ON THE EFFECTS OF THE KNEADING OF MUSCLES UPON THE CIRCULATION, LOCAL AND GENERAL.

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The experiments the results of which are given below had for their object (i) the determination of the changes occurring in the circulation in a given group of muscles during, and after massage of them, and (ii) the effect upon the general blood pressure of the massage of a considerable muscular area.

I.

The method adopted to detect any change in the amount of blood flowing through a given group of muscles was the same in principle as that invented by Ludwig and used by his pupils Sadler[1] and Gaskell[2], viz. the determination of the amount of blood issuing in a given time from the efferent vein.

All stasis of blood in the muscles was obviated by directing at will, by means of clamp forceps, the venous blood issuing from the muscles either through the efferent cannula, or through the femoral vein, back to the heart. The cannula, as described by Gaskell was inserted into the femoral vein, and all branches except that coming from the extension muscles were ligatured.

Two modifications in method were introduced by us. One consisted in the use of three-way cannulæ on the pattern of the François-Franck, with very large bulbs, and short necks, which were filled, as was the whole system of tubes into which the blood was received, with a 25 % solution of magnesium sulphate. The long horizontal limb of the cannula was closed by a glass stopper[3], made to fit tightly by having

[1] *Ludwig's Arbeiten*, 1869, p. 93.

[2] Gaskell. *Ludwig's Arbeiten*, 1876, p. 45.

[3] This method of closing the third way of a three-way glass cannula was used by one of us (Tunnicliffe) 2½ years ago in conjunction with Mr Locke for blood pressure work.

a piece of rubber tubing slipped over it. The second modification was that the volume of blood lost was measured, not by the change in level of the column of the anticoagulation fluid, in the distal limb of a U tube (vertically), but by the advance of this column along a long graduated tube placed horizontally exactly at the level of the vein, and of sufficiently narrow bore to give an even meniscus. The advantage of this method was, that starting with the long graduated tube at the level of the vein, there was no negative pressure tending to suck the blood out at the beginning of bleeding, and as the volume of blood lost increased, this latter did not, as when it was registered vertically, exert a positive pressure, and thus tend to diminish the volume of blood lost towards the end of the bleeding. When we bear in mind the lowness of venous blood pressure the influence exerted at the beginning by a negative pressure, and at the end by a positive one, is not to be neglected[1]. Before and after each observation the whole system of tubes including the portion of the vein next the cannula was washed out by means of a syringe, which was at other times clamped off. If during the washing out a clot was found, which thanks to the shape of the cannulæ and the $MgSO_4$ solution, was very seldom the case, the previously obtained readings on the graduated tube were discarded. As a rule both femoral veins were prepared and the right or left used at will for observation, by clamping off the tube leading from the other to the wash bottle. Time was measured by a metronome. The long graduated tube was provided with a number of rubber rings made by snipping ordinary red tubing of such a size as to permit of being easily moved up and down the tube, but fitting too tightly to slip. The arrangement of the apparatus is best seen from the accompanying diagram (Fig. 1, *A*). The long horizontal tube, which was graduated to $\frac{1}{4}$ c.c., is shown at *a*; by means of the screw clamp at *c* the recording apparatus could be completely cut off, this was useful during washing out. The screw clamp *b* and the T piece *d* were inserted for bringing back the level of the fluid to the zero of the scale at the end of each observation, by these means this could be accomplished without disturbing the rest of the apparatus. The other parts of the apparatus explain themselves. The cannula used is drawn at *B* (Fig. 1). To begin an observation, the syringe tube being clamped off, the vein cannula was by opening the corresponding clamps put into communication with the wash bottle, and through it with the long graduated tube, the current of venous blood was then directed through the cannula by applying the bulldog forceps

[1] The modifications in method were due to one of us (Tunnicliffe).

to the femoral vein on the proximal side of the opening of the muscular vein, and removing the bulldog forceps from that part of the femoral vein lying between the opening of the muscular vein and the cannula; almost immediately the column of fluid in the graduated tube began to

