

VI. *Experiments on the Nerves, particularly on their Reproduction; and on the Spinal Marrow of living Animals.* By William Cruikshank, Esq. Communicated by the late John Hunter, Esq. F. R. S.

Read June 13, 1776.

THE nerves on which these experiments were made are, the par vagum, and intercostal. The par vagum arise from the basis of the brain, pass through the basis of the skull, along with the internal jugular veins. They are distributed to the tongue, œsophagus, larynx, heart, and lungs; and, running on each side of the œsophagus, may be said to terminate in the stomach, liver, and semilunar ganglion of the intercostals, below the diaphragm; from whence they are again distributed to the viscera of the abdomen. The intercostals also arise from the basis of the brain, pass through the basis of the skull, along with the carotid arteries. They at first run by the fore part of the vertebræ of the neck, still adhering to the coats of these arteries; but having reached the chest, they leave these arteries, and run before the heads of the ribs, where, sending off branches which pass between the ribs, they have thence been named intercostals. Several of these branches uniting, form a trunk on each side, which, running forwards towards the middle of the spine, perforates the diaphragm, and then terminates in the semilunar ganglion of the intercostals. These trunks are distinguished by the name of the anterior intercos-

MDCXCXV.

A a

tals. The original trunks continue their course by the sides of the lumbar vertebræ; after which, they run before the os sacrum, and, approaching nearer each other as they descend, terminate before the os coccygis, in the ganglion coccygeum impar of WALTHER. Their branches all go to the heart, abdominal viscera, testicles in men, and ovaria and uterus in women. The trunks of these nerves are largest in the neck. In the human species, the two nerves of each side are distinct; but in those quadrupeds which I have examined, they are so closely connected through the whole length of the neck, as to make apparently but one nerve. The intercostal is the smallest nerve, and adheres so closely to the other, as to be with difficulty separated from it. They seem to me, likewise, larger in the dog, compared with his bulk, than in the human subject. The neck was the place in which I chose to divide these nerves; it was there they could be got at with least danger, a circumstance which, by making an experiment more simple, makes it consequently more to be relied on; and, in order to put the animal to as little pain as possible, and make the operations short, I chose to divide both nerves at once, rather than take up time in separating them, and dividing them singly; so that, instead of four operations on each animal, I confined myself to two. Instead of mentioning the names of the gentlemen present at each experiment, I shall observe once for all, that two or more of the following gentlemen were present at each experiment, except experiment VII, which I performed, assisted by Mr. HUNTER'S servant only:—Messrs. BARFORTH, BAYLEY, DAVIDSON, HARTLEY, HAWKINS, HOME, KUHN, NOBLE, PARRY, MARTIN, SHELDON, WHEATLY; besides others, who came in occasionally, during the time of the experiments, or who

afterwards saw the animals, while the described symptoms were taking place.

EXPERIMENT I.

January 24th, 1776, I divided, in a dog, one nerve of the par vagum, with the intercostal, on the right side. The symptoms, consequent to the operation, were heaviness, and slight inflammation of the right eye; breathing with a kind of struggle, as if something stuck in his throat, which he wanted to get up; sullenness, and a disposition to keep quiet: the pulse did not seem much affected, nor had he lost his voice in the least. The unfavourable symptoms did not continue above a day or two; and on the eighth day he was in very high spirits, and seemed perfectly to have recovered.

EXPERIMENT II.

February 3d, I cut out a portion of the two nerves of the opposite side, in the same dog; the piece might be about an inch long. His eyes became instantly red and heavy; his breathing was more difficult than in the former experiment; he was sick, and vomited frequently; the saliva was increased in quantity, and flowed ropy from his mouth; his pulse in the groin was about 160 in a minute; he ate and drank, however, even voraciously at times, and had stools; he never attempted to bark or howl, probably because he did not feel great pain; and yet his attention was not so much disengaged from internal uneasiness, as to be excited with ordinary causes from without; in breathing, the inspirations were slow and deep;

