A NEW METHOD FOR RECORDING PRESSURE-FLOW DIAGRAM APPLICABLE TO PERIPHERAL BLOOD VESSELS OF ANIMALS, AND ITS APPLICATION

STUDIES ON THE FLOW PATTERN IN THE PERIPHERAL ARTERY. II

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Shipley, Gregg and Schroeder (1) have already discussed the dynamic volume-elastic (*DV-E*) properties of the arterial tree, taking into consideration the interrelation between phasic arterial pressure and flow recorded simultaneously. Their work was based upon the construction of a *DV-E* diagram by plotting phasic change of arterial pressure (*P*) against that of its volume (*V*), which was obtained by integlating a curve of blood flow rate (*F*) recorded by an orifice meter simultaneously with *P*. This procedure being very tedious, it is surmised that they have not always carried out such plotting; in their later paper (2), they have rather taken "the volume of pulsatile deviation from the mean flow line" as its measure, because it "reflects the *DV-E* properties of the arterial tree." There is no doubt, however, that it is preferable to construct a *P-V* pattern as they have done, or a *P-F* pattern, in order to analyse the *DV-E* relation. It seems most appropriate for this purpose that phasic change in *P* and *F*, transformed into those of electrical potentials by means of suitable pickups and amplifiers, are led to the vertical and horizontal plates respectively of a cathode ray oscilloscope and instantaneous *P-F* patterns are made observable.

During preparation of this paper, McDonald's paper (3) has been published, in which he analysed the *P-F* relation in the femoral artery of dog taking into consideration an equation derived by Womersley (4). According to his view, *F* in the femoral artery oscillates in the same way as the gradient of *P* but with a phase lag. We have also noted already that the femoral flow pattern of dog and rabbit had a striking resemblance to that of dP/dt (5), which may be regarded as supporting his opinion. Womersly's derivation is essentially identical with Egami's work (6) published in this country about ten years ago. The *P-F* pattern recorded by the procedure of the above-mentioned principle is expected to offer a simpler qualitative means of obtaining a clue to analysing its phase lag caused by various haemodynamic characteristics of the arterial tree than

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the rather tedious procedure of McDonald.

P may be successfully recorded by a suitable electronic manometer (*e.g.* condenser type or strain guage type). The use of a mechano-electric transducer is, however, available for unopened (7–8) or opened (9–10) arteries and seems preferable, because it can be applied if necessary, without opening blood vessels, and does not require a high amplification so that it is especially suitable for DC amplification without causing a time lag in its responses. From this view-point we have used RCA 5734.

The chief problem is how to record phasic changes of F with stability and faithfulness. We have already described an electromagnetic flowmeter of the AC type applicable to peripheral blood flow of experimental animals (11). After its publication we had an opportunity to read the paper of Richardson, Denison and Green (12), which had, to our regret, escaped our notice before that time and in which they also described a flow-meter of AC system with high fidelity. Recently Green and his co-workers (13) have further had a great success in extraneous recording of blood flow by an electromagnetic flowmeter of AC type, of which we have also had successful results to some extent. But, from the view-points that the time lag in the response of the flowmeter should be avoided, to match the pressure recording, and that extraneous leading without opening the blood vessels is desirable, we were obliged to use an electromagnetic flow-meter of DC amplification. Indeed, in the DC system, drift due to polarization at pickup electrodes annoys us greatly, and disturbances from externals are difficult to eliminate completly. Under appropriate conditions, however, such difficulties can be minimized and made negligible for a short period of several cardiac cycles. Concerning the electromagnetic flowmeter with DC amplification, we already have available detailed description by Jochim (14) and especially recent work by Richards and Williams (15) in which DC amp. and extraneous pickup were used with the cathode ray oscilloscope, demonstrating a considerable stability of their meter at least for 3–5 cardiac cycles. In view of these facts we have attempted to construct a DC amp. of high gain and high stability, and to record flow rates without opening blood vessels simultaneously with recording blood pressure. In this report we intend to describe our new method of recording P-F pattern instantaneously and to present some examples of results obtained.

METHODS

Non-cannulating electronic manometer: Fig. 1 gives the construction details of the manometer assembly as built for application to the unopened blood vessel; the circuit diagram used for its amplification is given in fig. 2. The lever attached to the plate pin of the transducer, RCA 5734, is made of an aluminium tube, its diameter being about 1.5 mm. and its length 22 mm. The blood vessel is held in the plastic sleeve (whose length is less than 10 mm. with its internal lumen made similar to that of the flowmeter) and the lever is applied to the small portion of the artery exposed from the hole drilled at the centre of the sleeve. This portion of the artery is so small (about 2 mm. in diameter) and