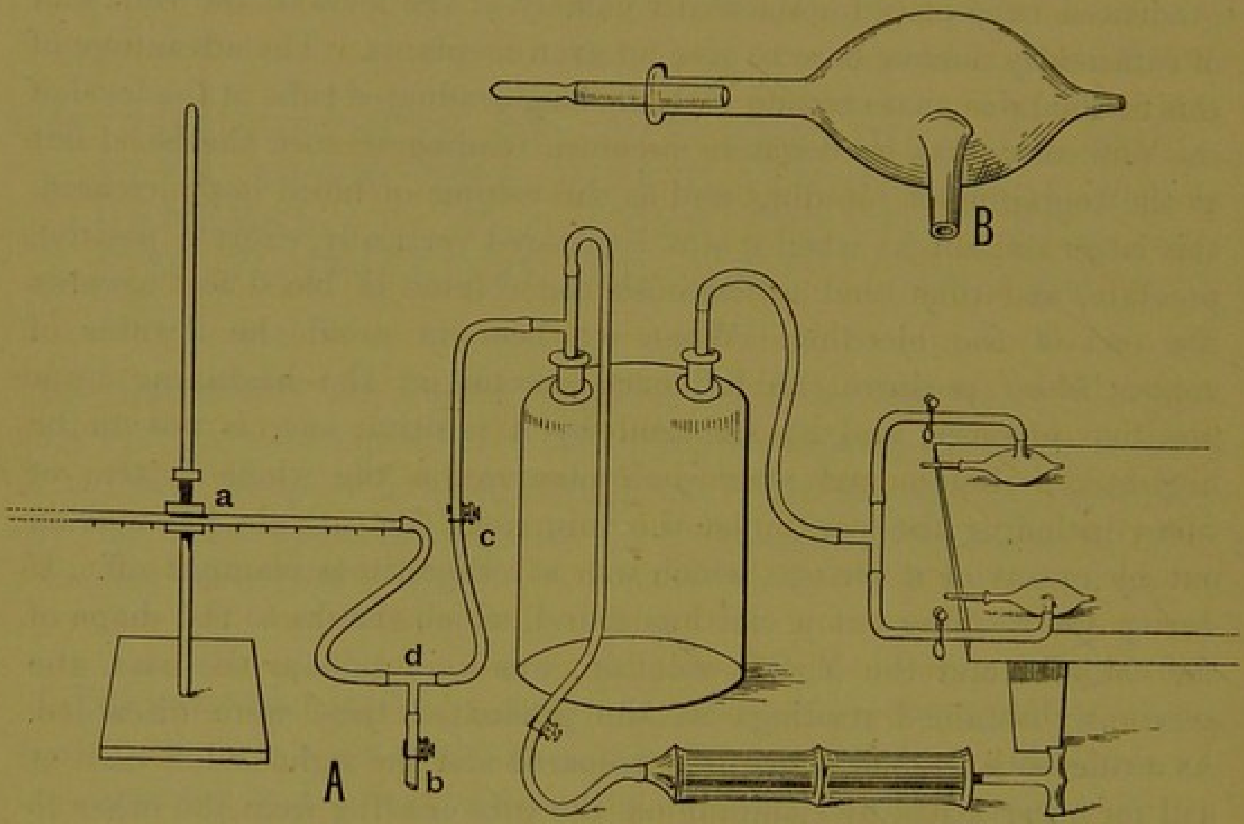


Fig. 1.

advance. When it was fairly started, a rubber ring was placed at the level of the fluid, and the time counted by the metronome. After an interval of 5, 10, 20, or 30 seconds as the case might be, another ring was placed at the level of the advancing column of fluid, which marked its position at the corresponding time. The position of the column was marked at the end of each interval in this way, throughout the whole observation, which was brought to a close by applying the distal bull-dog forceps to the femoral vein, and removing from it the proximal ones. The distances between the rings gave the amounts of blood lost in the corresponding time intervals, and could be noted at leisure at the end of each observation.

To save confusion the same time interval was always used throughout a given observation, and the rubber rings were differently turned for the intervals during simple bleeding, during massage and after massage.

This method greatly facilitated the exact determination of the amount of blood lost during a given short interval of time, and since the whole could be read off at the end of the observation, no interruption of this for the purpose of reading was necessary. Owing to the fact shown, by Gaskell[1], that bleeding from the efferent muscular vein tends to diminish with the length of the observation, any loss of time during a continuous bleeding introduces an important element of error.

The animals used for the experiments were cats and dogs, they were fully anæsthetized and were absolutely free from any manifestations of struggling during the bleeding observations.

The routine method was to ascertain the amount of blood lost in a given time (i) during simple bleeding, (ii) during kneading of the muscles, (iii) after kneading.

With regard to the method of massage it should be said that when the animal was under the anaesthetic the cords fastening the legs to the rabbit holder, or the dog table, as the case might be, were loosened, and the buttocks well raised on a cushion. The result of this was that at the desired time massage could be commenced at once, without altering the position of the leg, the hand being passed beneath the leg, and the muscles at the outside of the thigh firmly kneaded between the fingers and thumb. The raising of the limb alone apart from any massage, caused an increase in the flow of blood, and it was to avoid this source of error that the buttocks were well raised at the beginning of the experiment so as to leave room for the introduction of the hand between the board and the animal's thigh. The experiment protocols are as follows.

EXPERIMENT I. Female cat. 2·5 kilos. Left leg used. The number of c.c. given is in each case the average per 5 secs. during 30 secs.