the expirations were attended with repeated jerks of the abdominal muscles, as if he wanted more effectually to expel what air was contained in the lungs. The seventh day after this second operation, he was found dead, at a considerable distance from his bed. In the dead body, every thing seemed in a sound state, except the lungs: these contained little or no air; in consequence of which, they sunk to the bottom in water; they were of a red brown colour, resembling more the substance of a sound liver, than that of inflamed lungs. The inner surface of the trachea and its branches was exceedingly inflamed, and covered with a white fluid, in some places resembling pus, in others ropy, and more of the nature of mucus. The divided nerves of the right side were united by a substance of the same colour as nerve, but not fibrous; and the extremities formed by the division were still distinguished by swellings, rounded in form of ganglions. The same appearance had taken place, with respect to the nerves of the left side; though the divided extremities seemed to have been full two inches apart; the uniting substance was more bloody than that of the other side. This experiment was made, to prove that the original power of action in the thoracic and abdominal viscera was independent of the nerves. As I found the nerves regenerated, a circumstance never hitherto observed, it occurred to me, that it might be objected to the reasoning, that the two first nerves were doing their office, before the two last were divided; to obviate this objection, I made the following experiment.

EXPERIMENT III.

February 19th, I divided, at one operation, the four nerves

composing the first class, in a dog. His eyes became instantly dull and heavy ; he tottered as he walked ; foamed at the mouth ; vomited two or three times ; breathed with excessive difficulty ; his inspirations were long and deep, his expirations short and sudden, but not attended with the repeated jerks of the abdominal muscles as in the last animal ; he barked loud every time he threw out the inspired air from the lungs ; the pulse was quicker than before the operation. Next morning about half after eight, I found him apparently dead ; but on examining more attentively, found he breathed still, though exceedingly slow ; his pulse was gone, and he felt cold ; his limbs were stretched out. On placing him near the fire, he began in a few minutes to breathe distinctly, and the heart now and then gave a pulsation ; in about four hours, he seemed to have got to the same state the operation first left him in, and barked at every expiration, his pulse beating then fifty in a minute. About four in the afternoon he died, having survived the operation twenty-eight hours. The lungs in the dead body were found loaded with blood, but not so much as to carry them to the bottom in water. The trachea was not inflamed. The nerves of the right side, from which a portion had been cut out, seemed to have undergone little alteration ; they were only a little more vascular than usual, and had the rounded swell where they had been divided. The nerves of the left side, which had retracted but little, and had been only divided, had their extremities covered with a plug of coagulable lymph. I suspected that the reason of the first dog's dying so soon, was, that none of the nerves had yet acquired the power of performing their former offices ; and that, were the operations performed at a greater distance of time, the

animal would recover. With this idea, I was led to repeat my experiments, allowing a greater interval to take place between the first and second.

EXPERIMENT IV.

March 6th, I repeated experiment i. on a large dog. His eye on the right side seemed instantly affected, looked dull and inflamed; he coughed and breathed with some difficulty; the secretions from the salivary glands were much increased; he had tremors; these, however, I attributed partly to fear, as on caressing him they disappeared. He ate and drank very well, and had stools. Most of these symptoms continued but a few days, the eye becoming more clear, and the difficulty of breathing hardly perceptible; he vomited, but only after eating, a circumstance which often takes place in dogs in perfect health, from devouring their food too greedily. Thus he continued for three weeks; the external wound had healed, almost by the first intention; he ate greedily, and had perfectly recovered: I supposed the regenerated nerves might now be performing their offices.

EXPERIMENT V.

March 27th, I repeated experiment ii. on the same dog, but did not remove quite so much of the nerves. He was stupid for a minute or two, and gaped for breath; but in a few minutes more these symptoms went off; in a quarter of an hour after he ate some boiled meat, with his usual avidity; all the symptoms of the preceding operation again took place,

and in the same order. The vomiting and difficulty of breathing were rather more considerable; he ate and drank notwithstanding, and had stools. The convulsive jerks of the abdominal muscles, which hardly took place in the last experiment, were observed in this, during expiration, but were not constant, as in the first dog. On the 15th of April he was nearly as well as before the operations, only he was leaner, and perhaps weaker, from the confinement, as well as from the operations. I wished to see the state of the nerves; an artery was opened in the groin, and the animal expired in a few seconds. In examining the dead body, the viscera were all, to appearance, sound. The divided nerves of the right side were firmly united; having their extremities covered with a kind of callous substance; the regenerating nerve, like bone in the same situation, converting the whole of the surrounding extravasated blood into its own substance. The nerves of the left side were also perfectly united; but the quantity of extravasated blood having been less, the regenerated nerves were smaller than the original; I observed too, that they did not seem fibrous like original nerves, but the recollection that the callus of bone is dissimilar to the original bone, quieted whatever doubts could arise from this circumstance. The tonsils were considerably inflamed, and this circumstance alone might be sufficient to account for the increased secretion of the saliva, an attendant symptom of most sore throats; though I have also seen an increase of viscid saliva, in the human species, from hypochondriac affections of the digestive powers, and also from the causes of temporary debility. The regeneration of the nerves which took place in the first dog, and which I

think fully proved by this experiment, was a circumstance to me, then, unexpected and unthought of.

