might expect to obtain a dilatation of the glottis by subjecting the trunk of the recurrent to the local action of the drug. This procedure was accomplished by attaching a gutter to the shielded electrode, into which a solution of ether could be dropped directly on to the nerve-trunk, the effects on the glottis being watched through the mouth while stimulations were applied to the nerve below the point where the ether was working its local action. We have tested this local effect of ether on seven dogs without being able in a single experiment to obtain a dilatation. A six-per-cent. solution of ether was generally used. This was found to gradually paralyze the nerve in from two to six minutes, according to the dog. It was observed also

that when a nerve had become paralyzed in this manner and was afterward washed with a half-per-cent. solution of salt, the vocal band would in a few minutes regain its mobility. The shortest time that it took the vocal band to recover its motion was seven minutes and the longest twenty-two minutes. The only result of the stimulations of the recurrent nerve in chloralized dogs which had been subjected to the local action of ether was that, as the nerve became more and more paralyzed, it required a stronger and stronger stimulus to cause a contraction of the corresponding vocal band. Abduction was never obtained. We will describe one experiment in detail to show the different steps in the operations.

TABLE IV.

Time, A.M.	Intensity of irritation.	Results.	Remarks.
10.43....	2½	Contraction.	6% solution of ether applied locally to right recurrent nerve.
10.44....	2½	"	
10.45½...	2½	Contraction less vigorous; right vocal band paralyzed.	
10.46....	2½	Contraction feeble.	Necessary to increase intensity of stimulation.
10.47....	5½–7	Vibration, contraction.	
10.48....	5½–8	" "	
10.49....	7½–10	" "	
10.50....	9½–13	" "	
10.51....	10–15	" "	
10.52....	10–15	" "	More chloral given.
10.58....	12–18	" "	More ether on nerve.
11.01½...	12–20	" "	
11.03....	13–20	" "	
11.05....	15–25	" "	Contractions very feeble indeed; electrode changed to left recurrent; right recurrent washed with salt solution.
11.12....	....		Right vocal band has recovered its respiratory movements.
11.12½...	0·7–1	Vibration, contraction.	Stimulation of left recurrent; more chloral given.
11.18....	....		Ether locally on left recurrent.
11.18½...	0·7–1	Vibration, contraction.	
11.19½...	0·7–1	" "	
11.22....	7½–9	Vibration, contraction; left vocal band paralyzed.	
11.23....	7½–9	Vibration, contraction.	
11.24½...	7½–10	" "	More ether on nerve.
11.31....	9–12	" "	
11.34....	9–13	" "	More ether on nerve.
11.39....	10–15	" "	
11.40....	10–15	" "	Contractions very feeble.

January 27, 1887.—Collie dog, six months old. Ether was first administered. It was ascertained that the dog was most susceptible to the drug, and complete dilatation was obtained. The ether was now removed. The femoral vein was exposed and a cannula tied into it. Through this a twenty-five per cent. solution of chloral was slowly injected until the animal was thoroughly under its influence. The feeblest stimulus was then determined, which would produce a contraction of the glottis. This proved to be I = 2½ for the right side and I = 1 for the left; anything weaker caused merely a vibratory movement of the vocal bands. The results were as shown in Table IV.

It will be seen by this table that there was a slight difference in the behavior of the two nerves. Although the excessively weak stimulus of 2½ (which was so feeble that it could not be perceived by placing the wires on the end of one's tongue) called forth a contraction of the right vocal band, the left responded to a still weaker current. We have not infrequently noticed a difference in this respect between the two nerves, and presume the condition of the electrodes or some slight accident in the preparation of the nerves, or the completeness with which they were freed from the connective tissue surrounding them, may account for it. But the general results were identical. Each nerve became paralyzed in from two and a half to four minutes, and, as the paralysis was more complete, it needed a more powerful stimulus to produce contraction. As before mentioned, not a trace of dilatation could be obtained. In order to show how different dogs may be affected as regards the details, though in the main the results agree perfectly, we will add here another experiment:

January 20, 1887.—Rough-haired mongrel dog, about nine months of age. Not very susceptible to ether, as the mixed movement only could be obtained. Dog chloralized.