OBS. I.	Simple bleeding	·2 c.c.
	During massage	·6 c.c.
	Immediately after massage	·38 c.c.
	2 mins. after cessation of massage	·6 c.c.
	10 mins. „ „ „	·12 c.c.

Massage was repeated 11 mins. after first massage with following results:

During massage	·38 c.c.
Immediately after massage	·38 c.c.
7 mins. after massage	·12 c.c.

OBS. II. Taken after several minutes' rest.

Simple bleeding	·08 c.c.
During massage	·33 c.c.
Immediately after	·16 c.c.

[1] *Ludwig's Arbeiten*, loc. cit.

Exp. II. Female dog. 10 kilos. The dog lost a good deal of blood in the dissection. Left leg used.

Obs. III. 2.45. Average flow per 5 secs. during 15 secs.

Simple bleeding	·4 c.c.
During massage	·6 c.c.
Immediately after	·5 c.c.
30 secs. after	·3 c.c.

Obs. IV. After 5 mins. rest the following results were obtained.

Average flow per 5 secs. during:

15 secs. simple bleeding	·25 c.c.
30 secs. massage	·58 c.c.
15 secs. immediately after massage	·66 c.c.
15 secs. 90 secs. after cessation of massage	1·33 c.c.
15 secs. 3 mins. after cessation of massage	·66 c.c.
15 secs. 6 mins. after massage	·08 c.c.

During the next observation a clot formed in the system of tubes leading from the cannula to the wash bottle, the results were accordingly discarded, when the clot was removed the animal was allowed to rest and at 3.55, i.e. nearly an hour after the last observation, another (No. V.) was taken.

Obs. V. Average per 5 secs. during 15 secs.

Simple bleeding	·60 c.c.
Massage	·41 c.c.
Immediately after massage	·71 c.c.
3 mins. after massage	·66 c.c.
7 mins. after massage	·50 c.c.

Observation IV. shows strikingly the increase of flow both during and after massage, especially the latter, which in two cases after 30 secs., and 15 secs. massage, lasted for 3 minutes.

Exp. III. Dog. 10 kilos. Left leg used.

Obs. VI. The number of c.c. given is in each case the average per 5 secs. during 15 secs.

Simple bleeding	·5 c.c.
Massage	1·80 c.c.
Immediately after massage	1·13 c.c.

Obs. VII. After 5 mins. rest.

Simple bleeding	·30 c.c.
Massage	·33 c.c.
Immediately after massage	·56 c.c.
15 secs. 3 mins. after massage	1·33 c.c.

Obs. VIII. After 3 mins. rest.

Simple bleeding	·83 c.c.
Massage	1·33 c.c.
Immediately after massage	·90 c.c.
Next 15 secs.	·66 c.c.

Immediately after the last observation a very slight colourless clot was found. It was however so slight that it could scarcely have influenced the results.

Obs. IX. After 1 hr. rest.

Simple bleeding	·83 c.c.
15 secs. massage	·80 c.c.
Next 15 secs.	·70 c.c.
Next 15 secs.	·63 c.c.

Obs. X. After 4 mins. rest.

Simple bleeding	·80 c.c.
Massage	·43 c.c.
Next 15 secs.	·6 c.c.
Next 15 secs.	·84 c.c.

These last two observations show but a very slight change.

Exp. IV. Female dog. 8 kilos. Left leg used.

Obs. XI. Amounts in consecutive 5 second intervals were

During simple bleeding		·75 c.c.	·75 c.c.	1·00 c.c.	·6 c.c.
During massage	1·00 c.c.	·8 c.c.	1·0 c.c.	·9 c.c.	·9 c.c.
After massage	(·2+1·3)=1·5 c.c.	1·6 c.c.	1·3 c.c.	1·00 c.c.	·75 c.c.

This shows a slight increase during massage and a considerable increase after massage. Immediately after massage the column invariably moved very slowly, the above reading gave only ·2 c.c. for the first 2·5 secs. after massage. This result will occur again and will be discussed later.

Obs. XII. After 15 mins. rest. Same leg.

Simple bleeding	·6 c.c.	·8 c.c.	1·1 c.c.			
During massage	·8 c.c.	·9 c.c.	·7 c.c.	·75 c.c.	·76 c.c.	·75 c.c.
After massage	(·1+·7)=·8 c.c.	1·5 c.c.	1·3 c.c.	1·4 c.c.		

Obs. XIII.

Simple bleeding	1·25 c.c.	·75 c.c.	1·5 c.c.
During massage	1·1 c.c.	1·2 c.c.	1·5 c.c.
After massage	2·2 c.c.	2·2 c.c.	2·00 c.c.

Here the increase during massage is practically absent, but that after massage is more marked.

Exp. V. Dog. 12·5 kilos. Right leg used. In this experiment 10 second intervals were used instead of 5 second intervals.

