A MODIFICATION OF THE METHOD OF DIFFERENTIAL MANOMETRY FOR REGISTRATION OF THE VOLUME VELOCITY OF THE BLOOD FLOW

A. V. Dokunin

From the Laboratory of Pathophysiology and Pharmacology of the Cardiovascular System (Director – Prof. S. V. Andreev) of the Institute of Pharmacology and Chemotherapy (Director – Active Member of the AMN SSSR V. V. Zakusov) of the AMN SSSR, Moscow

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Several forms of apparatus for registration of the rate of the blood flow by the method of differential manometry are described in the literature [1-4]. They consist essentially of a cannula joining the proximal and distal ends of a divided vessel. The size of the lumen of the cannula is regulated by special cut-out plates with orifices of different diameters, or by screws. When the lumen is reduced, the linear velocity of the blood flow at the point of constriction increases, and the pressure falls in proportion to the reduction in the area of cross section of the lumen. The pressure difference before and immediately after the cannula, according to the Bernulli formula, is proportional to the difference of the squares of the velocities of flow at these points, and ultimately reflects the rate of the blood flow:

$$P_1 - P_2 = \frac{\rho v_2^2}{2} - \frac{\rho v_1^2}{2}, \tag{1}$$

where P_1-P_2 is the pressure difference; v_1 and v_2 are the linear velocities of the blood flow before and after the constriction; and ρ is the density of the fluid.

In another modification measurements are made of the difference between the lateral pressure and the pressure in a Pitot tube (a manometric tube turned to face the flow of blood). In this case the rate of flow in the Pitot tube v_1 is equal to zero, and the formula is simplified to:

$$P_1 - P_2 = \frac{\rho v^2}{2} . \tag{2}$$

The main drawbacks of these forms of apparatus are, in the first place, that where solid matter projects into the cannula, especially at points of constriction, sedimentation of blood cells takes place, with coagulation of the blood, altering the sensitivity and distorting the readings of the apparatus; in the second place, when the velocity of the blood flow is less than 50 ml/min the sensitivity of the apparatus is low. As shown by experimentally verified calculations, when registering the velocity of flow by the method of differential manometry of such a relatively viscous fluid as blood, then Bernulli's law is less applicable than Poiseuille's law:

$$P_1 - P_2 = V \frac{8\pi\eta l}{q^2}, \tag{3}$$

where η is the viscosity of the blood, l the length of the portion of vessel or tube; V the volume rate of flow in the portion of vessel. In consequence of this we used the following modification of the method.

A rubber tube 2 and 3 (Fig. 1), 2-3 mm in diameter is inserted into an artery of the organ to be tested.

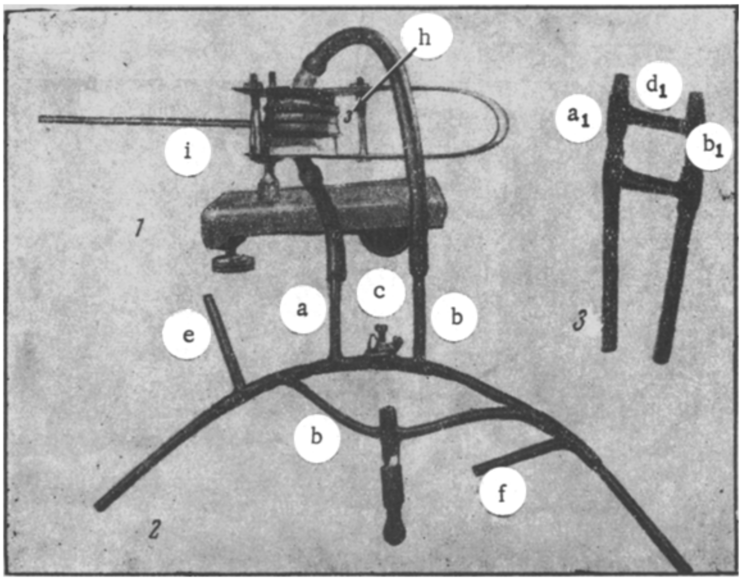

Fig. 1. Apparatus for registration of the magnitude of the blood flow.
1) Differential manometer; 2 and 3) rubber cannulas.