In this dog the right vocal band became paralyzed in six minutes, and did not respond to any stimulus short of the very powerful one of 150. It regained its mobility in twenty-two minutes, and after this it responded as before (not included in the table) to weak stimuli. It will be understood that the differences are only in time and in the strength of the irritation necessary to produce the salient points in these experiments. The results were very constant and show, we think, that the cause of the "ether-effect" in dogs need not be sought in the nerve-trunks.

TABLE V.

Time, A.M.	Intensity of irritation.	Results.	Remarks.
11.07....	2–3	Vibration, contraction.	6% solution locally on right nerve.
11.09½...	2–3	" "	
11.13....	150	Right nerve paralyzed, and only responds to this very powerful irritation.	
11.16....	....		Right nerve washed with salt solution.
11.23....	....		Electrode changed to left recurrent.
11.27....	3	Contraction.	6% ether locally on left recurrent.
11.28½...	3	"	
11.29½...	3	C'ntract'ns less mark'd; vocal band becoming paralyzed.	
11.30½...	....		Left nerve paralyzed.
11.31....	80	Slight contraction.	
11.33....	80–150	Vibration, slight contraction.	
11.35....	....		Respiratory movements of right vocal band just reappeared.

We have also tested the local effect of ether on the nerve-trunk when the animal was under the constitutional influence of the drug. The only noticeable effect under these circumstances was that as the nerve became paralyzed it required a stronger and stronger stimulus to produce the dilatation.

We endeavored to determine the relative strength and endurance of the dilating and closing nerve-fibers by a series of "exhaustion" experiments conducted by applying a continuous stimulation to the recurrent trunks of dogs when the animals were under the influence of different drugs with the view of converting, if possible, the dilatation of ether into a closure by exhaustion of the abductor fibers, or changing the contraction of chloral into dilatation by exhaustion of the closing fibers. Our researches in this direction showed that it was not possible to produce a change of this sort as a result of fatigue. In no instance was dilatation changed into closure or closure into dilatation by long-continued irritation of the nerves. Continuous stimulation was kept up in different experiments for from ten to thirty minutes without altering the first effect. When the animal was kept in the same stage of etherization, dilatation lasted as long as the stimulation was maintained, while in chloralized dogs the normal closure showed no signs of weakening. In these observations

the animals were tracheotomized and the weakest intensity used that was capable of causing a well-marked effect upon the glottis.

We must here leave this subject of the action of sulphuric ether upon the laryngeal muscles of dogs with the regret that we have no explanation to offer why the glottis should dilate under its influence and contract without it. We are inclined to doubt if much light will be thrown upon the cause of the phenomenon by experimental studies on the nerve-trunks themselves such as we have instituted. The secret resides more likely in some histological or chemical difference between the opening and closing muscles of the glottis, and researches in this direction may, we trust, furnish the explanation.

In coming now to our experiments on the cat, we shall find that the normal action of its recurrent nerves is to produce an opening of the glottis instead of a closure, as in the dog. We are at a loss to account for this difference in these two animals of allied genera. Of the animals we have used for experimental purposes—namely, dogs, cats, pigs, and the horse—the cat is the only one in which dilatation of the glottis is the rule under what may be called normal conditions. We can not speak, therefore, of the "ether-effect" in the cat, since abduction takes place equally well under chloral, chloroform, morphine, or ether.

The cat may be arranged for observation in a manner similar to that we have employed for dogs. The larynx of the cat is of a much more delicate pattern than the dog's, and the vocal bands are longer and more flexible in proportion to the size of the animal.

In the living cat dilatation of the glottis is the rule, when its recurrent or pneumogastric nerves are stimulated, or their peripheral ends after section. The mixed movement, however, is sometimes observed, oftentimes at the end of an experiment, when at the beginning no contraction of either the internal or lateral muscles could be detected. But after the cat is dead the effects change. The abductions grow gradually more feeble, while the closure of the ligamentous portion of the glottis becomes more marked, until finally closure only is elicited. This difference between the action of the recurrent nerves on the glottis in the living and dead cat suggested that the condition of the blood might play a part in the phenomena, and we consequently tried the effect of asphyxiating the animal in order to see if we could bring about a closure by the deprivation of oxygen. For this purpose the cat was tracheotomized and allowed to breathe into a small rubber bag attached by a short piece of tubing to the tracheal cannula. As asphyxia was being produced the recur-

