612.15(078)

A MECHANICAL STROMUHR.

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THE importance of measuring the amount of blood passing through various blood vessels under different conditions has been realized almost since the beginning of the study of the circulation. The methods which are used at present for blood flow measurement can be divided into two classes, indirect methods and direct methods. The modern indirect thermo-electric methods introduced by Gesell(1) and by Rein(2) involve complicated instruments and laborious calibration. The direct methods employ some variety of stromuhr based on the principle of the Ludwig(3) stromuhr, which is sufficiently well known to need no description here. The blood flow through the Ludwig stromuhr and the Tigerstedt(4) stromuhr was reversed by turning them about a central pivot. Stolnikov(5) working in Ludwig's laboratory reversed the blood flow through his stromuhr by using a hand clamp to divert the blood through suitably connected rubber tubes. Pavlov(6) introduced an electro-magnetic clamp worked automatically by contacts operated by floats placed on the surface of the blood in the reservoirs. To make certain that each float closed its contact effectively air occupied the space in the instrument above the floats. This, of course, involved a considerable error in the measurements owing to the effect of pressure changes upon the volume of air in the stromuhr. The use of the automatic clamp, however, eliminated the subjective error in the measurements made by these hand-reversed stromuhrs. Hürthle(7) and his pupil Burton-Opitz(8) eliminated the subjective error in another way, they kept the hand reversal, and recorded the movements of a piston in the stromuhr, but this introduced an additional resistance to the blood flow. Each of these methods has a certain disadvantage.

This paper describes a new stromuhr (Fig. 1) which has been used for a series of experiments, the results of which will be published shortly. Subjective errors are avoided by the use of the Pavlov automatic electro-magnetic clamp, and the air cushion has been eliminated by the use of a special pair of contacts which are closed in air outside the instrument. They are so constructed that neither the ease with which they are closed nor the accuracy of the measurements is affected by changes in the blood-pressure. Although the construction of these contacts is somewhat complicated their principle is simple.

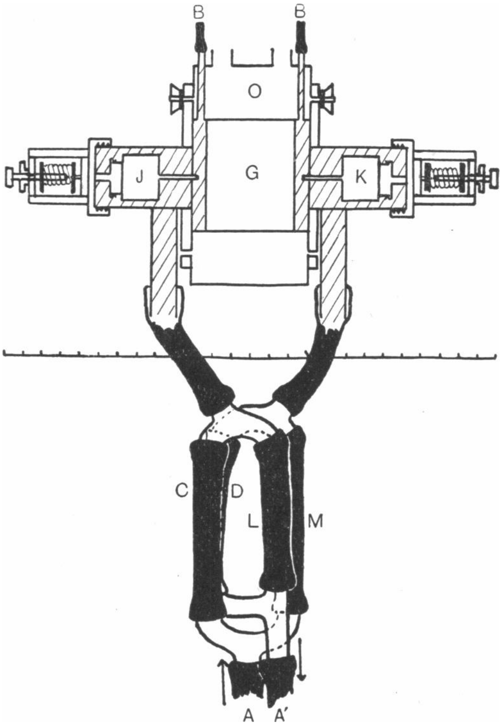

Fig. 1. Scale diagram of mechanical stromuhr. The rubber tubing and glass connections are slightly larger than their correct scale size. Scale: centimetres. Shaded area filled with blood. *A* and *A′* connected to canulæ in a divided vessel. When blood enters through *A* and the automatic clamp is set to close tubes *C* and *D*, then hollow piston *G* is moved to the left till it hits contact *J* which reverses the automatic clamp and the direction of flow till the piston closes contact *K* and so on. *O*, water bath. Tubes *B*, *B* for air escape when filling the stromuhr.

