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THE FORM OF THE PULSE-WAVE. As studied in the Carotid of the Rabbit. By CHARLES S. ROY, M.D. (Plate IV.)

(*From Observations made in the Strassburg Physiological Institute.*)

THE investigations, the results of which are recorded in the following pages, form part of a more extended series of researches on the subject of the pulse, which will shortly be published. I have to acknowledge with gratitude the material help which has been afforded me in making these inquiries by the British Medical Association, which has assisted me with a grant in defraying the cost of the instruments necessary for such work.

Methods employed.

The instruments used for studying by the graphic method the form of the pulse-wave, and the variations to which it is liable, may be divided into two classes, *viz.* those for use with the opened, and those for the unopened artery. The former kind includes the various kymographs, recording manometers, and pulse recorders (Blut- u. Pulswellen-zeichners), while the latter class comprises the different forms of sphygmographs.

As there has been no little discrepancy in the results obtained by these two kinds of instruments, I have been led to undertake a series of observations on the subject in the hope of obtaining further information, using a method which admits of the tracings taken from the unopened artery being rigorously compared with those obtained from the opened vessel.

(a) Method used with unopened Artery.

The instrument employed is represented in the accompanying woodcuts, and it may for convenience sake be referred to as the sphygmotonometer[1], a name which has been suggested to me as expressing the object for which it was constructed.

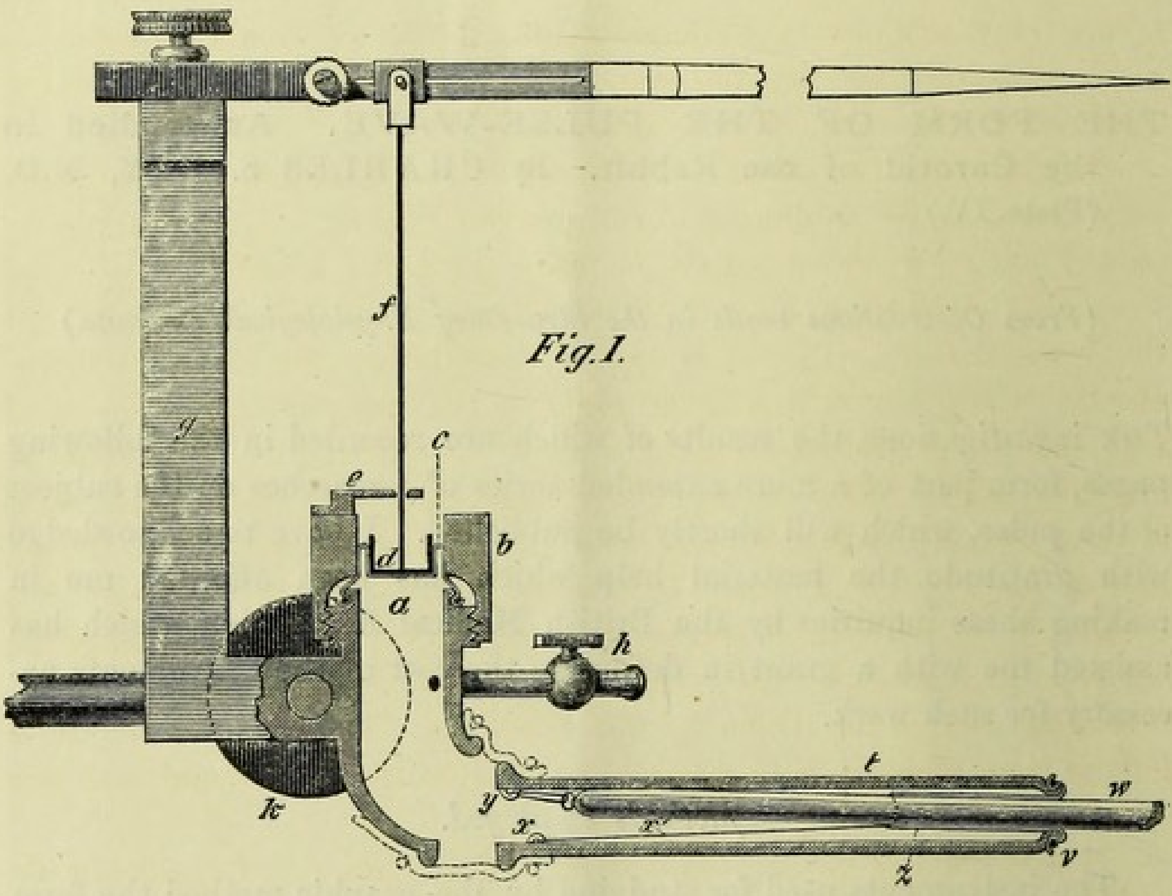


Fig. 1.

In Fig. 1 is represented in section the arrangement used when it was desired to obtain tracings from the unopened artery. In principle this instrument resembles that used by Poiseuille for measuring the diastolic expansion of the carotid of the horse, the artery in both being contained within a box with unyielding walls and filled with fluid. In detail, however, it differs much from Poiseuille's instrument.

As can be seen in Fig. 1 the box is, in this instrument, represented by a brass tube (t), into which the artery (w), after having been tied and cut, is drawn, being afterwards kept in position by a thread fastened to the small eyelet (y). In many experiments a form of box was used which did not require that the artery should be severed, but in the present communication we prefer to consider only the results obtained by the method figured in the woodcut.