rents were stimulated from time to time, but dilatation was invariably called forth even when the cyanosis was extreme and after the respirations had ceased. In our experience with the living cat we have been able to produce a contraction of the vocal band by but one method, and that reflexly through the pneumogastric nerve. By dividing one of the pneumogastrics about the middle of the neck and stimulating the cut end nearest the brain (care being taken not to include the sympathetic), stoppage of the respiration will occur and the vocal band of the opposite side will come to a standstill in the position of expiration; on increasing the intensity of the irritation a decided contraction of the vocal band will take place, it coming in contact sometimes with its fellow. The results of our observations, which have been made on twelve cats, were quite constant, the differences being not in the character of the phenomena, but, as in all experiments on different larynges, in the extent or degree to which the effects are manifested. We subjoin the details of specimen experiments:

February 17, 1887.—Male cat. Etherized; secured on its back with mouth held open; glottis observed through the mouth; pneumogastric and recurrent nerves laid bare; irritation of the trunks of both nerves with stimuli of varying strengths produced dilatation of the glottis; same effect followed stimulation of the peripheral ends of pneumogastrics and recurrents after section.

Solution of chloral injected into external jugular vein; stimulation of peripheral cut ends of both recurrents with all intensities produced dilatation.

February 20, 1887.—Male cat. Chloroform first given, afterward chloral. Experiments of February 17th repeated with like results. Left vocal band became paralyzed from some unknown cause. In twenty minutes it began to regain its mobility, the left recurrent meanwhile having been washed with a half-per-cent. salt solution; medulla destroyed; stimulation of cut recurrents immediately afterward gave dilatation.

February 22, 1887.—Male cat. Tracheotomized; ether given through tracheal cannula; stimulation of uncut pneumogastrics and recurrents followed by dilatation; left pneumogastric cut; stimulation of its central end causes a contraction of the right vocal band. Toward the end of the experiments on this animal it was noticed that complete dilatation had given place to the "mixed" movement, there being well-marked contraction of the anterior portions of the vocal bands.

February 24, 1887.—Female cat. Chloroform, later chloral; stimulation of uncut pneumogastrics and recurrents as in previous experiments; mixed movement was observed to follow dilatation after the nerves had been irritated many times; left pneumogastric cut; irritation of its central end produced stoppage of the respiration, the vocal band on the opposite side (the right) coming to a standstill in the median line.

This cat died suddenly without apparent cause; immediately after death, stimulation of the recurrents produced the mixed movement as before; the abductions, however, soon grew very feeble, and in twenty minutes were no longer elicited by stimulating the nerves, while the contractions were still noticed, though less vigorous.

February 27, 1887.—Male cat. Killed at 10.45 A. M.; a few moments later dilatation was called forth by feeble stimuli applied to the pneumogastric and recurrent nerves; the recurrent nerves were now stimulated alternately. At 10.55 irritation of the left recurrent with weak currents produced the mixed movement, which was replaced by complete contraction on increasing the intensity of the stimulus. After this no sign of abduction could be detected, and by 11.15 the contractions had also ceased to be manifested even by the strongest irritations. Stimulation of the right recurrent at 11 produced abduction, which changed into the mixed movement on increasing the intensity of the stimulus. At 11.10 abduction had disappeared; feeble irritation caused slight contraction, which became very marked as the intensity was increased. At 11.20 only very powerful stimuli (100 to 150) produced feebie contraction as the nerve was practically exhausted. The closure after death is more marked in some cats than in others, but the difference from the dilatation during life, with one exception, has been very striking.

This one exception was observed in a cat that had been the subject of one of our asphyxia experiments, and, as the failure to contract occurred on one side only, it may be put down to some accidental cause.

April 15, 1887.—Asphyxia experiment. Female cat. Ether, afterward chloral; tracheotomized; small rubber bag attached by a piece of tubing to tracheal cannula; asphyxia begun at

10.40 A. M. Stimulation of left recurrent produced abduction of left vocal band.

10.42. Respirations fast and violent; tongue and mucous membrane of mouth becoming blue; abduction.

10.45. Respirations much slower; cyanosis extreme; abduction.

10.46. Respirations have almost ceased; abduction.

10.46½. Respirations have ceased; bag removed; glottis is tightly closed, which, when asphyxia was coming on, was widely open; stimulation of left recurrent, as before, caused dilatation of the left vocal band; in a moment or two the cat's normal respirations recommenced; a few minutes later this experiment was repeated.

