EVALUATION OF PARAMETERS OF THE BLOOD VESSEL AND THE CARDIAC OUTPUT FROM THE SHAPE OF THE PRESSURE CURVE

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A method of assessing the volume elasticity, the peripheral resistance, and the stroke volume of the ventricle from the shape of the curve of intravascular pressure is suggested using the pulmonary artery as an example.

There are two main approaches to the determination of the volume elasticity of blood vessels. The first is based on preliminary determination of the minute volume, for example by the direct Fick method [3] and the second is based on measuring the time required for the pulse waves to spread from one part of the vascular system to another [4].

The writers propose a method of calculating the parameters of the pulmonary circulation from the shape of the curve of pressure within the pulmonary artery. In fact it combines the two approaches and it gives the opportunity of determining the stroke volume of the right ventricle. This is because the ratio between the effective length of the pulmonary vascular system and its effective cross section shows little variation not only under normal conditions, but in several pathological states.

EXPERIMENTAL METHOD

Curves of the pressure in the trunk of the pulmonary artery were recorded during holding the breath at expiration in the course of transvenous catheterization of the heart, on a minograph-42B (Elema-Schönander, Switzerland) apparatus. The tape-winding mechanism moved at speeds of 25, 50, and 100 mm/sec.

The volume elasticity (K) is defined as $\Delta P/\Delta V$, where ΔV is the change in volume and ΔP the change in pressure within the vessel.

Rashevskii [2] showed that an approximate estimate of the volume elasticity can be obtained by the equation

$$K \approx \frac{R}{T_d} \ln \frac{P_1}{P_2}, \tag{1}$$

where P_1 and P_2 are the pressures in the pulmonary artery at the beginning and end of diastole respectively (in mm Hg); T_d the duration of diastole (in sec); and R the peripheral resistance (in dynes. sec $\cdot$ cm^{-5}). An alternative equation for calculating K, requiring calculation of the area under the systolic and diastolic portions of the curve, will be found in Guyton's book [1].

According to the theory of spread of the pulse waves, the volume elasticity [4] can be estimated by the expression:

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TABLE 1. Results of Calculation of Parameters of the Pulmonary Artery and Minute Volume for 26 Patients with Various Heart Defects

Serial No.	Q (in liters/min) by Fick's meth.	Q, calculated (in liters/min)	ΔQ (in liters/min)	$\frac{\lvert\Delta Q\rvert}{Q}$ (in %)	Serial No.	Q (in liters/min) by Fick's method	Q, calculated (in liters/min)	ΔQ (in liters/min)	$\frac{\lvert\Delta Q\rvert}{Q}$ (in %)
1	4	3,9	0,1	2,5	14	5,5	5,5	0	0
2	4,2	4,6	—0,4	9,6	15	5,5	4,9	0,6	11,0
3	4,2	4,0	0,2	4,8	16	6,4	6,5	—0,1	1,6
4	4,6	4,8	—0,2	4,3	17	6,7	6,9	—0,2	3,0
5	4,7	4,4	0,3	6,4	18	6,8	7,8	—1,0	14,6
6	4,7	5,3	—0,6	13,0	19	7,8	6,2	1,6	20,0
7	4,8	5,5	—0,7	14,0	20	8,1	8,5	—0,4	5,0
8	5,0	4,6	0,4	8,0	21	8,7	8,4	0,3	3,5
9	5,0	4,5	0,5	10,0	22	9,7	10,2	—0,5	5,2
10	5,4	5,3	0,1	1,9	23	9,7	11,2	—1,5	15,0
11	5,4	4,9	0,5	9,3	24	12,2	12,6	—0,4	3,3
12	5,3	5,8	—0,5	9,5	25	16,0	18,0	—2,0	12,5
13	5,5	5,0	0,5	9,1	26	20,0	17,8	2,2	11,0

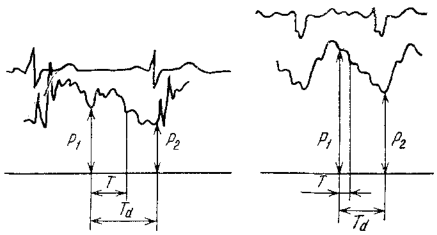

Fig. 1. Determination of initial parameters for calculating stroke volume from the shape of the curve of pulmonary arterial pressure (explanation in text).

$$v^2 \frac{\rho}{lS} \approx K, \tag{2}$$

where v is the rate of spread of the pulse waves in the vessel (in cm/sec), ρ the density of blood (in dynes $\cdot$ sec^2 $\cdot$ cm^{-4}); l the effective length of the vascular system (cm); and S the effective cross-section of the vascular system (in cm^2).