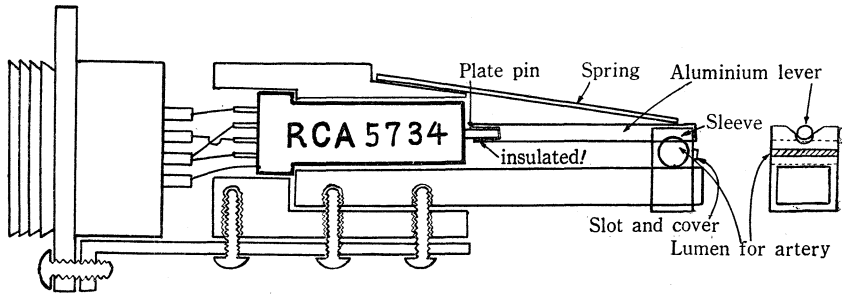


FIG. 1

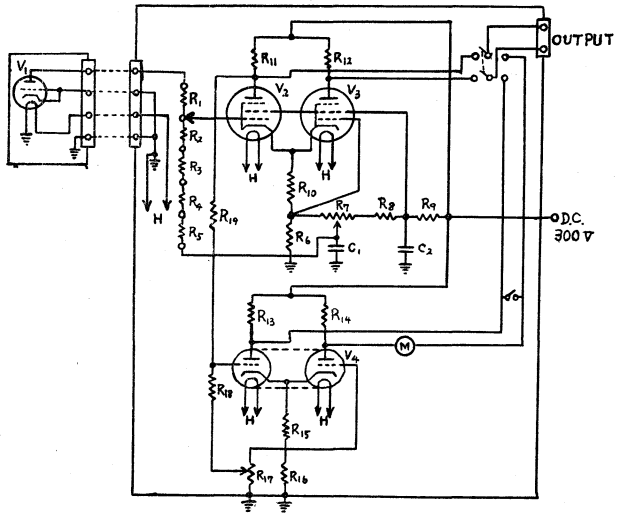


FIG. 2. Circuit diagram of amplifier for transducer manometer.

V_1: RCA 5734, R_1: 20 KΩ, R_5: 20 KΩ, R_9: 9 KΩ, R_{13}: 100 Ω, R_{17}: 50 KΩ, C_2: 40 μF,
V_2: 6 AK 5, R_2: 20 KΩ, R_6: 3 KΩ, R_{10}: 1 KΩ, R_{14}: 100 Ω, R_{18}: 50 KΩ, M: Milli-
V_3: 6 AK 5, R_3: 20 KΩ, R_7: 3 KΩ, R_{11}: 100 KΩ, R_{15}: 500 Ω, R_{19}: 500 KΩ, ammeter
V_4: 6 J 6, R_4: 20 KΩ, R_8: 1 KΩ, R_{12}: 100 KΩ, R_{16}: 5 KΩ, C_1: 40 μF, (10 mA.)

the other portion of the artery is fixed so firmly by the sleeve to prevent alteration of its volume, that the change in the volume of the exposed portion transmitted to the lever would be proportional to the change of its internal pressure. Recording is made by a cathode ray oscilloscope or a suitable electromagnetic oscillograph. Since the direct-coupled amplifier mentioned above has a frequency response which is linear up to about 1,000 cps. and the natural frequency of the manometer assembly is above 500 cps., it can be said that our meter is sufficient to record the phasic change of blood pressure.

The calibration pictured in the figure 3 demonstrates the linearity of this instrument up to about 200 mmHg. The relationship between deflection of the galvanometer or the displacement of the spot on the oscilloscope's screen (D)

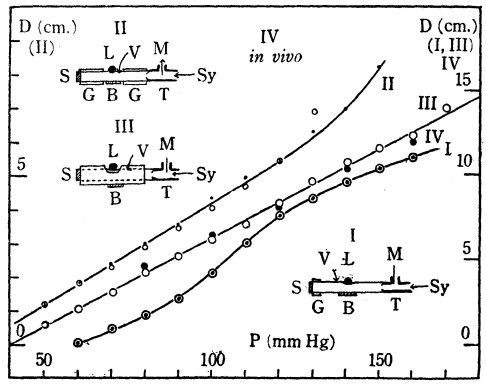


FIG. 3. Calibration of electronic manometer.

Ordinates (D): deflection of galvanometer or of spot on the screen. Abscissae (P): internal pressure measured by a mercury manometer, M. Inserted diagrams: schematic representation of conditions of calibration. L and B: lever and base of electronic manometer. V: excised carotid artery of dogs. S: fixed stopper of blood vessel. G: glas tube or sleeve for fixing artery. Sy: Syringe device for obtaining various P.

and internal pressure of a short segment of excised artery of dog (P) is not always linear when it is not thoroughly fixed, while the linearity of D-P relation is proved when the artery is fixed in the sleeve either *in vivo* or *in vitro*. We can obtain, therefore, a faithful record of phasic pressure change *in vivo* by means of this manometer without cannulation, though its absolute values should be computed from the calibration *in situ* under the same condition as that under which actual recordings have been made. Taking the above mentioned linearity between D and P into consideration, such calibration *in situ* may be readily accomplished by relating D to two known levels of blood pressure at the end of each experiment.