[1] The Instrument is made and may be obtained from Mr Robert Fulcher, 18, Panton Street, Cambridge.

The aperture of the tube at which the artery enters is closed without pressure on the blood-vessel by means of a membranous valve (z). This latter has usually been manufactured from the intestine of the water frog (R. esculenta), larger or smaller specimens being sacrificed for this purpose, according to the size of the artery from which the tracings were desired.

The intestine is washed out with water and the epithelium in great part removed by rubbing it between the fingers. After being distended with air and dried, it is ready for being attached to the instrument. A portion, an inch or so in length, is tied on the end of the brass tube (t), (this of course is done before the artery is introduced), where there is a groove (v) for the purpose. By means of a thread attached to the margin of its free extremity, the piece of intestine, which has been previously moistened with diluted glycerine, is then drawn inside the brass tube, being of course turned inside out in the process. The thread (x'), which is fastened to the eyelet (x), keeps the valve from slipping out of the tube. After the intestine has been thus arranged the central end of the carotid is drawn into the tube and secured as shewn in the woodcut. The cavity of the tube having been filled up with warm olive oil, it is then connected with the other part of the instrument.

This method of closing the aperture of the box was found to work well in practice; a somewhat more complicated arrangement was used at first in order to insure that the elasticity of the valve should not influence the form of the tracing obtained, but that above described was afterwards found to answer equally well. With it the pressure within the tube and outside the artery can be kept at any desired height for hours without a drop of the oil escaping by the side of the blood-vessel. As several sizes of tubes were used, it was always easy to find one whose aperture fitted the artery to be examined, and thus but little play was given to the elasticity of the valve.

In preparing the carotid for introduction into the tube, it is separated carefully and rapidly from the surrounding tissues, and, the small laryngeal branch having been tied and cut, it is secured high up in the neck with two ligatures, between which it is severed.

The rest of the apparatus consists of two separate arrangements, one for varying the pressure within the instrument, and which is shut off when tracings are being taken, and another for communicating the expansions of the artery to a recording lever, which writes on the blackened surface of a revolving cylinder.

The first-mentioned part is represented in Fig. 3 (reduced in size). It consists of a mercurial manometer, connected by a T tube on the one hand with the interior of the instrument proper (Fig. 1), and on the other hand with a compressor. This latter is formed of two brass plates (*n*), hinged together at one end, and capable of being pressed together by means of a screw (*s*). Between these plates is a caoutchouc bulb filled with oil. A small glass bulb placed between the T tube and the manometer, and filled with air, serves to prevent the oil entering the latter. An india-rubber tube passes from (*o*) to the tube (*h*), Fig. 1, with the stop-cock. There are two tubes with stop-cocks entering the instrument, only one of which (*h*) is shewn. The other is intended to permit of the air within the tube (*a*) being carefully replaced by oil.

That part of the tonometer which conveys to the lever the changes in the cubic capacity of the artery contained in the box is represented in Figs. 1 and 2 (natural size). The thin flexible membrane (*c*) closes the upper outlet of the tube (*a*), and upon the membrane rests a light aluminium piston (*d*), the movements of which are magnified by the recording lever. The piston and lever are connected together by the fine steel needle (*f*), which acts as a piston-rod, while the guide (*e*) keeps the piston nearly in the centre of the cylinder in which it oscillates, preventing it thus from rubbing against the sides of the latter, and reducing the friction to a minimum. The membrane used is a thin animal membrane, prepared from the peritoneum of the calf, and which must be kept moist with glycerine. Reference has already been made to it in a paper which appeared in a previous number of this Journal[1], in connection with another instrument.

Its chief characteristic is its extreme flexibility, while it is sufficiently inelastic to fulfil the part required from it for this instrument. As the external diameter of the hollow piston is only 1·5 mm. less than the internal diameter of the cylinder in which it moves, the elasticity of the membrane can come but little into play.

As is shewn in the woodcuts 1 and 2, the membrane is arranged in such a way that while it closes the tube (*a*) it does not interfere with the movements of the piston, unless the latter rise too high or sink too low, limits which, of course, are not reached in taking the tracings, the lever being kept as nearly horizontal as possible. The short tube (*b*), which prevents the expansion of the membrane in any direction except upward, is screwed on after the membrane has been tied in the groove cut for the purpose at the end of the tube (*a*).

[1] *Journal of Physiology*, Vol. I. p. 454.

It is evident that, if the lever and piston are to be kept nearly in the position they occupy in the woodcuts, some means require to be taken to counterbalance the hydrostatic pressure within the instrument, which, as we have seen, may be raised or lowered at pleasure by means of the compressor (Fig. 3). In some of the instruments which have been employed the piston was pressed down by a light spiral steel spring, which could be tightened by a screw, the arrangement being such that a stronger or weaker spring could readily be substituted, according to the amount of movement which was to be permitted to the piston. Caoutchouc threads as springs were however found to be an improvement upon the steel ones, and the arrangement shewn in Fig. 2 was found the most convenient.

Fig. 2.

