XXIV. *Some additional experiments and observations on the relation which subsists between the nervous and sanguiferous systems.* *By* A. P. Wilson Philip, *Physician in Worcester. Communicated by* T. Andrew Knight, *Esq. F. R. S.*

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In a paper which I had the honour to lay before the Royal Society, I observed that M. le Gallois founds his explanation of many of the phenomena which he describes in his Treatise, *Sur la Principe de la Vie*, &c. on the supposition that the circulation nearly ceases in any part when that portion of the spinal marrow from which it receives its nerves is destroyed. The accuracy of this supposition many circumstances led me to question. It is easy to subject it to the test of experiment.

Exp. 1. The spinal marrow of a frog was destroyed by moving, in various directions, a wire introduced into the spine by a hole made in the lowest part of it, and passed up into the brain. The animal was immediately deprived of sensibility and voluntary motion, and appeared to be quite dead. After it had lain in this state for several minutes, part of the web of one of the hind legs being brought into the field of a microscope, the blood was seen circulating in it as rapidly as in the web of a healthy frog. In making such experiments it is necessary to be aware, that handling and stretching the web tends to impair the vigour of the circulation in it. If this experiment is objected to on account of its being made on

an animal of cold blood, I may refer to the seventh and eighth experiments related in the paper above alluded to, in which the carotid and femoral arteries were found beating and performing the circulation after the spinal marrow had been wholly destroyed.

The labours of M. LE GALLOIS, by ascertaining some facts of great importance, while others immediately connected with them escaped his observation, have involved the subject in such seeming contradictions as, at first view, to have persuaded me that some of his experiments were inaccurate. On repeating many of them, however, I was convinced of their accuracy. In some the destruction of the cervical part of the spinal marrow immediately destroyed the function of the heart; yet in others the destruction, in a different way, of the same, or a larger portion of the spinal marrow, little affected it. In some, the greater part of the spinal marrow was destroyed without destroying the function of the heart; yet in others, after the spinal marrow had been divided, he found the function of the heart destroyed by the destruction of either half.

It was the confusion arising from these, and similar difficulties, that occasioned him to observe that he had almost as many results as experiments, and that he had resolved to abandon the investigation, when his explanation of the first of the foregoing difficulties, founded on the supposition which suggested the above experiment, presented itself to him. Had it occurred to him to compare this supposition with the latter difficulty, he would have doubted its accuracy.

The seeming contradictions which appear in the experiments of M. LE GALLOIS cannot be reconciled, except on prin-

ciples different from those hitherto assumed by physiologists. What these principles are, I have endeavoured to ascertain in the paper just mentioned. One part of the subject I left untouched, as it seemed at first sight to open too extensive a field of enquiry. It was evident in making the experiments related in that paper, that the laws which regulate the effects of stimuli applied to the brain and spinal marrow on the muscles of voluntary, and on those of involuntary motion, are very different. The following experiments point out more precisely in what this difference consists.

Exp. 2. Part of the cranium of a rabbit was removed, and a wire passed in various directions through the brain. I could not in this way in the least affect the muscles of voluntary motion, except when I made the wire approach those parts of the brain from which the spinal marrow and nerves originate. The muscles of voluntary motion were then thrown into violent spasms. I sliced off the whole of the upper and anterior part of the brain without affecting the muscles of voluntary motion. The knife only excited their action when it approached the source of the nerves.

Having deprived another rabbit of sensibility and voluntary motion by a blow on the occiput, that I might be enabled to judge of the effects which a stimulus applied to the brain would produce on the heart, I removed part of the cranium and laid open the thorax. The heart was found beating regularly. By passing a wire through the brain in any direction, the beats of the heart were accelerated and rendered stronger. I could not perceive that this effect was produced more powerfully when the wire was directed towards the source of the nerves, than when any other direction was given to it, provided it passed

through an equal portion of the brain. When an instrument was merely pressed gently on the surface of the brain, the effect was similar. When a pair of scissars, or any other thing of larger bulk than the wire was passed into the brain, the effect on the heart was greater than from the wire. It was still greater when the brain was wounded rapidly in many directions.