EXPERIMENT VI.

April 19th, I divided the spinal marrow of a dog, between the last vertebra of the neck and first of the back. The muscles of the trunk of the body, but particularly those of the hind legs, appeared instantly relaxed; the legs continued supple, like those of an animal killed by electricity. The heart, on performing the operation, ceased for a stroke or two, then went on slow and full, and in about a quarter of an hour after, the pulse was 160 in a minute. Respiration was performed by means of the diaphragm only, which acted very strongly for some hours. The operation was performed about a quarter of an hour before twelve at noon; about four in the afternoon the pulse was ninety only in a minute, and the heat of the body exceedingly abated, the diaphragm acting strongly, but irregularly. About seven in the evening, the pulse was not above twenty in a minute, the diaphragm acting strongly, but in repeated jerks. Between twelve at night and one in the morning, the dog was still alive; respiration was very slow, but the diaphragm still acted with considerable force. Early in the morning he was found dead. This operation I performed from the suggestion of Mr. HUNTER: he had observed in the human subject, that when the neck was broke at the lower part, (in which cases the spinal marrow is torn through), the patient lived for some days, breathing by the diaphragm. This experiment showed, that dividing the spinal marrow at this place

on the neck, if below the origin of the phrenic nerves, would not, for many hours after, destroy the animal ; it was preparatory to the following experiment.

EXPERIMENT VII.

April 26th, I divided all the nerves of the first class, in a dog. The principal symptoms of experiment III. took place. Soon after, I performed on the same animal the operation of experiment VI. ; the symptoms peculiar to this operation also took place, whilst those peculiar to experiment III. disappeared. His respirations were five in a minute, and more regular than in experiment III. ; the pulse beat 80 in a minute. Five minutes after, I found the pulse 120 in a minute, respiration unaltered ; at the end of ten minutes the pulse had again sunk to 80 in a minute, respiration as before. At the end of fifteen minutes, the pulse was again 120, respiration not altered. The operation was performed about two in the afternoon, at Mr. HUNTER'S, in Jermyn-street. At three quarters of an hour after five, the respirations were increased to fifteen in a minute ; the pulse beating 80 in the same time, and very regularly ; the breathing seemed so free, that he had the appearance of a dog asleep. At a quarter before eight, the pulse beat 80, respirations being ten in a minute. At three quarters of an hour after ten, respiration was eight in a minute, the pulse beating 60. The animal heat was exceedingly abated : I applied heat to the chest, he breathed stronger, and raised his head a little, as if awaking from sleep. At half after twelve, Mr. HUNTER saw him ; the breathing was strong, and twelve in a minute, the heart beating forty-eight in the

same time, slow, but not feeble. He shut his eyelids when they were touched; shut his mouth on its being opened; he raised his head a little, but as he had not the use of the muscles which fix the chest, he did it with a jerk. Mr. HUNTER saw him again between four and five o'clock in the morning; his respirations were then five in a minute, the heart beating exceeding slow and weak. We suppose he died about six in the morning, having survived the operation sixteen hours. This experiment I made from the suggestion of Mr. HUNTER, with a view to obviate the objections raised against the reasoning drawn from the three first experiments. It was urged, that though by these experiments I had deprived the thoracic and abdominal viscera of their ordinary connection with the brain, yet, as the intercostals communicated with all the spinal nerves, some influence might be derived from the brain in this way. This experiment removed also the spinal nerves, and consequently this objection.

As I found, by the two last experiments, that dividing the spinal marrow in the lower part of the neck did not immediately kill, although instant death was universally known to be the consequence of dividing it in the upper part of the neck, I expressed my surprise to Mr. HUNTER, that the spinal marrow should, according to modern theory, be so irritable in the one place, and so much less so in the other.