Cannulating electronic manometer: If it is desired to apply the transducer to the cannulating manometer, it is readily accomplished by applying the lever of its plate pin to the membrane of a suitable membrane manometer instead of attaching a mirror as in the work by Arnott, Cumming, Davison and Pincock (9). Selecting a suitable amplification and stiffness of membrane, this procedure has been successfully worked out in our laboratry. Our manometer of this type has the following characteristics:

(1) membrane—mica; its diameter about 5 mm., its thickness about 0.05 mm.
(2) lead tube—hard rubber tubing; its length 5 cm.
(3) natural frequency including lead tube; about 130 cps.
(4) linearity; linear up to about 200 mmHg.
(5) maximum sensitivity; 1 mm. per 1 mmHg, when displayed on the screen of cathod ray oscilloscope.

Non-cannulating electromagnetic flowmeter: The essential part of the electromagnetic flowmeter consist of a vessel sleeve, a magnet, non-polarizable electrodes, and a suitable electrical recording system.

The sleeve (fig. 4 *a*) is made of plastic, its length being about 15 mm. and its slot for the blood vessel about 1 mm. in width. To accomodate arteries of different sizes a set of sleeves is made with internal lumen of graduated diameters.

The permanent magnet (9 cm.×5 cm.×11 cm.) is used with steel pole-pieces of triangular shape (fig. 4 *b*), which are insulated by a coating of insulating

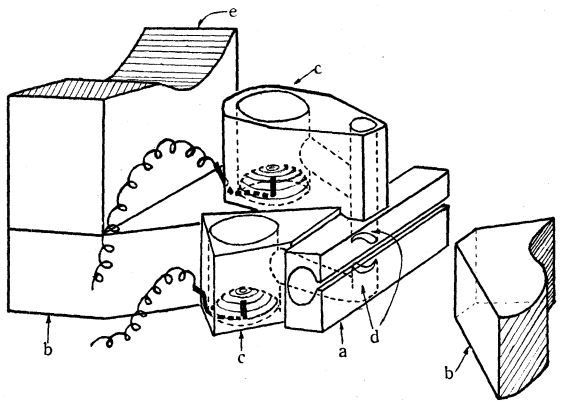


FIG. 4

a: vessel sleeve. *b*: pole piece. *c*: calomel electrode. *d*: junction lumen filled with saline-agar. *e*: magnet body.

varnish. Their apices have contact with the side wall of the sleeve, having a different gap according to the size of the sleeve (usually about 4 mm.).

Calomel half cells prepared properly have been found to be the most satisfactory electrodes (fig. 4*c*). Silver-silver chloride electrodes are not fit for attaining a high stability. Contact with the vessel wall is made by holes drilled in the sleeve and filled with agar-saline gel (fig. 4*d*), which is brought to contact with saturated KCl solution of calomel half cells. They are mounted on one of pole-pieces by adhesive material and then fixed on the magnet body as shown in figure 4. After cleaning out the internal lumen of the sleeve and moistening it with saline, a vessel segment freed from the surrounding structure is slipped into it through its slot and a thin plastic cover is placed on the slot. Then the other pole piece is fixed on the magnet body.

The electrodes are connected to a direct-coupled amplifier, whose circuit diagram is given in figure 5. It has a maximum gain of about 10^6 and a frequency response which is linear up to about 400 cps. The amplified potential is led to a cathode ray-oscilloscope or a suitable electromagnetic oscillograph. With the artery clamped, the potential between two electrodes at zero flow is compensated for by the compensation device attached if available and now recording of the blood flow rate is ready to begin.

During the experiment the drift of zero flow reference occurs gradually, and is easily adjusted by means of compensation device or balancing the imput stage of amp. Such a drift is negligibly small at least for several minutes and the zero reference remains stable for 10–20 minutes if non-polarizable electordes are properly prepared, compensation is satisfactory, and experimental conditions are favourable.

