MECHANOGRAM OF THE ISOLATED RAT'S HEART DURING HYPOTHERMIA

G. A. Poddubskii

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The duration of systole of the heart in situ is usually determined indirectly by measuring the duration of the mechanical, electrical, or electromechanical equivalent of systole. To overcome the difficulties associated with determination of the length of systole by the indirect method, the author has studied the relationship between the length of systole and the heart rate in the isolated heart. An essential condition was to make provision for regulation of the frequency of spontaneous cardiac contractions within a wide range. Hypothermia of the isolated heart was used as this regulator.

EXPERIMENTAL METHOD

Experiments were carried out on the heart of Wistar albino rats. After preliminary heparinization of the anesthetized animals the heart was extracted from the animal and perfused by Langendorff's method with a coronary pressure of 60-70 mm. The composition of the perfusate (per liter of solution) was as follows: NaCl 7.5 g, KCl 0.35 g, $CaCl_2$ 0.15 g, $MgCl_2$ 0.10 g, $NaHCO_3$ 1.70 g, NaH_2PO_4 0.05 g, glucose 2.00 g, Belen'kii's serum 12 ml, insulin 5 units, ascorbic acid 20 mg, thiamine 0.6 g, vitamin B_{12} 2 μg, nicotinic acid 16 mg, riboflavine 2 mg.

After the end of the control period the temperature of the perfusate was no longer maintained constant and the temperature of the heart fell from 37 to 20-22°. As the temperature changed, the transverse mechanogram and the unipolar electrogram were recorded every 0.5° using a tape winding speed of 160 mm/sec.

EXPERIMENTAL RESULTS

The mechanogram of the rat's heart is in the shape of an unequal-sided trapezium (Fig. 1). For this reason the duration of the principal phases of the mechanogram cycle can be determined relatively accurately: true contraction (ρ), tonic contraction (δ), relaxation (σ), rest (β), and the total period of the cycle (γ). The time interval from the beginning of contraction until complete relaxation was regarded as the phase of the active state of the myocardium (α).

As the temperature of the heart fell, the frequency of its spontaneous contractions fell in a strictly linear fashion. This was accompanied by an increase in the duration of the complete heart cycle with an increase in the duration of all its phases. The points corresponding to the duration of each phase for different temperature values were plotted on the curves given in Fig. 2. Analysis of the shape of the curves thus obtained showed that they were all regular hyperbolas with a common axis T_0M, a common center T_0 and common asymptotes (one asymptote — the temperature axis, the other — T_0N). Analytically, a regular

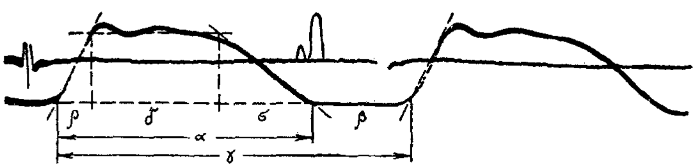

Fig. 1. Phases of the mechanogram of the isolated rat's heart. Explanation in text.

Laboratory of Radiation Genetics and Late Radiation Pathology, Central Roentgeno-Radiological Research Institute, Ministry of Health of the USSR, Leningrad (Presented by Active Member of the Academy of Medical Sciences of the USSR D. A. Biryukov). Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 64, No. 7, pp. 38-41, July, 1967. Original article submitted October 28, 1965.

TABLE 1. Phase Composition of Mechanogram of the Isolated Heart and Sensitivity of Phases to Change of Temperature (M±m)

	Phases of mechanogram					
	γ	ρ	δ	σ	β	α
Parameter a (in conventional units)	3,16±0,121	0,98±0,053	1,43±0,053	1,80±0,075	1,92±0,147	2,50±0,077
Relative duration of phase (in %)	100,0	9,3±1,49	21,1±1,16	32,8±1,94	36,8±3,46	63,2±3,44

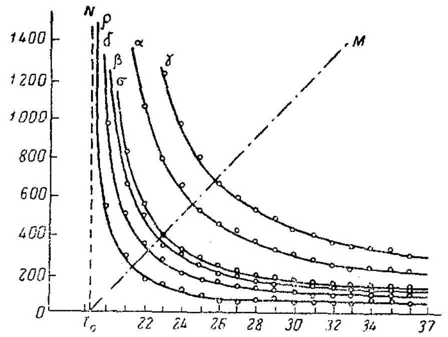

Fig. 2. Relationship between duration of phases of the mechanogram and temperature of the heart. Coincidence between experimental points and curves constructed analytically. Abscissa — temperature, ordinate—duration of various phases of mechanogram (in msec).

hyperbola ($xy = \frac{1}{2}a^2$) is determined by the single parameter a, i.e., by the length of the segment of the transverse axis from the center of the hyperbola to its apex. The biological significance of this parameter is essentially as follows: the greater the value of a, the greater the change in the duration of the investigated phase during the given change of temperature (24-37°).

In this way a hyperbolic model of the phase composition of the mechanogram of the isolated heart was constructed and used as a convenient working instrument for analyzing the experimental data. The properties of this model were as follows. 1) All the hyperbolas were monocentric and had common asymptotes. This meant that the various functional structures of the heart — the sinus node whose activity determines the frequency of contraction, and the contractile mass of the myocardium, whose state determines the time structure of the various phases of contraction, showed strict conformity in the conditions of hypothermia. 2) The values of the duration (τ) of each phase of the mechanogram expressed as functions of the temperature (t) are given by:

$$\tau_i \cdot t = \frac{a_i^2}{2},$$

where i is the symbol of any phase of the mechanogram (ρ, δ, σ, β, α, γ). The ratio between each "component" of the function and the "complete" function γ (t) is expressed ultimately by the ratio between the squares of the corresponding values of a:

$$\frac{\tau_i \cdot t}{\tau_\gamma \cdot t} = \frac{a_i^2}{a_\gamma^2}.$$

This means that for any value of the temperature this ratio for each "component" of the function is a constant value. Consequently, the relative contribution of each phase to the duration of the complete cycle in the region $T_0 < t \le 37°$ is constant and independent of temperature, although the absolute values of these durations differ at different temperatures. For example, the duration of the phase of relaxation (σ) for the heart of rats 8 months old is 32.8% of the duration of the cycle at both 37° and 25°, althought, expressed as milliseconds, this duration is 95 and 334 msec, respectively.

Table 1 shows that the phases of mechanical activity could be arranged in the following order of decreasing temperature sensitivity (magnitude of the parameter a) and of relative duration of these phases at any temperature: the phase of rest, relaxation, tonic contraction, and true contraction.

In the literature, the relationship between the duration of any of the equivalents of systole during investigation of the heart in situ is usually described as linear [1, 2, 6, 7], parabolic [1-5], or logarithmic [4]. Despite the variety of formulas suggested, they all refer to intervals of the functions which can be expressed by a straight line or may easily be approximated to it. This means, however, that the relative contribution of systole to the total duration of the cycle remains constant whatever the heart rate and is expressed quantitatively by the tangent of the angle of inclination of this straight line to the axis of duration of the complete cycle. In the present experiments further proof was obtained of the constancy of the relative duration both of systole and of its component phases.

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