10.52. Asphyxia begun; stimulation of left recurrent; abduction.

10.53. Respirations 84 to the minute; abduction.

10.54. Respirations much slower; cyanosis extreme; abduction.

10.55. Respirations have ceased; glottis closed; feeble irritation failed to produce abduction as in the previous experiment; on increasing the intensity a slight opening was observed; artificial respiration was used to resuscitate the animal without success, and the cat may be said to have died at 10.55. We then proceeded to obtain the closure after death, as in previous cats.

10.59. Glottis no longer shut; the vocal bands appear to be a little nearer the median line than the cadaveric position; stimulation of left recurrent gave contraction in anterior portion of vocal band and dilatation of the posterior part (mixed movement).

11.06. The same.

11.09. The same.

11.11. The contraction not so marked; dilatation as before.

11.13. Dilatation; no contraction noticed even on increasing the intensity of the stimulation.

11.16. Feeble dilatation.

11.18. Very feeble dilatation, practically gone.

11.20. Electrode changed to right recurrent; stimulation with feeble and strong stimuli produced contraction; no sign of abduction; the contractions grew gradually feebler, but were elicited for twenty minutes, when the nerve became completely exhausted.

April 17th.—Large male cat; chloralized; irritation of recurrents produced complete dilatation; tracheotomized and arranged for asphyxiation as in previous experiments.

11.05 A. M. Asphyxia begun; abduction.

11.07. Respirations rapid; cyanosis beginning; abduction.

11.09. Respirations about the same; cyanosis marked; abduction.

11.11. Respirations slow; glottis open; extreme cyanosis; abduction.

11.11½. Respiration has ceased; bag removed; glottis closed; abduction; artificial respiration restored the normal respiratory

movements in a few moments; this experiment was repeated three times on this animal with like results.

EXPERIMENT IV.—Cat breathing naturally; stimulation of recurrents and vagi produce abduction; left vagus and left sympathetic cut; stimulation of central end of vagus stops the respiratory movements, the vocal band of the opposite side (the right) stopping in the expiratory position. On increasing the intensity of the irritation, the contraction of the right vocal band was very marked, the right arytenoid cartilage coming sharply against the left.*

EXPERIMENT XXI.—12.08. Medulla destroyed; stimulation applied alternately to recurrents gave abduction.

12.14. Mixed movement; decided contraction of the anterior portions of the vocal bands, which was not noticeable before death.

12.20. The same.

12.25. Contraction in front; abduction behind very feeble.

12.30. Contraction both sides marked; abduction of right practically gone; of left very feeble.

12.35. Abduction entirely gone; feeble contraction still called forth with strong stimuli.

We may summarize the experimental results of this paper as follows: 1. The recurrent laryngeal nerves are purely motor in their function. 2. Their action upon the glottis differs in different animals. 3. In the dog their normal action is to close, while in the cat they open, the glottis. 4. In the dog, sulphuric ether and huge doses of morphine reverse the normal action of the recurrent nerves; the glottis, under the influence of these drugs, dilates instead of closing on stimulation of the recurrents. 5. The "ether-effect" varies according to the susceptibility of the dog, to the amount of the drug consumed, and to the intensity of the irritation. 6 Under small doses of ether, stimulation produces in dogs two effects upon the glottis, (1) vibration; (2) closure. Under larger doses, according to the intensity of the irritation, four effects may be observed: (1) vibration; (2) complete dilatation; (3) mixed movement; (4) closure. 7. Under very large doses of ether, closure, in certain dogs, can not be obtained with any intensity. 8. Under small doses of chloral, chloroform, and morphine, stimulation of

* Stimulation of the central end of the sympathetic increased the respiratory and heart-movements, and produced a great fluttering of the right vocal band, which was apparently due to the respiratory efforts. The vocal band was forcibly abducted, but did not remain fixed; it kept "fluttering" in and out, but the outward movements were the more pronounced.

the recurrent nerves of dogs is followed by the same results as under small doses of ether, namely: (1) vibration; (2) closure. 9. The mixed movement is occasionally seen in dogs when narcotics other than ether are given in large doses. 10. In the cat death reverses the normal action of the recurrent nerves. In from five to twenty minutes after death, stimulation causes a contraction of the glottis, while in the living cat dilatation is produced.