Calibration of the flowmeter can be performed by the use of an excised blood vessel and the syringe technique described in our previous paper (11). The results obtained by such a procedure show that our meter is at least linear up to 8 ml/sec. for the forward flow. Criticism of the electromagnetic flowmeter

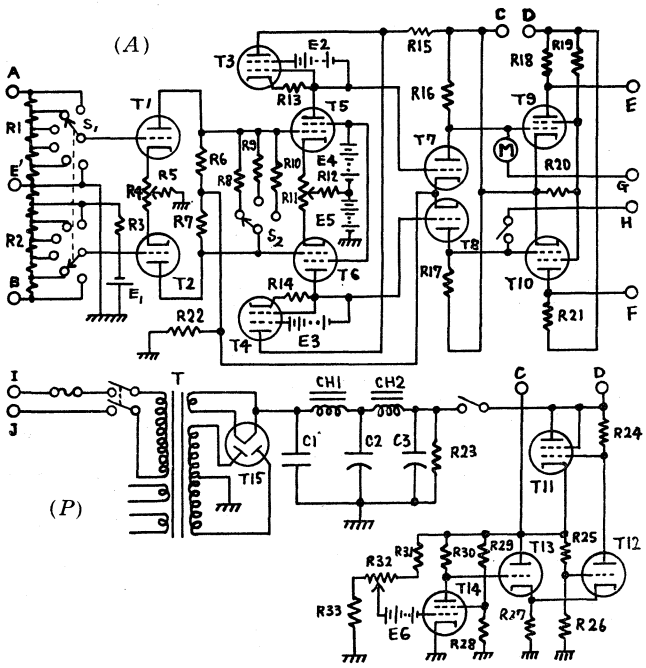


FIG. 5. Circuit diagram of amplifier (A) and power supply (P).

T_1, T_2, T_{12}, T_{13}: 6 SL 7,
T_3, T_4, T_5, T_6: 6 AK 5,
T_7, T_8: ½6 J 6,
T_9, T_{10}: 6 AC 7,
T_{11}: 6 V 6,
T_{14}: 6 SJ 7,
T_{15}: KX 80,
R_1: 100 KΩ+30 KΩ +30 KΩ+30 KΩ +10 KΩ,
R_1: 100 Ω+10 KΩ +30 KΩ+30 KΩ +30 KΩ+100 KΩ,
R_3: 1.5 MΩ,
R_4, R_{11}: 1 KVR,
R_5, R_{22}, R_{33}: 10 KΩ,
R_6, R_7: 1 MΩ,
R_8, R_{27}: 50 KΩ,
R_9, R_{18}, R_{19}, R_{21}, R_{23}, R_{29}: 100 KΩ,
R_{10}, R_{24}: 250 KΩ,
R_{12}: 20 KΩ,
R_{13}, R_{14}: 30 KΩ,
R_{15}, R_{25}, R_{30}: 200 KΩ,
R_{16}, R_{17}: 100 Ω,
R_{20}: 5 KΩ,
R_{26}: 75 KΩ,
R_{28}: 15 KΩ,
R_{31}: 350 KΩ,
R_{32}: 50 KVR,
E_1: 1.5 V,
E_2, E_3, E_4, E_6: 22.5 V,
E_5: 67.5 V,
C_1: 8 μF,
C_2, C_3: 40 μF,
CH_1, CH_2: 30 H, 100 mA,
A:B: Input,
C:D: Terminals for connection between (A) and (P),
E:F: Output for a cathod ray oscilloscope,
E': Grounded,
G:H: Output for an electromagnetic oscillograph,
I:J: Source trans. input,
S_1, S_2: Switch for sensitivity regulation,
M: Miliammeter (10 mA), T: Transformer (400 V×2 ×100 mA.)

hitherto has been mainly aimed at the point of whether or not it can faithfully record a phasic backward flow. A test on this point was made by undulating flow pulse, and its results are shown in fig. 6, which demonstrates the linearity of this instrument for both forward and backward flow in the two separate series of experiments. Calibration *in situ* may be best performed by the technique mentioned in our previous paper in which an artery is cannulated downstream to the meter for measuring the outflow into a graduated cylinder, and D evoked by the outflow through the cannula is related to the blood volume run out in unit time. This method is not preferable, however, not only because the blood vessel kept intact with so much care has to be sectioned, but also the

animal itself not infrequently, has to be sacrificed at the end of the experiment. The method of injecting a known volume of blood downstream to the meter and recording the backward deflection seems fairly convenient. By our experience, however, such calibration *in vivo* is occasionally troubled with the drift of zero reference level, while its results are almost identical with those of the *in vitro* calibration for the same sleeve and the same sensitivity setting, discrepancy between the two, if any, is only slight. It would be said, therefore, that the calibration *in vivo* is safely omitted if the *in vitro* calibration for the sleeve employed has been performed thoroughly at various sensitivity settings.

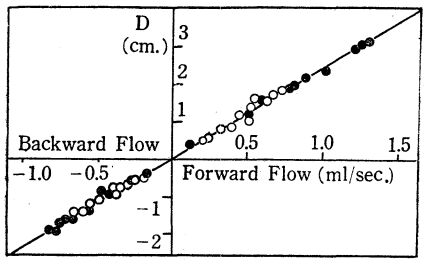


FIG. 6. Calibration of electromagnetic flowmeter of DC type on excised artery by undulating flow pulse
(○ and ● represent calibration variation from day to day).

