FURTHER RESEARCHES ON THE VASOMOTOR NERVES OF ORDINARY MUSCLES.

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In a paper published by me in Ludwig's Arbeiten* and in the Journal of Anatomy and Physiology†, I have shown that section of the nerve belonging to any particular muscle or group of muscles causes a great temporary, not permanent, increase in the amount of blood which flows from the muscle vein; further, that stimulation of the peripheral end of the nerve causes, as well as the tetanus of the muscle, a very marked increase of the rate of flow through the muscle; which increase takes place, either after the termination of the tetanus, or (if the stimulation last long enough) even during the tetanus itself.

Both these facts were confirmed and received their explanation in a second research, published in the Journal of Anatomy and Physiology‡, upon the variations of the circulation in the mylohyoid muscle of the frog. By the direct observation of the muscle vessels under the microscope, I came to the conclusion that in the frog and, by inference, in the dog also, this increased flow of blood through the muscle was due to the action of dilator fibres contained in the nerve; that, in fact, when the muscle is made to contract by the direct stimulation of the motor nerves, its arteries are at the same time made to dilate by the direct stimulation of dilator nerves; and that section of the nerve produces its effect, because it removes the tonic action of the central nervous mechanisms, and also because the mechanical act of section constitutes a strong stimulation of these dilator fibres. At the same time I left it doubtful whether dilation of its vessels always accompanies contraction of a muscle, *i.e.* when that contraction is not due to direct stimulation of the nerve, but either to voluntary

* Ludwig's *Arbeiten*, 1876.

† *Journal of Anat. and Physiology*, Vol. XI. p. 360.

‡ *Journal of Anat. and Physiology*, Vol. XI. p. 720.

or reflex action, until the completion of certain experiments upon mammals, which I had then commenced; although my observations upon the circulation in the frog's muscle seemed to point to the conclusion that such was the case, that in fact an increased blood-supply went hand in hand with activity of the muscle, however caused.

Before however I was able to complete a series of experiments to settle this point, a paper by Heidenhain* appeared in Pflüger's Archiv, upon the whole question of the regulation of the muscular vascular system, which to a certain extent was directly contrary to my views, and which therefore necessitated a reconsideration of my former conclusions.

In order to estimate at their true values Heidenhain's results and mine, and if possible to reconcile their apparent discrepancies, it is necessary to bear in mind the essential difference between our two methods of observation. He bases his conclusions upon measurements of temperature in the muscle, so that he assumes that a rise or fall of temperature denotes a dilation or constriction of the muscular blood-vessels. I, on the other hand, measure directly the rate of blood-flow through the muscle, and therefore have to make a much less questionable assumption; viz. that when more blood flows from the vein the vessels are dilated, and when less they are constricted, apart of course from direct mechanical obstruction to the blood-flow.

In this paper then I propose, first of all, to give the results of my further experiments upon the rate of flow through the muscle, and then to compare these with Heidenhain's, and discuss the correspondences and discrepancies between the two sets of experiments, especially with reference to the relations between variations in temperature and variations in blood-flow, as far, that is to say, as I am able to do at present.

First, however, I must say a few words about my method of experimentation. This was essentially the same as in the experiments made at Leipzig. The animals used were dogs, the blood-flow was measured in the same way, with the exception that instead of using ligatures round the femoral vein, in order to alter the direction of the blood-flow either towards the heart or into the cannula, I used two clamps fixed in a holder, by means of which I could clamp the femoral either above or below the orifice of the extensor vein, by the simple process of turning two screw-heads in opposite directions. Each clamp

* Pflüger's *Archiv*, Vol. xvi. p. 1.

was composed of a lower hook which could be slipped underneath the vein, and an upper hook which fitting tightly upon the lower one clamped the vein absolutely when it was screwed down. The whole of each clamp was made of german-silver, and the edges of both upper and lower hooks were perfectly smooth and rounded so as not to injure the vein in the least. The two clamps could be moved as close to each other or as far off as required, so that they were adjustable to any size of dog. The use of these clamps has enabled me to continue any single experiment longer than was possible by the use of ligatures, and at the same time with more accuracy, for the continual tying and untying of thin ligatures soon damaged the coats of the vein to such an extent as to make coagulation occur frequently, and also the process of tying and untying necessitated continual interference with the wound in the thigh. Neither of these objections applies to the use of the clamps; the upper hook compresses the vein against the lower gently and firmly, and the vein opens by the simple withdrawal of the upper hook, so that neither the opening nor the closure of the vein causes any great damage to the condition of the walls or to the position of the vein; and as the screw-heads project beyond the wound, the vein can be opened or shut at pleasure, without any interference whatever with the wound. Of course an apparatus of this sort could not well be used in the case of unanæsthetised animals, and therefore was not suitable to the experiments made at Leipzig; but in the present series this objection falls to the ground, for in every case the animal was under the influence of morphia or chloroform, or both, during the whole course of the experiment, besides being sometimes curarised, sometimes not. Further, in my former paper*, I mentioned that occasionally a valve occurred just below the orifice of the extensor vein, which had then to be broken down; I now find however that this valve is not occasionally present, but is always there, the only difference being that in some dogs it is situated nearer to the extensor vein than in others, and in large dogs such as I made use of at Leipzig, the distance between valve and extensor vein is in most cases sufficient to allow of the insertion of the cannula above the valve, while in small dogs, such as are the rule here, the valve must be broken down before the blood will flow; I therefore in every case took the precaution of tearing down the valve by means of a sharp crochet-hook before inserting the cannula.

* *Loc. cit.*

There is one other precaution that should be mentioned. From Lepine's* and Bernstein's† papers it appears that by cooling down the surface, it is possible to obtain a rise of temperature by operations which would ordinarily give a fall; in order therefore to prevent any action of this sort, I always placed a sheet of wadding loosely over the body and legs of the animal, and so prevented any great cooling of the surface from exposure to the air. In all the experiments then, given in this paper, it is to be understood that the body and legs of the animal were loosely covered with wadding, unless the contrary be expressly stated.

The curves that accompany this paper are either facsimiles of the original curves, or as explained in my former paper are the deduced curves giving the rate of flow for successive five seconds. In every case ten of the divisions on the ordinate correspond to 1 cc. of blood, whatever the scale be; it was impossible to use the same scale for every figure, for either then some of the effects would not have been manifested sufficiently, or some of the figures would have been too large for any reasonably sized page.

In order to confirm the experiments made at Leipzig, I have made a few of the same kind on animals under the influence of morphia and chloroform, with results exactly similar to those given in my former paper. It is not worth while therefore to give these experiments in detail, with the exception perhaps of the effect of section of the nerve; for, as I was not able at Leipzig to obtain many curves of section, confirmation on this point is perhaps advisable.

I. Section of the muscle nerve causes a great increase in the rate of blood-flow through the muscle, which attains its maximum in from 20 to 40 seconds after the section, and which has entirely disappeared in from two to four minutes after the section. This is true whether the animal be anæsthetised or unanæsthetised or curarised.

I give here two examples, in both of which the dog was partially curarised.

15 Feb. 1878. Terrier bitch quite young, weight 7½ kilo. Extensor vein prepared on both sides; ligature placed under left crural nerve. Mor-

* *Mémoire lu à la Société de Biologie*, 4 March, 1876.

† Pflüger's *Archiv*, Vol. xv p. 575.

phia and curare given. Artificial respiration. See Pl. IX. Fig. 1. Sample of rate of flow was now taken, there flowed out in successive 5 seconds

0·65, 0·55, 0·45, 0·45, 0·45, 0·5 cc.

The flow was turned towards heart, cannula washed out, and nerve exposed ready for cutting. Flow again measured, and while the blood was flowing the nerve was cut. At the section the slightest trace of contraction.

nerve cut

0·7, 0·9, | 0·7, 1·4, 3·0, 7·0 ?, 6·9, 6·8?, 5·25, 4·6, 3·525, 2·9, 2·375, 1·875, 1·625, 1·375, 1·2, 1·0, 0·85, 0·75, 0·7, 0·6, 0·5 cc.

The blood now flowed to the heart for 8 minutes, during which the cannula was washed out, without any sign of coagulation, and the end of nerve was ligatured. The rate of flow then gave

0·5, 0·4, 0·35, 0·35 cc. in successive 5 seconds.

31 Jan. 1878. Dog, weight 8 kilo. Morphia and curare. Artificial respiration. Right extensor vein and right crural nerve prepared. See Fig. 2, Pl. IX. Blood-flow turned into cannula gave for successive 5 seconds

0·2, 0·175, 0·15, 0·175, 0·125, 0·15, 0·125, 0·15 cc.

Flow now turned to heart for 2¼ minutes and cannula washed out; then again measured, and nerve cut while blood was flowing. The section caused the slightest trace of contraction.

0·2, 0·2, 0·175, 0·175, 0·15, 0·15, 0·15, 0·1, 0·175, 0·225, 0·1,

nerve cut

0·15, 0·175, 0·075, | 0·275, 0·225, 0·475, 1·35, 3·375, ?, 2·85, 2·1, 1·35, 1·25, 1·05, 0·925, ?, 0·7, 0·55, 0·45, 0·425, 0·375, 0·35, 0·325, 0·275, 0·225, 0·25, 0·175, 0·25, 0·2, 0·25, 0·2 cc.

The flow was now turned towards heart for 21 minutes, and the cannula washed out; more curare was also given.

The rate of flow then gave

0·225, 0·225, 0·225, 0·15, 0·2, 0·2, 0·2, 0·2 cc.

From these two examples, which are typical of the effect of section, it is seen that in each case the maximum of flow is reached very quickly about 20 seconds after the section, that in the one case the rate is then 9 times, in the other 18 times as great as before the section, and that the normal rate is recovered in the one case 1 minute 35 seconds, and in the other 2 minutes after section.

Two objections may possibly be made to these experiments: firstly, it might be asserted that the outflow becomes less and less because the blood tends to coagulate; and secondly, that the amount of blood lost is sufficient to account for the rapid recovery to the normal rate of flow. One reason against the second objection is, that the amount of blood lost is not sufficient to alter the blood-pressure as measured in the carotis; and both objections are shown to be groundless by the fact, that the normal rate of flow returns in the same time after the section,

even when the blood is not permitted to flow from the vein. The following experiment shows this.

April 1, 1878. Bull terrier bitch, weight 9 kilo. Morphia and chloroform. Left extensor vein and left crural nerve prepared. Animal quiet. Sample of flow taken:

0·75, 0·775, 0·7, 0·7 cc. in successive 5 seconds.

Flow turned towards heart, cannula washed out, and the nerve cut, while blood still flowed towards heart. The section caused strong contraction of muscles and violent action of the abdominal expiratory muscles, which lasted only a short time, and then animal remained perfectly quiet. Five minutes after the section, the animal being still quiet, the following was the rate of flow:

0·8, 0·8, 0·775, 0·75, 0·8 cc.

This experiment shows that the difference between the rate of flow before section and 5 minutes after section was so slight, as to fall within the normal variations of the rate of flow, so that in this case, as in all other examples, the normal rate was regained in probably between 2—4 minutes after section, although there was no loss of blood after the section of the nerve.

II. Section of the abdominal sympathetic trunk also causes a temporary, not a permanent, increase of flow from the extensor vein.

Before describing a typical experiment it is necessary to make a few observations upon the method of manipulation. In the first place, as to the anatomy of the abdominal sympathetic in its relations with the crural nerve.

The crural nerve arises with the obturator almost exclusively from the 4th and 5th lumbar roots, the 3rd lumbar supplying only a small branch, and after their exit from the spinal foramina these two branches are joined each by a well-defined sympathetic branch, which springs from the ganglion of the sympathetic trunk lying on the corresponding vertebra. Branches therefore from the 4th and 5th lumbar sympathetic ganglia accompany directly the crural and obturator nerves. For this reason then it is of no use to cut the abdominal sympathetic trunk at the division of the aorta, as in Ostroumoff's and Heidenhain's experiments, but it must be cut much higher up, above the 4th lumbar ganglion; an unfortunate circumstance, as this operation is more difficult than at the division of the aorta.

In the second place, as to the method of making the section. I at first attempted to cut the nerve above the 4th lumbar ganglion by

means of a very fine steel wire after Heidenhain's* method; the steel wire was passed under the nerve, so as to form a loop, and then through a glass tube flattened at its end, and shaped so as not to press on the nerve until the wire was tightened; at a given time the wire was forcibly pulled through the tube, and the nerve thus cut or rather torn through. For reasons which will appear later on, I did not curarise the animal, but gave morphia and chloroform only; and the deep quick respirations, the strong movements of various muscles, showed plainly enough that tearing through the nerve in this manner was by no means equivalent to a simple section, and that therefore it would not be fair to consider the variations in the blood-flow that occurred as the results of the section only.

In order then to cut the nerve more satisfactorily I placed under it a piece of thick gutta-percha, which was held tight against the end of a brass tube by means of ligatures fastened to the tube; to prevent the nerve being pressed upon by the tube, a groove was cut in the end of it, so that the nerve could lie freely on the gutta-percha; inside the tube a knife was made to slide up and down, and so arranged that at any moment it could be pressed down suddenly through the nerve, and into the gutta-percha up to a certain depth. The following experiment gives the result of the use of this instrument. See Fig. 3, Pl. IX.

4 March, 1878. Spaniel bitch, weight 13·75 kilo. Morphia and chloroform. Throughout the animal remained perfectly quiet and unconscious. The cannula was placed in the left extensor vein and a sample of the rate of flow taken. As the figure shows, this varied between 0·7 and 0·85 cc. The abdomen was now opened in the middle line, and the cutting apparatus placed over the nerve; this operation was performed very quickly and without causing any disturbance; the wound in the abdomen was then sewed up and the cannula re-adjusted in the vein, and another sample of rate of flow taken; this was found to vary between 0·7 and 0·9 cc., so that the opening of the abdomen had not in this case caused any variation in the rate of flow. While the blood was still running from the vein, the knife was pressed down and the abdominal sympathetic cut; the animal remained quiet, no movements were caused by the section.

As is seen in the figure, the rate of flow 40 seconds after the section had reached its maximum, and was then 6·75 cc., that is, was 9 times as rapid as before the section. When the blood had run out for 65 seconds after the section, the rate being then 5·3 cc., the flow was turned towards the heart and the cannula washed out.

Three minutes after the section a fresh sample of rate of flow was taken, and it was then found to vary between 0·85 and 0·9 cc., showing that the blood-flow had now regained its former rate.

Upon dissection it was found that the nerve was not quite cut through;

* *Loc. cit.* p. 15.

it was, however, pressed deep into the gutta-percha, and the two pieces were so slightly connected that I have not the least doubt but that the section was an efficient one. The nerve was rightly cut above the fourth lumbar ganglion.

This experiment shows that the section of the abdominal sympathetic causes the same effect as the section of the crural nerve, and that in each case the increase of flow through the muscle is temporary, not permanent, that the maximum increase is reached in from 20 to 40 seconds after the section, and that the whole increase is over and gone in from 2 to 4 minutes after the section.

I consider the above experiment to be the most trustworthy of any similar experiments that I have yet made, because the animal remained quiet the whole time, because the apparatus above described was used to make the section, and because the whole of the necessary operations were done quickly. This last reason, viz., the quickness of the operation, is, it seems to me, an important factor in all experiments upon the abdominal sympathetic; if, for any reason, such as movements of the animal, fulness of the stomach, or a large quantity of fat over the sympathetic trunk, &c., the abdomen has been opened for any length of time, and the intestines &c. have necessarily been considerably disturbed, then, even without a section of the nerve, the blood-flow from the muscle vein is greatly increased; and not only so, but the rate of flow remains much greater than the normal for a considerable length of time, so that it is no longer possible to feel sure how far any increase of flow is due to the section of the nerve, and how far to the manipulation preparatory to that section. The following example is a case in point.

Feb. 25, 1878. Mongrel greyhound, weight 28 kilo. Morphia and chloroform. Left extensor vein used and normal flow taken. The rate of flow was then

5·0, 5·5, ?, 5·3, 4·8, 5·3, ?, 5·0, 4·9, 5·2 cc.

