EXPERIMENTAL DETERMINATION OF THE TRANSPORT FUNCTION OF THE BLOOD AND LYMPHATIC CIRCULATIONS

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Existing methods of determining the velocity of a fluid in the vessels do not satisfy the requirements of experimental accuracy. This is particularly true of measurement of the transport function of the lymphatic circulation, which is judged from the number of drops of lymph or perfusion fluid flowing from the lymphatic vessel per unit time [2]. Requiring to make a detailed study of the transport function of various parts of the lymphatic system, V. V. Kamenskaya and Yu. I. Borodin developed a method of objective recording of the flow of fluid in the lymphatic circulation, possessing high sensitivity. The readings are recorded as a continuous curve on a moving paper tape.

The physical principles of the suggested method are as follows. A thermister (MT-54), used as detector of the flow velocity of the liquid, is heated by passing an electric current through it. The thermal balance of the detector (TR) and the magnitude of its resistance are determined by the medium in which it is placed (flow velocity and temperature).

$$T = T_0 + \frac{P}{H},$$

where T_0 is the temperature of the medium surrounding the thermistor (TR), P its scattering power, H the coefficient of scatter, and T the mean temperature of the working part of the thermistor. Knowing the environmental temperature T_0, the coefficient of scatter of the detector H, the necessary temperature T of the thermistor may be obtained by changing the power of the current supplied to it.

To calculate the working conditions of the detector, its temperature $R = f(T)$ and volt-ampere $V = f(I)$ characteristics were taken, together with the relationship between the excess of the temperature of the TR over that of the medium (blood) and the strength of the current passing through the thermistor, $T_{nog} = f(I)$ with T_0 = const and V = const.

The excess of temperature TR over the temperature of the medium is determined from the simple relationship $T_{nog} = T - T_0$. The structure of the characteristic $T_{nog} = f(I)$ is determined from the results of measurement of the resistance of TR at several different values of current passing through it and at constant temperature and velocity of the medium.

The relationships $R = f(I)$ and $R = f(T)$ were used to determine the characteristic $T = f(I)$ at V = const, T_0 = const, from which the required temperature conditions of operation of the TR were selected. During calculation of the temperature conditions of operation of the detector it is important to select an optimal temperature at which the scatter power does not cause irreversible changes in the characteristic of the thermistors, no perceptible heating of the flowing fluid takes place, and yet the maximal possible sensitivity to changes in flow velocity is ensured.

The quantity of heat transmitted by a hot body (TR) to a medium when thermal balance is established is determined by $f = 0.24I^2Rt$, where Q is the amount of heat lost by the detector during time t, I the strength of the cur-

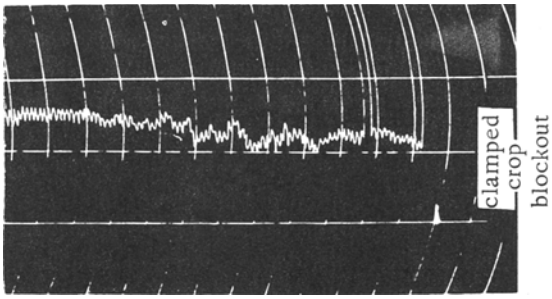


Fig. 1. Oscillographic recording of the velocity of the blood flow in the coronary sinus of a dog.

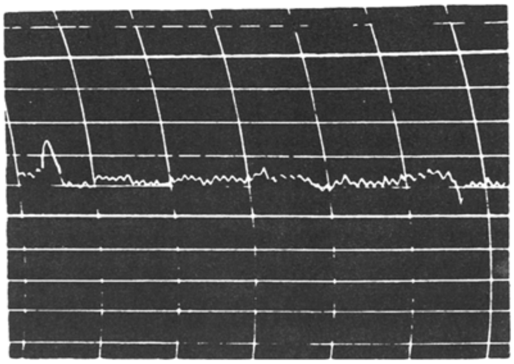


Fig. 2. Oscillographic recording of the velocity of flow of fluid in the lymphatic vessels of a dog's hind limb.