Obs. XIV.	Simple bleeding	1·25 c.c.	1·0 c.c.	1·0 c.c.
	During massage	2·0 c.c.	1·4 c.c.	2·0 c.c.
	After massage	1·75 c.c.	2·4 c.c.	2·0 c.c.
Obs. XV.	After 8½ mins. rest.			
	Simple bleeding	1·5 c.c.	2·4 c.c.	1·8 c.c.
	During massage	2·1 c.c.	1·25 c.c.	1·8 c.c.
	After massage	·75 c.c.	1·1 c.c.	1·0 c.c.

This last observation shows a diminution in the flow both during and after massage. In this case however the simple bleeding average is very high, nearly double what it was in the same animal 8½ minutes before (vide Obs. XIV.), and the point which naturally strikes one here, is whether this increase in the simple bleeding average at the commencement of the observation, is not itself a post massage effect.

Obs. XVI. After 10 mins. rest.

Simple bleeding	1·75 c.c.	1·6 c.c.		
During massage	2·5 c.c.	2·0 c.c.		
After massage	(·25+1·0)=1·25 c.c.	2·25 c.c.	1·8 c.c.	1·00 c.c.

Obs. XVII.	Simple bleeding	1·25 c.c.	1·5 c.c.	1·6 c.c.	
	During massage	2·5 c.c.	1·6 c.c.	1·9 c.c.	
	After massage	(·5+·9)=1·4 c.c.	2·0 c.c.	1·6 c.c.	1·4 c.c.

Obs. XVIII. After 15 mins. rest. This observation consisted entirely of simple bleeding, and its object was to show the diminution in the amount of blood lost during a given time interval towards the end of a series of such intervals. The blood flow in consecutive 10 sec. periods was

1·0 c.c. ·9 c.c. ·8 c.c. ·8 c.c. ·75 c.c. ·75 c.c. ·75 c.c. ·7 c.c. ·6 c.c.

In putting the results of the above protocols together we shall in each case compare the amount of blood lost during a given interval of time, either during massage, or after massage, with that lost during an equal time interval during simple bleeding, and shall quote the one as being half, double or treble the other. We judge it best however to point out, that these figures are strictly speaking not comparable, since the longer the duration of bleeding the less the amount of blood lost in a given time. This is shown by Obs. XVIII., which is in accordance with Sadler's[1] and Gaskell's[2] results. Since the readings during massage

[1] *Loc. cit.* [2] *Loc. cit.*

were generally taken after 30 secs. bleeding the fallacy here would probably be small, but the post massage readings taken after 60 secs. continuous bleeding, i.e. after the animal had lost from 10 to 15 c.c. of blood are in all probability very much too small. The diminution of bleeding caused by the loss of blood tending very materially to mask the increase due to the post massage condition of the muscles.

Neglecting the simple bleeding observation, in all 17 observations were made, in 3 of these the results were negative, i.e. the bleeding from the efferent muscular vein was neither increased during massage of the respective muscles nor after massage of them. In two of these instances the observations were taken rather late in the experiment, i.e. after the animal had lost a considerable amount of blood. In the third experiment this was not the case, and the cause of the result is difficult to see. These results are however interesting in showing that the matter is not a simple one. In one of the remaining 14 observations the quantity of blood was slightly diminished during massage, in all the others it was considerably increased both during and after massage.

The following table shows at a glance the amount of this increase.

The denominator of the fractions denotes the amount during simple bleeding, the numerator the amounts during and after massage respectively.

Massage			Post Massage	
Number of Obs.	Ratio of simple bleeding to massage.	Approximate increase.	Ratio of simple bleeding flow to post massage flow.	Approximate increase.
I.	$\frac{\cdot 6}{\cdot 2}$	Treble	$\frac{\cdot 6}{\cdot 2}$	Treble
II.	$\frac{\cdot 33}{\cdot 08}$	Treble	$\frac{\cdot 16}{\cdot 08}$	Double
III.	$\frac{\cdot 6}{\cdot 4}$	One and a half times	$\frac{\cdot 5}{\cdot 4}$	One and a quarter times
IV.	$\frac{\cdot 58}{\cdot 25}$	Double	$\frac{1\cdot 33}{\cdot 25}$	Five times
V.	$\frac{\cdot 41}{\cdot 60}$	—	$\frac{\cdot 71}{\cdot 60}$	—
VI.	$\frac{1\cdot 8}{\cdot 5}$	Treble	$\frac{1\cdot 1}{\cdot 5}$	Double
VII.	$\frac{\cdot 33}{\cdot 30}$	—	$\frac{1\cdot 33}{\cdot 30}$	Four times
VIII.	$\frac{1\cdot 33}{\cdot 8}$	One and a half times	$\frac{\cdot 9}{\cdot 8}$	—
IX.	$\frac{\cdot 80}{\cdot 83}$	—	$\frac{\cdot 70}{\cdot 80}$	—