Flow turned to heart, cannula washed out, and another sample of flow taken. The rate was then

4·8, ?, 4·7, 4·6, 4·7 cc.

The abdomen was now opened in the middle line, and a thin wire passed under left sympathetic above fourth lumbar ganglion; although the animal was quiet, the operation was difficult, and lasted some time, owing to the presence over the psoas muscle and the sympathetic trunk of a layer of fat, which bled freely on being cut through. The wire was passed through a glass tube which was held in position over the nerve, but which did not press on the nerve. The abdomen was then sewed up, the cannula in femoral vein readjusted, and the following rate of flow observed; the animal remained quiet, and the flow began about twenty minutes after the steel wire had been placed under the nerve.

11·8, ?, 12·0, ?, ?, 11·0, 11·0, ?, 10·5, ?, 10·8, 10·6, ?, 10·7, ?, 10·5, ?, ?, ?, 9·8, ?, 9·6, ?, 9·2 cc.

The flow was now turned towards the heart for eight minutes, and the cannula washed out. On again allowing the blood to run into measuring tube there flowed out

8·8, ?, 8·8, 8·5, ?, 8·0, 8·0, ?, 8·1, 7·9, ?, ?, 7·3, 7·2, ?, 6·85, 6·65, ?, 6·6, 6·4 cc.

At this moment the nerve was cut by means of the wire, the animal being quiet at the time; the section caused violent respiratory action and movements of all parts of the body, which lasted some time; the continuation of the measurement of flow gave

8·6, ?, 8·95, 8·15, ?, 7·65, 6·95, 6·5, ?, ?, 4·8, 4·2, 3·9, 3·7, ?, 3·85, 3·55, 3·6, 3·3 cc.

This experiment is sufficient to show why it often happens that the rate of flow is decidedly increased some time after the sympathetic has been cut, although this is not the case after the section of the crural nerve; the manipulation alone entailed by the section of the nerve, and the placing of it in tube electrodes, is sufficient to cause a more or less lasting increase of flow; an increase which is very much more permanent than is ever found after section of the crural, or indeed after section of the sympathetic, when that section has been performed under favourable circumstances.

I therefore think that the section of the abdominal sympathetic above the 4th lumbar ganglion causes only a temporary increase of flow similar to what is seen upon the section of the crural nerve, as is shown in Fig. 3; for, in that experiment, the effects of the section only are manifested, the animal remained quiet throughout, the necessary operations were performed quickly and without causing much disturbance, and after the abdomen was sewed up the rate of flow was the same as before.

The effect of section of the crural nerve after the abdominal sympathetic has been cut, I will discuss later on, as it is advisable first to make sure about the action of curare and of central stimulation upon the blood-flow.

III. Stimulation of the peripheral end of the muscle nerve in the dog causes an increase of blood-flow through the muscle because dilator fibres are stimulated; and this increase is absent in the case of the thoroughly curarised animal because the curare paralyses these fibres.

In the case of the non-curarised animal, stimulation of the nerve causes not only a great increase of blood-flow but also a tetanus of the

muscles; and the difficulty of determining the true cause of the increased flow arises from the fact, that one is not able to say with certainty what effect the contraction of the muscles *per se* may have upon the blood-flow through them. Three solutions seem to me possible; 1st, the increased flow may be due to the after effect of the obstruction to the circulation caused by the contracted mass of muscle; for any hindrance to the circulation through an organ is followed by an increased flow of blood through that organ, as Mosso has shown by means of his plethysmograph for the circulation in the fore-arm and through the excised kidney; 2ndly, it may be due to chemical changes set up in the walls of the vessels in consequence of the presence of the products formed by the contraction; and 3rdly, it may be due to direct nervous action on the vessels themselves, *i.e.* to the direct excitation of dilator nerves.

In order somewhat to test the first of these hypotheses I have compared the effect of stopping the flow from the muscles by clamping the femoral vein both above and below the orifice of the extensor vein; of preventing the flow into the muscles by clamping the femoral artery above the exit of the extensor arteries, and of hindering the flow through the muscles by the contraction of the muscles themselves.

Figs. 4, 5 and 6, Pl. IX., give examples of these three operations respectively. In order, however, to show the differences between the three most clearly, I will give as well the numbers from which these figures are taken. Figs. 4 and 5 are taken from the same experiment; the dog was under morphia; and Fig. 4 was obtained directly after Fig. 5, the cannula having been washed out and the flow turned towards the heart for 1 minute after the termination of Fig. 5. In Fig. 6 the crural nerve had been cut, and the effect of the section on the blood-flow measured; then long after the flow had reached the normal rate, 21 minutes after the section, Fig. 6 was obtained.

The numbers represent the rate of flow in cc. every successive 5 seconds.

Effect of clamping the vein for 25 seconds. See Fig. 4.

vein clamped

0·7, 0·625, 0·675 | 0, 0, 0, 0, 0, | 1·725, 0·95, 0·8, 0·675, 0·675, 0·675 cc.

If we take the whole amount of flow from the beginning of the clamping to the time when it was again normal, we find that 4·85 cc. of blood flowed out in 50 seconds, during the first 25 of which the blood was prevented from flowing by the clamping of the vein. During the same time at the normal rate 6·5 cc. of blood would have flowed out.

Effect of clamping the femoral artery for 1 minute. See Fig. 6.

artery clamped

0·775, 0·75, 0·775, 0·8, 0·75, | 0·5, 0·3, 0·275, 0·225, 0·175, 0·225, 0·175, 0·25, 0·175, 0·175, 0·2, | 2·3, 2·35, 2·05, 1·775, 1·4, ?, 1·125, 1·05, 0·9, 0·9, 0·8, 0·75, 0·7 cc.

Therefore, during the two minutes from the beginning of the clamping, *i.e.* up to the time when the normal flow had again been reached, the outflow of blood amounted to 19·0 cc. During the same time the amount at the normal rate would have been 18·6 cc.

Effect of stimulating the nerve so as to cause a strong tetanus lasting four seconds. See Fig. 5.

tetanus

0·875, 0·825, 0·875, 0·85, ?, ?, 0·725, | 0·7 | 4·65, 6·925, 7·95, 5·8, 3·85, 2·75, 1·95, 1·25, 1·0, 0·775 cc.

Neither in the figure nor in these measurements have I given the outspurt which occurred at the beginning of the tetanus, but simply the whole amount of blood which poured out in the 5 seconds during the first 4 of which the muscles were tetanised, *i.e.* 0·7 cc. We see then that during 55 seconds from the beginning of the tetanus, which lasted during the first 4 seconds of this period, the whole amount that poured out was 37·6 cc. During the same period, at the normal rate, only 9·1 cc. would have flowed out.

From these three examples it is seen that the increase of flow due to obstruction is counterbalanced by the diminution of flow during the obstruction, when the flow is hindered by the clamping of the vein or the artery; while, on the other hand, no such relation holds good when the obstruction is caused by the tetanus of the muscles, the increase of flow in this case overbalancing to an enormous extent the diminution during the tetanus. Of course I do not suppose that the circulation in the muscles is absolutely stopped when the femoral artery or vein is clamped; the anastomoses with the vessels of the skin and with the terminations of the profunda artery, &c. are always sufficient to allow a certain amount of collateral circulation; still Fig. 6 shows that the collateral circulation is but small when the femoral artery is clamped, and in fact, the rate of flow obtained in this case during the clamping is no greater than is often seen to occur during a shortly lasting strong tetanus of the muscles. Further, if the tetanus of the muscles in consequence of stimulation of the crural nerve lasts as long as a minute, it is always found that during the last part of the stimulation the rate of flow is very decidedly greater than the rate before the beginning of the stimulation, even though the tetanus has continued in full strength during the whole time; a fact which shows that the clamping of the femoral artery is a more efficient hindrance to the circulation through the muscles, than a tetanus of the same; for, in the example given of the effect of clamping the artery, it is seen that the rate of flow at the end of the clamping, which lasted one minute, was still only $\frac{1}{4}$th of the rate before the artery was clamped.

Again, if the increase of flow were due to obstruction in consequence

of the contraction of the muscles, it seems unlikely that a single contraction should be able to produce any measurable effect; yet upon stimulation of the nerve with a single induction shock, a decided increase of flow was produced after the momentary contraction of the muscles. See Fig. 7, Pl. IX. Clearly then the increase of flow upon stimulation of the crural nerve is not due to the mere effect of obstruction to the circulation caused by the tetanus of the muscles.

It is more difficult to decide between the hypothesis of dilator fibres and that of chemical action due to contraction, but, as I have already said in my former paper, the first of these two seems to me to be preferable, especially as my experiments on the mylohyoid muscle of the frog seem clearly to point to the presence of dilator fibres.

Finally, I consider that in our present state of knowledge the hypothesis of dilator fibres will explain more easily than that of chemical action the fact, that it is possible to obtain a marked increase of flow without any visible contraction of the muscles, if so small a dose of curare be given as just to paralyse all muscular action. It is difficult to be sure of obtaining this effect, for if too large a dose be given, then the increase of flow disappears as well as the contraction of the muscles, and if too small a dose, then, although the increase is manifest, there is at the same time a trace of muscular contraction.

The fact that curare paralyses dilator nerves, while leaving the constrictors intact, is no new one; thus, in the case of the *chorda tympani*, a large enough dose of curare will prevent the stimulation of it producing any effect, although at the same time the sympathetic is still active, and v. Frey* found that a dose of curare just sufficient to prevent muscular contraction, although it did not entirely stop the action of the chorda on the blood-flow in the submaxillary gland, yet greatly diminished that action. Again, Eckhard† says expressly, that stimulation of various parts of the cord produces no erection whatever, as soon as sufficient curare has been given to just paralyse all muscular action, but instead, that there is a diminution of flow from the cut surface of the *corpora cavernosa*, during the stimulation; a case very similar to the one under consideration. It is then no incredible assumption, that in the present case the dilator nerves are paralysed as well as the motor ones.

Before describing the separate experiments it is better to mention the electrical arrangement used for stimulation; at first I made use of

* Ludwig's *Arbeiten*, 1876.

† Eckhard's *Beiträge*, Vol. VII. p. 67.

an ordinary du Bois-Reymond induction coil with the core not taken out, worked by a single Daniell cell, and afterwards the arrangement with tuning-fork and capillary contact, described in Langley's paper in the first number of this Journal. In every experiment, as an indication of the strength of stimulation used, I will give the distance of the secondary from the primary coil in millimetres at which the first sensation of acidity was felt when the electrodes were placed on the tip of the tongue. The electrodes used were either naked platinum ones or Ludwig's electrodes, as used by me in Leipzig, or else ⊥-tube electrodes, as used by Heidenhain and Ostroumoff.

By giving successive small doses of curare and testing the contractility of the muscles at intervals, I have succeeded in various instances in obtaining a decided increase of flow upon stimulation of the crural nerve with strong currents, although at the same time I was unable to see any motion of the muscles, and also there is no sign on the curve of flow which would indicate muscle contraction. I give an example of the nature of this action of curare.

20 Feb. 1878. Terrier bitch, weight 6¼ kilo. Morphia given. Left extensor vein prepared, and left crural nerve cut and ligatured at 4.2 p.m. Between 3.40 and 4.7 p.m. 0·015 grms. curare were injected into jugular vein; artificial respiration. Tuning-fork arranged to make and break contact, so that with sec. coil at 75 mm. the first sensation of acidity was given to the tongue. At 4.28 p.m. the blood was allowed to run into the measuring tube; previous trials having shown that the muscles did not contract upon strong stimulation of the nerve. There flowed out in successive 5 seconds (see Fig. 8 *a*, Pl. IX., upper curve):

0·45, 0·45, 0·45, 0·375, 0·45 cc.

The key was now put down, and the nerve stimulated for 20 seconds, the sec. coil standing at 30 mm. from the primary. There was no visible sign of contraction of the muscles, and the continuation of the measurement of flow which was not interrupted gave

stimulation sec. coil 30 mm.
| 0·375, 0·475, 0·55, 0·75, | 0·975, 1·225, ?, 1·225, 1·075, 1·0, 0·875, 0·775, 0·775, 0·7, 0·75, 0·65, 0·6 cc.

The effect of the stimulation then was to cause a steady increase in the amount of outflow, which reached its maximum 15 seconds after the end of the 20 seconds stimulation, the rate being then 2·5 times as great as before the stimulation; the increase had not quite disappeared 65 seconds after the end of the stimulation.

The upper half of the nerve was now crimped (see Fig. 8 *b*), and the flow measured, then at 4.39 p.m. 0 015 grms. curare were injected, and at 4.57 p.m. the blood-flow again measured, the animal having lost by this time 40 cc. of blood.

The following are the numbers obtained (see Fig. 8*a* dotted curve):

0·45, 0·425, 0·425, 0·425 cc.

The lower part of the nerve was now stimulated for the same time as before (20 seconds), with the same strength of stimulation (sec. coil at 30 mm.) without interrupting the flow of blood. There was no sign of any contraction of the muscles; the continuation of the flow gave

| 0·45, 0·45, 0·475, 0·6, | 0·525, 0·525, ?, 0·45, 0·45, 0·425, 0·425, 0·375, 0·425, 0·325, 0·325, 0·325 cc.

The effect then of doubling the amount of curare injected was to diminish very greatly the maximum of the increase of flow caused by the stimulation, and also to shorten very markedly the length of time that increase lasted.

As one would expect, if curare really paralyses the dilator fibres, the increase is slight in comparison to what is seen in the uncurarised animal, and it requires a strong stimulation to cause even this slight effect.

A possible objection which might be made to this and similar experiments is, that the increase observed was due to an increase of blood-pressure owing to an escape of current on to sensory nerves; apart however from the fact that due precautions were taken to prevent any escape of current, the fact that the increase is less when more curare is given, as the dotted curve in Fig. 8*a* shows, or even is absent altogether, tends to disprove this objection; for the rise of blood-pressure, as is well known, occurs on stimulation of a sensory nerve, when the animal is thoroughly curarised. All doubt however of the matter is at once set at rest by using mechanical instead of electrical stimulation.

If in a slightly curarised animal the crural nerve be crimped, after the method of Goltz, from the point of section peripherally, then each cut causes a contraction of the muscles and the curve of flow shows an increase during the stimulation, which is interrupted by the several outspurts of the successive contractions; this is followed after the end of the crimping by a steady rise of the curve. If more curare be given, so that the effects described above are obtainable on electrical stimulation of the nerve, then the crimping causes a steady rise without any sign of muscular contraction. (See Figs. 8*b*, 9, and 10, Pl. IX.) Fig. 8*b* was obtained directly after the upper figure in Fig. 8*a*, the blood having been allowed to run to the heart for 5 minutes after the termination of the latter curve, and the cannula washed out. Further, if more curare be given so as to obviate all chance of even imperceptible contraction, then even is it possible to obtain a slight increase of flow with crimping, although strong electrical stimulation is ineffective.

This one would expect, as in all probability a series of cuts in a nerve causes a stronger stimulation than any electrical current that I have yet used.

I conclude therefore from these experiments, that the increase of flow, caused by stimulation of the crural nerve in dogs, is due, as in the frog's muscle, to the direct excitation of dilator fibres, and that the difference between the vessels of the muscle and of the skin is, that in the former the dilator fibres predominate, in the latter the constrictors.

IV. At the same time it can be shown by measurement of the blood-flow in a thoroughly curarised animal that, as Heidenhain concludes from his experiments, constrictor fibres also are present in the muscle nerve. In the first place, the effect of section of the crural nerve or of the abdominal sympathetic in the curarised animal points strongly to a removal of tonicity, and therefore to the presence of constrictor fibres; and in the second place, stimulation both of the crural and of the abdominal sympathetic causes a slight diminution in the rate of flow, when the animal is thoroughly under the influence of curare. Here, however, a difficulty arises due to the method of experimentation; for, in consequence of the progressive loss of blood, and perhaps also of the tendency of the blood to coagulate, if allowed to run out of the vein for any length of time, there is, as a rule, a very slow continuous diminution in the rate of flow during the course of each separate experiment; so that it is always open to doubt, whether a very slight diminution in the rate of flow during a stimulation is really due to the stimulation, or whether it would not have occurred to the same extent if no stimulation had been present; and as far as I have been able to see, the diminution of flow due to the stimulation of the nerve is always very slight. For this reason I am unwilling to conclude that the stimulation has really caused constriction of the vessels, unless the rate of blood-flow returns afterwards at least to that rate which existed before the stimulation. In the case of stimulation of the abdominal sympathetic nerve in the thoroughly curarised animal, this test is satisfied, as the following experiment shows, see Fig. 11, Pl. IX.