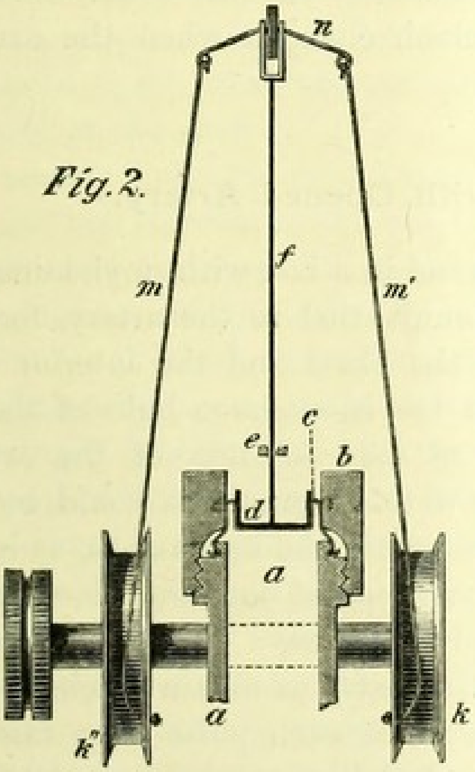
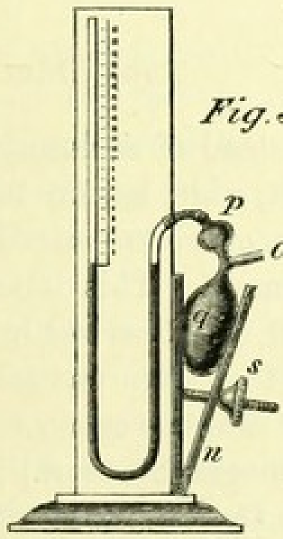


Fig. 3.



The two caoutchouc threads (m, m') attached above to the steel wire (n) which forms the axle of the junction of the needle (f) and the recording lever, can be tightened or slackened by turning the little pulleys (k,' k''), round which they pass, and which are moved by the milled head (l). The pulleys retain any position given to them, in the same way as the pins for tightening fiddle-strings, that part of their axle which fits in the bush being of brass like the latter.

The chief advantage of the india-rubber springs, besides that of lightness, is that they can be made stronger or weaker with little trouble. By using four, six, eight, or more fine threads instead of two, or by using two thicker ones, the movement of the piston which will result from a given rise of pressure within the instrument can be regulated at will.

When the instrument is arranged as in Fig. 1, and the tubes (*t*) and (*a*) filled with oil, the pressure which acts upon the exterior of the artery can be regulated as desired, and tracings may be obtained with an extra-arterial pressure of 5, 10, 20, 30, or more millimeters of mercury, while the movements of the piston and lever can be regulated as is thought fit by changing the strength of the india-rubber springs, and by varying the distance which separates the sliding coupling of the lever from its fulcrum.

It need scarcely be added, that, with the unopened artery, the springs had best have but little resistance, in order that the extra-arterial pressure may not be too much changed when the artery is distended by the pulse-wave.

(b) Method used with Opened Artery.

Instead of enclosing the blood-vessel in a box with unyielding walls, a short, wide, leaden tube and a cannula, tied in the artery, form the means of communication between the blood and the interior of the instrument. This latter, as well as the caoutchouc bulb of the compressor, is filled with bicarbonate of soda solution of the orthodox strength. Care was taken to use as wide a cannula as could be introduced into the artery. The pressure within the instrument, as is usual in kymographic work, is raised to the supposed medium blood-pressure before the communication with blood is opened.

Although, with this instrument, it is easy to obtain tracings of any desired height (some were taken in which each pulse-wave raised the lever-point four inches), yet a spring of such strength was usually chosen as allowed only a slight movement of the piston, in order to admit of more absolute comparison of the tracings with those obtained from the unopened artery.

Pulse-curve from the Opened Carotid.

The tracings 1 and 2, Plate IV., which, like all the others given, must be read from right to left, shew the usual form of the curve obtained from the carotid of the Rabbit. They are both from the same animal, the one being taken a few minutes after the other, and differ only in this that the movement of the cylinder was more rapid with the second than with the first. The two lines running parallel with the abscissa in Fig. 1, and marked 128 and 138, give the positions of the lever-point when the pressure within the instrument was 128 and 138 mm. of mercury respectively.

These pressure lines are obtained in the following manner. After the cylinder has made a revolution the communication with the interior of the blood-vessel is closed for a moment, and the stop-cock (*h*) having been opened, the pressure within the tonometer is raised or lowered by the compressor until the lever-point stands at the height desired. The cylinder is then turned by the hand and a horizontal line thus drawn on its surface. The pressure having then been read off on the manometer is written on the cylinder close to the line. As many of these pressure lines as is desired may be drawn through the tracing, enabling us to tell what was the absolute blood-pressure at any particular height of the curve.

In tracing 1 the pulse and respiratory curves can be readily recognized, and the increase in the height of the pulse-curve and the temporary arrest of the respiration, which are so readily induced by various exciting causes, are illustrated by that part of the tracing to the left of the point (*s*) at which the mucous membrane of the respiratory passages was stimulated by weak sulphur fumes.

Tracing 2 is better fitted to shew what is the form of the pulse-wave, with which we are more immediately concerned in the present paper. From it, as well as from the first tracing, it can be seen that the pulse-wave causes a simple rise and fall of the lever, without any trace of dicrotism or polycrotism. And this absence of secondary waves has been found constant in the carotid pulse of the rabbit under normal conditions and with the opened artery. The blood-pressure with each pulse-wave rises more rapidly than it falls, and different tracings differ from one another considerably in so far as the sharpness of the apex of the curve is concerned, in the strength of the wave, &c., but dicrotism is invariably absent.