Synchronization of flowmeter with manometer: When the properly amplified e.m.f. from the above-mentioned manometer and flowmeter are led respectively to the vertical and horizontal plates of the cathode ray oscilloscope, the position of the spot on its screen being adequately controlled, we should then readily obtain a *P-F* pattern. In performing this procedure, the manometer is applied 0.5–1.0 cm. upstream to the flowmeter; hence the distance between two recording points is approximately 2 cm., which produces a time lag of a few milliseconds in recording *F*. This lag is inevitable in its nature and need not be taken seriously, since even an initial abrupt rise in *P* and *F* requires several times ten milliseconds in order to reach its crest, and furthermore we do not claim so high a degree of accuracy for our recording system in view of the frequency characteristics that come into play.

Niveau of *P* and *F* exhibit slow periodic waxing and waning (respiratory wave), hence the *P-F* patterns of each cardiac cycle do not always overlap each other (see fig. 7 *a* and *b*). Accordingly it seems desirable to photograph a pattern of one cardiac cycle alone. Several lines of procedure to synchronize photography with cardiac rhythm may be considered, but they are all very complicated. For this reason we have employed a simple method in which the time of exposure was chosen to be nearly equal to the period of one cardiac cycle, and photographs were made repeatedly at the moment a cardiac cycle was judged to be starting by inspecting the spot on the screen. From a series of pictures thus obtained, we can construct a *P-F* pattern for a single cardiac cycle. After some experience it is not difficult to obtain pictures such as shown in figs. 7 to 10 by a single photographing.

APPLICATION

Dogs used were anaesthetized by ouropan-soda (*N*-metyl cyclohexenyl methyl barbiturate) and fastened to the board in dorsal posture. The artery to be

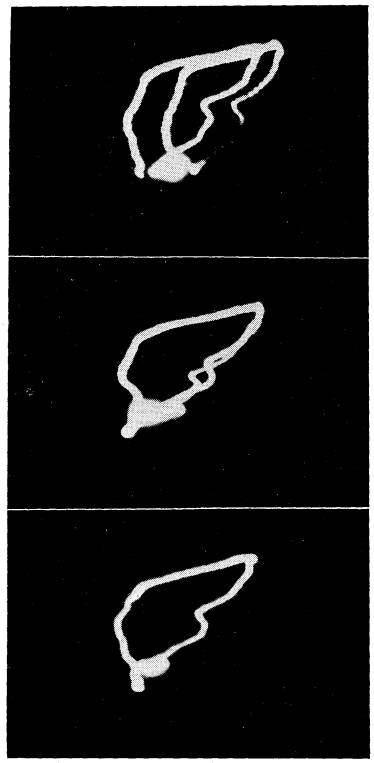


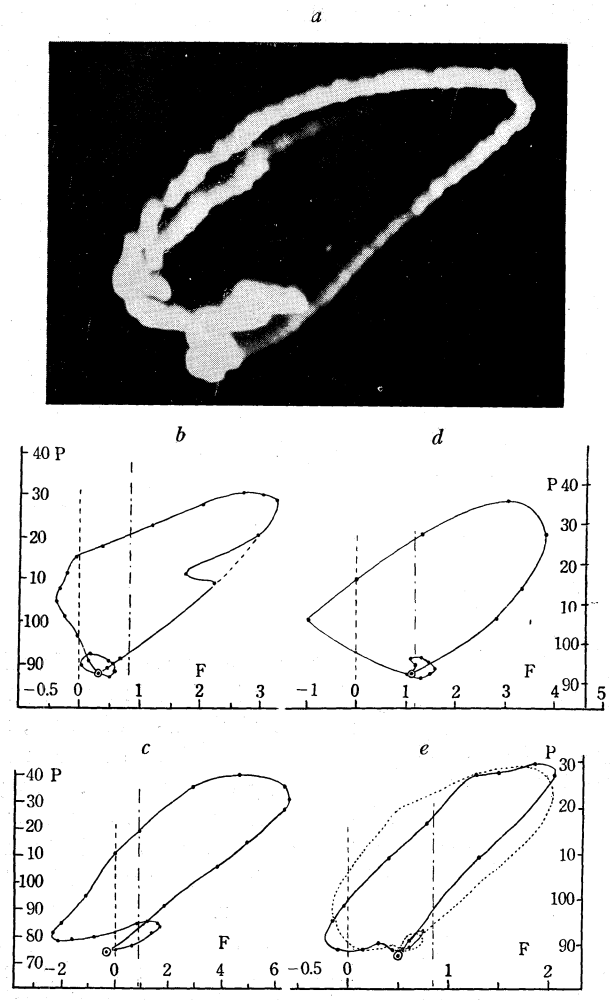
FIG. 7. Femoral *P-F* patterns photographed successively under normal circulatory condition. (Time of exposure varied.)