Feb. 18, 1878. Large sheep-dog, weight 20·5 kilo. Morphia given, 0·075 grms. curare injected into jugular vein. Abdomen opened in middle line, and left abdominal sympathetic trunk cut and ligatured above the fourth lumbar ganglion, and the peripheral end placed in ⊥-tube electrodes; the

abdomen then sewed up and wadding replaced; cannula in left femoral vein. Tuning-fork used; sec. coil at 70 mm. gave first feeling of acidity when the electrodes were applied to the tongue. Artificial respiration.

The figure shows the effect of the first three stimulations, none of which caused the slightest movement in the animal; it is seen from it that the sec. coil at 50 mm. caused a decided diminution in the rate of flow, which was followed after the end of the stimulation by a return to the former rate. Other curves in the same experiment and in other experiments show the same effect, but to a less marked extent.

Stimulation then of the abdominal sympathetic trunk above the 4th lumbar ganglion causes a slight constriction of the vessels of the extensor muscles in the curarised animal. In the case of the animal under morphia and chloroform alone without curare, I have not as yet been able to decide what is the exact result of stimulation of different parts of the sympathetic trunk. As I have already mentioned, the crural nerve is supplied by two well-defined branches springing from the 4th and 5th lumbar ganglia of the sympathetic respectively, and therefore I have endeavoured to ascertain the influence of each of these branches on the blood supply of the extensor muscles. In order to do this, I cut the sympathetic trunk below the 3rd, 4th, and 5th lumbar ganglia and placed the piece of nerve in connection with the 4th ganglion in one of the ⊥-tube electrodes, and that in connection with the 5th ganglion in another; I then stimulated these two separate pieces of nerve alternately with different strengths of current. This method of experimentation has however as yet not given sufficiently trustworthy results, chiefly because owing to the absence of curare the slightest movement is apt to shift the position of the electrodes (even though the upright arm of the ⊥-tube be firmly held), and therefore to make any result obtained a doubtful one; still perhaps it may be worth mentioning, that an analysis of the curves so obtained shows that in the majority of cases the stimulation of the nerve in connection with the 5th lumbar ganglion causes a very slight increase rather than a diminution in the rate of flow, while stimulation of that piece in connection with the 4th lumbar ganglion always causes a very slight diminution in the rate of flow or else no effect at all. The difference in the rate in one direction or the other is however so slight, that without further confirmation I am not inclined to attach much value to the observations.

The whole question of the course of the dilator and constrictor fibres for the muscle vessels I have not yet been able to work out, and must leave for a future paper; there is however one observation

to which I have already referred which may perhaps tend to elucidate this question.

As I have already shown, section of the abdominal sympathetic causes a great increase in the amount of blood flowing from the extensor vein, which increase is not lasting; now if the abdominal sympathetic be cut, and the animal be thoroughly curarised, and then when the flow has nearly or quite recovered its original rate the crural nerve be cut, the section of the crural produces no effect; there is no contraction of the muscles, no change in the rate of flow; if however the animal be only partially curarised and then the crural cut, there is on section some muscular contraction and at the same time a slight increase in the rate of flow; and finally, if the animal be not curarised at all, but under the influence of morphia and chloroform alone, then the section of the crural produces as great, or nearly as great, an effect as it would have done had the sympathetic not been previously cut. I give the following examples.

March 4, 1878. Spaniel bitch, weight 13¾ kilo. After the termination of the curve given in Fig. 3, 0·06 grms. curare were injected into the jugular vein; artificial respiration was performed, and the left crural nerve was laid free. Thirty-one minutes after the end of the curve in Fig. 3, the measurement of the blood-flow began; there flowed out in successive 5 seconds,

0·925, 0·95, 0·875 cc.

The crural nerve was now cut without interrupting the blood-flow; there was a decided contraction of the muscle; the continuation of the blood-flow measurement gave

1·55, 1·3, 1·2, 1·15, ?, 0·975, 0·875, 0·775 cc.,

and 50 seconds afterwards,

0·85, 0·8, 0·775, 0·75, 0·825 cc.

Of the 1·55 cc. which poured out in the first 5 seconds after the section, 0·65 cc. was due to the outspurt, which is characteristic of the contraction of the muscles, and which lasted 0·75 seconds.

This example shows the slight increase in the rate of flow following section of the crural nerve after section of the sympathetic in a slightly curarised animal.

The following shows the effect of section of the crural after section of the abdominal sympathetic, when no curare has been given. See. Fig. 12, Pl. IX.

June 13, 1878. Terrier bitch, weight about 8 kilo. Morphia and chloroform. Both vagi cut; thermometers placed between crureus and vastus

internus muscles on each side. Manometer in connection with right carotis; right extensor vein used; wadding over abdomen not over legs.

After some experiments upon the effect of stimulating the central end of the vagus upon the temperature of the muscles and of the rate of flow through them, in the course of which not much blood was lost, the abdomen was opened in the middle line and the right abdominal sympathetic cut above the fourth lumbar ganglion without taking the blood-flow. The temperature, however, on that side rose 2° C., showing that the section was effective; the abdomen was then sewed up, and an hour afterwards the crural nerve on that side cut with the effect shown in the figure. Upon section of the nerve there was a marked contraction of the muscles, and at the same time a great increase in the frequency of the respirations, the expirations being very forcible and the abdominal muscles brought into play; this forced respiration lasted some little time, about 20 seconds, or perhaps rather longer, and then the animal remained quiet. Subsequent dissection showed that the abdominal sympathetic had been rightly cut.

The great increase in the rate of flow in this case is certainly surprising; the curve presents much the same appearance as in the case of a section of the crural alone without previous section of the abdominal sympathetic; the maximum rate is reached in 30 seconds after section, and is then nearly seven times as great as before section, and the previous rate of flow is not attained until about $2\frac{1}{2}$ minutes after the section.

The question naturally arises, How far can this great increase be due to the forced respiration that was observed? What effect does this strong action of the abdominal muscles have upon the circulation in the leg?

Undoubtedly this action of the muscles of respiration, which occurs upon strong stimulation of an ordinary sensory nerve, is able of itself to cause a marked increase in the rate of flow through the muscles. The following experiment shows this. See Fig. 13, Pl. IX.

April 1st, 1878. Bull terrier bitch, weight 9 kilo. After the termination of the experiment described on page 267, the saphena branch of the crural nerve was prepared on the right side and placed on the electrodes, and twelve minutes after the section of the left crural nerve, the rate of flow was again measured and Fig. 13 obtained. With the sec. coil at 120 mm. and 100 mm. no marked effect was produced on the respiration, and also, as is seen, the rate of flow was not altered; when however the sec. coil was pushed up to the 50 mm. mark, rapid forced respiration was caused which lasted as long as the stimulation lasted, *i. e.* for 25 seconds, without of course any contraction of the extensor muscles of the side on which the blood-flow was being measured, for the crural had been cut on that side; as the figure shows, the rate of flow increased immediately this forced respiration began, and 10 seconds after the end of the stimulation had reached its maximum; being then rather more than twice the rate before the stimulation began.

This experiment shows that the strong action of the abdominal muscles is of itself able to produce a decided increase of flow from the extensor vein; a comparison however of Figs. 12 and 13 seems to show that the section of the crural following upon section of the abdominal sympathetic causes a greater increase of flow than is explainable by the action of the increased respiration alone; for, although in each of the two cases the expiratory movements caused by the section of the crural and the stimulation of the saphena respectively were very strong and lasted about the same time, yet the maximum increase of the rate of flow was in the one case nearly seven times as great as the normal rate, in the other a little more than twice as great; also in the one case the increase lasted a much longer time than in the other.

In order to test this question further I performed the following experiment.

June 17, 1878. Dog, weight 8 kilo. Morphia and chloroform. Thermometers between muscles in each leg. Abdomen opened in middle line and right sympathetic trunk cut at 2.14 p.m. and left sympathetic at 2.16 p.m., each above 4th lumbar ganglion; in each case the temperature rose in the extensor muscles, and after-dissection showed that the nerves were rightly cut. After the abdomen had been sewed up, and wadding placed over it, the left extensor vein was prepared and both crural nerves. During the cutting of the sympathetic nerves the animal had remained quiet, being well under morphia and chloroform. At 3.46 p.m., *i.e.* 1½ hours after section of the abdominal sympathetic nerve, the first tracing in Fig. 14, Pl. IX., was taken; the flow was then turned to the heart for 3 minutes, and the cannula washed out, and then the curve showing section of the left crural obtained. Upon section of the nerve the muscles contracted (the outspurt is not shown in the curve), and there was violent forced respiration, which lasted some time. After the termination of this curve the flow was turned to the heart for 15 minutes, the cannula washed out, a little more chloroform given, and then the blood-flow again measured, while the crural on the other side, that is, the right crural, was cut; again, the section caused violent forced respiration, which was perhaps not quite so violent as before, and which commenced a little later after the section; the effect of it, however, is well marked on the curve of flow.

The difference between the curves showing the effect of section of the crural on the two sides is well marked; a much greater effect is produced by the section of the nerve on the same side as the measurement of the blood-flow; if however the increase of flow was due in each case simply to the effect on the respiration, there ought to have been a greater similarity between the two curves; for the only difference between the effects of the two sections is upon the assumption, that in the one case a momentary contraction of the muscles was added to

the increase of respiration, while in the other no such contraction took place.

The similarity between Fig. 13 and the last curve in Fig. 14 makes it probable that either curve may be said to represent fairly the effect of the increased respiratory action alone upon the flow from the muscles; while the resemblance between Fig. 12 and the middle curve in Fig. 14 enables one to appreciate the extra increase of flow caused by the section of the crural nerve.

I conclude then from these experiments, which I hope however to supplement by others, that section of the crural nerve acts as a strong stimulation of the dilator fibres of the muscle vessels, provided that these fibres are not paralysed by the action of curare; that therefore when the crural is cut the increase of flow caused by the section is due to two causes, first, the removal of tonicity, and secondly, the excitation of dilator fibres.

The first of these may be studied by curarising the animal; for the increase of flow that then occurs upon section of the nerve is due to the removal of tonicity, because the dilator fibres are not capable of being stimulated. On the other hand, the second cause may be separated from the first by a previous section of the abdominal sympathetic, for then all tonicity due to central action is removed (otherwise an increase of flow ought to occur in the curarised as well as in the uncurarised animal) and the effect produced is due to the excitation of the dilator fibres.

From the foregoing observations and experiments, combined with the original experiments made at Leipzig, I conclude that in the dog as in the frog, the vasomotor system for the muscles consists essentially of dilator nerve fibres: nerves which, in the magnitude of their action, are quite comparable either to the chorda tympani or the nervi erigentes; and of constrictor fibres, which are insignificant in comparison to the dilator, but which are manifested, when the dilators are put out of play by the action of curare. And here I may best make a remark upon an objection of Heidenhain's*, where he says, that I am inclined to apply the results of my experiments upon the mylohyoid muscle in the frog to the case of the circulation in the muscles of the dog; and he objects to any application of this sort because the laws of the innervation of the vessels are different in the cold-blooded animals and in mammals, owing especially to the fact, that in the latter there is a necessity for

* *Loc. cit.* p. 46.

a complicated temperature-regulating machinery, which is wanting in the former. This objection, no doubt, applies with considerable force, when the vascular system under consideration is essentially concerned in the regulation of the bodily temperature, as is the case with the area of the skin; but in the case of the muscle, as well as that of a gland, the calls made upon the blood supply are of a different character. The function of the vascular system here is only secondarily the regulation of the general body temperature: its primary function, its chief care, must be, to regulate itself according to the needs of the muscle or gland in question. If then work done by the muscle or the gland necessitates a greater supply of nutrient material, either for the purpose of continuing that work, or for the purpose of recovery after the exhaustion entailed by the work, some mechanism for the provision of this greater supply is sure to be present, whether the animal be cold blooded or warm blooded; and it seems to me, that if experiments on the frog's muscle show that the increased blood supply is brought about by the agency of dilator nerves, one is justified in believing in the probability, that the increased supply seen in the case of the muscle of the dog is produced in the same way, until at all events this supposition is negatived by direct observation.

V. I will now pass to the question of what is the effect of the stimulation of an afferent nerve upon the blood-flow through the muscle. As yet I have experimented upon only three kinds of afferent nerves; 1stly, upon that sensory nerve which corresponds to the motor nerve of the muscle: in this case therefore the long saphena branch of the crural nerve; this nerve accompanies the femoral artery and vein, and is easily found at the edge of the sartorius muscle, either just above the knee or a little below the orifice of the extensor vein; in most cases, for the sake of convenience, I stimulated the central end just above the knee; 2ndly, upon some more remote ordinary afferent nerve: in the majority of cases, the radial; and 3rdly, upon the vagus of both sides. I shall therefore consider the effect upon the blood-flow of the stimulation of the central ends of these three nerves, in the animal under the influence of morphia and chloroform alone, and in the curarised animal.

1stly, in the uncurarised animal.

A moderately strong stimulation of either the saphena or radial nerves may cause an increase of blood-pressure, a contraction of various muscles, among others possibly the quadriceps extensor group, a quickened respiration with strong action of the abdominal muscles, and

finally, a marked increase in the rate of blood-flow from the extensor vein.

It is therefore necessary to determine whether the increase of blood-flow is associated with any one of these three simultaneously occurring effects of the stimulation, more than another.

In the first place, the increase of blood-pressure is not the cause of the increased blood-flow; for, as Ostroumoff* has shown, the blood-vessels are able to adapt themselves to a slight increase of pressure when their nerves are intact; and also since the animals were always under the influence of morphia, and sometimes of chloroform as well, the stimulation of the nerve sometimes produced, as in the chloralised animal, a fall rather than a rise of blood-pressure, and yet the increase of blood-flow was apparent; further, a rise of blood-pressure may occur on vagus stimulation, and yet, as will be shown directly, no increase of flow be produced. See Figs. 16, 18, 19, Pl. IX., X.

In the second place, as I have already shown, the violent action of the expiratory muscles is quite sufficient to account for the increase of flow observed, however that effect may be brought about, whether by obstruction of the venous flow to the heart, as Heidenhain suggests†, or by some other method. Yet this too is not sufficient any more than the rise of blood-pressure to account for every increase of flow observed, for if the stimulation be weak, or perhaps when the animal is very thoroughly narcotised, the stimulation may cause hardly a trace of alteration in the respiration, and yet a marked increase in the rate of flow. See Figs. 16, 18, 19, Pl. IX., X.

Finally, in every instance that I have as yet observed, the increase of flow is preceded by a reflex contraction of the extensor muscles. If the stimulation is too weak to cause a contraction of the muscles, then the rate of flow is not increased. Whether contraction occurs at the beginning or end of the stimulation, whether the blood-pressure rises or not, whether the respiration is greatly affected or hardly at all, in all cases there is a marked increase in the rate of flow after the contraction. See Figs. 16, 17, 18, 19, 21, Pl. IX., X.

When the central end of the vagus is stimulated the effects are different; there may be a rise or fall of pressure according to circumstances, for the vagus of the dog contains depressor fibres; there may be inhibition of the respiration followed by a more rapid respiration, which is what I have generally observed; or there may be more rapid respi-

* Pflüger's *Archiv*, Vol. XII. p. 240.