Fig. 2 is a sketch showing the principle of the contact. The rod *A* is attached to the cylinder *B* by two rubber membranes *C* one at either end of the cylinder. The inside of the cylinder is air-tight and blood surrounds the outside. The area of the two membranes is the same, hence variations in the blood-pressure cause equal and opposite differences of pressure across the membranes, and the position of the cylinder *A* is uninfluenced by changes in the blood-pressure. A stout wire *D* attached to the cylinder *B* runs up a hole in the centre of the rod *A*. Another stout wire *G* is attached to the outside of the cylinder and

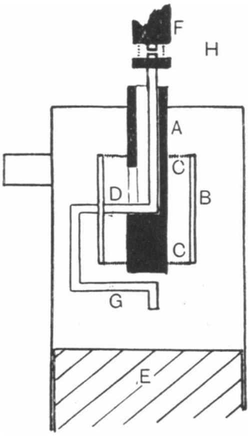

Fig. 2.

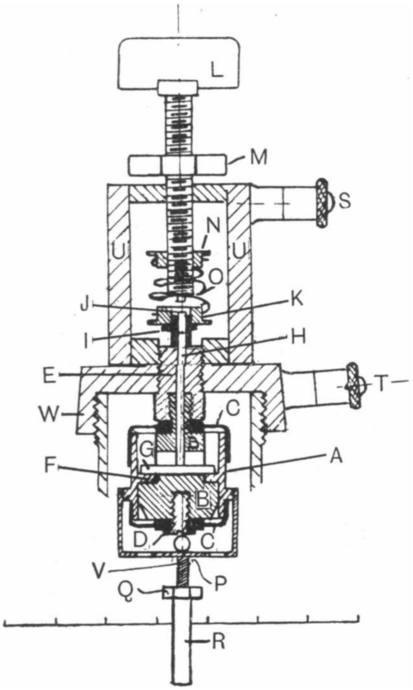

Fig. 3.

Fig. 2. Diagrammatic sketch of the principle of the contacts used in the mechanical stromuhr. See text.

Fig. 3. Scale diagram of one of the two contacts used in the mechanical stromuhr. Scale: centimetres. *A* cylinder with shoulders *F* resting on bearing *B* can move upwards only. *C* rubber membranes and washers connecting cylinder *A* to either end of bearing *B*. Bearing *B* threaded to rod *E* fixed to cap *W*. Cross-bar *G* passing through large hole in bearing *B* rests on shoulders *F*, carries light rod *H*, brass cap *I*, platinum point *J* and ebonite disc *K*, can be moved upwards only. Terminal for this contact *T*. Fixed platinum point carried by screw *L*. Terminal for this contact *S*, incalated from *T* by ebonite strips *U*. After adjusting distance between contacts screw *L* is locked by wing-nut *M*. Perforated cap *P* threaded to cylinder *A* carries threaded rod *V*, threaded tube *R* and lock-nut *Q*. Upward pressure on tube *R* causes upward movement of cylinder *A*, shoulders *F*, cross-bar *G* and light rod *H* till platinum point *J* hits corresponding fixed point on screw *L*. After the upward pressure is removed the points are separated by the light spring *O*, the tension of which is adjusted by turning the ebonite disc *N*.

projects below it. When the piston *E* moving upwards reaches *G*, the cylinder *B* and the wire *D* are moved upwards till *D* touches *F*. This makes an electric contact in air which throws the automatic clamp into action, the direction of the blood flow is reversed, the piston is forced downwards and the contact broken by the light spring *H*.

A scale diagram of one of the contacts used in the instrument is shown in Fig. 3. Fig. 4 shows a side view of the stromuhr and clamp and a front view of the clamp. Details of the automatic clamp are given in Pavlov's paper (6).

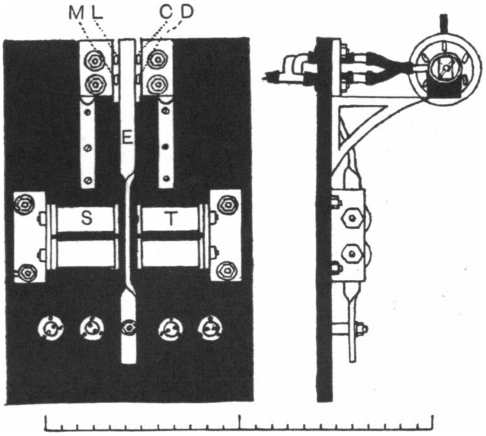

Fig. 4. Left: Electro-magnetic clamp. When magnet *S* is electrified, lever *E* clamps rubber tubes *L* and *M* so that the blood flows through the tubes *D* and *C*. Right: Electro-magnetic clamp with stromuhr in position. Side view. Scale: inches.