	Massage		Post Massage	
Number of Obs.	Ratio of simple bleeding to massage.	Approximate increase.	Ratio of simple bleeding flow to post massage flow.	Approximate increase.
X.	·43/·83	—	·84/·83	—
XI.	·92/·77	Slight	1·17/·77	One and a half times
XII.	·78/·83	—	1·25/·83	One and a half times
XIII.	1·22/1·16	Slight	2·1/1·6	One and one-third times
XIV.	1·8/1·08	One and two-thirds	2·05/1·08	Double
XV.	1·71/1·90	—	·95/1·90	—
XVI.	2·2/1·6	One and a half times	1·7/1·6	Slight
XVII.	2·1/1·4	One and a half times	1·6/1·4	Slight

These same results are shown graphically in Fig. 2, which is arranged on the same plan as Ludwig and Sadler's[1]. The Figure is to be read from left to right. Each group of ordinates corresponds to the observation which is indicated by the Roman figure at its base. The left-hand ordinate of each group (a) shows the amount of flow during simple bleeding in 5 seconds, the middle one (b) the amount in

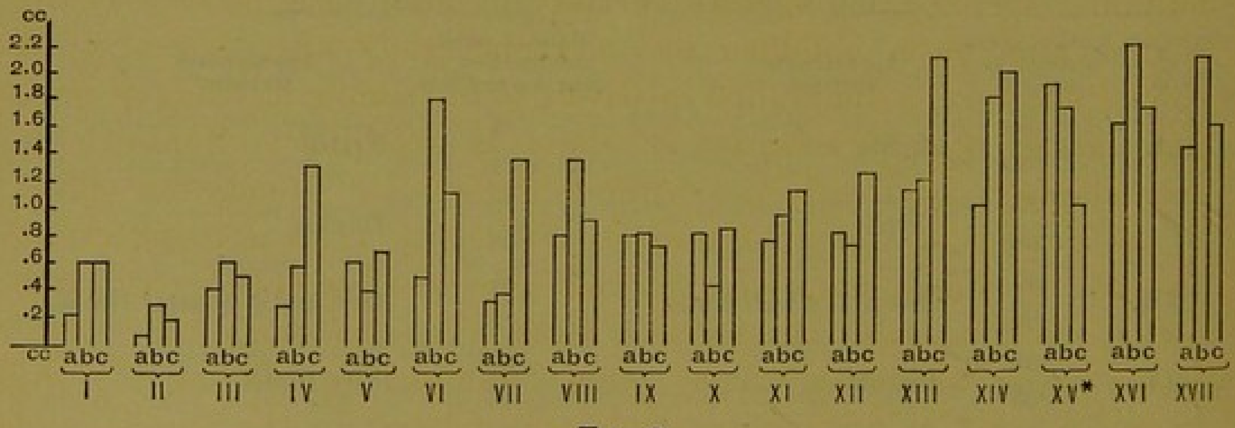


Fig. 2.

* Obs. XV. This apparently anomalous result is probably to be explained by the fact that the high simple bleeding average is itself a post massage effect (see text).

the same time during massage, the right-hand one (c) the amount in the same time after massage. The amounts can be easily read off in cubic centimetres by the help of the scale at the left of the diagram.

In observations XVI. and XVII. the first post massage interval was

[1] *Ludwig's Arbeiten*, loc. cit.

divided into two parts, this was done in order to enable us to represent numerically what we had often observed, viz. that immediately after the cessation of massage the flow from the efferent vein was very much diminished. During massage the advance of the column was not uniform, but occurred in leaps corresponding to some extent to the manipulations. These two facts tend to show that during massage blood is alternately sucked into and expelled from the massaged muscles, and that the immediate effect of this manipulation is an accumulation of blood in the respective muscles which is in all probability due to dilatation of the vessels. This condition of vascular dilatation, as evidenced by the increased flow from the efferent vein, lasts from 1 to 2 minutes (Obs. III.), and even longer, after the cessation of the massage. In this connexion it is interesting to note that this jet-like increase (stossartiges Auswerfen) in the amount of blood lost was noticed by Gaskell[1] at the beginning of the tetanisation of muscle. Further in one experiment quoted under the head of the effect of division of the motor nerve trunk upon the circulation in corresponding muscles, the figures are as follows:

Average in 5 secs. simple bleeding =	2·4 c.c.
First 5 secs. after division of nerve	1·6 c.c.
Second 5 secs. ,, ,,	10·1 c.c.