Exp. 3. Part of the cranium of a rabbit was removed, and after passing a knife through the brain in various directions towards the origin of the nerves, which excited the strongest spasms in the muscles of voluntary motion, the blood being absorbed by a sponge, I applied strong spirit of wine to the surface of the brain, and dropt it into the cuts, without at all affecting the muscles of voluntary motion. The upper part of the brain was then wholly removed, and the space filled with strong spirit of wine, but no spasms were excited in the muscles of voluntary motion.

Another rabbit was deprived of sensibility and voluntary motion by a blow on the occiput. Part of the cranium was then removed, the thorax laid open, and the heart found beating regularly. Spirit of wine was now applied to the surface of the brain, by which the frequency and force of the heart's beats were immediately increased. Several cuts were then made in the brain, and the spirit of wine dropt into them, by which the action of the heart was increased in a much greater degree. Spirit of wine increased the action of the heart more than any mechanical injury, which never produced the strong action in this organ, that it does in the muscles of voluntary motion.

This experiment was repeated with a watery infusion of

opium instead of spirit of wine; the result was in all respects the same, except that the action of the heart was less increased than by the spirit of wine.

Under the term brain, I mean to include the cerebellum as well as cerebrum. From many trials on rabbits made to ascertain the point, I could not perceive that the heart is more or less affected either by chemical or mechanical stimuli applied to the cerebellum than to the cerebrum; nor are the muscles of voluntary motion affected by wounding the cerebellum, except we approach the source of the spinal marrow and nerves. In some of my experiments, I thought that stimuli applied to the cerebellum affected the action of the heart rather more powerfully than when applied to the cerebrum; but this was contradicted by other experiments.

Exp. 4. I repeatedly cut off the head of a rabbit close to the occiput. For some time the trunk and limbs were affected with violent spasms. The cut end of the spinal marrow was so sensible that the slightest touch of a wire, after the spasms had subsided, immediately excited the action of the muscles of voluntary motion. The strongest spirit of wine and watery infusion of opium were applied to it, without producing the least effect on those muscles. The application, however, of stronger chemical stimuli, the nitric and muriatic acids, throw them into powerful contractions.

Having deprived a rabbit of sensation and voluntary motion, in an experiment already laid before the Society, I found that both spirit of wine and a watery infusion of opium applied to the spinal marrow, increase the action of the heart.

Exp. 5. I found both in rabbits and frogs that, after all stimuli applied either to the brain or spinal marrow had ceased to

produce any excitement in the muscles of voluntary motion, both chemical and mechanical stimuli still increased the action of the heart; the former more than the latter.

Exp. 6. I tried, in every possible way, both by mechanical and chemical stimuli, and both before and after the sensibility was destroyed, to excite, through the brain or spinal marrow of rabbits and frogs, any irregular action in the heart which is so readily excited in the muscles of voluntary motion, but could not. Nor could I by sedatives, applied to the nervous system, occasion any irregular action in it. Its action was rendered quicker or slower, more or less frequent, stronger or weaker, but never irregular. The only instance in which irregular action was excited in the heart, was when its power was nearly destroyed by crushing the brain or spinal marrow.

Exp. 7. I found from many trials both on rabbits and frogs, that the excitement of the muscles of voluntary motion took place chiefly at the time the stimulus was applied to the brain or spinal marrow. It was generally necessary to move the instrument; thus applying it to a new surface in order to support the effect. The repeated contractions of the muscles of voluntary motion will sometimes continue, assuming the form of a fit, as long as the instrument remains in the brain, although it be kept as still as the motions of the animal will admit of. The increased action of the heart on the contrary, continued as long as the stimulus, whether chemical or mechanical, was applied, unless it was of a nature to produce the sedative, after the stimulant effect. The sedative effect was so far from being the consequence of the previous excitement, as many physiologists have supposed, that spirit of wine and mechanical stimuli, which produced no sedative

effect, but continued to stimulate the heart as long as they were applied, produced a much greater degree of excitement than tobacco, whose slight stimulant effect was quickly succeeded by a powerfully sedative one.