† Pflüger's *Archiv*, Vol. IX. p. 259.

ration alone or tetanic inspiration; I have not attempted to settle under what different conditions these different effects occur, as such an investigation was foreign to my purpose; Burkart's paper* gives the latest information on the subject. Still, whatever effect stimulation of the vagus may have, it never, as far as I have yet seen, produces any reflex contraction of the leg muscles in the anæsthetised animal, at least with any strength of stimulation that I have as yet used; further, with the absence of contraction of the extensor muscles, there is a complete absence of any sign of increase in the rate of flow, either during or after the stimulation, except under circumstances to be mentioned presently. In the majority of cases the stimulation of the vagus has seemed to cause a slight diminution rather than an increase of flow, although in every case the efficiency of the stimulation was manifested by the effect on the respiration, independently of variations in the blood-pressure curve. See Figs. 15, 20, 22, 26, Pl. IX., X., XI.

If the vagus stimulation causes a rise of pressure followed by a decided fall, or if there is a decided fall of pressure without an antecedent rise, then at the commencement of the fall of pressure there is often a slight increase in the rate of blood-flow. See Figs. 15, 20. This increase occurs only at the commencement of the fall of pressure, and appears to have no dependence upon the length or strength of the stimulation, except so far as the latter affects the time when the fall of pressure occurs. Heidenhain observed a similar phenomenon to this upon stimulation of the splanchnic nerve†, and he suggests that the antecedent rise of pressure causes a stimulation of dilator nerves, and so of its own accord tends to restore the vessels to their normal state. This explanation, however, will not apply to the case where the fall of pressure takes place without any preliminary rise, as in Fig. 20; for my own part I am inclined to think, that this phenomenon, combined with the fact of the slight diminution of flow often observed on vagus stimulation, points to the possibility that the vessels of the muscles are part agents in the production of the variations of pressure caused by the stimulation of the vagus.

The following experiments may serve as examples of the different effects described above, produced by the stimulation of an afferent nerve.

Jan. 30, 1878. Black and tan terrier bitch, pregnant. Morphia and chloroform. Both vagi cut; central end of left vagus on electrodes; right

* Pflüger's *Archiv*, Vol. XVI. p. 427. See also a paper by Langendorff in "Mittheilungen aus dem Königsberger Physiologischen Laboratorium" von W. v. Wittich. 1878.

† *Loc. cit.* p. 41.

radial nerve cut and central end ligatured. Right extensor vein used. Tuning-fork arrangement, sec. coil at 75 mm. gave first feeling of acidity to tip of tongue. Manometer in right carotis. After trying the effect of stimulation of the vagus on the blood-pressure curve, the following curve of flow was obtained. (See Fig. 15, which gives deduced curve of flow and a facsimile of the pressure curve.)

0·75, 0·7, 0·725, 0·725, ?, 0·8 cc.

The vagus was now stimulated for 15 seconds with sec. coil at 40 mm.; the respiration was inhibited, and the blood-pressure rose as shown in the curve; there was no contraction of the extensor muscles; the continuous measurement of the rate of flow gave

0·65, 0·65, 0·6 cc.,

and after the stimulation,

0·525, 0·55, 0·675, 0·95, 1·0, 0·725, 0·55, 0·5, 0·5, ?, 0·45, 0·5, 0·5, 0·45, 0·45 cc.

Without interrupting the flow, the vagus was again stimulated with sec. coil at 40 mm. for 30 secs. producing again a rise of pressure, inhibition of respiration followed by a more frequent respiration, and no contraction of the extensor muscles:

0·45, 0·4, 0·4, 0·35, 0·35, 0·35 cc.

and after the stimulation,

0·35, 0·4, 0·575, 0·825, 0·85, 0·675, 0·6, ?, 0·5, 0·525, 0·575 cc.

The flow was now turned to the heart for 16 minutes, during which the cannula was washed out, and the radial nerve placed on the electrodes and the effect of stimulating its central end tested. Then the blood was again allowed to flow, and the two following curves obtained (see Figs. 16 and 17, which are facsimiles of the original curves),

0·55, 0·6, 0·55 cc.

The radial nerve was now stimulated with sec. coil at 120 mm. for 15 seconds; no contraction occurred until the last 5 seconds of the stimulation, as seen in the figure; the continuation of the rate of flow gave

0·6, 0·6, 0·9 cc.

and after the stimulation,

0·95, 1·975, 1·825, 1·25, ?, 0·925 cc.

The flow was now turned to the heart for 3 minutes, and the cannula washed out; upon again measuring the rate of flow, there poured out

0·6, 0·5, 0·475, 0·425, 0·5, 0·475, 0·525, ?, 0·525 cc.

The radial was now stimulated for 8 seconds with sec. coil at 110 mm.; there was violent respiration, rise of pressure, and contraction of the muscles near the end of the stimulation. See Fig. 17. The measurement of the flow during the stimulation gave

0·525, 0·8 cc.,

and then

1·4, 2·0, 1·5, 1·2, 1·1 cc.

After further similar radial stimulations, the vagus was again stimulated for 30 seconds with precisely the same effect as before, except that the rise of pressure lasted longer after the stimulation, and therefore the increase of flow which was coincident with the commencement of the fall of pressure took place a longer time after the end of the stimulation.

May 4, 1878. Spaniel bitch, weight 8·5 kilo. Morphia and chloroform. Both vagi cut; central end of left vagus in ⊥-tube electrodes. Right extensor vein used, and central end of left saphena nerve placed in Ludwig's electrodes; thermometer placed between muscles on each side. No wadding. With sec. coil at 80 mm. first feeling of acidity was given to the tip of the tongue. (See Figs. 18, 19, 20, 21, which give the deduced curves of flow, and facsimiles of the pressure curves.)

At 4.39.45 p.m. the measurement of the blood-flow began, and gave

0·6, 0·55, 0·55 cc.

The left saphena was now stimulated for 48 seconds, the sec. coil being pushed from 150 to 100 to 80 mm. In the first 5 seconds a slight contraction occurred; the stimulation caused a fall of blood-pressure and a slight quickening of the respiration. See Fig. 18. The rate of flow during the stimulation was

0·725, 0·475, 0·5, 0·675, 0·825, 0·9, 1·1, 1·15, ?, 1·4 cc.,

and after the stimulation,

1·525, 1·4, 1·375, 1·275, 1·225, 1·2, ?, 1·15, 1·05, 0·95, 0·925, 0·85, 0·85, 0·8, 0·775, 0·775, 0·75, 0·7 cc.

After a pause of 14 minutes, the flow was again measured, and the saphena stimulated for 1 min. 55 seconds with sec. coil at 150 mm., then at 100 mm., and then at 80 mm. As Fig. 19 shows, the stimulation caused no rise in the curve of flow until the sec. coil was pushed to 80 mm., when a contraction of the extensor muscles occurred; during the stimulation the pressure fell slightly and the respiration was almost unaffected.

After a pause of 7½ minutes the flow again recommenced, and the left vagus was stimulated for 1 min. 45 seconds, and as Fig. 20 shows, when the sec. coil was at 100 mm. very slight effect was produced on the curve of pressure, while the rate of flow was slightly diminished; when the sec. coil was pushed up to 60 mm. the pressure fell rapidly and a more rapid respiration occurred; the rate of flow rose slightly with the commencement of this fall of pressure, and then during the rest of the stimulation remained slightly below the normal rate; after the stimulation the pressure rose, the respiration ceased altogether for a time, and the rate of flow remained below the normal rate. After a pause of 8½ min. the measurement of the flow recommenced, and gave a steady normal rate of 0·5 cc. The vagus was stimulated for four minutes with sec. coil from 50 mm. to 30 mm. During the whole time the pressure remained very markedly fallen with the respiration increased, and at the end inhibited. As the blood was only allowed to run for the first part of the stimulation, the main object being a measurement of temperature, I do not give the curve of flow. Here again, however, with the commencement of the sharp fall of pressure, there was a slight shortly lasting increase in the rate of flow.

After 6½ minutes from the termination of the last stimulation the flow recommenced, and Fig. 21 was obtained. It is seen from it that the stimulation of the saphena caused no increase of flow and no contraction of the muscles with the sec. coil at 100 mm., but when the sec. coil was suddenly pushed to 60 mm., then, although the stimulation lasted at this strength hardly a second, there was a marked increase of the rate of flow accompanied by contraction of the muscles, violent respiration, and a rise of blood-pressure, which had sunk during the first part of the stimulation.

As a further example of the effect of stimulation of the vagus, the following will serve.

Jan. 22, 1878. Small white terrier bitch. Morphia and chloroform. Both vagi cut; left vagus central end in ⊥-tube electrodes; right saphena and right radial nerves prepared; right extensor vein used. Manometer in right carotis.

After various curves of radial and saphena stimulation, showing the usual effects, had been obtained, the curves shown in Fig. 22 were described, and show how the stimulation of the vagus with sec. coil at 150, 100, and 70 mm. respectively, caused inhibition of the respiration, no contraction of the muscles, and a diminution rather than an increase of rate of flow from the extensor vein.

2ndly, in the curarised animal.

Although now all the mechanical effects due to muscular action are necessarily absent, yet the stimulation of the three kinds of nerves produces the same effect as before, an increase of flow upon stimulation of the radial or saphena nerves; and either no effect or a slight diminution of flow upon stimulation of the vagus. In order to obtain the increase of flow upon stimulation in the curarised animal, the strength of the current must be as great as in the uncurarised; and the increase seems to take place in the same way as in the examples already given, except that all signs of muscular contraction are wanting.

There is, as far as I can judge, no great difference between the effect of stimulation of either saphena or of the radial, except that the increase of flow may be obtained with a weaker stimulation in the case of the former nerves. This is to be expected, because stimulation of these nerves is able to produce reflex contraction of the extensor muscles more easily than stimulation of the radial nerves. The following examples may serve to illustrate the above remarks.

Aug. 14, 1877. Dog small. Morphia and curare; left vagus central end prepared; right vagus not cut; manometer in connection with right carotis. Right extensor vein used. No wadding. Induction coil used without tuning-fork, therefore first sensation to tongue with sec. coil at 130 mm. Artificial respiration. After various stimulations of saphena, which caused the usual

increase of flow, the left vagus was placed on the electrodes, and Fig. 23, Pl. XI., obtained. Each of the three stimulations, sec. coil at 120, 120, and 80 mm. respectively, caused a rise of blood-pressure; in the last the rise was very marked, amounting to between 20 and 30 mm. Hg. As is seen, the stimulation caused a fall rather than a rise in the curve of flow.

Nov. 24, 1877. Mongrel bull-dog of medium size. Morphia and curare. Right and left saphena nerves prepared; vagi not cut. Manometer in connection with right carotis, and right extensor vein used. Artificial respiration; no wadding. Induction coil alone used, therefore sec. coil at 130 mm. gave first sensation of acidity to tongue. See Figs. 24 and 25, Pl. XI. The curves given show the effect of stimulation of the saphena on the same side as the measurement of blood-flow, and on the opposite side for the same length of time, viz. 15 seconds, and with the same very weak stimulation, viz. sec. coil at 300 mm. Between the two curves there was a pause of 12 minutes. In neither case was there any contraction of the muscles. The saphena on the opposite side produced the greater effect, but then a greater rise of pressure than the former stimulation had produced was also caused. Therefore for some reason the stimulation acted stronger in the second case than in the first, and so caused a slightly greater effect on the rate of flow.

March 20, 1878. White terrier, weight $6\frac{1}{2}$ kilos. Morphia and chloroform. Both vagi cut; left vagus in $\perp$-tube electrodes; right extensor vein prepared and right carotis in connection with manometer. Tuning-fork arrangement; sec. coil at 75 mm. gave first sensation to tip of tongue. After section of the vagi the respiration was very slow and very deep, as seen in curve of pressure.

Fig. 26, Pl. XI., shows the effect on blood-pressure and on blood-flow of the stimulation of the left vagus for 1 min. 20 sec. with the sec. coil at 30 mm.

The animal was then curarised, artificial respiration used, and Fig. 27, Pl. XI., obtained. The vagus was stimulated for 1 minute with the sec. coil at first at 30 mm. and then gradually pushed up fully over the primary. The curve shows much the same characteristics as were obtained in the experiment before curare was given.

As a final example, I give a case where curare and chloroform alone were given without morphia.

March 26, 1878. Dog, weight 6 kilos. Both vagi cut, left vagus in tube electrodes. Right extensor vein used and right carotis. Left saphena prepared near its junction with crural. Tuning-fork; sec. coil at 70 mm. gave first sensation to tongue. Artificial respiration.

Fig. 28, Pl. XI., shows the effect of a 30 sec. stimulation of the left saphena with sec. coil at 100 mm. There was not the slightest trace of movement of any sort; the blood-pressure rose during the stimulation as much as 40 mm. Hg. and the flow increased as seen in the curve.

In the same experiment the vagus stimulations, whatever their strength or length, always caused the usual effect; a slight diminution rather than an increase of flow.

From these and many similar experiments I conclude then, that dilation of the muscle vessels takes place upon stimulation of an afferent nerve, when that stimulation causes either an actual or potential contraction of the muscle: meaning, by a potential contraction that the contraction would have occurred but for the hindrance interposed between the central nerve cells and the muscular fibres in consequence of the action of curare.

Also that constriction rather than dilation of the muscle vessels is caused when an afferent nerve, such as the vagus, which does not cause any contraction of the muscles, is stimulated. These two conclusions correspond very closely to what I observed in the mylohyoid muscle of the frog; both with respect to dilation occurring with reflex contraction, and to a slight and doubtful constriction taking place under other circumstances.

Further, the difference between the action of curare when an afferent nerve is stimulated and when the muscle nerve itself is stimulated, I imagine to admit of explanation in the following manner.

Curare is a poison which does not appreciably affect, in moderate doses at all events, the central nervous mechanism, but at the same time does affect certain peripheral groups of nerve cells; thus the muscle does not contract in the curarised animal upon reflex any more than upon direct stimulation, because the impulses sent out by the central cells as the result of the afferent stimulation are not able to reach the muscular fibres, owing to the disorganisation of the end plates of the motor nerves, and not in consequence of any alteration in the action of the central cells. The mechanism by which dilation of the muscle vessels is produced is however of a different character to this; instead of a single kind of nerve fibre we have here two kinds of fibres, the constrictor and the dilator fibres, and one supposes that the curare prevents the action of the latter, however that action may be produced, while it leaves intact the central nervous mechanism and the constrictor fibres which are especially regulated by this mechanism. Further, one supposes that, with the crural nerve intact, the tonicity of the vessels is kept up by impulses continually proceeding from the central nervous mechanism, and that these are capable of being augmented or inhibited by different means. When then curare has been given, direct stimulation of the crural nerve is unable to produce an increase of flow or a contraction of the muscle, because the curare affects that part of the peripheral mechanism which may be summed up by the

words "dilator fibres" as well as the end plates of the motor nerves; while stimulation of an appropriate afferent nerve, although unable to cause a contraction of the muscle, yet can produce dilation of its vessels, because it is still able to diminish the tonic impulses sent by the central nervous mechanism along the unaffected constrictor fibres.

It is difficult, upon this hypothesis, to explain certain experiments that I have made, viz. experiments as to the effect of afferent stimulation when the abdominal sympathetic has been previously cut. Here, as in other cases, I have noticed a decided increase of flow consequent upon contraction of the muscles caused by stimulation of the saphena or radial nerves, and no increase upon stimulation of the vagus; and this too when in consequence of a small dose of curare there has been no reflex contraction. As however I did not at the time realize the importance of watching carefully the respiratory action produced by the stimulation, but fixed my whole attention upon the question whether the muscles contracted or no, I cannot assert positively that the increase of flow observed was not entirely due to the action of the increased respiration, and therefore had nothing to do with any special dilation of the vessels. Further experimentation must settle this point; and if it be found that, in the thoroughly curarised animal, stimulation of an ordinary sensory nerve causes an increase of flow even when the abdominal sympathetic is cut, then either the above argument must be modified or else one must suppose that all the constrictor fibres do not run in the abdominal sympathetic, a supposition which is contrary to what I imagine at present to be the case.

VI. It is now time to compare the conclusions arrived at in the foregoing pages with those arrived at by Heidenhain in the paper already quoted. Upon reading that paper it is seen, that Heidenhain experimented on curarised animals, and therefore, as he himself expressly says, makes no attempt to explain the increase of flow attendant upon muscular contraction. His main conclusions are,

That stimulation of the sciatic nerve, or of the abdominal sympathetic, causes a slight fall of temperature in the gastrocnemius muscle, because the muscle vessels are slightly constricted.