This, the only experiment in which the above diminution in the flow after nerve section appears, is especially interesting in view of the similar diminution obtained by us immediately after massage. A similar effect, i.e. a diminution relatively to the simple bleeding average immediately after the cessation of tetanus is according to Gaskell the rule, although apparently not without exceptions. Hence the effects of the massage of a group of muscles are strictly, so far as its effects on the local circulation are concerned, analogous to those of the contraction of the same muscles. An increase more or less spasmodic takes place in the circulation during massage, this is followed by a dilatation of the vessels causing at first an accumulation of blood in the muscle, and subsequently an increased circulation through it.

II.

The effect of the massage of a considerable muscular area upon the general blood pressure.

The animals chosen for these experiments were cats, they were fully

[1] *Ludwig's Arbeiten*, loc. cit. p. 77.

anæsthetized, the blood pressure was registered in the usual way by a cannula in the carotid which was connected with a mercurial manometer. The area chosen for massage was both hind legs (legs and thighs), which were massaged simultaneously: the buttocks were well raised previously so that massage could be begun rapidly at a given signal.

The effects of the massage, best shown by the adjoining curve, were briefly as follows. First a slight rise, second a fall continuing throughout the massage, and third, a second sudden fall occurring upon the cessation of the massage. In illustration of these changes in blood pressure accompanying and following massage, we purpose giving the results of two experiments. In the first the numerical results will be stated in a tabular form, in the second they will be considered in greater detail, and the tracing itself (Fig. 3) described.

EXP. I. The subject of this experiment was a large muscular male cat; the massage practised was essentially muscular, i.e. the muscles of both hind limbs were firmly kneaded and the skin was not pinched. The massage was kept up continuously for 100 secs. and was discontinued gradually. The massage was not begun until the blood pressure had remained for a considerable time absolutely uniform. The following were the results obtained.

Blood pressure before commencement of massage	= 68 mm. (mercury)
Maximum height during massage, reached four secs. after commencement	= 70 mm.
Height at the end of massage	= 61 mm.
Height immediately after cessation of massage	= 53 mm.
Height 3 mins. after cessation of massage	= 67 mm.

In this experiment therefore the massage was accompanied by a fall of blood pressure amounting to 7 mm. (mercury) or rather more than $\frac{1}{10}$ of the initial pressure, and followed by a fall of 15 mm. of mercury or nearly $\frac{1}{4}$ of the initial blood pressure.

EXP. II. The blood pressure tracing, of which Fig. 3 is a reproduction, shows exactly what took place in this experiment. The curve is to be read from left to right. The scale at the side corresponds to centimetres of mercury above the abscissa. The time marker indicates every 5 seconds. The top line is traced by an electric signal, which by its upstroke marks the beginning, and by its downstroke the end, of the different manipulations practised. Owing to the somewhat awkward relative positions of the Du Bois Reymond key and the animal's hind legs, the electric signalling is in each case a little late.

The marks x' x' on the electric signal line indicate the time and the duration (90 seconds) of the massage of the hind limbs.