Resistance and accuracy of measurements.

(1) *Resistance.* A curve showing the resistance which the stromuhr opposes to different water flows is shown in Fig. 5. This low resistance is only made possible by the small friction between the piston and its cylinder. It has 1/1000″ clearance, and can be blown from one end of the cylinder to the other by a puff of air like the piston of a piston recorder. There is no leak past it.

(2) *Stroke capacity.* The velocity of the flow of a liquid through the stromuhr can be calculated from the formula

$$C = \frac{S \times 60}{T},$$

where C is the velocity of flow in c.c. per minute.

S is the quantity of fluid passing through the instrument between two reversals or, as I shall call it, the stroke capacity.

T is the time interval between two reversals.

Each reversal of the stromuhr is marked on a drum, and a time marker marks seconds on the same drum. From the records of these two markers T can be found. S, the stroke capacity of the stromuhr, is found by collecting the fluid which passes through the stromuhr during 50 reversals and dividing this quantity by 50.

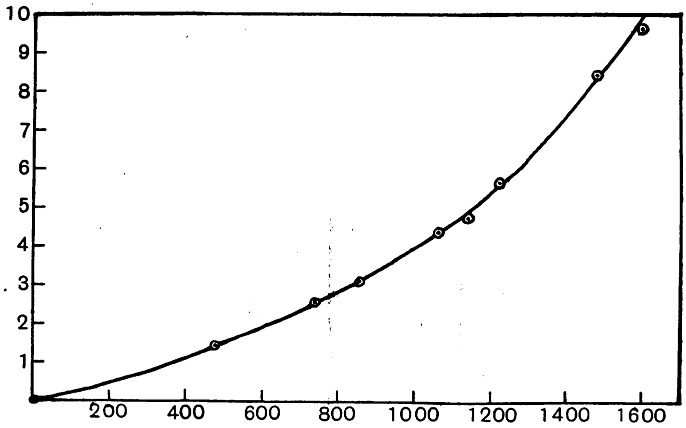

Fig. 5. Curve showing the resistance offered by the mechanical stromuhr to different water flows. Ordinate: Resistance in mm. of mercury. Abscissa: Flow in c.c. per minute.

The stroke capacity differs slightly with different flows and different pressures as the figures in the first three columns of Table I show.

Table I.

Water flow through the stromuhr c.c. per min.	Pressure mm. Hg	Stroke capacity	P.c. error in taking an average stroke capacity of 26·9 c.c. as a standard
138	20	25·9	3·85
126	180	26·4	1·9
352	20	26·2	2·65
308	200	26·8	0·37
741	20	27·1	0·74
615	200	27·7	2·9
994	20	27·4	1·8
933	200	27·6	2·5

These differences in the stroke capacity are not due to leak past the piston, but to the fact that the reversing of the clamp is not completely instantaneous and for an instant all four rubber tubes are open simultaneously.

The average of these stroke capacities is 26·9 c.c. If this average stroke capacity is taken as S for calculating the velocity of flow for any one of these different flows and pressures instead of the actual stroke capacity, then there will be a small error in the calculated flow. This error is shown in the fourth column of Table I. The error is so small that it justifies the use of an average stroke capacity in calculating flows within these limits of flow and pressure.

(3) *Calibration after blood-flow measurement.* The stroke capacity of the stromuhr varies slightly each time it is taken to pieces to be cleaned and must be found for each experiment. In practice the stroke capacity used in the calculations of the velocity of the blood flow in any experiment is that found after the experiment for a water flow of 500 c.c. per minute. That it is justified is shown by the following test.