That section of the abdominal sympathetic and (as one judges from the details of some of his experiments) of the sciatic causes a more or less lasting rise of temperature, *i.e.* a dilation of the vessels of the gastrocnemius muscle, which lasts hours rather than minutes.

That stimulation of any afferent nerve, whether it be sciatic or

vagus, causes a rise of temperature, *i.e.* a dilation of the vessels in the muscle.

That dilator fibres can be shown to be present in the muscle nerve, as in the nerves to the skin, by cutting it three to four days beforehand, and then stimulating.

Apart then from the question of the effect of curare, the results of the two sets of experiments, Heidenhain's and my own, differ chiefly, as to the effect of section of the muscle nerve or abdominal sympathetic, and of stimulation of the central end of the vagus nerve.

First then, as to the section of the nerve fibres supplying the muscle vessels.

In all the numerous experiments that have been made of late years upon the temperature of the foot, one fact stands out clearly and is agreed to on all sides, viz. that section of the sciatic causes a rise of temperature in the foot which may last not minutes or hours, but days or even weeks; a rise therefore which is rather of a permanent than a temporary character. Now Heidenhain comes to the conclusion, that the innervation of the muscle vessels follows the same laws as that of the skin vessels, although perhaps the effects are not so pronounced in the muscle as in certain parts of the skin; and in accordance with this conclusion, section of the nerve fibres supplying the muscle vessels causes a more or less permanent rise of temperature in the muscle; thus, in the two experiments given by him*, section of the abdominal sympathetic caused a rise of temperature, which in the one case had amounted to 2·73° C. and 2·66° C. in the right and left gastrocnemii respectively, 28 min. after the section; and in the other to 0·62° C., 25 min. after the section; in neither instance is it clear that the maximum had been reached when the observation ceased. Also, later on†, an experiment is given in which the left sciatic was cut; when the measurement of temperature began, it is seen that the temperature of the left muscle was very nearly 2° C. higher than that of the right, and about 2 hrs. after the section, when the experiment finished, there was still a difference of 2° C. in the two muscles.

One can say then from these experiments, that section of the muscle nerve causes a rise of temperature which lasts at all events hours rather than minutes.

On the other hand, my experiments show clearly that the increase of blood-flow due to the section of the crural nerve does not last so long

* *Op. cit.* p. 15. † *Ibid.* p. 21.

as 5 minutes, and that the maximum increase in the rate of flow is reached during the first minute; *i. e.* the increase of flow caused by the section is not of a permanent character. This conclusion is based not only upon the experiments given in Figs. 1 and 2, and many others like them, but also upon the great number of experiments that I have made involving section of the crural nerve, in which the effect of the section on the rate of flow was not measured, owing to the advisability of not using any blood unnecessarily. In all these experiments the first flow of blood has, as a rule, been allowed to run into the water manometer from 20 to 30 minutes after the section of the nerve, and I have always found that the rate was then no greater than one would have expected from the size of the dog.

Here then is the simplest experiment by which to test the relation between rate of blood-flow and rise or fall of temperature. From these two sets of experiments alone it can be asserted, that section of the muscle nerve causes a rise of temperature which lasts an hour or more, and at the same time an increase in the rate of flow which lasts not so long as 5 minutes. In order, however, to be sure of the difference between the length of time occupied by the rise of temperature and by the increase of flow, I have made a few experiments with simultaneous measurement of temperature and rate of flow.

By making a small slit through the skin a little above the knee along the inner edge of the rectus muscle, it is easy to push the bulb of a thermometer between the rectus and crureus muscles, so that it shall be entirely covered with muscle, and at the same time without damaging the muscles. In order to make still more sure that the thermometer is influenced only by muscular blood, it is only necessary to make a small slit in the tendinous fascia over the crureus and vasti muscles, and then the thermometer slips with the greatest ease between the vastus internus and crureus muscles; the bulb lies against the thickest fleshiest part of these two muscles, and is absolutely surrounded by them; it is not advisable to push it in too far, as there is then a possibility of the end of the bulb pressing against the nerves and vessels of these muscles.

The following is an example of the simultaneous measurement of temperature and rate of flow.

April 26, 1878. Young retriever, weight 13 kilos. Morphia and chloroform. Thermometer between rectus and crureus muscles on the left side. Cannula in left femoral; left crural nerve prepared. The temperature was taken every minute or half minute; the rate of flow was measured at intervals, as shown below. The figures in brackets give the times when the thermometer

measurements took place, and are printed underneath the number which give the amount of blood that flowed out in the preceding 5 seconds:

Remarks.	Time.	Temp.	Remarks.	Time.	Temp.
	12.49	32·5		1.22	32·7
	52	·1		23	·6
	56	31·7		23.5	·5
	1.1	·8		24	·45
	12	·8		24.5	·4
	14	·9		25	·35
	15	·8		26	·25
At 1.15′.15″ the crural	15.5	·8		27	·15
nerve was cut; with	16	·8		28	·15
measurement of blood-	16.5	·9		28.5	31·95
flow.	17	32·1		29.5	·9
	17.5	·4		30	·85
	18	·65		30.5	·8
	18.5	·9		31	·75
Blood-flow	19	33·0		32	·7
	20	32·9	Blood-flow	33	·65
	20.5	·85		34	·6
	21	·8		35	·55

The measurement of the blood-flow commenced at 1.14′.45″, and gave in successive 5 seconds:

0·75, 0·6, 0·8, 0·75, 0·75, 0·8 cc.
(1.15′)

The nerve was now cut without interrupting the flow; there was a marked contraction of the muscles with the characteristic outspurt in the curve of flow; the continuation of the measurements gave:

1·05, 0·95, 1·7, 2·4, 4·0, 6·3, 7·4, 7·45, 8·3, ?, 7·25, 7·65, ?, 7·45, 6·4,
(1.15′.30″) (1.16′) (1.16′.30″)

6·3, 6·0, 5·55, 5·4, 5·2, 5·0, 4·9, 3·4, 3·85, 3·6, ?, 2·85, 2·75, 2·35, 1·9,
(1.17′) (1.17′.30″)

1·6, 1·6, 1·5 cc.
(1.18′)

The flow was now turned to the heart and the cannula washed out; at 1.19′.30″ the measurement of flow recommenced, and gave:

0·7, 0·75, 0·65, 0·6, 0·6 cc.
(1.19′.30″)

The flow was again turned to the heart, and a new sample of flow taken at 1.33′.30″. This showed:

0·85, 0·85, 0·8, 0·75, 0·75, 0·7, 0·75 cc.
(1.33′.30″) (1.34′)

From these two sets of figures it is seen, that at the time when the blood-flow had reached its maximum the temperature had not begun to rise; while, when the temperature had reached its maximum, the rate of flow had returned to the normal rate, at which it remained, although the temperature did not return to the height it possessed before the section until 15 minutes after the section.

On page 267 an experiment is described, in which a sample of the rate of flow was taken before and five minutes after section of the crural, and as is seen from the figures given the increase of flow caused by the section had disappeared within five minutes, although no blood had been lost. In order to compare the effect of the section of the nerve upon the temperature, I placed a thermometer between the rectus and crureus muscles of the other leg and then cut the crural on that side, with the following result:

Remarks.	Time.	Temp.	Remarks.	Time.	Temp.
	6.19	31·5		6.36	32·45
	20	·5		37	·45
	21	·5		38	·4
Nerve prepared for cutting.	22	·75		39	·35
	23	·75		40	·35
Crural cut between 6.23′ and 6.23′.30″. Considerable increase of respiration and various movements. At 6.24 and afterwards, animal quite quiet.	23.5	32·0		41	·3
	24	·5	Took wadding off leg.	42	·25
	25	·75		43	·25
	26	·9		44	·2
	27	33·0		45	·1
	28	32·85		46	·0
	29	·8		47	·0
	30	·75		48	31·95
	31	·7		49	·9
	32	·65		50	·85
	33	·55		51	·85
	34	·5		52	·8
	35	·5		53	·75
				54	·75

The numbers again show that the maximum of temperature occurs at a time when the blood-flow, judging from the effect of section on the other side (for the measurement of blood-flow, see p. 267), had already returned to its normal rate, and 30 minutes after the section the temperature had not quite regained its former height.

If the thermometer be placed in the deeper position, between the crureus and vastus internus muscles, then the section of the nerve does not always cause a marked rise of temperature, because the temperature of the muscles is already too near that of the internal temperature; still the effect of the section is clearly marked, if the temperatures on the two sides be compared, as the following example shows:

May 7, 1878. Dog, weight 10·5 kilos. Chloroform, no morphia. Curare. Thermometer placed deeply between crureus and vastus internus on each side; each thermometer very sensitive, divided into 10ths of a degree, so that it is easy to read finer than 0·05° C. Artificial respiration. Cannula in left femoral vein; left crural nerve prepared; no wadding over any part of body.

The blood was allowed to flow during the section of the left crural; the increase of flow, which was very marked, reached its maximum in 20 sec. after the section, and the original rate of flow was regained 1 min. 15 sec. after section. The readings of the two thermometers took place every minute:

From this table (see table over leaf, p. 296) it is seen that the section of the left crural, although it caused the usual effect on the blood-flow, yet caused no appreciable rise of temperature; at the same time the section produces a marked effect upon the temperature curve, for, while the right side shows a steady fall of temperature owing to the exposure of the leg, the temperature of the side on which the nerve was cut remains nearly at the same height for a considerable length of time, so that though the temperature was at the outset very slightly higher on the right than on the left side, there is a difference of 0·75° C. to the benefit of the left side 40 minutes after the section, and of 1·1° C. in 1 hr. 15 minutes after. The right nerve was now cut, the temperature of that side being 2° C. lower than that of the left side at the time when the left crural was cut. The section now caused a decided rise of temperature to the extent of 0·61° C., and the temperature on the right side remained raised as long as the observation lasted, *i. e.* for 24 minutes after the section, so that during the last 4 minutes of the observation the temperatures on the two sides had again become equal.

These observations all show how much more permanent is the rise of temperature due to the section of the muscle nerve than the increase in the rate of blood-flow through the muscle. The difference in time between the two effects of the section is sufficiently great to make it difficult to accept the usual explanation, that the rise of temperature is due to the increased flow of blood alone; and yet it is not easy to prove that the rise of temperature is partially due to any other cause, such, for example, as the action of "thermic nerves" suggested by Claude Bernard.

Bernstein* endeavours to explain the abnormal length of the rise of temperature, which occurs in the foot under certain conditions after stimulation of the sciatic nerve, by the supposition, that a rise of temperature once started is able by a kind of cumulative action to produce a continuous increase of temperature up to a certain point; the initial rise, however brought about, causes a dilation of the vessels and therefore a further increase of temperature, which again causes a further dilation and so on, until at last equilibrium is established in conse-

* Pflüger's *Archiv*, Vol. xv. p. 590.

Remarks.	Time.	R. leg.	L. leg.
	4.14	35·3	35·1
	15	·3	·05
	16	·28	·05
	17	·25	·03
	18	·2	·01
	19	·2	·01
	20	·2	·0
Left nerve cut at 4.21′.45″. Merest trace of contraction.	21	·0	34·98
	22	·15	35·0
	23	·1	·0
	24	·1	·05
	25	·05	·05
	26	·0	·0
	27	34·98	·0
	28	·96	·0
	29	·9	·0
	30	·9	·0
	31	·82	34·96
Left crural prepared for stimulation.	32	·8	·9
	33	·77	·9
	34	·75	·9
	35	·7	·9
	36	·7	·88
	37	·68	·88
	38	·65	·9
	39	·6	·85
	40	·6	·9
	41	·6	·9
	42	·55	·95
	43	·5	·95
	44	·5	35·0
	45	·5	·0
Between 4.45′ and 4.46′ L. nerve stimulated for 30 sec.	46	·5	·0
	47	·48	·0
	48	·4	·0
	49	·4	·0
Curare.	50	·4	·0
	51	·38	·0
	52	·3	·0
	53	·25	·0
	54	·2	34·9
	55	·18	·88
	56	·15	·82
	57	·1	·8
	58	·05	·8
	59	·05	·78
	5.0	·0	·75
	1	·0	·75

The nerve was now stimulated with various strengths of current without producing any marked effect on the temperature which continued to fall on both sides.

Remarks.	Time.	R. leg.	L. leg.
	5.24	33·25	34·4
	25	·2	·4
	26	·2	·35
	27	·2	·35
	28	·2	·35
	29	·16	·3
	30	·16	·3
	31	·15	·3
R. crural nerve prepared.	32	·15	·3
	33	·1	·28
	34	·1	·2
	35	·08	·18
Between 5.36′ and 5.37′ right crural was cut, no trace of contraction.	36	·05	·15
	37	·3	·2
	38	·55	·1
	39	·65	·05
	40	·66	·05
	41	·6	·0
	42	·55	·0
	43	·5	33·98
	44	·5	·9
	45	·5	·9
	46	·5	·88
	47	·55	·85
	48	—	—
	49	·5	·8
	50	·5	·8
	51	·5	·8
R. crural crimped, no contraction.	52	·5	·7
	53	·5	·65
	54	·55	·6
	55	·5	·6
	56	·5	·55
	57	·5	·5
	58	·5	·5
	59	·5	·5
	6.0	·5	·5

quence of the loss of heat from the surface, and the rise of temperature ceases. This explanation, however, necessitates a continual dilation of the vessels, proceeding *pari passu* with the increase of temperature, and will not therefore explain the present case. I have endeavoured to find out whether any thermic effect can be produced by cutting the nerve in the curarised animal, when the femoral artery has been previously clamped. At present, however, I am in doubt, whether such experiments can give any trustworthy result, for, although the section stops to a great extent the fall of temperature caused by the clamping, yet I do not feel certain that the anastomoses of the muscle vessels with those of the skin, &c. are not sufficient to explain the effects produced, on the assumption that rise of temperature is due to increase of blood-flow alone.

I must then for the present leave the question undecided, and can say only, that the temperature at any given moment is not an indication of the state of the blood-vessels at that moment, but that, if a rise of temperature in the muscle is really due to an increase of blood-flow through the muscle, then the heating effect of the greater supply of blood takes a long time to attain its maximum, and a still longer time to disappear.

The other main discrepancy between Heidenhain's results and mine consists in the difference observed upon stimulation of the central end of the vagus. In order to confirm his results, I have taken temperature measurements with the thermometers placed both superficially between the rectus and crureus muscles and deeply between the crureus and vastus internus muscles, with and without simultaneous measurement of the blood-flow; as yet however, in accordance with the absence of any increase of flow in consequence of the stimulation, I have found no satisfactory sign of any increase of temperature. It is possible that this difference between his and my experiments may be due to the fact, that his animals were under curare alone, mine under curare and morphia or chloroform. Whether this is so, whether the use of anæsthetics prevents this action of the vagus nerve, I must leave to others to decide, as I am not able to settle the question in England, and will conclude with the remark that Heidenhain himself* is inclined to doubt the universality of the law, that the vessels of the muscles dilate upon stimulation of any afferent nerve; for, as he points out, if the skin vessels and the muscle vessels throughout the body dilate, whenever an afferent nerve is stimulated, then it is ex-

* *Loc. cit.* p. 50.

tremely difficult, if not impossible, to explain the rise of blood-pressure which he has observed on central stimulation, when the abdominal viscera have previously been cut off from the circulation. If, however, the dilation is confined to certain muscles, viz. those which contract reflexly in consequence of the stimulation, while the vessels of the rest of the muscles in the body are slightly constricted, then it becomes easy to understand how a slight rise of blood-pressure may be brought about, even without the co-operation of the vessels of the abdominal viscera.

VII. The chief results arrived at in the foregoing pages may be summed up as follows:

1. Section of the muscle nerve or of the abdominal sympathetic trunk, in the case of the muscles of the leg, causes a very great dilation of the arteries of the muscle. This dilation attains its maximum very quickly and lasts only a few minutes after the section.

2. On the other hand, the rise of temperature, as measured by a thermometer, caused by the section, attains its maximum at a time when the dilation of the vessels has already ceased, and the temperature remains high for a considerable length of time after the section.