That the absence of those secondary waves, whose existence has been pretty generally accepted on the strength of the curves obtained by Marey's sphygmograph, is not due to any fault in the instrument or method we employed, is sufficiently proved by the fact that under certain abnormal conditions a dicrotic wave appears in tracings taken from the opened artery. Tracing 3 is intended to illustrate this fact. It was taken from a rabbit, the blood-pressure of which had been very considerably lowered by repeated venesection. Another proof that the absence of dicrotism cannot be ascribed to any fault in the instrument, will be found in the fact that with the same instrument and with almost similar conditions, except that the artery is unopened, very marked dicrotism or tricrotism is encountered.

It has been stated that the blood-pressure of the animal from which tracing 3 was obtained had been lowered by blood-letting. It should be added that any considerable reduction of the medium blood-pressure from whatever cause leads to the appearance of a dicrotic pulse-wave.

It may be surmised that the reason why a secondary wave does not appear when the blood-pressure is normal might be sought in the fact that with the comparatively powerful pulse-beat of a healthy animal more blood would require to enter and leave the instrument with each wave than would be the case with the weak pulse which usually accompanies any considerable fall of the blood-pressure. For it need scarcely be said that a comparatively narrow passage, such as the entrance of the cannula, is unsuited for the transmission of rapid changes of pressure if the resistance of the spring be so slight as to allow of much fluid passing through it with each pulse-wave. This possible cause of error was however excluded by using springs of considerable strength, so as to reduce sufficiently the movements of the piston.

Form of the Pulse-curve from the Unopened Artery.

With the sphygmotonometer arranged as in the woodcut, Fig. 1, its cavity being filled with warm olive oil, and the artery unopened, we obtain a very different form of pulse-curve from that taken from the opened artery. The tracings 4, 5, 6, and 7 may serve to illustrate the curve given by the unopened blood-vessel. The figures annexed to these refer to the pressure within the instrument but outside the blood-vessel. As a relatively weak spring was used in most of these experiments the extra-arterial pressure rose but little with the diastole of the artery.

As might have been anticipated, the height of the extra-arterial pressure exercises a very important influence on the tracings taken with this method, and the action of this factor may be first referred to. It is illustrated by the four curves of tracing 4, which were taken with an extra-arterial pressure of 10, 20, 40, and 50 mm. of mercury respectively. It can be seen that the form of the curve remains practically the same with the different pressures, in so far as the notches on the descending line are concerned, these being repeated in all, and that the chief difference is as to the height of the individual pulse-waves. These become higher as the pressure on the outside of the artery is raised, and this is the case until the pressure has reached a certain height.

It is not intended here to refer to the degree to which a given portion of artery expands on a given rise of the blood-pressure, nor to enter into details as to the influence of different extra-arterial pressures on the degree to which the blood-vessel distends with each pulse-wave.

These points, which are of considerable importance from the light which they throw on the elasticity of the arterial wall in the living condition, we prefer, as they have no immediate bearing on our subject, to treat of on another occasion.

It has been said that the height of the primary wave rises with the extra-arterial pressure until this has reached a certain height, and it is the same with the notches on the descending line of the curve. These become at first accentuated, as the pressure on the artery is raised, as is shewn in tracing 4; but as that pressure approaches the minimum blood-pressure the notches become more and more indistinct.

With an extra-arterial pressure about 20 mm. below that of the blood (medium pressure), the notches have usually disappeared almost entirely, and the tracing comes to resemble more and more that which has been described as taken from the opened artery. The tracings taken with a high extra-arterial pressure resemble so closely those obtained from the opened artery, that it is unnecessary to illustrate them by a special figure.

After the extra-arterial has been raised as high as the minimum blood-pressure, *i.e.* after it has reached the pressure which exists at the lowest part of those pulse-waves which occupy the valleys of the respiratory waves, any increase of the pressure in the instrument results in the lower part of the tracing being left out. When, for example, the pressure outside the artery is nearly as high as the maximum blood-pressure, only the apices of those pulse-waves situated at the highest part of the respiratory curves are seen, the lever-point describing a straight horizontal line in the intervals.

On the maximum blood-pressure being surpassed, of course no blood can enter that part of the artery contained within the box, and the blood-vessel remains collapsed, and the lever at rest.

With this method we have, thus, a means of learning the height of the blood-pressure with accuracy, without opening any artery. I have found it useful for various kinds of observations, and, as the blood does not coagulate within the artery for many hours, there is no necessity for interrupting the experiment, such as occurs with the usual kymograph when the cannula becomes blocked by a clot.

The indentations on the descending line are usually most accentuated with a pressure somewhere between 25 and 50 mm. (mercury), the exact height varying with the medium blood-pressure of the animal from which the tracings are taken. They resemble, as can be seen from the figures, those to which we are accustomed from the tracings obtained by Marey's sphygmograph.

One of them, tracing 7, copies very faithfully the normal tracing from the human radial, tracing 8, which was taken by an instrument constructed on the same principle as that described in the foregoing pages. Tracings 4 and 5 shew varieties of curves which are often met with in sphygmographic tracings. In tracing 5 an anacrotic curve is given, such as is not infrequently obtained from the rabbit's carotid. The most frequently encountered curves are those illustrated by tracings 4, 5 and 7. In tracing 7 is shewn the effect of electric stimulation of the peripheral end of the cut vagus on the form of the curve, the small elevation immediately before the arrival of the pulse-wave with the slowed rhythm being especially noteworthy.