It appears from these experiments, that chemical stimuli, applied to the nervous system, exert a greater power over the heart than mechanical stimuli, while the latter exert a greater power over the muscles of voluntary motion than chemical stimuli; that both chemical and mechanical stimuli, applied to the nervous system, excite the heart, after they cease to produce any effect on the muscles of voluntary motion; that stimulating every part of the brain and spinal marrow equally affects the action of the heart, while the muscles of voluntary motion are only excited by stimuli applied to those parts of the nervous system from which the spinal marrow and nerves originate; that stimuli applied to the nervous system never excite irregular action of the heart, while nothing can be more irregular than the action they excite in the muscles of voluntary motion; that their effect on these muscles is felt chiefly on their first application, but continues on the heart as long as the stimulus is applied. These differences in the effects of stimuli applied to the nervous system, on the muscles of voluntary and those of involuntary motion, which seem involved in so much obscurity, must be explained before we can be said to understand the relation which subsists between that system and the heart.

In the following part of this paper, I shall, in the first place, endeavour to trace the causes from which these differences arise; and afterwards to ascertain whether the power of the blood-vessels, like that of the heart, is indepen-

dent of the nervous system, and whether they are directly influenced by that system, or only through the medium of the heart.

It appeared to me probable, from many experiments, that the cause of chemical stimuli, applied to the nervous system, producing a greater effect on the heart than mechanical stimuli do, is, that the former from their nature act on a larger portion of the brain and spinal marrow. If this opinion is correct, the mechanical stimulus will be rendered the most powerful by confining the chemical to a smaller space than the mechanical stimulus occupies.

Exp. 8. Both in frogs and rabbits I applied to various parts of the brain and spinal marrow, and particularly to those parts from which the nerves originate, minute portions of strong spirit of wine, without at all influencing the action of the heart. When these small portions were applied to a great many parts, the heart began to beat more frequently. This of course was much the same thing as at once applying the spirit of wine to a larger part. We have seen in the foregoing experiments, that mechanical stimuli applied to any considerable portion of the nervous system, increase the action of the heart. It appears from the following experiments that we cannot affect the heart by mechanical stimuli confined to any small part either of the brain or spinal marrow.

Exp. 9. In a rabbit deprived of sensibility by a blow on the occiput, I wounded different small parts of the brain with a wire, particularly all those parts near which the nerves of the heart appear chiefly to originate; but could not affect the motion of this organ, while at the same time passing the wire

through any considerable portion of the brain immediately accelerated it.

Exp. 10. I laid open the cervical part of the spine of a rabbit, rendered insensible by a blow on the occiput, and repeatedly passed the wire transversely through the spinal marrow, without being able at all to affect the motion of the heart; but on passing the wire longitudinally, so as to bring it in contact with a larger portion of the spinal marrow, I found the motion of the heart immediately accelerated. On the same principle, when the wire was made to wound many minute portions of the brain and spinal marrow in quick succession, the action of the heart was increased. In another rabbit, I divided the spinal marrow at the occiput without at all affecting the heart.

Mr. CLIFT, in an account of experiments on the Carp, published in the Philosophical Transactions for this year, observes, that on dividing the spinal marrow at the occiput, the action of the heart was greatly accelerated for a few beats; but he divided the spinal marrow while the animal retained the power of the muscles of voluntary motion, which never fail to be called into action by wounding it, and whose action, by increasing the flow of blood, always accelerates the motion of the heart.*

Thus we see that neither chemical nor mechanical stimuli applied to the nervous system, affect the action of the heart,

* It is particularly satisfactory to me that Mr. CLIFT, on repeating my experiment, in which the spinal marrow was destroyed by a hot wire, found the same result in the carp, which I had done in rabbits and frogs. He did not ascertain whether the circulation continued after the destruction of the spinal marrow, but from this occasioning little or no diminution in the action of the heart, we can have little doubt of the continuance of the circulation.

unless they make their impression on a large part of this system. In the various experiments I have related, every part of the nervous system was stimulated individually, without the action of the heart being influenced, and the stimulus being the same, the force with which it acted on this organ, was always proportioned to the extent of surface to which it was applied. I could not find that it was of any importance what part of the brain was stimulated. Even stimulating the surface alone, either mechanically or chemically, immediately increased the action of the heart. The muscles of voluntary motion, on the contrary, we have seen, are wholly insensible to stimuli applied to the nervous system, except near the origin of the nerves. It is remarkable that while a rabbit perfectly retains its sensibility, and expresses great pain on any of the muscles being wounded, it exhibits no expression of pain whatever from the brain being sliced, until the knife approaches the origin of the nerves or spinal marrow.