3. For this reason thermometric measurements do not afford a good indication of the fulness of the muscle vessels at any given time.

4. Section of the muscle nerve following upon section of the abdominal sympathetic causes a very marked dilation of the arteries in the muscle. If a small dose of curare be given, this effect is lessened; and if the animal be thoroughly curarised, then the second section produces no effect.

5. When any operation, such as section or stimulation of a nerve, causes strong expiratory action of the abdominal muscles, this alone is sufficient to bring about an increased flow of blood through the muscles of the leg. Some portion then, though in all probability not the whole, of the effect noticed in the preceding paragraph must be ascribed to this cause.

6. Electrical or mechanical stimulation of the peripheral end of the muscle nerve causes a very marked dilation of the muscle arteries in the uncurarised animal, and a slighter dilation in the case of an animal curarised so as just to prevent contraction of the muscle upon stimulation of the nerve.

7. In the thoroughly curarised animal stimulation of the abdominal sympathetic trunk, or of the muscle nerve in all probability, causes a slight constriction of the arteries of the muscle.

8. According to present theories the easiest explanation of the above facts seems to be:

That the muscle nerve contains dilator and constrictor fibres of which the former predominate.

That the dilator fibres alone are affected by curare.

That section of the constrictor fibres removes the tonicity of the vessels which depends on the central mechanism, while section of the dilator fibres acts as a strong stimulation to them.

That the loss of tone consequent upon the section of the constrictor fibres is quickly regained by the action of the peripheral mechanism.

And that the constrictor fibres run in the abdominal sympathetic trunk.

9. Stimulation of an afferent nerve causes dilation of the muscle arteries, when it causes a reflex contraction of the muscle.

10. The same strength of stimulation causes a similar dilation without contraction of the muscle when the animal is curarised.

11. Stimulation of the central end of a nerve, such as the vagus, which does not cause any reflex contraction of the muscle, or any strong expiratory action of the abdominal muscles, produces no dilation, but rather, if anything, a slight constriction of the arteries of the muscles.

12. From the foregoing it follows, that the activity of the muscle however caused* is accompanied by a greater flow of blood through it; and the question is raised, whether the vessels of muscles do not assist in the production of the variations of blood-pressure brought about by stimulation of an afferent nerve, in those cases where that stimulation does not cause any contraction of the muscles in question.

In this paper I have spoken only of the effect of stimulating the muscle nerve by means of the interrupted current, or mechanically. I purposely abstained from discussing the effects of other kinds of stimulation, such as rhythmical, chemical, &c., because I have as yet

* With respect to voluntary contraction Mosso has shown by means of his Hydrosphygmograph that in this case too an increased flow of blood accompanies muscular contraction. *Sulle Variazioni locali del polso nell' antibraccio dell' uomo*, p. 59. Turin.

only made one or two experiments in this direction; and, therefore, preferred to leave this question for a future paper. And I am the more inclined to do this since the appearance of Grützner's paper* on the effects of different kinds of stimulation upon various nerves. It will be especially interesting to see whether stimulation of the peripheral end of the crural nerve by means of heating, or of the constant current, is without effect upon the nerve-fibres which regulate the blood-flow through the muscles, as Grützner shows by direct observation to be the case in the majority of centrifugal nerves, or whether the dilator fibres of the muscle vessels will in this respect behave similarly to the dilator nerves of the skin of the foot, which, according to the temperature measurements relied on by Grützner, afford a single and remarkable exception to what is otherwise a universal law.

In the carrying out of the foregoing experiments I have been greatly assisted by a grant of money kindly voted to me by the Grant Committee of the British Medical Association.

EXPLANATION OF FIGURES.

Plates IX., X., XI.

The majority of the figures represent the rate of blood-flow every 5 seconds. To obtain them the amount of blood which poured out during each interval of 5 seconds was estimated from the original curves and new curves drawn from the numbers so obtained, as is fully explained in my former paper. Some of the figures are facsimiles of the original curves of blood-flow and of the blood-pressure curves. All these are reduced to half their original size. The abscissa line is in every case divided into intervals of 5 seconds. To each figure is attached a vertical scale, each unit on which represents 0·1 cc. of outflow, so that in all cases the number 10 signifies an outflow of 1 cc. of blood during an interval of 5 seconds, 20 an outflow of 2 cc., &c. Further, when the blood-pressure curve is given as well as the curve of flow, then the same numbers represent each a blood-pressure of 10 mm. Hg., so that in Fig. 18, for example, 13 represents a blood-pressure of 130 mm. Hg. and an outflow of 1·3 cc. of blood during an interval of 5 seconds. All the curves read from left to right. The arrows indicate the commencement and termination of the stimulation or the place of section of the nerve. The curve of blood-pressure is always placed exactly over the curve of blood-flow, so that the arrows apply equally to the two curves.

* Pflüger's *Archiv*, Vol. xvii. p. 215.

Fig. 1. Feb. 15, 1878. Weight 7·5 kilo. Curare and morphia. Section of crural nerve.

Fig. 2. Jan. 31, 1878. Weight 8 kilo. Curare and morphia. Section of crural nerve.

Fig. 3. March 4, 1878. Weight 13·75 kilo. Morphia and chloroform. Section of abdominal sympathetic.

Fig. 4. Dec. 18, 1877. Small dog. Figure was obtained 1 min. after the termination of Fig. 5, and shows the effect of clamping the femoral vein below as well as above the orifice of the extensor vein.

Fig. 5. Same experiment as Fig. 4. Strong stimulation of crural nerve for 4 seconds. In the figure the whole amount of blood, which flowed out in the 5 seconds interval during the first 4 of which the muscles were tetanized, is given, without any separate measurement of the outspurt which occurred at the beginning of the tetanus.

Fig. 6. May 9, 1878. Weight 6·5 kilo. Morphia and chloroform. Clamping of femoral artery.

Fig. 7. Same as Fig. 4. Single induction shock. The outspurt due to the single contraction of the muscles is shown.

Fig. 8. Feb. 20, 1878. Weight 6·25 kilo. Curare and morphia. Figures under 8*a* give stimulation of crural nerve with different doses of curare. Fig. 8*b* shows the effect of crimping the nerve. Between the upper figure in 8*a* and 8*b* there was a pause of 5 minutes.

Fig. 9. Same as Fig. 1. Crural nerve crimped. No contraction of the muscles.

Fig. 10. Same as Fig. 2. Crural nerve crimped. No contraction.

Fig. 11. Feb. 18, 1878. Weight 20·5 kilo. Curare and morphia. Stimulation of the abdominal sympathetic.

Fig. 12. June 13, 1878. Weight about 8 kilo. Morphia and chloroform. Section of crural following upon section of the abdominal sympathetic. The outspurt due to the momentary contraction of the muscles is shown in the curve.

Fig. 13. April 1, 1878. Weight 9 kilo. Morphia and chloroform. Stimulation of saphena after section of crural nerve. Shows the effect of violent expiration on the blood-flow through the muscles.

Fig. 14. June 17, 1878. Weight 8 kilo. Morphia and chloroform. The curve consists of three parts. The first portion shows the rate of flow 1½ hours after section of the abdominal sympathetic; the second gives the effect of section of the left crural, and the third of section of the right crural. The blood-flow was measured on the left side in all three portions of the figure.

Fig. 15. Jan. 30, 1878. Morphia and chloroform. Blood-pressure curve one half original size. Deduced curve of flow. Stimulation of central end of vagus.

Fig. 16. Same as Fig. 15. Original curve of blood-flow and blood-pressure curve, both reduced one-half size. Stimulation of central end of radial

nerve. The reflex contraction of the extensor muscles is shown on the curve of blood-flow. Between Figs. 15 and 16 there was an interval of 16 min.

Fig. 17. Same experiment as Figs. 15 and 16. Between Figs. 16 and 17 there was a pause of 3 minutes. Stimulation of central end of radial nerve. Original curves of blood-flow and blood-pressure, both reduced one-half size. The reflex contraction of the muscles is shown on the curve of flow.

Fig. 18. May 4, 1878. Weight 8·5 kilo. Morphia and chloroform. Stimulation of central end of saphena. Deduced curve of blood-flow in which the outspurt shows when the contraction of the muscles occurred. Blood-pressure curve.

Fig. 19. Same as Fig. 18. An interval of 14 minutes between the two curves. Stimulation of saphena. Deduced curve of flow showing where contraction occurred and blood-pressure curve.

Fig. 20. Same as Fig. 19. A pause of 7½ minutes between the two curves. Stimulation of central end of vagus. Blood-pressure curve and deduced curve of flow.

Fig. 21. Same as Fig. 20. Stimulation of saphena. Blood-pressure curve and deduced curve of flow. The contraction of the muscles which occurred when the sec. coil was pushed to 60 mm. is not shown on the curve, but the whole outflow during the 5 seconds in which the contraction occurred is given instead.

Fig. 22. Jan. 22, 1878. Small terrier bitch. Morphia and chloroform. Stimulation of the central end of vagus. Blood-pressure curve and deduced curve of flow.

Fig. 23. Aug. 14, 1877. Dog, small. Morphia and curare. Stimulation of central end of vagus.

Fig. 24. Nov. 24, 1877. Dog, medium size. Morphia and curare. Stimulation of central end of saphena.

Fig. 25. Same as Fig. 24. Stimulation of central end of saphena.

Fig. 26*. March 20, 1878. Weight 6·5 kilo. Morphia and chloroform. Stimulation of central end of vagus. Blood-pressure curve and deduced curve of flow.

Fig. 27. Same as Fig. 26. Curare. Stimulation of central end of vagus. Blood-pressure curve and deduced curve of flow.

Fig. 28. March 26, 1878. Weight 6 kilo. Chloroform and curare, no morphia. Stimulation of central end of saphena.

* The scale in this figure has not been drawn quite correctly for the blood-pressure curve; 16 should have been 15, 15 have been 14, and so on. The scale is correct for the curve of blood-flow.

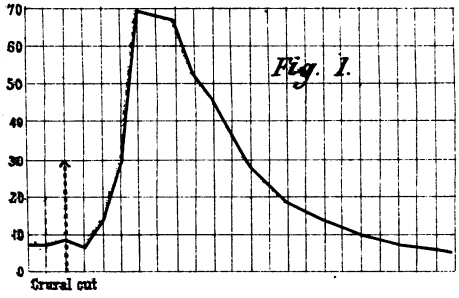


Fig. 1.
Crural cut

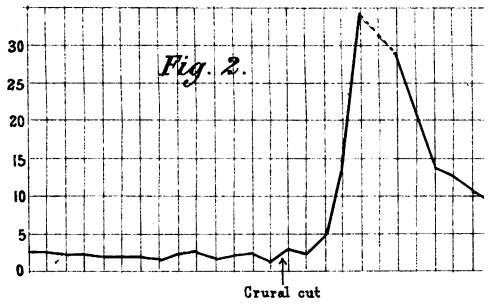


Fig. 2.
Crural cut

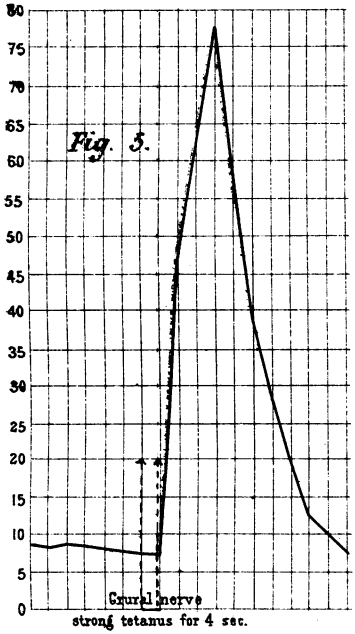


Fig. 5.
Crural nerve
strong tetanus for 4 sec.

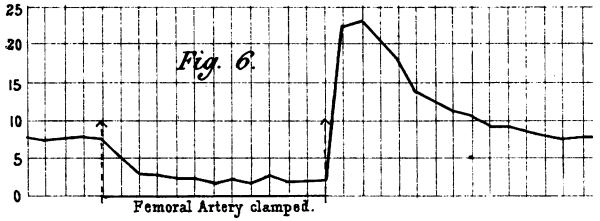


Fig. 6.
Femoral Artery clamped.

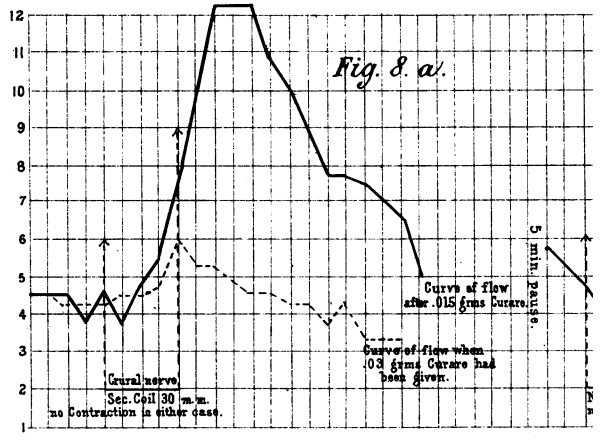
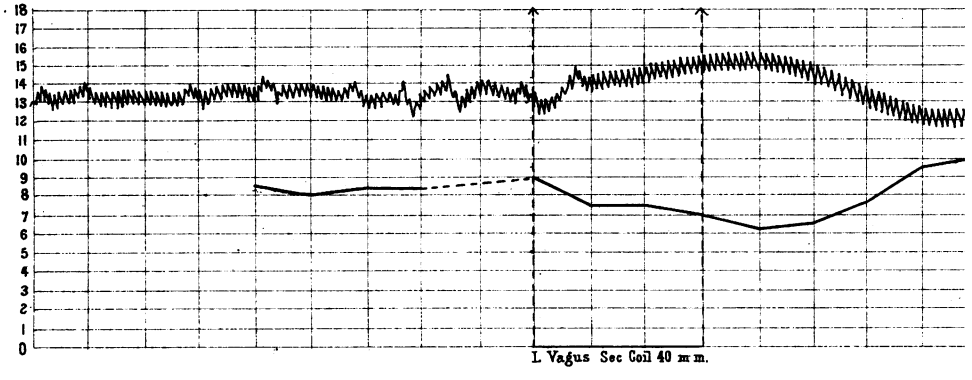


Fig. 8. a.
Curve of flow after .015 grms Curare.
5 min. pause.
Curve of flow when .03 grms Curare had been given.
Crural nerve
Sec. Coil 30 m.m.
no Contraction in either case.


L Vagus Sec Coil 40 m m.