Dog weight; 11 kg. Artery; right femoral.

used was exposed and slipped into the sleeves of the manometer and flowmeter through the slot as already described. When the cannulating manometer was employed, *a* a stainless needle cannula was inserted into a suitable arterial branch near the recording point of the flowmeter (*e.g.* thyroid artery for carotid flow), minimizing the time lag between juxtaposed meters to less than several milliseconds.

Typical patterns of normal animals, *i.e.* anaesthetized animals without any alteration *b* of circulatory conditions other than the procedure necessary for its recording are given in fig 7 *c*, 8 *a*, 9 *a* and 10 *a*. In all cases the ordinates represent pulse pressure and the abscissae, pulsatile flow rate. There is not so much variation in the magnitude of the former from dog to dog, but the latter varies considerably with the size of the animals. *c* Hence a fixed setting of sensitivity of both meters gives a pattern of various shapes and sizes. It is difficult also to grasp the general feature of the *P-F* diagram, if the ratio between sensitivities of both meters is chosen arbitrally case by case. As pointed out in our previous report (11), the results reported hitherto appear to indicate that the phasic change in F runs parallel with that of P or of dP/dt in its general trend. (Concerning this point, an inference in preliminary form has already been made by us that F is proportional to $P+(dP/dt)$ (16).) In order to avoid the confusion of impression due to difference in the magnitude of proportionality constant in either case, and to make their common factors clear at a glance, it therefore seems reasonable to choose the sensitivity of meters which brings the amplitude of pulsatile P and F displayed on the screen into comparable magnitude. From such a point of view, photographing took place under a condition, not strictly, but nearly so.

We were convinced of the stability of our method by the results illustrated in fig. 7 *a-c* and 8 *b*; the former three are some of the photographs taken successively for about 10 minutes and almost identical with each other, while the latter was constructed from pressure and flow curves of the same dog recorded simultaneously by an electromagnetic oscillograph about 30 minutes after the above pictures were photographed and bears a striking resemblance to the former three. Also serveing as proof are figs. 9 and 10, obtained after the action of drugs had almost passed away. They are nearly identical with those



prior to the intra-arterial injection.

For comparison with other methods, *P-F* patterns of the femoral artery are constructed from the available results reported hitherto, *i.e.* that of Shipley *et al.* (1) (orifice meter), McDonald (3) (high speed cinematography) and ours obtained by electromagnetic flowmeter of AC type (11). The figures obtained are illustrated *en bloc* in fig. 8. At a glance it will be recognized that, in spite of considerable difference in the amplitude of *F* or some slight discrepancies in their detail, these patterns bear a striking resemblance to each other and might be roughly represented by an ellipse, having the point determined by mean pressure and mean flow rate as its centre. This fact seems to the present authors to indicate that our method does not cause serious distortion in recording. But McDonald has recently again cast serious suspicion on the fidelity of electromagnetic flowmeter (3). It seems necessary for us, therefore, to give some con-

FIG. 8. Comparison of femoral *P-F* patterns of dog obtained by various methods of flow recording.

a: recorded by the method presented in this report.
dog weight; 12.5 kg., *P*; 155/90 mm Hg., *F*; 3.5/−0.6 ml/sec.

b: constructed from our record on the same dog as that in fig. 7, which was recorded by an electromagnetic oscillograph about half an hour after photographing pictures shown in fig. 7.

c: constructed from McDonald's data.
P; recorded by condenser manometer, *F*; recorded by high speed cinematography.

d: constructed from the result of Shipley *et al.*
P; recorded by a membrane manometer, *F*; recorded by an orifice meter.

e: constructed from our result.
P; recorded by a membrane manometer, *F*; recordred by the electromagnetic flowmeter of AC type described in our previous paper. Dog weight; 8.0 kg. (Dotted curve was constructed assuming our flowmeter had time lag of about 10 msec.)

Ordinates: blood pressure (*P*) in mm Hg.
Abscissae: flow rate (*F*) in ml/sec.
Dotted lines: zero flow reference.
Broken lines: mean flow level.