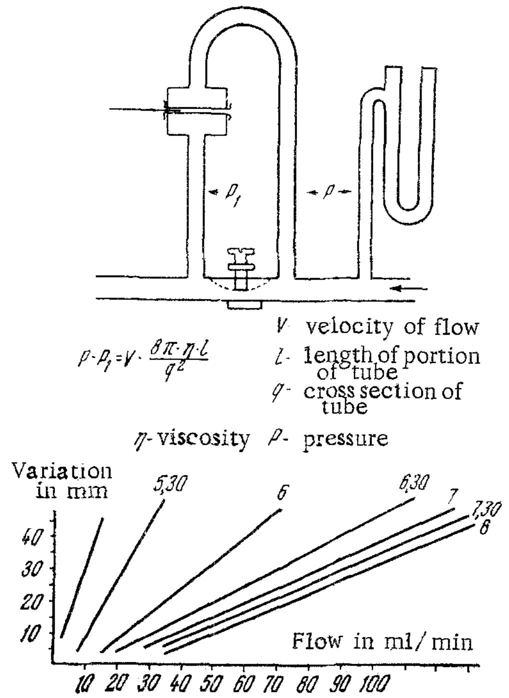

Fig. 2. Scheme of the apparatus and calibration graphs for different degrees of sensitivity of the apparatus.

The tube has two branches situated at some distance from each other (see Fig. 1, a and b or a_1 and b_1) and connected to the chamber of a differential manometer 1 (Fig. 1). According to Poiseuille's formula, the fall in pressure in the tube between the branches is proportional to the volume rate of flow of the blood. Since η, l, q, and consequently the value $8\pi\eta l / q^2$, expressing the resistance of the portion of the tube, are constant throughout the experiment, and the formula acquires the form:

$$P_1 - P_2 = Vk, \tag{4}$$

i. e. the readings of the differential manometer are directly proportional to the volume rate of blood flow; $8\pi\eta l / q^2$ (the resistance of the portion of tube) is the coefficient of proportionality – k.

A screw clamp c (see Fig. 1) is applied to the tube between the branches, enabling the cross section of the tube to be varied. In this way k, i. e. the sensitivity of the apparatus, is changed in inverse proportion to the square of the section, q^2. In each experiment the clamp is placed in a definite position to allow adequate sensitivity of the apparatus for a given blood flow.

The apparatus is calibrated as a first step: graphs are prepared for different degrees of sensitivity showing the slope of the curve (in millimeters) in relation to the magnitude of the volume blood flow (in milliliters per minute). The graph is a straight line, the gradient of which increases as does the sensitivity of the apparatus (Fig. 2).

Calculation of the value of the slope starts from the zero level, i. e. from the level of the readings at equal pressures in both chambers of the manometer. For this reason, in the course of the experiment, it is