He told me, that from the time he first observed, that men who had the spinal marrow destroyed in the lower part of the neck lived some days after it, he had established an opinion, that animals, who had the spinal marrow wounded in the upper part of the neck, did not die from the mere wound; but that in dividing it so high, we destroyed all the nerves of the

muscles of respiration, and reduced the animal to the state of one hanged; whereas in dividing it lower, we still left the phrenic nerves, and allowed the animal to breathe by his diaphragm. If this opinion be well founded, though dividing the spinal marrow in the lower part of the neck does not kill instantly, whilst the phrenic nerves are untouched; yet if I divide the phrenic nerves first, and then divide the spinal marrow in the lower part of the neck, the consequence, I said, will be the same, as if I had divided it in the upper part.

EXPERIMENT VIII.

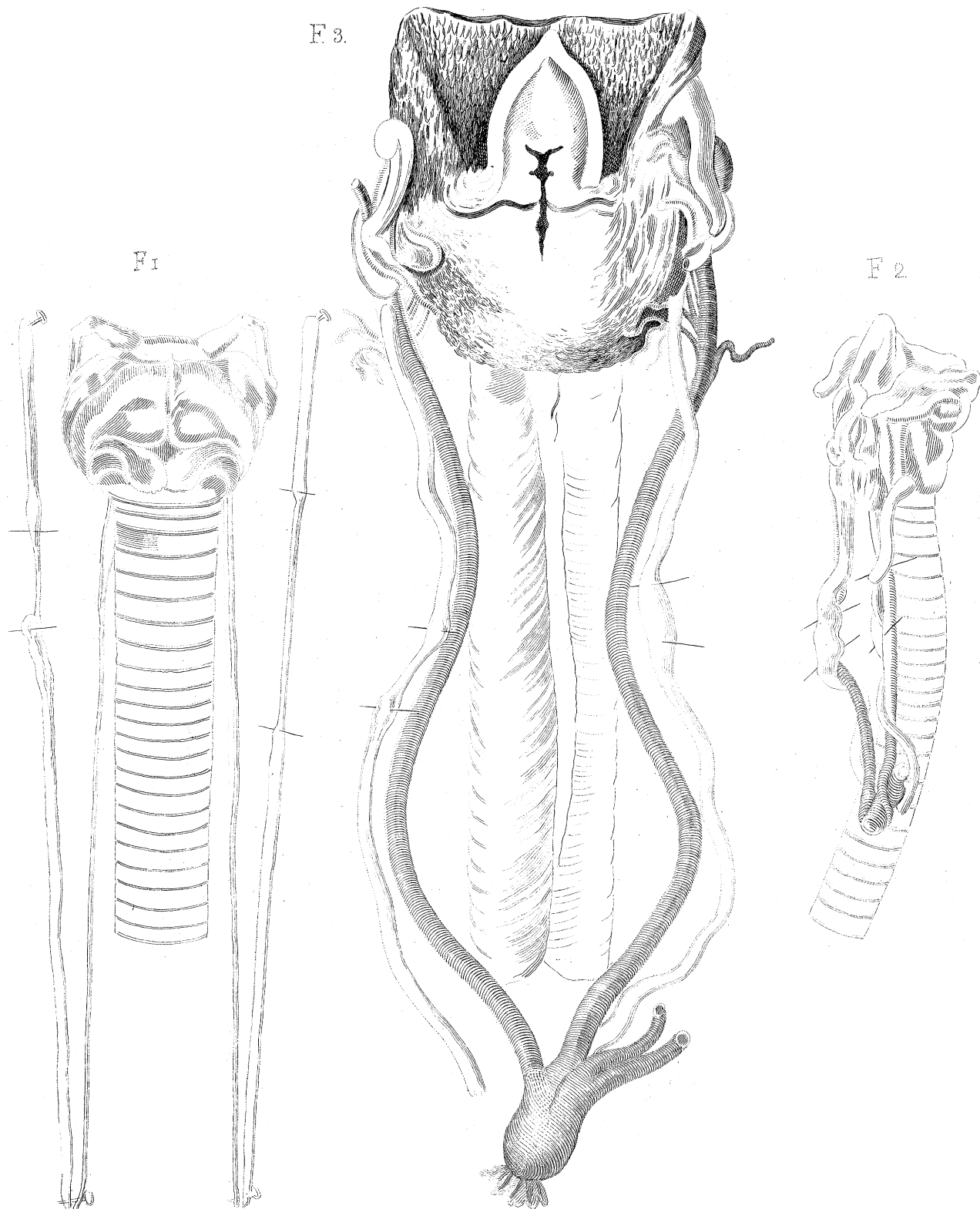
By detaching the scapulæ of a dog from the spine, and partly from the ribs, I got at the axillary plexus of nerves, on both sides, from behind. I separated the arteries and veins from the nerves, and passed a ligature under the nerves, close to the spine. I thought I could discern the phrenic nerves, and instantly divided two considerable nerves going off from each plexus. The action of the diaphragm seemed to cease, and the abdominal muscles became fixed, as if they had been arrested in expiration, the belly appearing contracted. His respirations were now about twenty-five in a minute, the pulse beating a hundred and twenty. As I was not willing to trust the experiment to the possibility of having divided only one of the phrenics (which I afterwards found was really the case), and some different nerve instead of the other, after carefully attending to the present symptoms, I divided all the nerves of the axillary plexus, of each side. The ribs were now more elevated in inspiration than before; respirations were increased to forty in a minute; the pulse still beating