Another circumstance, which appears to be of great importance in tracing the cause of the different effects of stimuli applied to the nervous system on the muscles of voluntary and involuntary motion, is, that the heart obeys a much less powerful stimulus than the muscles of voluntary motion do. We have seen that only the most powerful chemical stimulus affects them, while all that were tried readily influenced the action of the heart. Mechanical stimuli which, by bruising and dividing the parts, occasion the greatest possible irritation, are best fitted to excite the muscles of voluntary motion. Chemical stimuli, indeed, from their effects on the heart, we should consider the most powerful. But their greater effect on this organ is readily explained, by the influence of stimuli applied

to the nervous system on the heart, being proportioned to the extent of surface to which they are applied. It is evident that the stimulus can be applied to a greater extent of surface in the fluid than in the solid form. When the effect of the mechanical agent is rendered extreme and general on the nervous system, we find its influence on the heart far greater than that of any chemical agent I tried. From experiments I lately laid before the Society, it appears, that suddenly crushing any considerable part of the nervous system instantly destroys the power of the heart.

The conclusions then at which we arrive, are,—that the heart is excited by all stimuli applied to any considerable part of the nervous system, while the muscles of voluntary motion are only excited by intense stimuli applied to certain small parts of this system.

These facts being ascertained, the other differences observed in the effects of stimuli applied to the nervous system, on the heart and muscles of voluntary motion, are easily explained.

Irregular action of a muscle arises from stimuli acting partially, or at intervals, on its nerves, or on the particular part of the brain or spinal marrow, from which its nerves arise. But partial action of a stimulus on the nervous system, we have just seen, is incapable of exciting the heart, and while the stimulus is applied to any part of the nervous system, as all parts of this system seem equally to influence the heart, it cannot act upon it interruptedly, as an instrument does on the muscles of voluntary motion when it is moved from place to place in the brain. When the instrument is kept still after it is introduced into the brain, the action of the muscles of voluntary motion often ceases; its merely being in contact with the parts

of the nervous system which excite these muscles, not being sufficient to call them into action. It must bruise or lacerate to produce this effect. As the muscles of voluntary motion feel the impressions made on a very small part of the nervous system only, in proportion as this part is small, the impression must be great to affect them; but the heart, which is influenced through all parts of the nervous system, though not very powerfully through any one, feels all the impressions made on this system, provided they are made on a sufficiently extensive portion of it; thus, as long as the instrument remains in the brain, its stimulant effect on the heart continues.

It is true, that although the heart is only influenced by agents applied to a large portion of the brain, we may conceive them so applied as to produce irregular action in it, and we find that certain irritations of the nervous system have this effect. But it is evident, that the heart not being subject to stimuli whose action is confined to a small portion of this system, and being equally affected through all parts of it, must render it much less subject to irregular action; which may be one of the final causes of this organ, whose regular action is of such importance in the animal economy, being made subject to the whole, and not to any one part of the nervous system; and readily accounts for our not being able to produce irregular action in it, in the above experiments.

What has been said also explains why those, who have endeavoured to influence the heart by stimulating its nerves or the parts of the brain from which they seem chiefly to originate, have failed. When indeed the connection of the nerves of the heart is considered, it will be found to derive its nervous influence from every part of the nervous system, and not very

remarkably from any one part, a circumstance which particularly corresponds with the result of the foregoing experiments.

From the same facts we explain, why the heart is stimulated through the nervous system after the power of this system is so far weakened as no longer to convey the effect of the stimulus to the muscles of voluntary motion. As these obey stimuli applied to only one part of the nervous system, if the change in this part is not strong enough to produce the effect, it cannot be assisted by any other. Thus I have found by experiment, that a blow which affects the brain generally, without materially injuring it, produces comparatively little effect on the muscles of voluntary motion, because no one part suffers greatly, but it produces a great effect on the heart, because it feels the sum of all the impressions. The nervous system, therefore, may be so far exhausted as not to admit of the vivid impressions necessary to excite the muscles of voluntary motion, and yet capable of those which influence the heart.