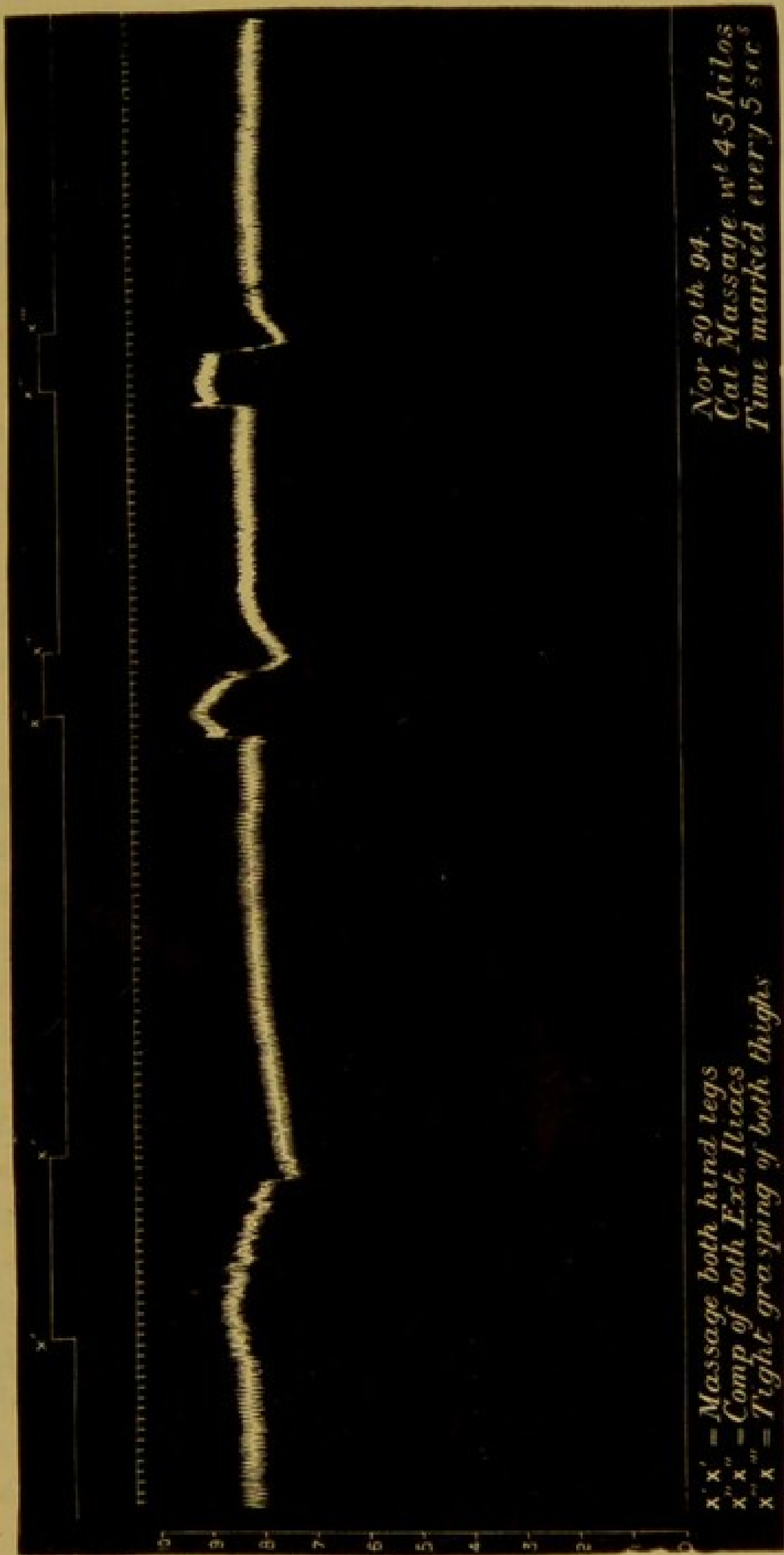


FIG. 3.

In this, as in the preceding experiment, a small initial rise took place during the early part of the massage, this rise is here relatively less, but of somewhat longer duration than in Exp. I., and amounts to 2 mm., the initial blood pressure being 86 mm. During the latter part

(50 secs.) of the massage period a fall occurred, the pressure sinking to 80 mm., or 6 mm. below its initial height. Upon the cessation of massage a further sudden fall of 11 mm. took place. This "post massage" fall is less than in Exp. I., being in this case $\frac{1}{10}$ of the initial blood pressure. With regard to the duration of this lowering of blood pressure, we see upon looking at the curve that the blood pressure was still 2 mm. below its initial height, $3\frac{1}{2}$ minutes after the cessation of the massage. In view of the fact that in massage of a given set of muscles alternate compression and release of the arteries and veins contained in the muscles must take place, we thought it would be interesting to have recorded on the same curve the effect on the blood pressure of the simultaneous compression and release of both external iliac arteries. This was done at the points marked x'' and x'' on the electric signal line of the tracing, the effect was a rise and a fall of blood pressure, which is well seen on the actual blood pressure curve below these marks. Upon careful inspection of the figure it will be seen that after release of both external iliacs the blood pressure fell below its initial level; this fall amounted to 6 mm. It differed however from the fall occurring during and after massage, in being less in extent and further, in being more transient, the pressure having regained its former level 40 secs. after the vessels were released. In this case the muscles were not stimulated, the arteries were compressed between the thumbs and bone, hence the result was due entirely to their sudden occlusion and release. We thought it would be of further interest to have recorded on this same curve, the effect on the general blood pressure produced by the firm grasping between the fingers and thumb, of the muscular masses of both thighs, and their subsequent release. This was practised at the marks x''' and x''' on the electric signal line, and the rise and fall of blood pressure consequent upon it is seen below. In this instance the fall which occurred upon the release of the thighs is greater in amount and less transient than that which took place upon the release of the two common iliac arteries, but less in amount and of considerably shorter duration than the post massage fall. In the grasping of the muscular mass of both thighs the muscles themselves were of necessity stimulated, and although we should be probably correct in attributing the main part of the resulting changes in the blood pressure tracing to compression and release of the large arterial trunks, yet the manipulation of the muscles themselves seems to have increased the amount and lengthened the duration of the subsequent fall. Upon comparing the last three results, we see that the gentle kneading of the two hind limbs for

90 secs. is more potent in producing a fall of blood pressure than either the compression and release of both external iliacs or both thighs.

The marked quickening of the respirations, which in our experiments always accompanied massage, led us to watch the effect upon blood pressure produced by massage practised during artificial respiration.

