ABSOLUTE AND RELATIVE DURATION OF VENTRICULAR SYSTOLIC PHASES

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The present communication includes data on the duration of the phases of isometric contraction and expulsion of blood from the ventricles obtained from examination of 100 healthy persons. As a method which would permit a phase analysis of the cardiac cycle we chose the dynamocardiograph proposed by E. B. Babsky and co-workers [1].

The average duration of the fundamental systolic phases of the ventricle and the limits of the variations in the length of these phases under normal conditions have been adequately studied at the present time. Individual variations in ventricular systolic phases are determined principally by the heart rate. It is well known that with increased frequency of heartbeat there is a reduction in the length of ventricular systole [6] and in the length of the blood expulsion phase [8]. There were no indications in prior literature of a relationship between the duration of the isometric contraction phase and heart rate [4]; in 1953, however, Askanas [3] noted this relationship.

Data are listed in the table which demonstrate at a glance the relationship between the duration of both phases of ventricular systole and heart rate.

This relationship is so precise that, as will be shown below, it can be expressed mathematically.

As well as examining the absolute duration of ventricular systolic phases, we are also studying their relative length. We call the relative length of any ventricular systolic phase the ratio, expressed in per cent, of the absolute duration of the given phase to the total length of the systole as a whole. Since the relative length of the isometric contraction phase and the expulsion phase together total 100%, for judging intrasystolic relationships an analysis of any one relative value is completely adequate. We utilize the relative length of the blood ejection phase, which we call the intrasystolic index (ISI):

$$\text{ISI} = \frac{\text{length of the ejection phase in seconds } (t_e)}{\text{length of ventricular systole in seconds } (S)} \times 100\% \qquad (1)$$

From this expression it is apparent that the intrasystolic index is a relative value which shows what part of the entire time of contraction of the ventricles is taken up by the expulsion of blood from them into the main vessels.

The values of the ISI computed for healthy individuals of different sex and age fluctuate within comparatively narrow limits — from 69 to 81%, with an average value of 75%. Thus the explusion of blood from the ventricles lasts approximately $^3/_4$ of systole, and consequently their isometric contraction amounts to only $^1/_4$ of systole.

Low values of ISI (69–72%) are encountered among people over 40 years of age, while high values (78–81%) are found among young individuals who are physically well developed. When muscles are doing work, the value of the ISI value increases in comparison with its value during the resting state. With certain heart ailments (mitral stenosis, myocardial infarct, etc.) the value of the ISI is considerably lower than under normal conditions. This indicates that value of the ISI depends on the functional state of the heart muscle; and therefore the given index can be used to evaluate the effectiveness of cardiac contraction.

The relative duration of the phases of systole, in opposition to their absolute duration, does not depend on the heart rate (see table). This means that with increased or decreased frequency of heartbeat, in which there occurs respectively a shortening or a lengthening of ventricular systole as a whole, the relationship between the

TABLE

Duration of the cardial cycle C (in seconds)		Duration of the expulsion phase t_e (in seconds)			Duration of the isometric contraction phase t_t in seconds			Intrasystolic index (average experimental data (in %)
Variation limits	Average duration	Average experimental data	Computed according to the formulae: $t_e = 0.244\sqrt{C}$	Computed according to the formulae: $t_e = 0.137 \cdot C + 0.106$	Average experimental data	Computed according to the formulae: $t_t = 0.081\sqrt{C}$	Computed according to the formulae: $t_t = 0.046 \cdot C + 0.035$	
0.60–0.69	0.628	0.192	0.192	0.192	0.065	0.064	0.064	74.7
0.70–0.79	0.735	0.207	0.208	0.207	0.069	0.069	0.069	75.0
0.80–0.89	0.828	0.222	0.222	0.219	0.072	0.073	0.073	75.5
0.90–0.99	0.927	0.231	0.234	0.232	0.075	0.077	0.077	75.5
1.00–1.09	1.025	0.244	0.245	0.246	0.079	0.081	0.082	75.5

individual phases is not altered. Hence it follows that both with a rapid and with a slow heart rate the time of expulsion of blood from the heart into the vessels continues to take up $^3/_4$ of the time of systole as a whole, and the time expended in creating the pressure necessary to open the semilunar valves still amounts to $^1/_4$ of systole. This fact seems extremely important to us, because it characterizes the definite regularity of heart contraction in the presence of physiological variations in heart rate.