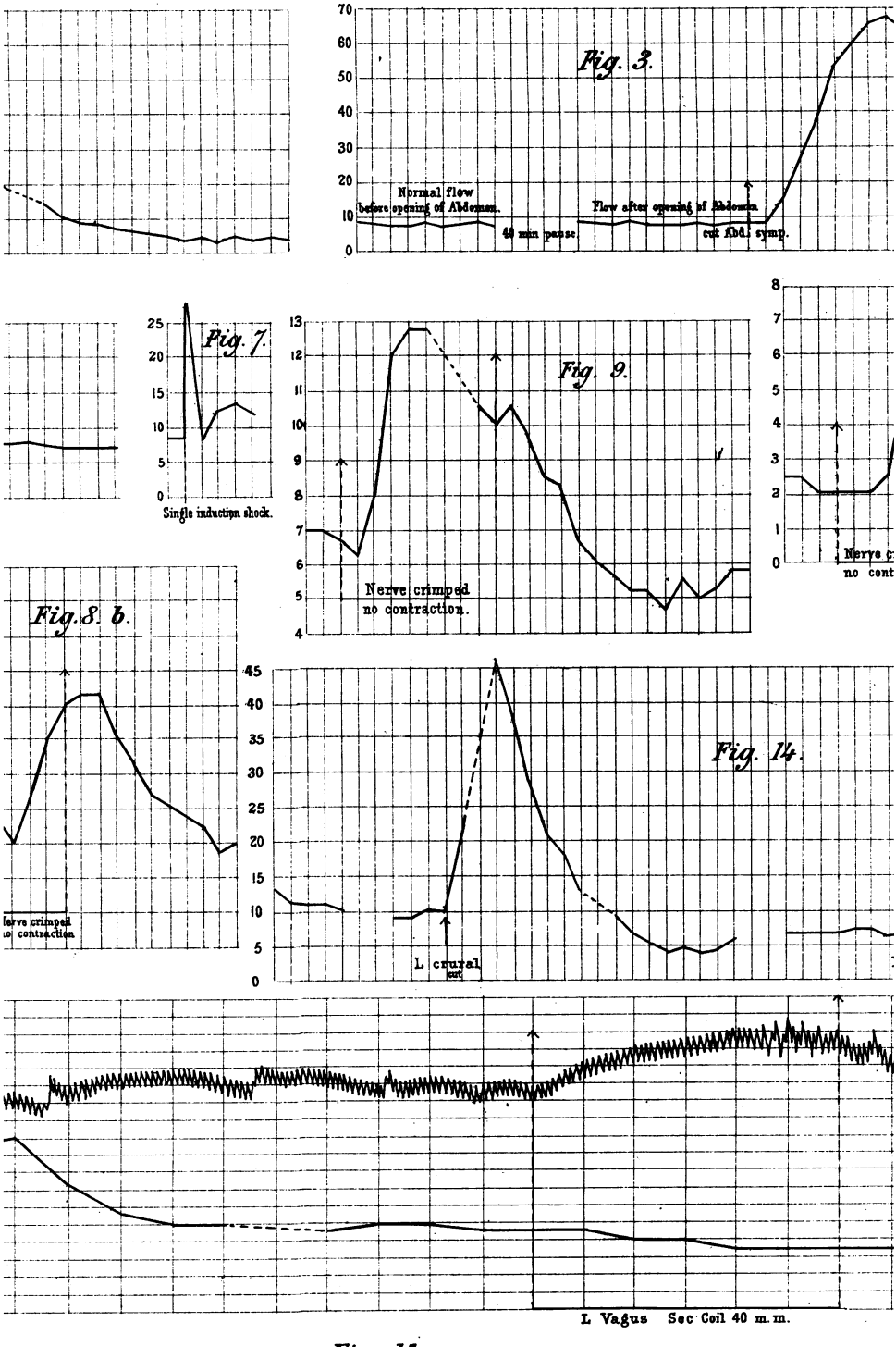
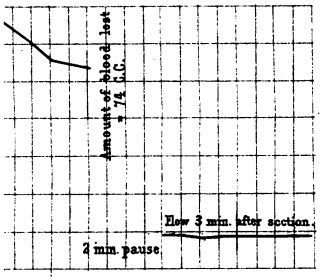


Fig. 3.
Normal flow
before opening of Abdomen.
40 min pause.
Flow after opening of Abdomen
cut Abd. symp.
Fig. 7.
Single induction shock.
Fig. 9.
Nerve crimped
no contraction.
Nerve c
no cont
Fig. 8. b.
Nerve crimped
no contraction
Fig. 14.
L crural
cut
L Vagus Sec Coil 40 m.m.

Fig. 15.


Amount of blood lost
= ¼ C.C.
Flow 3 mm. after section.
2 mm. pause

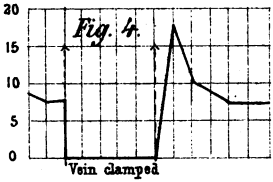


Fig. 4.
20
15
10
5
0
Vein clamped

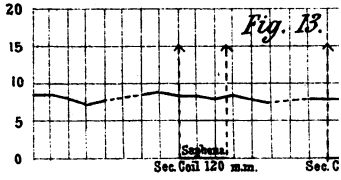
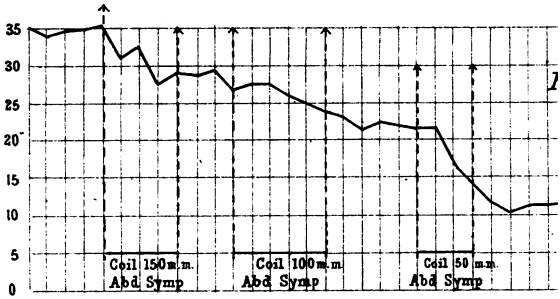


Fig. 13.
20
15
10
5
0
Sec. Coil 120 m.m.


35
30
25
20
15
10
5
0
Coil 150 m.m.
Abd. Symp
Coil 100 m.m.
Abd. Symp
Coil 50 m.m.
Abd. Symp

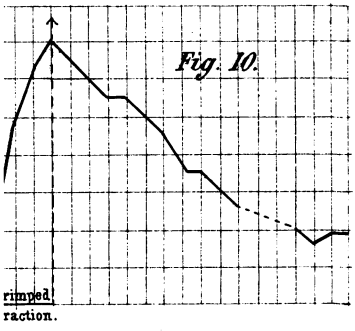
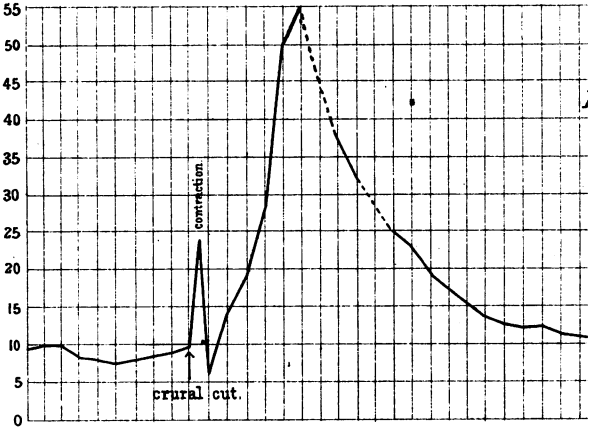
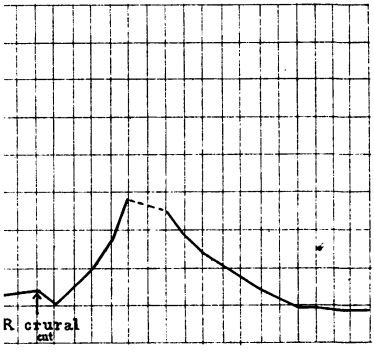
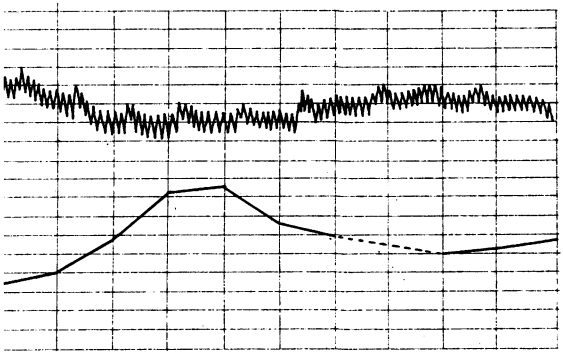


Fig. 10.
rimped
raction.


55
50
45
40
35
30
25
20
15
10
5
0
contraction
crural cut.


R. crural
cut



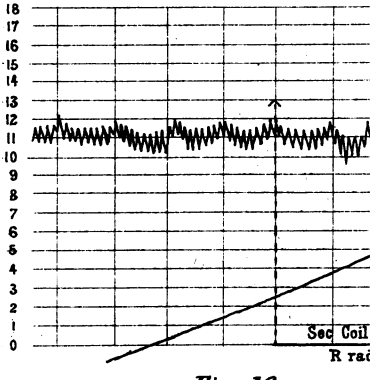

18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Sec. Coil

Fig. 16.

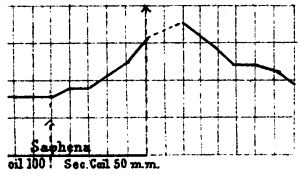


Fig. II.

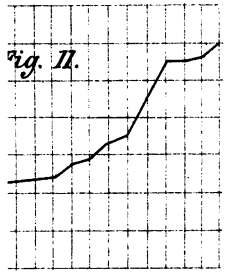
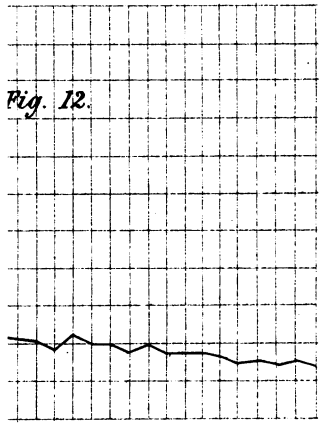
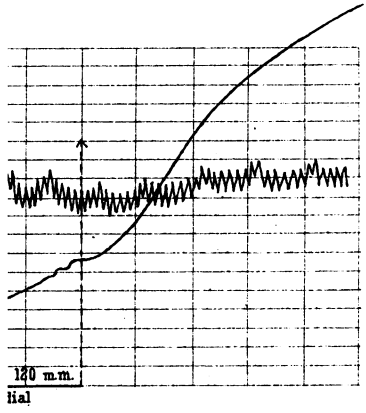


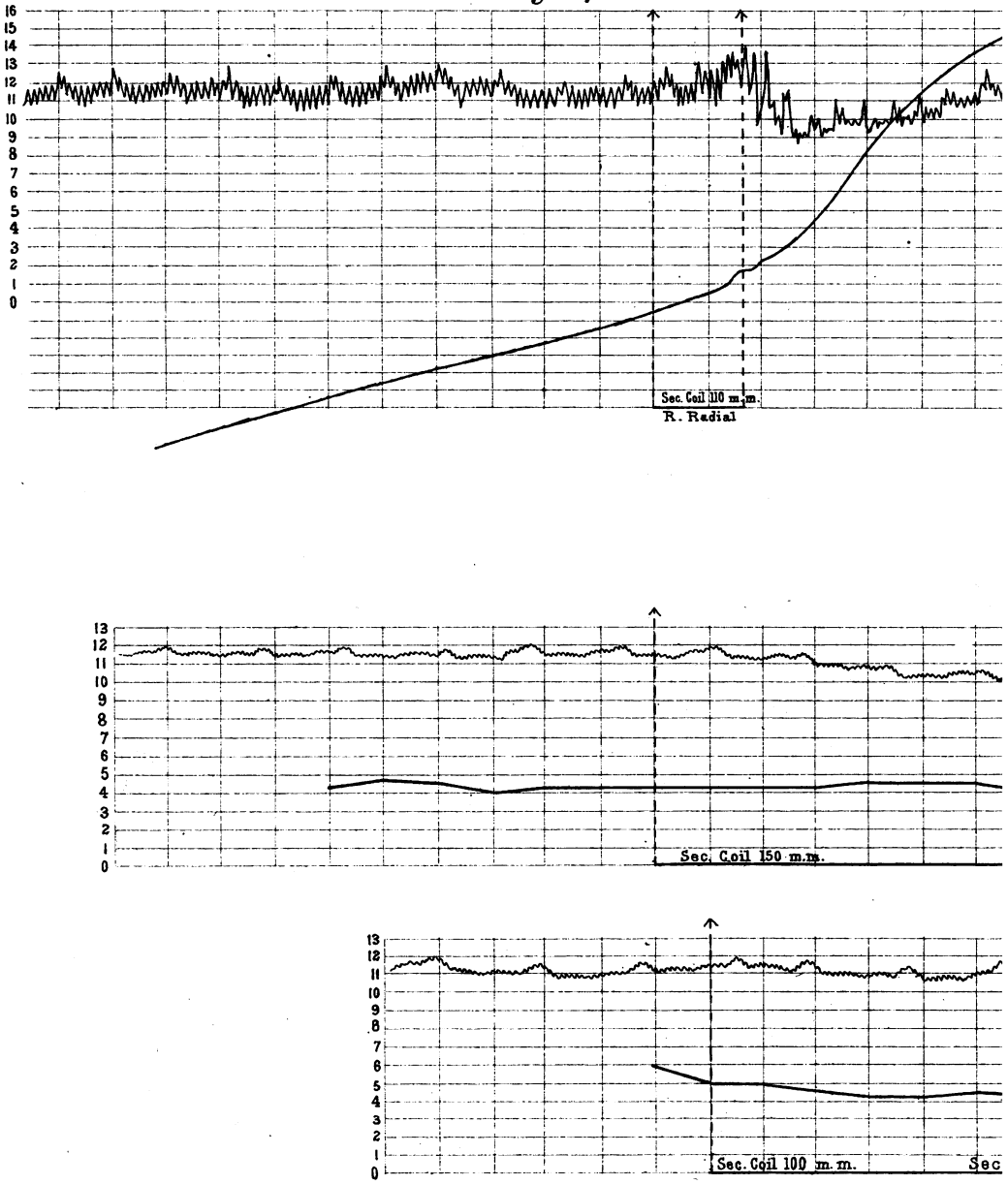
Fig. 12.

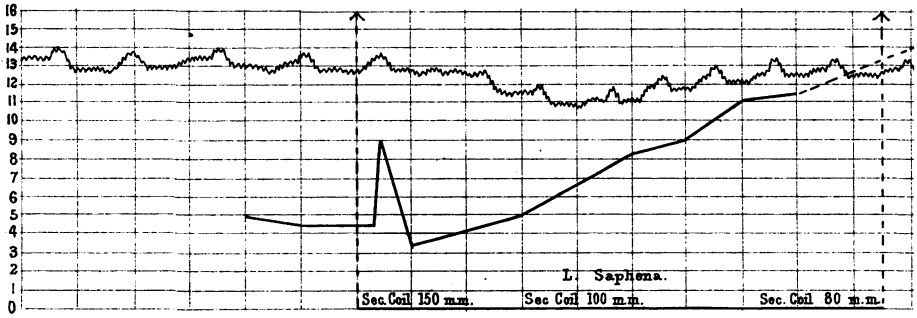


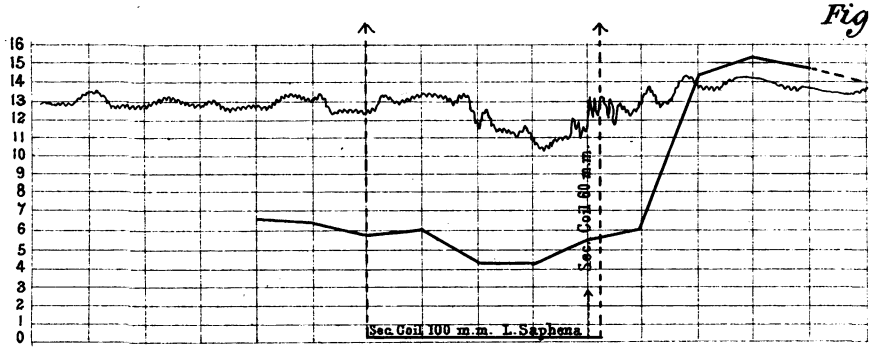


F. Huth, Lith^r Edin^r

Fig. 17.







Fig

Fig 19.

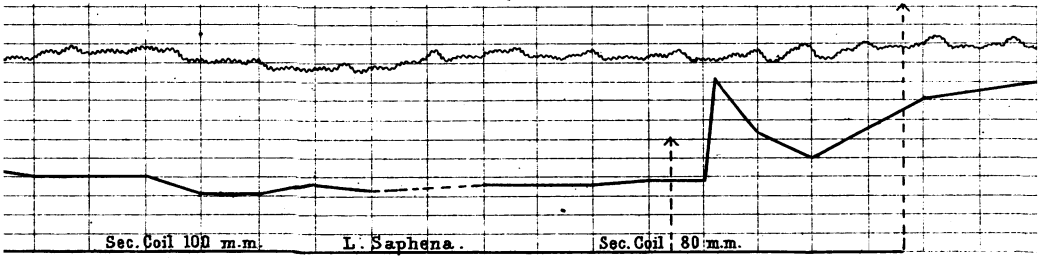


Fig. 20.