It appears from the foregoing experiments, that the heart is influenced by every part of the nervous system; and in a former paper I pointed out why we have reason to believe that the intestines obey the same laws with the heart, although this cannot be so directly proved. From the situation of the ganglia compared with the whole of the experiments here alluded to, I think we cannot help believing, that their office is to combine the influence of the various parts of the nervous system, from which they receive nerves, and to send off nerves endowed with the combined influence of those parts.

Without some such means, it would be difficult to conceive how any organ should be influenced by every part of the nervous system. We cannot suppose that it receives nerves from every part of this system. Indeed we know, that no organ does so. The following seems to be the state of the question. We see some parts influenced by every part of the nervous system, others only by certain small parts of it. In the latter instances, we see nerves going from these small parts directly to the parts influenced. In the former instances, namely, where it is found that the part is influenced by all parts of the nervous system, we see no nerve going directly from any part of this system to the parts influenced; but we see these parts receiving nerves from ganglia, to which nerves from every part of this system are sent. It is therefore evident from direct experiment, that the nerves issuing from ganglia convey the influence of all the nerves which terminate in them, to the parts to which they send nerves; and consequently that this is one use of the ganglia; nor does there seem any reason to induce us to believe, that they have any other use. Thus it would appear, that the ganglia and nervous filaments connecting them, which have been called the great sympathetic nerve, are, if I may be allowed the expression, a channel of nervous influence flowing from every part of the brain and spinal marrow, from which those organs are supplied, which are subjected to the influence of the whole nervous system; those subjected to any particular part of this system, being supplied directly from that part. This view of the subject is consistent with the observations of anatomists, who remark that the great sympathetic has by no means the character of a nerve. Nothing surely can be

more different than this string of ganglia and a nerve, such as it passes directly from the brain and spinal marrow to the muscles of the trunk or limbs. It may also be worth remarking, that the nerves sent off from ganglia, have a very different appearance from those coming directly from the brain and spinal marrow. *Recherches Physiques sur la vie et la mort, &c. par M. Bichat.*

The question has been much agitated, why the will has no influence over the muscles of involuntary motion. It has been supposed that the ganglia intercept its influence, but we see in the above experiments, that the ganglia do not intercept the influence of either stimuli or sedatives applied to the nervous system. We can be at no loss to account for our want of power over these muscles, when we consider, that in their ordinary action, they obey stimuli over which we have no influence; and that, at all times, we neither see nor are otherwise conscious of their motions, and consequently cannot direct them.

I have endeavoured by the following experiments to ascertain, whether the power of the blood vessels is as independent of the nervous system, as that of the heart; and whether this system possesses over them the same kind of influence, as over the heart.

These experiments were made on the capillaries of the frog, which, from the extent and transparency of the web of its hind feet, and from its great tenacity of life, appeared the best subject for such experiments. It has been questioned, how far inferences drawn from experiments made on cold blooded animals, can be supposed to apply to those of

warm blood. Both FONTANA and Dr. MONRO observe, that in their experiments they found the system of both obeying the same laws. The experiments I have had occasion to lay before the Society, tend to confirm this observation; and I may say the same of all the experiments I have made on both sets of animals. There are certain circumstances in which they evidently differ, in all others they seem to agree. The following experiments ought not to be unnecessarily repeated, and as there is no part of the warm blooded animal on which they could be satisfactorily made except the mesentery, they would be attended with much greater suffering in this, than in the cold blooded animal. Some of them, from the warm blooded animal being less tenacious of life, could not be performed on it.

Exp. 11. A strong ligature was thrown round the neck of a frog, and the head cut off without any loss of blood; much loss of blood immediately destroys the circulation in the extremities. The spinal marrow was then destroyed by a wire. On bringing the web of one of the hind legs before the microscope, the circulation in it was found to be vigorous, and continued so for many minutes. This experiment was repeated with the same result.

It appears from this experiment, that the blood vessels retain their power after the nervous system is wholly destroyed. In order to ascertain, how far the vessels can be stimulated through the nervous system, independently of any action of this system on the heart, it is necessary in the first place to determine, whether the vessels can support the motion of the blood independently of the heart.

Exp. 12. A ligature was thrown round all the vessels

attached to the heart of a frog, and the heart was then cut out. On bringing the web of one of the hind legs into the field of the microscope, the circulation in it was found to be vigorous, and continued so for many minutes; at length gradually becoming more languid.