The independence of the ISI from heart rate makes considerably easier the mathematical analysis of the relationship between the length of the phases of systole and the frequency of heart contractions. Thus, substituting in expression (1) the formula for the length of ventricular contraction with varying heart rate, $S = 0.324\sqrt{C}$ (2), and transcribing it with respect to t_e, we obtain after simple conversions a formula characterizing the dependence of the time of expulsion of blood from the ventricles on heart rate:

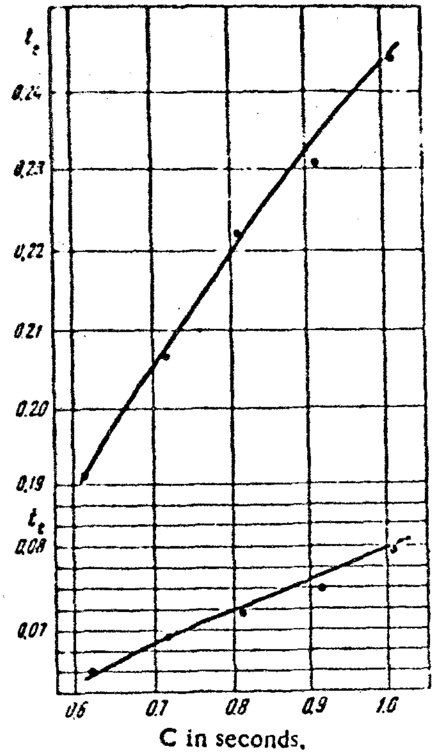
$$t_e = 0.244\sqrt{C}, \quad (2)$$

where C is the duration of the cardiac cycle in seconds.

Proceeding from the fact that the relative length of the isometric contraction phase equals 0.25 or 25%, its absolute length (t_t) will be three times shorter than the absolute length of the ejection phase. Hence the relationship between the duration of the isometric contraction phase and heart rate can be written in the following form:

$$t_t = 0.081\sqrt{C} \quad (3)$$

As is apparent from the table and the graph, the values of the length of the ventricular systolic phases computed according to formulas (2) and (3) and their values obtained by analysis of dynamocardiograms are extremely close.



The relationship of the duration of the isometric contraction phase of the ventricles (t_t) and the phase of expulsion of blood from them (t_e) to the duration of the cardiac cycle (C). The lines are constructed according to formulas (2) and (3); the experimental points are derived from the table.

When it is taken into account that the curve of the functions is negligible in the studied range of variation of the independent variable, the relationship between the duration of the isometric contraction phase, the expulsion phase and the heart rate can be expressed in a type of straight line equation.

For this, repeating the reasoning adduced above with the single difference that the value of S is equal to $0.183 \cdot C + 0.142$ [8], we obtain the following expressions:

$$t_e = 0.137 \cdot C + 0.106 \qquad (2)$$

$$t_t = 0.046 \cdot C + 0.035 \qquad (3)$$

As is evident from the table, these formulas also give values close to the experimental values.

According to data in the literature which is known to us, the mathematical relationship between the duration of the phases of systole and heart rate has been noted only for the phase of the expulsion of the blood from the ventricles [5]. This function, however,

$$t_e = a \sqrt[2.9]{p}$$

is inconvenient in practical work, since in order to determine the duration of the ejection of blood with a given heart rate prior use of logarithms is required.

From a comparison of our formula, $t_e = 0.244\sqrt{C}$, with the formula characterizing the relationship between the duration of the interval H–K of a ballistocardiogram and heart rate, $H–K = 0.247\sqrt{C}$ [6], their close concurrence is evident.

Apparently the H–K interval of a ballistocardiogram, which is called "hemodynamic systole," is a reflection of the phase of expulsion of blood from the ventricles

SUMMARY

The duration of the isometric contraction and of the ejection of blood from the ventricles may depend on heart rate. The dependence of isometric contraction (t_t) and blood ejection (t_e) can be expressed by the formulas:

$$t_e = 0.244 \cdot \sqrt{C} \text{ and } t_e = 0.137 \cdot C + 0.106$$

$$t_t = 0.081 \cdot \sqrt{C} \text{ and } t_t = 0.046 \cdot C + 0.035$$

The idea of an intrasystolic index is adopted: it is the relation between the duration of the ejection phase and the duration of ventricular systole. This index estimates the efficiency of heart contraction. The relative length of the ejection phase (intrasystolic index) and that of the isometric contraction phase are practically independent of heart rate.

length of the ejection phase (intrasystolic index) and that of the isometric contraction phase are practically independent of heart rate.

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