After having verified by oft-repeated experiment the facts noted in the foregoing pages, several points naturally presented themselves for elucidation, and these may be stated categorically as follows :

a. Why no indentations are found in tracings from the opened artery with a normal blood-pressure, while they are constantly present in those taken from the unopened artery.

b. Why the indentations seen in tracings from the unopened artery disappear, when the extra-arterial pressure is raised nearly as high as the minimum blood-pressure.

c. Why with the opened artery a dicrotic wave should appear with a reduced blood-pressure, while it is absent when the pressure is normal.

These may be considered seriatim.

(*a*) Presence of indentations in the pulse-curve with one method while they are absent with the other method.

If we accept the facts recorded in the preceding pages, which, as has been said, were verified by oft-repeated experiments, and which, moreover, are not opposed to what is at present known on the form of the pulse-wave, we have only one explanation open, *viz.* to regard the arterial wall as the element which leads to the appearance of the characteristic indentations in the pulse-curve obtained from the unopened artery, and to reject completely the theories which would ascribe these to reflected, opening and closing waves, &c., &c., or in fact, to secondary waves at all of whatever origin.

None of the tracings which we have obtained from the opened artery with a normal blood-pressure shew the slightest trace of secondary waves superposed on the primary or pulse-wave, although the sphygmotonometer, as we have attempted to prove, is quite delicate enough to record them, did they really exist. The tracings coincide, in so far as this is concerned, with the tracing from the dog which has been published by Fick, and upon which, from the fact of the absence in it of dicrotism or polycrotism, suspicion has been cast.

It is impossible to overlook the fact that the data, upon which the more generally received views as to the origin of these undulations in sphygmographic curves have been founded, are far from satisfactory. There have been no observations made on the form of the pulse-wave in the opened artery with an instrument comparable in point of delicacy with the sphygmograph, those instruments which have been employed for the purpose having been constructed mainly with a view to their serving as kymographs, and being endowed on that account with too great a resistance to permit of their acting as reliable pulse-recorders. For this reason it is, from experiments made on an artificial circulation of some kind or another, that the facts necessary to found a coherent theory on the cause of the peculiar form of the pulse-curve have been drawn. The large majority of experiments with the *schema* are however vitiated by the fact that nature is imitated but imperfectly. The recording instruments employed in these kinds of experiments are often calculated to introduce further error from being unfitted for such work, and the results obtained have been, it need scarcely be added, sufficiently contradictory. Observations on the *schema* have doubtless assisted in clearing up many points connected with the circulation, but they seem scarcely fitted to elucidate the more delicate questions connected with the form of the pulse-curve. It is scarcely possible without considerable exercise of the imagination to explain with their help the cause of the various forms of pulse-curve which are encountered in sphygmographic tracings. It need, therefore, cause little astonishment that many physiologists have refused to allow themselves to be convinced as to the cause of the peculiar forms of the sphygmographic pulse-curve, and, in the midst of much conflicting evidence, have preferred to consider the question as still *sub judice.*

It has been said that the pulse-curve from the opened artery presents in normal circumstances no trace of reflected waves. This, it must be remembered, is only what we ought to expect *à priori.*

The existence of such waves would be a proof that the walls of the aorta and arteries are not sufficiently elastic to prevent a useless expenditure of force in friction. Judging from what we know of the high perfection of the circulatory system in other particulars, we have little reason to look for such an imperfection in this respect.

If, then, it is to the arterial wall alone that we must look for the cause of these undulations of the pulse-curve, the further question arises whether, in producing them, the wall of the artery plays a passive or an active *rôle*—whether, in other words, they are due to the elasticity of the wall or to an active contraction of its muscular coat.

The former view, which has been advocated by some, it is scarcely possible to accept. The indentations vary greatly in the different varieties of pulse-curve, but in no case are they such as we could imagine would be produced by elasticity-vibrations of the arterial wall. Those curves which are figured in Plate IV., as well as those obtained by Marey's sphygmograph, shew definite varieties of form, such as could scarcely be explained by the vibration of a passive elastic tube, whose internal pressure simply rose and fell. It would, for example, be extremely difficult on such a supposition to explain the occurrence of an anacrotic pulse-curve, like tracing 6, which resembles those not infrequently encountered in sphygmographic tracings from the human radial. Moreover, it would be easy to shew that a membrane, such as constitutes the rabbit's carotid, is incapable of vibrating with a rhythm fit to cause such secondary curves as those in question.

If, however, we assume that the arterial wall is able, in virtue of its muscular coat, to contract actively behind each pulse-wave, the difficulties which beset the subject become remarkably simplified. This view, which is not without advocates at the present day, was held by many during the earlier decades of the present century, and numbered among its active supporters such names as Hope, Thomson, Poiseuille, C. Bell, &c. In more recent times it has been pretty generally rejected, more, however, from the absence of proofs to support it, than from any evidence to the contrary which has been advanced. Against the assumption that the arteries have the power of vermicular contraction behind each pulse-wave and of pushing the latter on, so to speak, towards the periphery, in addition to the power of tonic contraction which they are generally admitted to possess, various objections might be urged. The most important of these, perhaps, is, that what we know of the properties of smooth muscular fibres in other organs leads to the belief that this tissue is endowed only with the power of slow contraction. This must not however be allowed to carry too much weight, seeing that, in the other organs where they occur, a rapid contraction of the unstriped muscular fibres is not required and that too little is known as to the properties of unstriped muscular tissue to permit of our drawing any definite limits as to its capabilities.