Blood has been passed through the stromuhr at a known velocity and 50 readings taken for each of 12 different conditions of flow and blood-pressure. The limits of blood flow were 195 c.c. per minute and 935 c.c. per minute, and of blood-pressure 50 mm. of Hg and 150 mm. of Hg. The average stroke capacity of the instrument has then been found by water calibration and the blood flow calculated for each of the 600 readings obtained. These 600 calculated flows when compared with the actual flows show the following results: 57 p.c. of the readings have an error of less than 3 p.c., 78 p.c. have an error of less than 5 p.c., 3 p.c. have an error of more than 9 p.c., and no error of 12 p.c. was found. Subjective errors in taking the measurements from the tracing are included in this.

(4) *Rapidity of response to changes in flow.* Fig. 6 shows the response

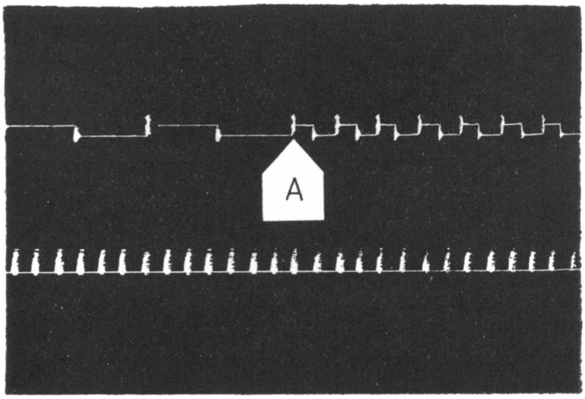

Fig. 6. Top tracing: Reversals of the stromuhr. Bottom tracing: Seconds. At *A* the constant flow through the stromuhr was instantaneously increased. This increase is recorded immediately.

of the stromuhr to a sudden change in the flow. At *A* the flow through the instrument was altered from 480 c.c. per minute to 1880 c.c. per minute. The lag in the change of the record is scarcely perceptible.

(5) *Sample tracing of blood-flow measurement.* Fig. 7 shows a sample tracing taken while the stromuhr was measuring the total output of the heart with the exception of the coronary flow, the variations in the blood-pressure and blood flow are due to an intravenous injection of adrenaline. The blood flow calculated from this tracing is shown below in the same figure.

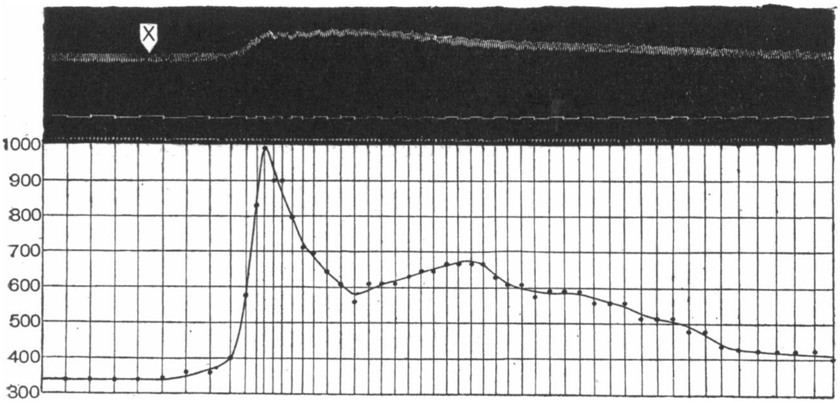

Fig. 7. Top tracing: Blood pressure. Middle tracing: Mechanical stromuhr, stroke capacity 34·5 c.c. Bottom tracing: Time marker, marking in seconds. The curve below shows the output of the heart before and after an intravenous injection of adrenaline at *X* on the tracing. Ordinate: Output of the heart (except coronary flow) in c.c. per minute. Quarter actual size.

SUMMARY.

This paper describes a mechanical stromuhr which is suitable for the measurement of the blood flow through the larger arteries of operated animals.

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