Assuming that as a result of the spread of the pulse wave along the vessel a reflected wave is formed, moving from the periphery toward the center (toward the heart), and that the periodic oscillations thereby produced are observed on the diastolic part of the curve of pressure recorded in the pulmonary artery, the period T of these oscillations will be $2l/v$. Substituting the value of v from Eq. (2) in this formula, we obtain

$$T = 2\sqrt{\rho \frac{l}{S} \cdot \frac{1}{K}}. \tag{3}$$

The period T is the time of one oscillation. It is defined as the distance between corresponding points of two successive oscillations on the diastolic part of the curve. For example, it can be measured as the distance between the initial points of two successive reflected waves (Fig. 1).

It will be noted that values of the pressure at any moments of diastole, separated by time nT, can be used in Eq. (1) as P_1 and P_2. Under these circumstances, T_d must be taken as equal to nT.

By means of the equation given above, the parameters of the vessel ($\rho\, l/S$, R, and K) could be determined if the minute volume was known.

Knowing the minute volume Q, calculated by Fick's method, and also, consequently, the peripheral resistance $R = \overline{P}_{pa}/Q \cdot 80$, the volume elasticity was calculated by Rashevskii's Eq. (1) and the value of $\rho \times l/S$ was determined by Eq. (3). The results showed that, unlike the values of R and K, the value of $\rho \times l/S$ varies negligibly. This fact can be used to solve the converse problem, i.e., to calculate the minute volume, peripheral resistance, and volume elasticity from the curve of intravascular pressure.

We obtain from Eq. (3)

$$K = \frac{4\rho \frac{l}{S}}{T^2}. \tag{4}$$

From Eq. (1) we obtain

$$R = \frac{K \cdot T_d}{\ln \frac{P_1}{P_2}}. \qquad (5)$$

In that case, using Eqs. (4) and (5), we obtain

$$Q = \frac{\overline{P}_{pa}}{R} \cdot 80 = \frac{80 \cdot \overline{P}_{pa} \, T^2 \ln \frac{P_1}{P_2}}{4 T_d \rho \frac{l}{S}}. \qquad (6)$$

Substituting $\rho \times l/S = \text{const}$, it is possible to calculate parameters of the vessel and the minute volume from Eqs. (4), (5), and (6).

EXPERIMENTAL RESULTS

The parameters of the pulmonary circulation were calculated for 32 persons aged from 6 to 43 years, with functional murmurs and various defects of the heart. The systolic pressure in the pulmonary artery varied from 22 to 120 mm Hg. Preliminary results showed that the ratio $\rho \times l/S$ was constant in every case unless marked pulmonary hypertension was present. In 26 patients with a pressure of not more than 100 mm Hg in the pulmonary artery, the ratio $\rho \times l/S$ varied from 1.78 to 2.2, with a mean value of 1.95. In the presence of marked pulmonary hypertension the mean value of $\rho \times l/S$ was increased to 3.1 and varied from 2.2 to 4.5. This increase in the ratio may be an indication of considerable structural changes in the pulmonary vascular system.

The results of calculation of the minute volume in the pulmonary circulation in 26 patients using Eq. (6), for a value of $\rho \times l/S = 1.95$ are given in Table 1. In the last two columns of the table the absolute value of ΔQ and the relative deviation of the calculated values from those obtained for the same patients by Fick's direct method $(/\Delta Q/)\,Q$ are given. Clearly the relative error lies mainly within the limits of error of Fick's method. This means that the stroke volume can be determined from the shape of the curve of pressure in the great vessels not only under normal conditions but also in certain pathological states unaccompanied by severe lesions of the blood vessels.

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