The example of the red and pale striped muscles (e.g. of the rabbit) teaches us that muscular fibres, resembling one another closely in structure, may present very considerable difference as to their vital properties. All things considered, it is difficult to avoid feeling that if we accept the view that the arterial wall is capable of a vermicular contraction enabling it to assist actively in conveying the blood to the periphery, we have found the simplest, if not the only, means of explaining the results of the investigations which have been recorded in the preceding pages, as well as many otherwise inexplicable phenomena, both physiological and pathological, connected with the circulation. Looked at from this point of view, we can find a ready explanation of the different forms of pulse-curve from the unopened artery in a difference in the force of the arterial contraction or contractions accompanying each pulse-wave, and in a difference in the relation which the active expansion and contraction of the artery bear to the apex of the pulse-wave.

Tracing 7 may be briefly referred to in connection with this subject. It can be seen that in it there is a slight elevation, immediately before the arrival of the pulse-wave, on the descending line of the two curves which lie towards the left of the tracing. A small elevation of this kind might appear insignificant, were it not that it is frequently met with in like circumstances, i.e. in cases where the rhythm of the pulse is more or less suddenly slowed. I have met with a similar elevation also, in sphygmographic tracings in cases of irregularity of the heart, in which, with every alternate beat, the left ventricle either did not contract, or contracted so feebly, that only one pulse-beat reached the radial for every two apex beats. In these circumstances, a slight elevation on the tracing, immediately before the upstroke, is not infrequently met with. These elevations do not correspond to any active phase of the left ventricle, and can scarcely be due to reflected waves, since they bear no definite relation as to time with the preceding pulse-wave. They can most readily, it would seem, be explained by putting them down to an active change in the elasticity of the arterial wall, such as has been said might best account for the form of the sphygmographic pulse-curve.

Before leaving this part of our subject, it is necessary to add that in accepting or rejecting the explanation offered above as to the cause of the difference in form of the pulse-wave obtained from the opened and from the unopened artery, the part of the arterial system of the rabbit from which the tracings were taken must not be left out of account. Since the structure of the wall of the aorta is not such as would lead us to ascribe to it the power of active contraction, we must assume that the form of the pulse-wave which enters the carotid will not already have been modified by any contraction of the aortic wall. The carotid is thus favourably situated for studying the influence of the muscular coat of the arteries on the form of the pulse-wave. It is different however with arteries situated nearer the periphery, for in them we should anticipate that the pulse-curve (obtained from the opened artery) would already have been changed by the vermicular contraction, if such really exist, of the more central-lying parts of the blood-vessel. On the other hand the muscular coat of the carotid of the rabbit is sufficiently developed to justify us in considering it capable of causing such indentations as are present in the tracings obtained from the unopened vessel.

The bearing of tracings obtained by the "haemautographic" method of Landois[1] on this question would lead us into detailed discussion which would be unadvisable in a preliminary paper such as this.

(*b*) Why, in tracings from the unopened artery, the indentations disappear when the extra-arterial pressure approaches the blood-pressure.

The explanation of this is not difficult to find. Whether the undulations be due to elasticity-vibrations or to active contractions of the arterial wall, the latter must be distended in order that they may appear. With a high extra-arterial pressure the pulse-wave cannot, and does not, distend the artery to its normal extent, the elastic tube oscillates passively in a half-contracted half-expanded condition. If we take the view that the undulations are due to active contraction, the stimulus of distension by the pulse-wave is here absent, sufficiently explaining the absence of contractions. If on the other hand we look upon the undulations as due to elasticity-vibrations, the same change in

[1] Landois, Pflüger's *Arch.*, Band IX. (1874) p. 71.

the degree of distension might explain their absence with a high extra-arterial pressure. Their disappearance in the above conditions is only a further proof that they can in no case be looked upon as being due to reflected waves.

(*c*) Why, in tracings from the opened artery, the pulse-curve becomes dicrotic when the blood-pressure sinks.

With a reduced blood-pressure the pulse-curve is dicrotic in tracings both from the opened and the unopened artery. The tracings from the unopened artery in these circumstances resemble those sphygmographic curves which are obtained from the human radial in cases where the blood-pressure is reduced from fever, loss of blood, &c. This form of dicrotism must not be confounded, as is too often done, with those undulations, more or less marked, which give to the pulse-curve in health its characteristic outline. The origin of these latter has already been considered. The dicrotism from reduction of the blood-pressure, as it is seen in tracings from the unopened artery, is characterized by the fact that it does not disappear when the extra-arterial pressure is raised nearly as high as the blood-pressure, shewing that it is really due to a secondary and most probably reflected wave.

It would be difficult to shew in what way the conditions are more favourable for the production of a reflected wave when the blood-pressure is reduced, if the elasticity-curve of the arterial and aortic wall given by Werthheim, Volkmann, &c. be accepted. According to these observers the elasticity-curve of the arterial wall (taking the expanding weights as the abscissæ, and the resulting increase in length of the piece of artery wall experimented upon as the ordinates) is a hyperbola. In other words the aortic and arterial wall would become more elastic with a reduction in the blood-pressure. That a diminished elasticity modulus of the aortic and arterial wall would *cæteris paribus* be more fitted to produce a reflected wave, whether from the aortic valves or from the periphery, than a higher elasticity of these structures, it is impossible to admit.

In a series of observations on the subject of the elasticity of the aortic and arterial wall, made with the help of a new method, and one by which it is believed the various causes of error are fairly well avoided, I arrived at very different results from those of previous workers on the subject. As these observations are not yet published, it is impossible to refer to them here, further than to state that they seem to afford a sufficient explanation of the appearance of a reflected wave when the pressure falls.