rent in the detector, and R the resistance of the detector. The amount of heat obtained by the medium from TR during the same time interval is given by $Q_1 = S \cdot V \cdot dc\Delta Tt$, where S is the cross section of the vessel, c the specific heat of the medium, ΔT the rise of temperature of the medium, t the time, V the velocity of the blood flow, and d the density of blood. When thermal balance is established, $Q_1 = Q$, and hence $0.24I^2R = S \cdot V \cdot d \cdot c\Delta T$, but $0.24I^2R = V_0 d \cdot c \cdot \Delta T$, from which $V_0 = V \cdot S$—the volume velocity of the flow of fluid.

On the basis of this equation of thermal balance, the mean temperature of additional heating of the fluid flowing through a cross section of the vessel with the detector may be determined. The calculation given above shows that, even at very low velocities in the immediate neighborhood of the detector the temperature of the fluid (blood) rises by 0.1°, which is perfectly permissible, because it does not cause irreversible physiological changes. The sensitivity of the method is such that changes in the linear velocity of flow can be detected down to 0.03 cm/sec; the sensitivity to changes in volume velocity is the greater, the smaller the diameter of the vessel, if the linear velocity is constant.

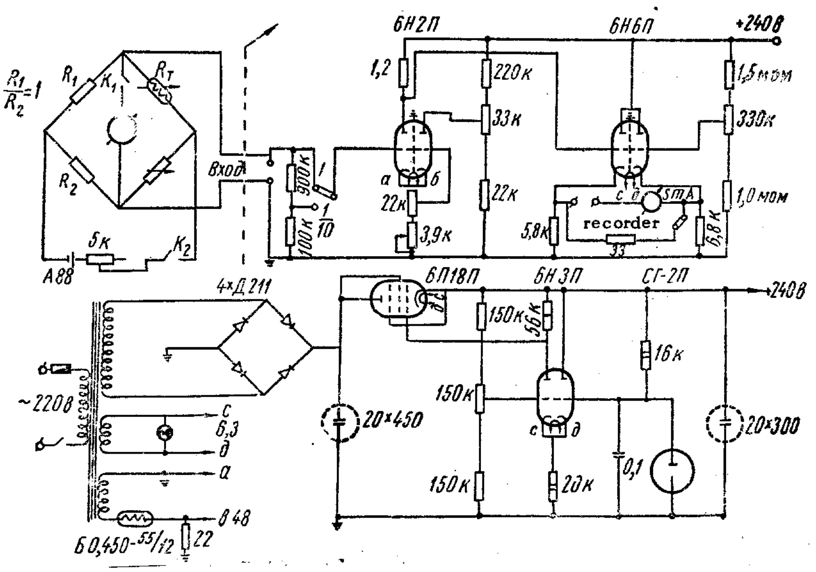
The detector was inserted into a tube connecting the reservoir of perfusion fluid to a needle introduced into the lymphatic vessel in the direction of flow of lymph. Consequently, when the experiment was performed in this way the velocity of fluid injected into the lymphatic vessel was measured indirectly. A very small change in the permeability of the lymphatic vessel was immediately reflected in the velocity of the fluid in the tube and in the working of the detector. This method was used to investigate the transport function of the superficial lymphatic vessels and popliteal nodes in the hind limbs of dogs and cats, the superficial lymphatic vessels of the forelimb and neck, and the superficial cervical lymphatic nodes of the same animals. Acute experiments were conducted on 15 dogs and 10 cats. The curves recorded during these experiments show that fluid flows irregularly in the lymphatic system (Fig. 1). Small peaks can be seen in the curve, synchronized with the respiratory movements of the chest, and larger waves not corresponding in frequency to the pulse or respiration of the animal. These waves may possibly reflect the intrinsic contractile activity of the lymphatic system.