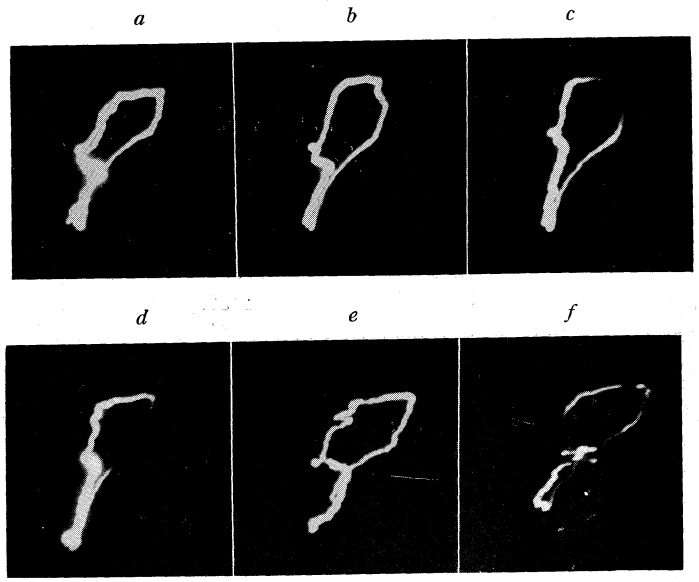
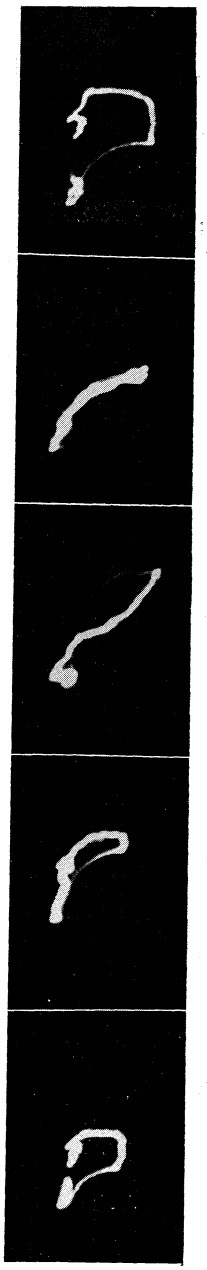


FIG. 9. Effect of intra-arterial injection of adrenaline (20 μg.).
Dog weight: 9.5 kg., Artery: right common carotid.

a: before injection.
b: immediately after injection.
c: 2 minutes after injection.
d: after 4 minutes.
e: after 6.5 minutes.
f: after 14 minutes.

sideration to this aspect of the work.

McDonald pointed out first that peak flow recorded by Richardson *et al.* (12) was too low (2 ml/sec.), which is in the same order of magnitude as ours, presented in fig. 8*e*. We have recorded much smaller peak values as illustrated in fig. 10 of our previous report (11). As far as our measurements are concerned, however, the explanation of such discrepancy may be found in the size of the animal used. As required by the dimension of the cannulating electrode for an opened artery, in the experiment under discussion we used chiefly dogs weighing 5–6 kg. and 8–9 kg. For the former group we recorded a peak flow of 0.8–1.2 ml/sec., and a back flow of about 0.15 ml/sec. was observed in the femoral flow of only one of four dogs, while the latter group gave peak values of 1.8–2.6 ml/sec. for femoral flow and we observed a back flow component of about 0.2–0.35 ml/sec. in three of six dogs. Now, in the present study, dogs weighing 10–12.5 kg. were used for recording femoral patterns and, as shown in fig. 8, the peak forward flow was 3.0–4.0 ml/sec. and in all four cases a back flow of 0.3–0.8 ml/sec. was found. The values of the last group do not appear incompatible with those of Shipley *et al.* (1) or Pritchard *et al.* (2), who have used dogs weighing 10–22 kg. Furthermore, Richards and Williams (15) recorded peak flow rates comparable with those of McDonald (3). As to the forward flow, therefore, the electromagnetic flowmeter apparently does not give distorted values.



McDonald's second and most important doubt concerns the point that the femoral flow pattern recorded by an electromagnetic flowmeter differs markedly from that recorded by high speed cinematography or by orifice meter, and he emphasized the fact that the former did not give such a back flow as the latter two always did. But the above stated fact, that the femoral *P-F* diagrams are very similar in shape to each other irrespective of the methods of recording flow rate, seems to indicate that McDonald's suggestion is not always correct. The existence of back flow in normal femoral flow pattern has not yet been confirmed by an electromagnetic flowmeter and it is quite

FIG. 10. Effect of intra-arterial injection of histamine (150 μg.). Dog weight; 10.5 kg., Artery; right common carotid.
a: before injection.
b: 15 sec. after injection.
c: after 1 min.
d: after 4 min.
e: after 6 min.

natural that McDonald recently and Shipley *et al.* (1) about ten years ago have cast suspicion on the fidelity of this meter. That was the very reason why calibration of linearity for positive and negative flow of our meters had been elaborately carried out. As proved in the previous and present papers, however, the fidelity of our meters to phasic flow is satisfactory for practical purposes. Moreover, in our laboratory (17), a back flow in the femoral artery under normal conditions has been recorded not infrequently with our meters, as shown in fig. 8 or stated above. It seems to support the presence of back flow in the normal femoral pattern as pointed out by Shipley *et al.* or by McDonald to some extent and, at the same time, to demonstrate that our meters do not record a seriously distorted pattern.