Under these circumstances this point may well be left to be taken up again on a future occasion.

Conclusion.

It cannot be pretended that the facts recorded in the foregoing pages suffice, in themselves, to prove that the arterial wall is capable of a vermicular contraction such as would enable it to assist actively in conveying the blood to the periphery. All that is advanced is, that the assumption of such a power for the arterial wall is best fitted to explain the results arrived at in these investigations. Many facts which might have been adduced in support of this view have been omitted in the present paper, because they were drawn from observations made either by other methods or on other animals and which therefore could not be referred to without going into details somewhat foreign to the immediate subject. The question will be discussed more fully in a future communication.

Fig. 1.

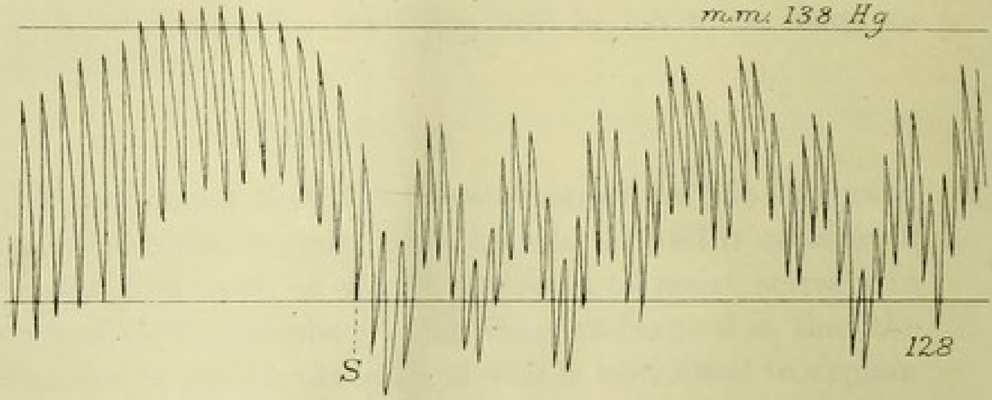


Fig. 2.

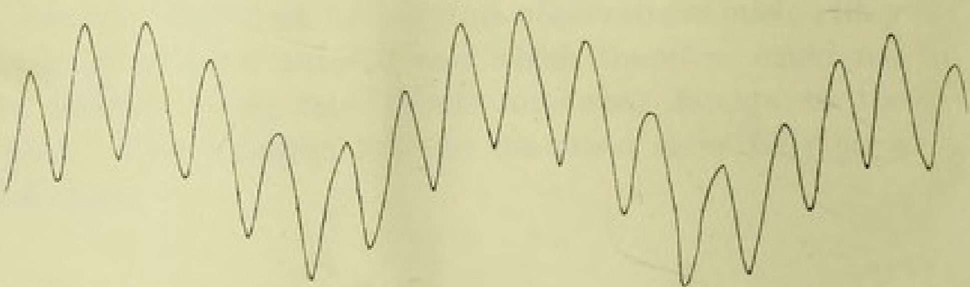
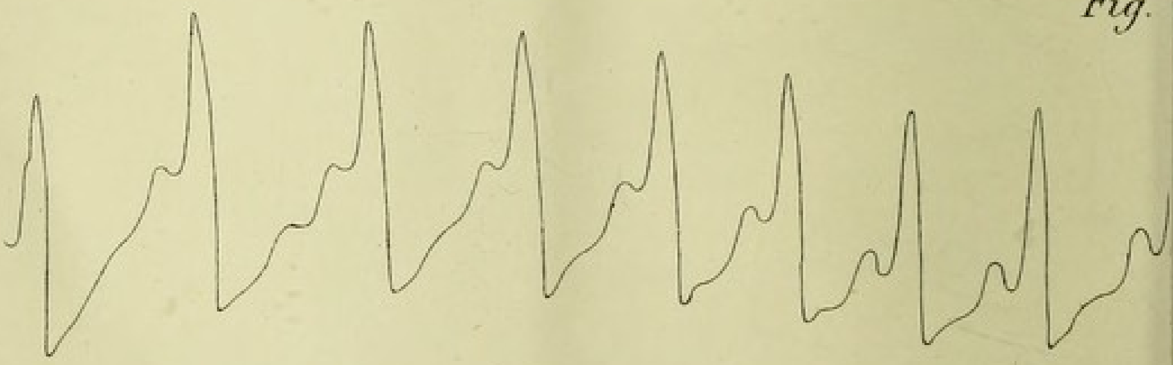


Fig. 3.

Fig.



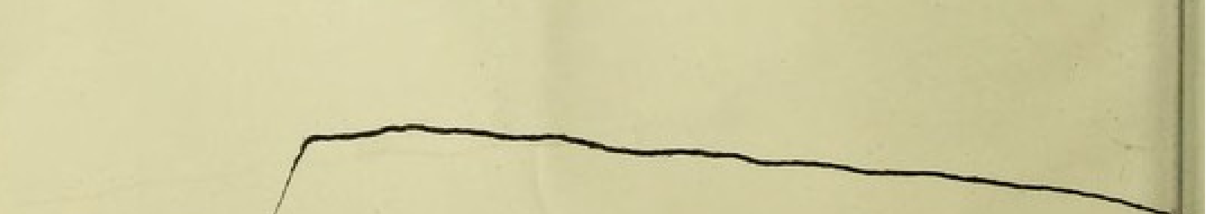


Fig. 4.