a hundred and twenty in the same time. Finding that respiration went on very easily without the diaphragm, in about a quarter of an hour after dividing the axillary plexus of each side, I divided the spinal marrow, as in experiment vi. The whole animal took the alarm, all the flexor muscles of the body seemed to contract, and instantly to relax again; he died as suddenly, as if the spinal marrow had been divided in the upper part of the neck. I then opened the chest, and found the heart had ceased its motion; I immediately introduced a large blowpipe into the trachea, below the cricoid cartilage, and inflating the lungs, imitated respiration. The heart began to move again, and in about three minutes was beating seventy in a minute. I recollected that there was still a communication between the brain, and the thoracic and abdominal viscera, that the par vagum and intercostals were entire, and turning to the carotids, divided the nerves. I then went on inflating the lungs as before; the heart, which had stopped, began to move again, beat seventy in a minute, and continued so for near half an hour after the animal had seemingly expired. These appearances were not confined to the neighbourhood of the heart; one of the gentlemen who assisted me, cried out once, that he felt the pulse in the groin. I now ceased to inflate the lungs, and presuming that I could easily reproduce the heart's action, allowed three minutes to elapse. On returning to inflate the lungs, I found the heart had now lost all power of moving; and that irritating the external surface with the point of a knife, did not produce the smallest vibration. I then irritated the phrenic nerves with the point of a knife; the diaphragm contracted strongly as often as the nerves were irritated. I irritated the stomach

F 3.

F 1.

F 2.



and intestines, which also renewed their peristaltic motions. I then irritated the par vagum and intercostals, about an inch above the lower cervical ganglion of the intercostal; the œsophagus contracted strongly through its whole length, but the heart continued perfectly motionless. On dissection, I found a small branch of a nerve, running down from the second cervical to join the phrenic of the right side, but too insignificant to have any effect on the experiment. This experiment confirms those made by Mr. HUNTER, in which he recovered the animals by inflating the lungs, and on which his method of recovering apparently drowned people principally rests. It shews that respiration is the prime mover of the machine, and it takes off whatever objections might have been raised, from the animals, upon which he made his experiments, having the connection with the brain entire (as the par vagum and intercostals were not divided), since here the same thing took place in these experiments where nerves could have no effect.

If, in the opinion of the judicious, these experiments have a tendency to be useful to mankind, the author will forgive those censures, which unphilosophic severity may throw on him, whilst it views, only, some unavoidable circumstances attending the performance of them.

EXPLANATION OF THE PLATE (Tab. XVI.)

Fig. 1. shows the trachea, par vagum, and intercostals of the subject of experiments I. and II; the transverse bristles show the quantity of nerve lost by excision, and of course the quantity gained by regeneration.

Fig. 2. shows the same parts in the subject of experiment III:

The bristles point out the mode of reunion of the divided nerves by coagulated blood.

Fig. 3. shows both the complete reunion of the nerve after division, and its regeneration after the loss of substance, in the subject of experiments IV. and V.