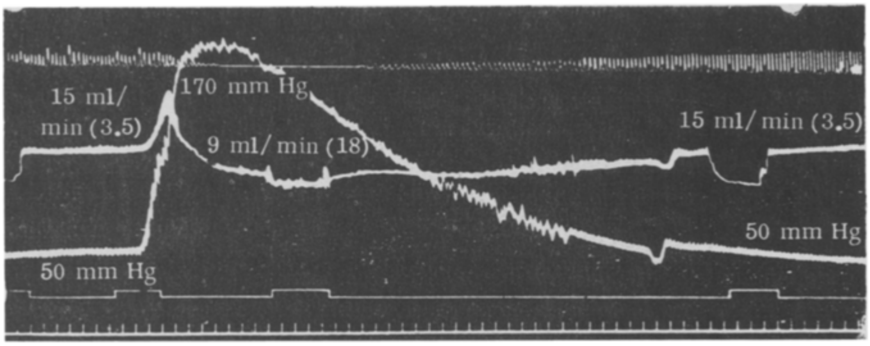

Fig. 3. Registration of the blood flow in the hind limbs of a cat during the intravenous injection of adrenalin (75 γ/kg). Significance of the curves (from above downward): respiration, blood flow, blood pressure, marker for injection of the drug and verification of the zero level, time marker (5 seconds). The sharp falls in the line registering the blood flow correspond to observations of the zero level. The figures in brackets show the resistance of the vascular bed of the limb.

essential to equalize the pressures in the chambers periodically (every 5-10 minutes) and to observe the zero level. This is done by including in the circuit a parallel tube d (see Fig. 1), or better still – by joining the two branch tubes a_1 and b_1 (see Fig. 1) with a cross tube d_1 (see Fig. 1), on which a clamp is applied. When this clamp is transferred to the branch a_1 or b_1 immediately below the cross tube d_1, the pressure in the chambers is equalized without any alteration in the conditions of the blood flow.

The differential manometer which we used 1 (see Fig. 1) was constructed from two small Marey's capsules (manometer chambers h; see Fig. 1), firmly fixed to each other by means of rubber membranes. Between the membranes is attached one arm of a lever with two arms, i (see Fig. 1). The axis of rotation of the lever is placed alongside the point of contact of the capsules, at the margins of which small, narrow cuts are made to allow movement of the lever. The second arm of the lever traces on the drum of the kymograph, either directly or through a system for magnifying the variations. During the experiment the entire system is filled with physiological saline.

Other and more sensitive systems of manometers (optical, electromanometers, and so on) may be used. Under these circumstances the coefficient k, i. e. the resistance, included in the blood flow can be reduced to a minimum.

Among the advantages of the proposed modification are the simplicity of the apparatus and the absence of hard, angular projections from the path of the blood, thanks to which there is no destruction of blood cells and no coagulation of the blood. In the course of an experiment lasting 4-5 hours the sensitivity of the apparatus stays constant. Another advantage of the apparatus is the adequate fall in pressure; with volume rates of blood flow of 10-50 ml/min, it is several times higher than in the apparatus working on Bernulli's formula, with the same minimum diameter of cannula (approximately 2 mm).

As the experiments showed, the apparatus allows registration of the volume velocity of the blood flow – 10 ml/min and over. If the degree of sensitivity is arranged close to its maximum value (for example, 5, 30 on the graph; see Fig. 2), the deviation of the recording lever corresponding to a change in the volume velocity of 1 ml/min is 1.5 mm. Such sensitivity readily allows registration of the changes in the blood flow in the limbs, kidneys, head and abdominal viscera of average laboratory animals (cats), not to mention the larger ones (dogs; Fig. 3).

A slight modification also allows Bernulli's law to be utilized (see Fig. 1, 3). The first branch a_1 is in practice a Pitot tube. In this way a useful combination of both methods of differential manometry can be brought about.

Finally, an advantage of the method described is the direct proportion between the manometer readings and the volume velocity of the blood flow.

In practice it is convenient to have two further branches from the tube: one for registration of the blood pressure (see Fig. 1, e) and the other (see Fig. 1, f), situated beyond the branches to the differential manometer, for injection of drugs directly into the arterial system of the organ under examination. The method is also applicable for registration of the flow of nutrient fluid in organ perfusion experiments.

SUMMARY

A modification of the method of differential pressure measurement for registering the volume velocity of the blood flow is described. A rubber tube is connected to the blood vessel. The difference in the lateral pressure exerted in its two consecutive points is, in accordance with the Poiseuille formula, proportional to the volume velocity of the flow. This difference is registered by a differential pressure gauge. The rubber tube has a screw clamp between the side branches connected to the pressure gauge, providing means of controlling the resistance of the corresponding section of the tube, and thereby the sensitivity of the whole instrument.

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