In endeavouring to proceed farther, I found much difficulty. It was not only necessary, in order to ascertain the effect of stimuli applied to the nervous system on the vessels of the web, to remove the heart, and to lay open the cranium, but also to prevent the voluntary motions of the animal, which continually occurred, and never failed to accelerate the motion of the blood in the web.

Exp. 13. A frog was deprived of sensibility and voluntary motion, by the upper parts of the body being immersed in laudanum; part of the cranium was then removed, after a ligature had been thrown round the neck to prevent loss of blood. The thorax was now opened, and all the vessels attached to the heart included in a ligature. But notwithstanding this experiment was repeatedly performed with the greatest care, the circulation by all these preparatory means was so enfeebled, that although the blood still moved in the web, it was in so irregular and uncertain a way, that I never could arrive at any positive conclusion respecting the effect of the stimulus applied to the brain. After many fruitless attempts, therefore, I abandoned this mode of making the experiment.

Although the action both of the heart and the muscles of voluntary motion so influence the effect of stimuli applied to the brain, on the circulation in the foot, that, without wholly preventing the effect of both, no conclusion can be drawn, it is evident that the action of the latter cannot increase the effect of

sedatives; and the sedative lessening the power of the heart will not affect the result of the experiment, if it be made on the web of the frog. We have just seen, that the total ceasing of the action of the heart, does not for a considerable time affect the circulation in it. The following experiment appears to be decisive of the effect of the sedative, and of the stimulus, as far as this can be decisive, the action of the heart remaining. It is evident that the action of either stimulus or sedative is equally conclusive respecting the direct influence of the nervous system on the blood vessels.

Exp. 14. Part of the cranium of a frog was removed, the web of one of the hind legs brought into the field of the microscope, and the circulation in it observed. The animal was now rendered insensible by the immersion of the other hind leg in laudanum. The insensibility did not in the least affect the circulation in the web before the microscope. Spirit of wine was then applied to the brain with an evident increase of the velocity of the blood in the web. The same effect was produced in a less degree by watery solutions of opium and tobacco. After the tobacco had been applied for about half a minute, the motion of the blood was much less frequent than before its application. On washing off the tobacco the velocity of the blood increased, and was again lessened on applying it. This was repeated several times with the same effects. The following way of performing the experiment, is equally conclusive.

Exp. 15. A frog was rendered nearly insensible by having its back immersed in laudanum. A ligature was then thrown round the neck to prevent loss of blood, part of the cranium

removed, the web of one of the hind legs brought before the microscope, and the circulation in it, which was rapid, observed. A strong infusion of tobacco was then applied to the brain, with the effect of at first rendering the circulation more rapid. In about half a minute it became more languid, and soon stopped altogether. On the infusion of tobacco being washed off, the circulation returned and regained considerable vigour. The tobacco was several times applied to the brain and washed off, with the same effects. I may observe, that when the circulation in the web had almost ceased after the tobacco had been washed off, its velocity was immediately increased on applying spirit of wine to the brain.

Exp. 16. Analogous to what I had occasion to observe respecting the heart, I could never, either by chemical or mechanical agents, excite any irregular action in the blood vessels. Their action was only rendered more or less powerful.

The irregular appearances in the circulation in the web of a frog's foot, mentioned by Dr. THOMPSON, Professor of Military Surgery in the University of Edinburgh, in his Lectures on Inflammation lately published, and which he ascribes to inflammation, may be observed in any case, if the vessels be at all compressed in applying the foot to the microscope; and although they are not compressed, these appearances very generally occur when the circulation begins to fail. The blood will then stop and go on at intervals, and move backwards and forwards in the same vessel. I have often watched the capillaries from the commencement of inflammation to its greatest height, when the part is about wholly to lose its vital power, in the mesentery of a rabbit, the web of a frog's

foot, and the fins of fishes, without perceiving the least tendency to this irregular motion when the part viewed was so applied to the microscope as not to compress any of its vessels.*

The power of the blood vessels, like that of the heart, is capable of being directly destroyed through the medium of the nervous system.

