ESTIMATION OF THE CARDIAC OUTPUT IN THE PRESENCE OF A PATHOLOGICAL ARTERIOVENOUS SHUNT

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The aim of the investigation was to develop a quantitative method of determining the cardiac output by the thermodilution principle in patients with congenital heart diseases accompanied by a pathological arteriovenous shunt. A method of graphic analysis of the curves based on standard ratios between heights of the descending part is suggested. Values of left–right shunts similar to results obtained by the Fick method can be obtained by the method now suggested.

KEY WORDS: thermodilution; arteriovenous shunt; cardiac output.

The thermodilution method has been widely adopted in clinical practice in the last 5 years for estimation of the cardiac output. Determination of the cardiac output and the shunt of blood by this method is a particularly difficult and urgent task in patients with congenital heart diseases [1, 2, 5-10].

The object of this investigation was to continue development of a method of quantitative determination of large and small shunts of blood from left to right and of the cardiac output itself by the thermodilution principle and to increase its accuracy.

This paper is based on the results of 10 experiments on dogs and of clinical investigation of 17 patients: 12 with a ventricular septal defect and five with an atrial septal defect. Thermodilution curves before and after closure of the defect were recorded in each patient repeatedly (up to 3-5 times) during the operation on the heart. Thermodilution curves were recorded by means of an apparatus with independent power supply, constructed in the Laboratory of Medical Electronics of the M. F. Vladimirskii Moscow Regional Clinical Research Institute. An "Edwards" catheter with thermistor secured to its end was introduced through the radial artery as far as the ascending aorta. The open channel of the catheter was used to monitor the arterial pressure directly during the operation. Sterile physiological saline, cooled to 4-10°C, injected into the right atrium through a catheter introduced either by puncture of the jugular vein or by venisection along the innominate vein, was used as the indicator.

The thermodilution curve recorded on a patient with a left–right shunt is illustrated in Fig. 1. The maximal height of the curve was usually less than on curves obtained from the same patient after closure of the defect. In the presence of a defect the slope of disappearance of the indicator was more gradual, the rise time of the maximal temperature gradient (t_2) was appreciably increased, and the indicator elimination time (t_4) was even more protracted. The greater the shunt of blood from left to right, the greater the changes in these parameters. The degree of steepness was determined from the ratio between the heights of the descending part of the curve. Intervals of t_2, $2t_2$, and $3t_2$ were plotted along the time axis. From these points perpendiculars were drawn to intersect the curve. The ratios of these heights were then calculated: h_{max}/h_1; h_1/h_2, and h_2/h_3. In the absence of a shunt, as experimental investigations and recording of thermodilution curves showed, the decrease in the temperature gradient obeys a definite rule: the ratios of the heights averaged 2.1 ± 0.16, 1.68 ± 0.11, and 1.55 ± 0.14. In the presence of a left to right shunt the mean ratios between the heights were 1.41 ± 0.08, 1.34 ± 0.07, and 1.16 ± 0.05 if there was a ventricular septal defect, and 1.06 ± 0.02, 1.2 ± 0.09, and 1.2 ± 0.05 if there was an atrial septal defect. The decrease in the ratios h_n/h_{n+1} in the presence of left to right shunts occurred because some of the indicator solution, mixed with the blood flowing around the pulmonary circulation, was returned over and over again to the right heart, thus delaying disappearance of the indicator from the zone of the central circulation.

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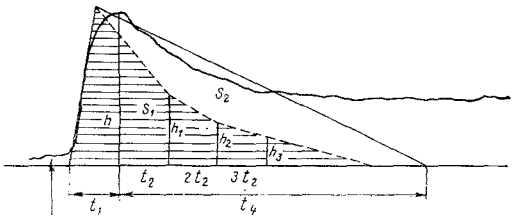

Fig. 1

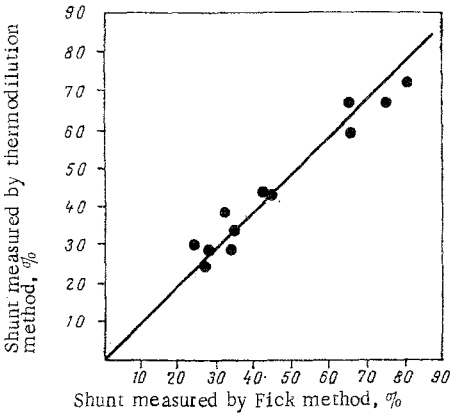

Fig. 2

Fig. 1. Thermodilution curve of patient Ya. with ventricular septal defect (43% shunt from left to right). Explanation in text.

Fig. 2. Comparison of results of measurement of arteriovenous shunt by Fick and thermodilution methods.

In view of this rule, using values of the maximal temperature gradient and its rise time it was possible to distinguish from the area bounded by the thermodilution curve recorded in the presence of a left–right shunt, an area corresponding to the minute volume of the pulmonary circulation without superposition of repeated recirculations of the shunted blood. For this purpose the maximal height h_{max} was divided by a coefficient 2.1, h_1 was divided by 1.68, and h_2 by 1.55, and a line drawn through the resulting points was taken to be the descending part of the curve characterizing the blood flow in the pulmonary circulation at that moment, i.e., a flow increased by the left to right shunt, but without distortion by subsequent cycles of recirculation through the shunt. After measurement of the total area and the area bounded by the "theoretical" curve thus drawn, their difference was found and characterized the shunt. This difference, expressed as a ratio of the total area and multiplied by 100, gave the shunt as a percentage of the cardiac output to the pulmonary circulation.

The suggested method of determining the magnitude of a left–right shunt showed good agreement with the results of measurements by the oxyhemometric method. For the group of patients studied the shunt estimated by the Fick method averaged 46 ± 3.8%, compared with 44 ± 3.3% by the method now suggested; by the "inscribed and anterior triangle" method [4, 6] it was 55 ± 5.7%, and by Carter's equations [8] it was 70 ± 6.5%. The coefficient of correlation for the group of patients with ventricular septal defect was 0.89 and for the group with an atrial septal defect it was 0.97 (Fig. 2). Disparity between the values of the relative shunt and results obtained by the Fick method did not exceed 5%, with a level of significance of the difference of 0.35 by Student's t-test.

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