Subsequently G. D. Mysh, V. V. Kamenskaya, L. A. Kulikova, and V. N. Vorob'ev used this method to measure the linear velocity and volume velocity of the coronary blood flow. Several methods of determining the velocity of the blood flow in the coronary system exist: Kravkov's method of the isolated organ, Gregg's back flow method, and cannulization of the coronary sinus, suggested by N. P. Bisenkov and others [1, 3, 4]. However, these methods can be used only on the heart during standstill or they are associated with a disturbance of the natural blood flow.

The suggested method has none of these disadvantages. The apparatus was tested on 6 adult dogs in which various operations were subsequently performed to revascularize the heart. The oscillographic recording took the form of a curve in which waves of the second order could be clearly distinguished (Fig. 2). The detector was placed in a flexible catheter and introduced into the coronary sinus through the jugular vein. The velocity of the blood flow was recorded throughout the experiment, after which the catheter was implanted subcutaneously in the dorsal region of the animal, where it was fixed. Readings were then recorded for 1, 2, and 3 days after the operation. The catheter was then extracted, the experiment having ended.

More recently, Yu. I. Borodin and V. V. Kamenskaya used this method to measure the velocity of the blood flow in the hind-limb veins of a dog. In this case the detector was placed inside a sharp-pointed needle introduced into the vessel. The blood flow was investigated in the femoral, popliteal, and lateral subcutaneous veins. Bearing in mind the superficial position of the lateral subcutaneous vein, the velocity of the blood flow in it may be investigated by inserting the needle-detector percutaneously. The apparatus consists of the following basic components: detector, measuring, apparatus, and source of current.

The detector, the principal element of the apparatus, placed directly in the stream of fluid (blood, perfusion fluid), is a type MT-54 thermistor (TR), consisting of a miniature bead of semiconducting material, 0.5 mm in diameter, housed in a glass capillary tube. Two fine wires pass from the bead, to which thicker leads are soldered. The microthermistor, with a milliameter included in series, is placed in the working arm of a universal Wheatstone bridge, used without any modification. A continuous objective recording is made of the readings by means of a self-registering ampere voltmeter (type H370-M) after preliminary amplification of the input signal in accordance with the following scheme (Fig. 3).



Some of the following Russian abbreviations may be found in the figure: *Л* = tube, *Д* = diode, *Тр* = transformer, *Др* or *др* = choke, *Вк* = switch, *в* = V, *М* = MΩ, *к* = kΩ, *мк* = μF or μH, *п* = pF or pH, and *н* = nF or nH.

Fig. 2. Block diagram and electrical circuit of apparatus.

During investigation of the velocity of the blood flow, after insertion of the thermistor into the vessel the blood temperature is measured with the bridge supplied by a small current. In this case the power scattered by the electric current in the detector is so small that it does not warm it appreciably, and the magnitude of the resistance of the thermistor (after 1-2 sec) is determined purely by the blood temperature. The temperature of the detector, and hence of the blood, is determined from the temperature characteristic of the TR. The current required to warm up the detector is then established. With this current, the readings of the bridge and of the self-registering apparatus are dependent on the velocity of the blood flow.

At the end of the experiment the small current to feed the bridge is again determined and the temperature of the animal correlated with the resistance of the TR. The corresponding temperature correction can be made from the temperature data at the beginning and end of the experiment. Hence, in the suggested method, both the temperature and velocity of flow of the blood may be measured on the same apparatus with one thermistor.

Our observations show that the method is technically simple and sensitive and may be used in chronic and acute experiments to investigate the functional state of various divisions of the vascular system.

SUMMARY

The authors developed and tested (in experiments on dogs and cats) a method for determining the fluid volume and linear circulation rate in the lymph vessels and veins with the aid of microthermoresistance. Thermistor MT-54 used for this purpose was highly sensitive to the changes in the rate of the fluid circulation (up to 0.3 cm/sec). Constant objective recordings taken with the aid of an autorecorder of the H370-M type gave highly accurate oscillographic recordings of the velocity of the fluid circulation in the blood and lymph vessels.

This method may be widely used in acute and chronic experimental conditions.

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4. D. E. Gregg, Physiol. Rev., 26, p. 28 (1946).

All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.