Exp. 17. The web of one of the hind legs of a frog was brought into the field of the microscope, and while Mr. HASTINGS, who was good enough to assist me in this and the 14th experiment, observed the circulation, which was vigorous, I crushed the brain by the blow of a hammer. The vessels of the web instantly lost their power, the circulation ceasing. In a short time the blood again began to move, but with less force. This experiment was repeated with the same result. If the brain is not completely crushed, the blow increases the rapidity of the circulation in the web.

Exp. 18. The spine of a frog was laid open at the lower end, and a wire of nearly the same dimensions with its cavity, forced through it, as in M. LE GALLOIS's experiments. The web of one of the hind legs was then brought into the field of the microscope, and the circulation in it was found to have wholly ceased. In another frog, as we have seen,† the spinal marrow was destroyed by the introduction, in the same way, of a wire much smaller than the cavity of the spine, and by its being moved in various directions. The frog soon appeared

* An account of these experiments is published in the introduction to the second part of my Treatise on Febrile Diseases, and a plate given representing the state of the vessels in the different stages of inflammation.

† See Experiment 1.

to be quite dead, but the circulation in the web was found to be vigorous.

From the foregoing experiments and observations, it appears,

1. That the laws which regulate the effects of stimuli, applied to the nervous system, on the muscles of voluntary and involuntary motion, are different. Exp. 2, 3, 4, 5, 6, 7.

2. That both mechanical and chemical stimuli, applied to any considerable portion of the nervous system, increase the action of the heart. Exp. 2, 3.

3. That neither mechanical nor chemical stimuli applied to the nervous system, excite the muscles of voluntary motion, unless they are applied near to the origin of the nerves and spinal marrow. Exp. 2, 3, 4.

4. That mechanical stimuli applied to the nervous system, are better fitted to excite the muscles of voluntary motion, and chemical stimuli, those of involuntary motion. Exp. 2, 3, 4.

5. That after all stimuli, applied to the nervous system, fail to excite the muscles of voluntary motion, both mechanical and chemical stimuli, so applied, still excite the heart. Exp. 5.

6. That both mechanical and chemical stimuli applied to the nervous system, excite irregular action in the muscles of voluntary motion. Exp. 2, 3, &c.

7. That neither excite irregular action in the heart, nor is its action rendered irregular by sedatives, unless a blow which crushes the brain be regarded as a sedative. Exp. 6.

8. That the excitement of the muscles of voluntary motion takes place chiefly at the moment at which the stimulus is

applied to the nervous system, that of the heart continues as long as the stimulus is applied. Exp. 7.

9. That the muscles of voluntary motion are excited by stimuli applied to very minute parts of the nervous system. Exp. 2, 3, 4.

10. That no stimulus applied to any minute part of the nervous system, can excite the heart. Exp. 8, 9, 10.

11. That the heart obeys a much less powerful stimulus than the muscles of voluntary motion. Exp. 3, 4, &c. and observations after Exp. 10.

12. That the facts expressed in the three last sentences 9, 10, 11, afford an easy explanation of those expressed in the preceding sentences. See the observations after Exp. 10.

13. That the power of the blood vessels, like that of the heart, is independent of the nervous system. Exp. 1, 11.

14. That the blood vessels can support the motion of the blood after the heart is removed. Exp. 12.

15. That the blood vessels are directly influenced through the nervous system in the same way that the heart is. Exp. 14, 15.

16. That analogous to what we observe in the heart, no stimulus or sedative applied to the nervous system, excites irregular action in the blood vessels. Exp. 16.

17. That the power of the blood vessels, like that of the heart, may be destroyed through the nervous system. Exp. 17, 18.

18. That the office of the ganglia is to combine the influence of the various parts of the nervous system, from which

they receive nerves, and to send off nerves endowed with the combined influence of those parts.

19. That the will has no influence over the muscles of involuntary motion, because in their ordinary action they obey stimuli, over which we have no influence, and because at all times we neither see, nor are otherwise conscious of, their motions; and consequently cannot direct them.

20. That we have reason to believe that the division of the encephalon into the cerebrum and cerebellum, relates to the sensorial functions, since it does not appear to relate to the nervous functions, the muscles of voluntary and those of involuntary motion being influenced in the same way by both.

21. That the sedative effect is not the consequence of previous excitement, but the effect of a certain class of agents. Exp. 7.