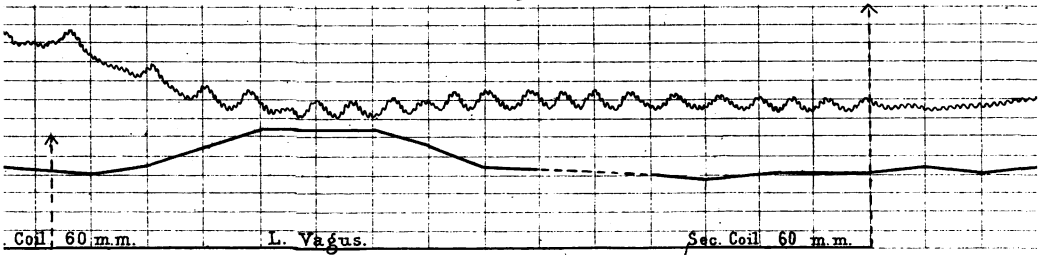
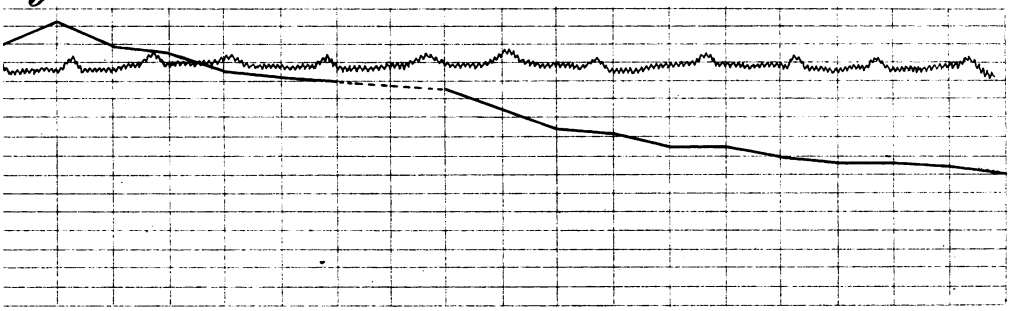
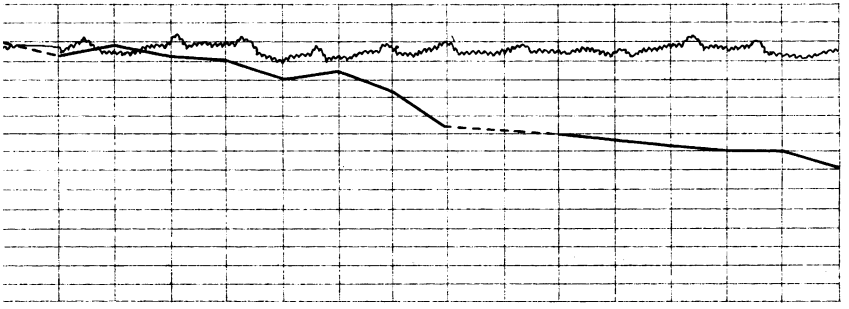


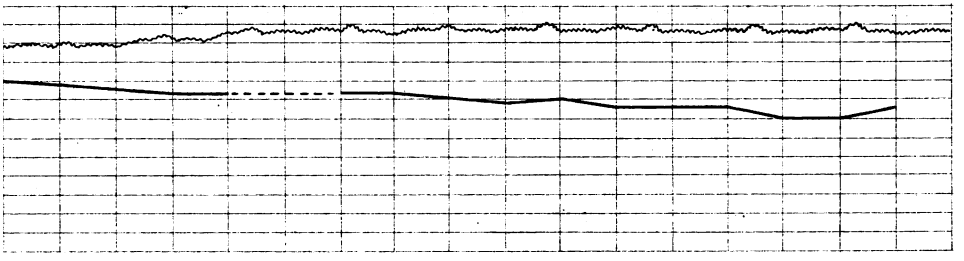
Fig. 18.

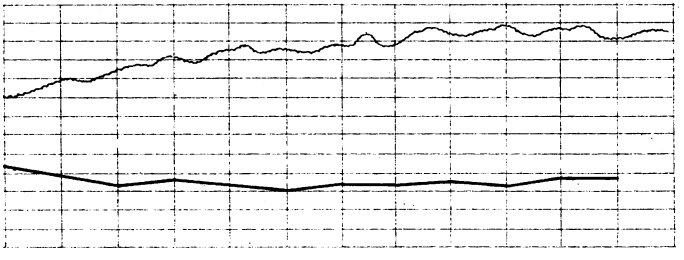
Vol. I Pl. X.



. 21.







F. Huth, Lith.r Edin.r

Fig. 22.

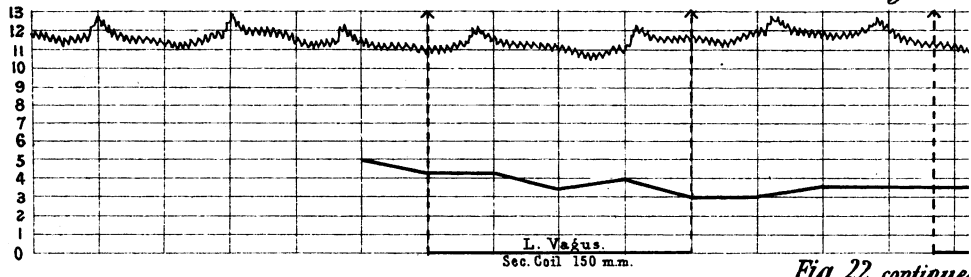
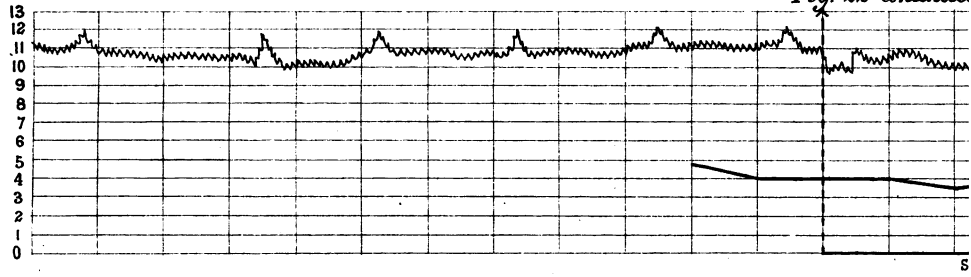
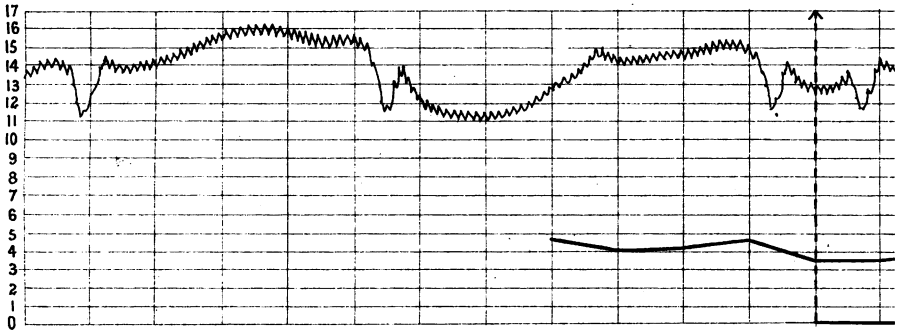
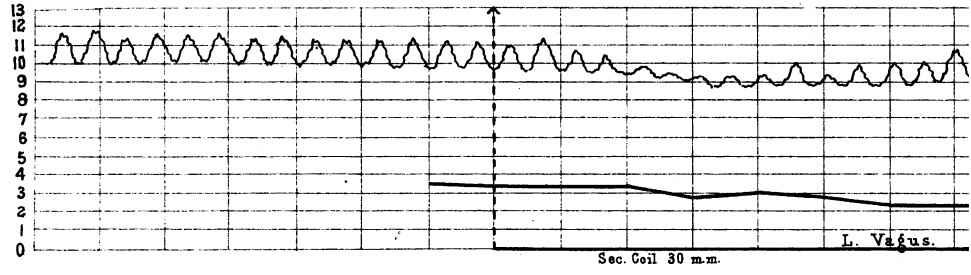


Fig. 22 continued.







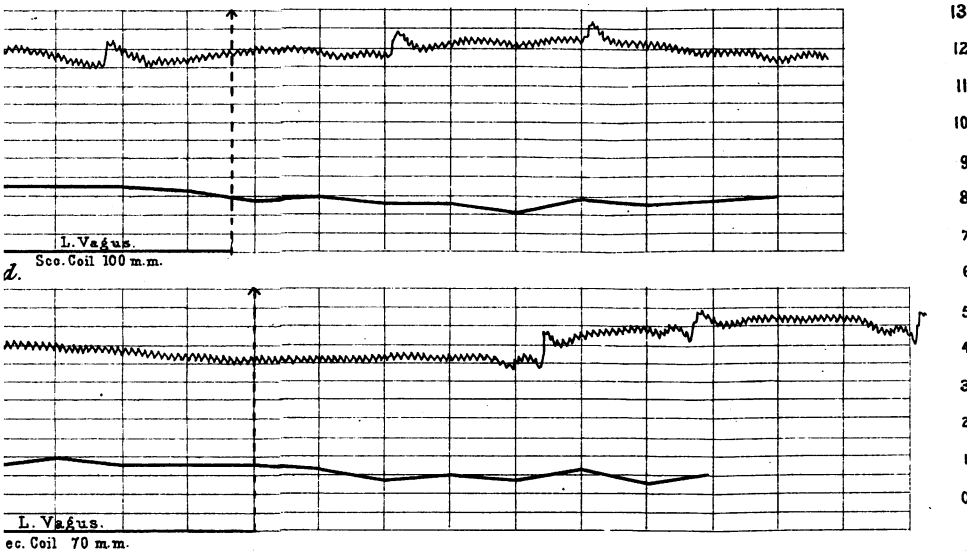

13
12
11
10
9
8
7
6
5
4
3
2
1
0
L. Vagus.
Sec. Coil 100 m.m.
d.
L. Vagus.
ec. Coil 70 m.m.

Fig. 26.

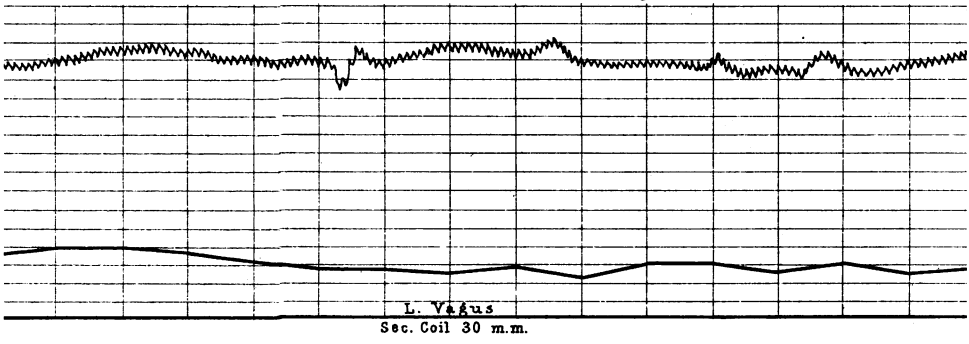

L. Vagus
Sec. Coil 30 m.m.

Fig. 27.

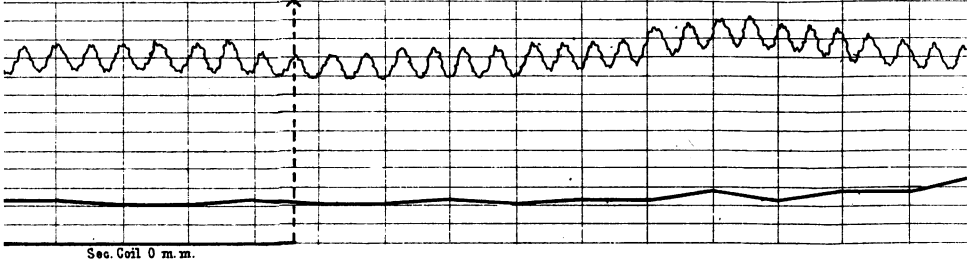
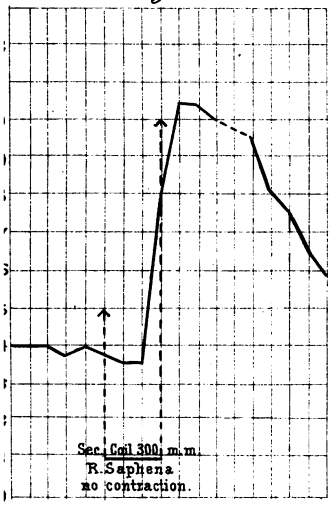

Sec. Coil 0 m.m.

Fig. 24.



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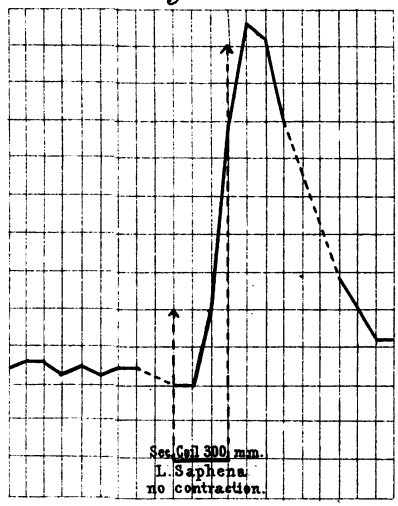
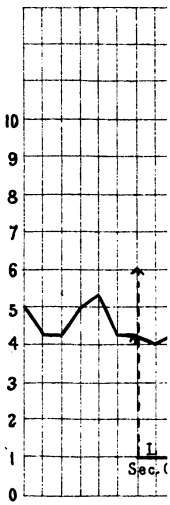
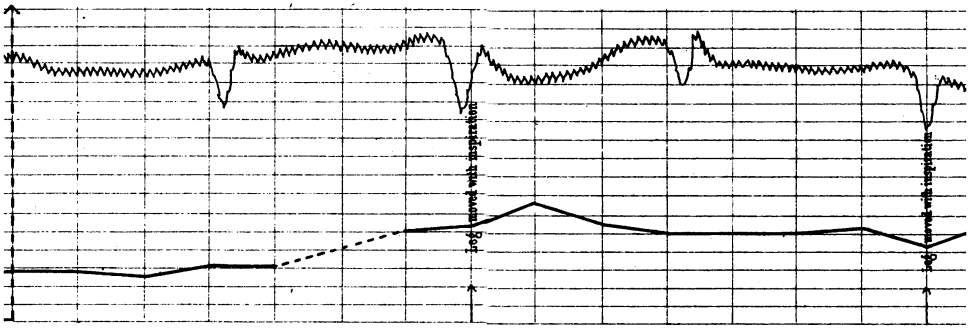






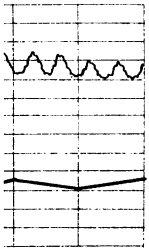
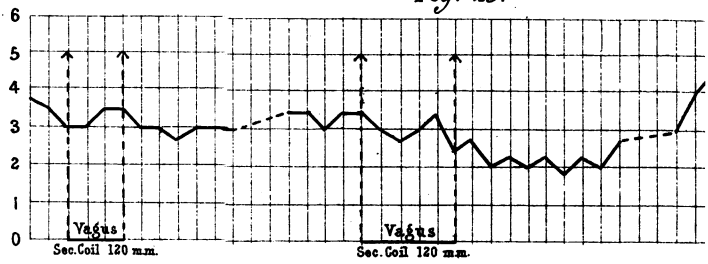
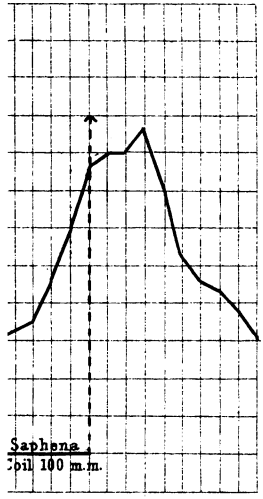


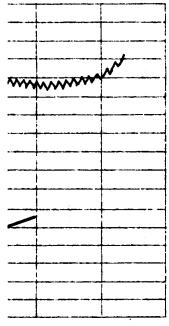
Fig. 23.

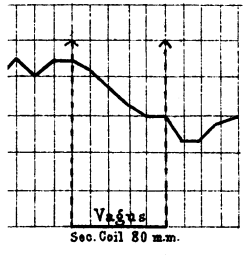


Vol. I. Pl. XI.

Fig. 28.







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