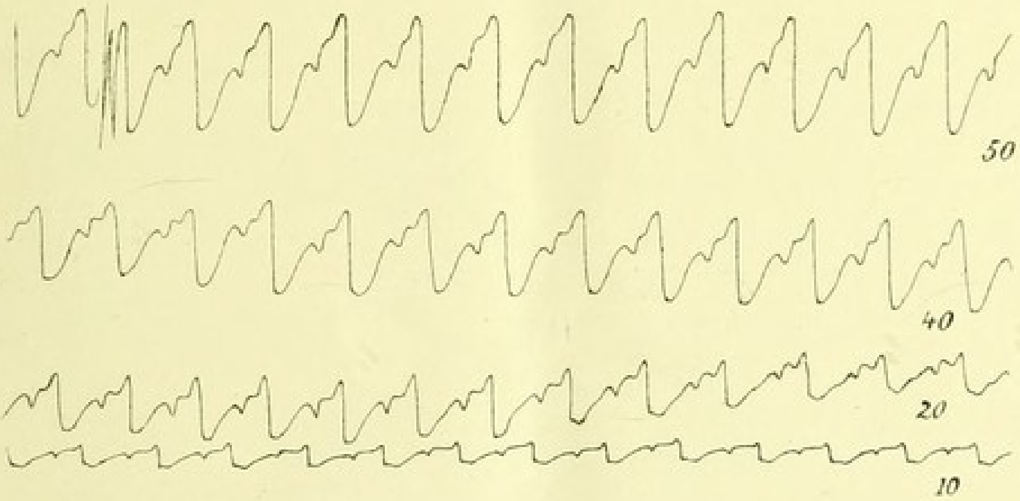
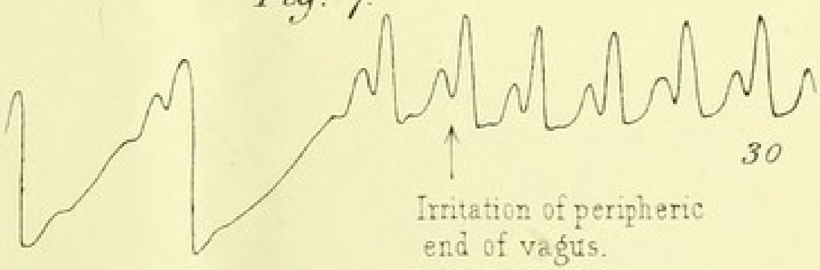
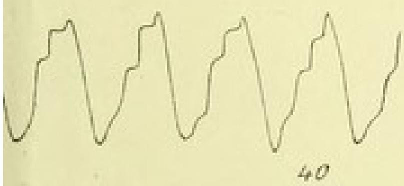


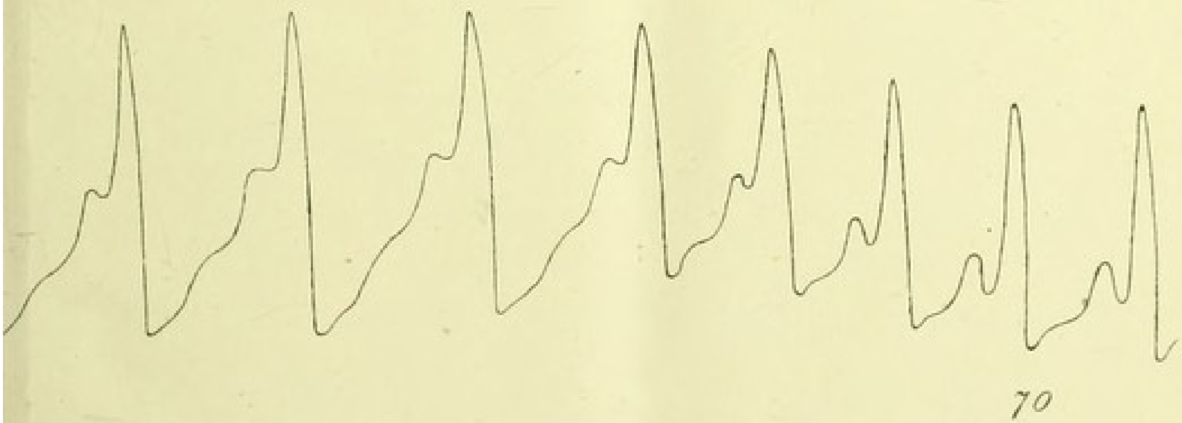
Fig. 6.

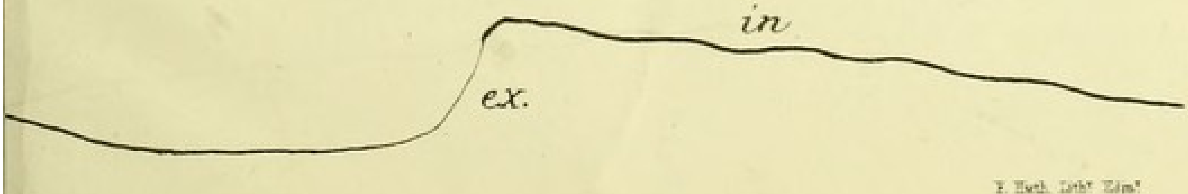
Fig. 7.



[F]ig. 5.







F. Huth, Lith^r Edin^r