Back flow in the femoral pattern should occur at the point near the lower pole of obliquely running long axis of elliptic *P-F* contour. The occurence and magnitude of the back flow depends, not solely but chiefly, upon the mean flow level and the amplitude of pulsatile flow as predicted from fig. 8. In fact, the mean levels of about 1 ml/sec. and amplitudes (peak to peak) of about 4 ml/sec. in the experiment of Pritchard and his co-workers (2) were always accompanied by back flow of about 1 ml/sec., while the flow records of the Richards group, in which amplitudes were compatible with those of Pritchard group but the mean flow levels were considerably higher (about 3 ml/sec.), exhibited no back flow. If the zero reference level in the latter flow curve is elevated so as to make the height of its mean flow level accord with that of the former research group, a back flow of about 0.5 ml/sec. would appear and this is not incompatible with the magnitude of ours or Pritchard *et al.* (2). But there still remains for discussion the question as to what factors cause such a discrepancy of the mean flow rate between the measurements of Richards *et al.* (15) and other investigators, and why high speed cinematography alone gives much higher peaks in forward and backward flow than other methods. McDonald has suggested some factors which result in a damping effect on phasic flow recording made by methods other than his own. The mechanical high resistance of the meter to blood flow would be safely ruled out when an electromagnetic flowmeter is adequately constructed. From our experience in calibration of our meters, other factors pointed out by him seem improbable. To summarize, though it is difficult to explain these discrepancies at present, it might be said that the results illustrated in fig. 8 indicate the effectiveness of the electromagnetic flowmeter in analysing phasic *P-F* relations to be inferior to no other methods.

The diagrams illustrated or obtained hitherto by this method on eight dogs seem to suggest that the carotid and femoral artery have *P-F* patterns characteristic of their own; namely the carotid pattern consisting of two distinct parts, an oval loop (exclusively systolic period) and a trailing part (diastolic period and initial phase of systolic period), while the femoral pattern has no trailing part, its diastolic phase being represented by a small loop or a very short linear segment tending upward. The diastolic phase of the femoral pattern is so small and the elliptic loop so predominant that it gives an impression of an elliptic contour on the pattern as a whole. The distinct trailing tending downward, on the contrary, gives an impression of a tadpole-like con-

tour to the carotid pattern. Such differences may be explained by the fact that the carotid flow does not show a back flow and its phasic change rather resembles that of P than of dP/dt, while the femoral flow frequently shows a back flow or has an abrupt fall at the end of the systolic phase, bearing a striking resemblance in its temporal course to that of dP/dt.

After injection of adrenaline in a minute dose (10–30 μg.) into the carotid artery, prompt changes in P-F pattern occur: the long axis of the systolic loop and of diastolic trailing tend toward a more vertical direction, indicating an increased resistance to the flow within the peripheral bed, while the loop becomes somewhat rounder. But the general feature of its shape is not lost (fig. 9). These changes are considered to be mainly due to the vasomotor change within its peripheral bed, since its systemic effect is scarcely observed. The intra-arterial injection of a larger dose (100–200 μg.) causes an elevation of blood pressure level, slowing of the heart beat, and an increase in amplitude of flow pulse, while the loop component becomes distinctly more rounded. These results suggest that an increase in vasomotor tone in the flow bed and/or elevation of pressure head causes an increase in the DV-E component (as in the report of Pritchard *et al.*) or in the phase shift between P and F.

The effect of intra-arterial injection of histamine is, as shown in fig. 10, quite the reverse of that of adrenaline: immediately after its injection the loop disappears and an almost linear P-F pattern is seen transiently, even a reversal of ascending and descending limbs of the loop occurs, while it tends to be more horizontal. Intra-arterial injection of acetyl choline also produces a similar effect. These facts appear to suggest that a decrease in peripheral resistance due to vasodilation brings about an almost linear P-F relation, diminishing or annihilating the DV-E component.

It seems far too early, however, to draw a definite conclusion on haemodynamic principles from these scanty materials, rather we wish merely to point out that our method is applicable and seems promising in studying haemodynamics under various circulatory conditions, reserving discussion on these problems for a later paper.

SUMMARY

The present authors described a new method of recording the P-F diagram of each cardiac cycle on an intact peripheral artery. The patterns obtained by this method were almost constant under constant circulatory conditions and bore a striking similarity to those constructed from the results of previous workers. In this connexion, some considerations on the fidelity of an electromagnetic flowmeter have been given. The carotid and femoral patterns under normal conditions differ from each other, suggesting haemodynamical characteristics of respective arterial trees. It has also been illustrated that the effect of vasoconstriction or vasodilation produced by vasomotor drugs upon haemodynamics of peripheal circulation could readily be followed up by this method and increase or decrease in peripheral resistance would cause enhancement or diminution of the DV-E component or those of phase shift between P and F.

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