The results obtained in this set of experiments were substantially the same as those in the experiments quoted. The only difference between them was, that in the artificial respiration experiments the oscillations of pressure during massage were less, a continuous fall taking place, and that speaking generally the "post massage" fall was slightly less.

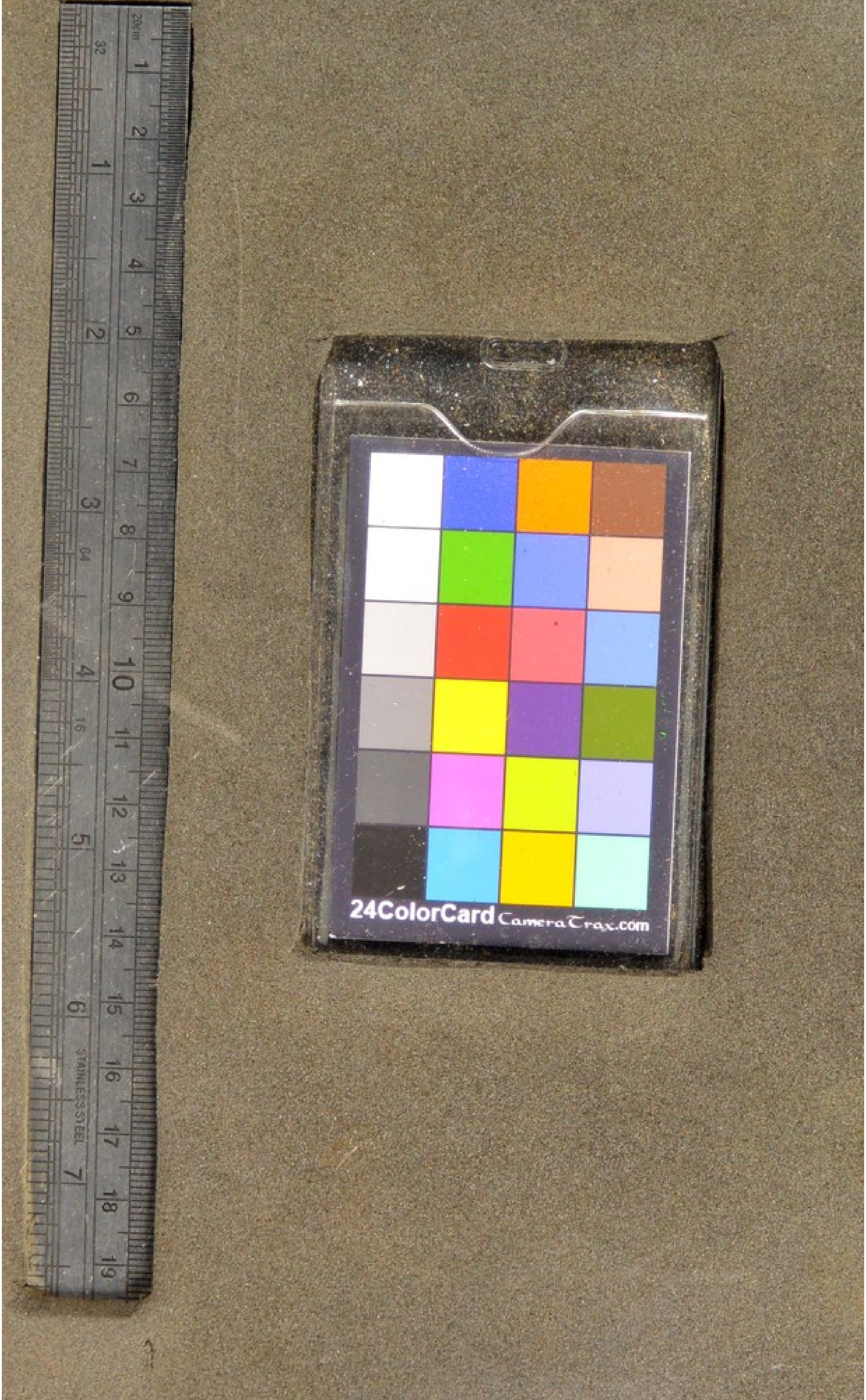
These effects on the general circulation of the massage of a considerable muscular area, confirm the results obtained in the case of the local circulation. Both during and after the kneading of muscles a lowering of peripheral resistance in the corresponding area takes place, as a consequence of this, more blood is propelled at each heart beat from the arteries into the veins, and hence arterial tension falls.

The main results in the preceding pages may be briefly summarized as follows:—

I. During the massage of muscles the flow of blood through them is increased.

II. Immediately after the cessation of massage, an accumulation of blood occurs in the massaged muscles, this is rapidly followed by an increased flow through the muscles.

III. The massage of a considerable muscular area causes at first a slight rise in the general blood pressure, this is followed by a fall which in some cases amounts to one fifth of the initial blood pressure.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