EFFECT OF TEMPERATURE ON CONTRACTILITY OF THE FROG MYOCARDIUM

V. V. Vovereidt

UDC 612.172.014.43

Changes in the parameters of mechanical activity of the isolated frog myocardium during a change of temperature were studied. Between 0 and 35° lowering the temperature led to an increase in the force of contractions, but the velocity of contractions reached its optimum at 20°C. The velocity of contractions is a more appropriate and sensitive criterion for the study of the effect of cold on contractility than the force of contractions. It is concluded from analysis of the results that contractility of the myocardium is depressed during cooling.

KEY WORDS: Isolated myocardium; contractility; temperature.

Existing views on the increased contractility of the cooled myocardium are based on the results of many investigations which showed that the force of the heart muscle, expressed as the amplitude of its contractions, rises as the temperature falls in warm-blooded animals between 37 and 20°C, and in cold-blooded animals down to near-zero temperatures [1, 3, 6, 8-11]. Meanwhile other workers [4, 5, 12, 13], who used the velocity of contractions as their index of contractility, concluded that contractility is depressed by cold.

This paper describes a comparative study of the dynamics of the force and velocity of contractions as indices of the mechanical activity of the myocardium during the study of the effect of temperature on contractility of the isolated frog myocardium.

METHODS

Experiments were carried out on 24 isolated strips of myocardium from the frog (*Rana temporaria*) ventricle, 5-8 mm long and not more than 1 mm in diameter. The preparation was placed in a chamber (volume 6 ml), fitted with a thermostat, in which the temperature could be regulated between 0 and 35°C with an accuracy of 0.2°C. During the experiment the preparation was immersed in a solution of the following composition (in mM): NaCl 112.0, KCl 1.8, $CaCl_2$ 1.1, $NaHCO_3$ 1.8. The experiment began after stimulation of the preparation for 30 min with a frequency of 0.1 Hz at a temperature of 20°C, and during stretching by 10% of its initial length. In all the experiments the maximal force of isometric contraction (P_0), the time taken for development of maximal for e (t_f), and the mean velocity of contraction (V_m) during contraction at the optimal frequency for that temperature, i.e., at a frequency of contraction at which maximal force was observed, and with the optimal degree of stretching, were determined. The optimal degree of stretching was determined at 20°C, and it remained constant thereafter, for the amount of stretching does not affect the optimal frequency of contraction for the frog [2]. The measurements were made at intervals of 5°C between 0 and 35°C. The rate of change of temperature was 0.2-0.5 deg/min. Above-threshold negative pulses, 5 msec in duration, from a type ESU-1 electronic stimulator were used for stimulation. The initial length of the strip was measured and gradual stretching carried out by means of a traction apparatus. Mechanical activity was recorded by means of a 6MKh1S mechanotron, the signal from which was amplified and led to a type N337 automatic writer.

RESULTS

The study of the temperature characteristics of the parameters of mechanical activity (Figs. 1-3) showed the following results. As Fig. 1 shows, a rise of temperature from 20 to 35°C led to a reduction in the force of contraction by 3.4 times ($P < 0.001$), whereas a fall in temperature from 20 to 5°C caused an increase by 2.2 times ($P < 0.001$). Below 5°C a small

---

Department of Normal Physiology, Red Army Kuban Medical Institute, Krasnodar. (Presented by Academician of the Academy of Medical Sciences of the USSR V. N. Chernigovskii.)
Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 88, No. 11, pp. 522-524, November, 1979. Original article submitted October 13, 1978.

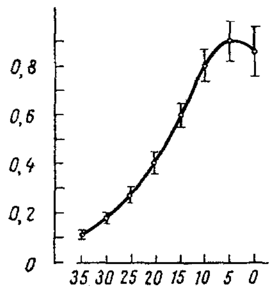

Fig. 1

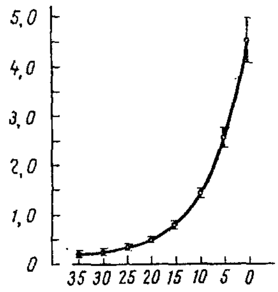

Fig. 2

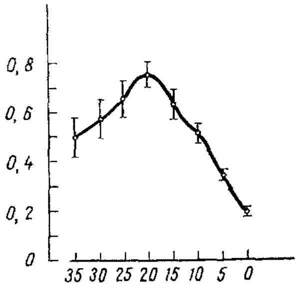

Fig. 3

Fig. 1. Effect of temperature on force of contractions of isolated myocardium of frog ventricle at optimal frequencies of contraction for given temperatures and with optimal degree of stretching. Abscissa (here and in Figs. 2 and 3): temperature, in °C; ordinate: force of contraction (in g).

Fig. 2. Effect of temperature on time taken for development of maximal force. Ordinate: time (in sec). Conditions and remainder of legend as in Fig. 1.

Fig. 3. Effect of temperature on velocity of contractions. Ordinate: velocity of contractions, in g/sec. Conditions and remainder of legend as in Fig. 1.

decrease in force was observed ($P > 0.75$). Between temperatures of 0 and 35°C the force of contractions of the isolated myocardium of the frog ventricles, with the optimal degree of stretching and at optimal frequency of contractions for the given temperatures, thus has a maximum at 5°C. However, changes in force during cooling from 10 to 0°C were not significant ($P > 0.29$).

Under these same conditions the duration of development of the force increased by 18.2 times during a change in temperature from 35 to 0°C, and the relationship was exponential in character (Fig. 2).

The velocity of contractions decreased with both a rise and a fall of temperature from 20°C (Fig. 3). For instance, a rise of temperature to 35°C led to a decrease in velocity by 1.6 times ($P < 0.02$), and cooling to 0°C to a decrease of 3.9 times ($P < 0.001$). Unlike force, the velocity of contractions fell significantly within the range 0-10°C ($P < 0.001$), but a change in temperature from 25 to 15°C had virtually no effect on velocity ($P > 0.32$).

When changes in contractility during cooling are assessed on the basis of the force of contractions, as most investigators have done [1, 3, 6, 8-11] it must be accepted that optimal contractility occurs at 5°C, for the force which can be developed is maximal at this temperature. Similar results are given by Kruglov [3]. However, no allowance is made in this case for the fact that the force of contractions of the cooled myocardium is the resultant of interaction between two opposite processes: an increase in the duration of development of force (Fig. 2) and a decrease in the velocity of contractions (Fig. 3); i.e., the fact is ignored that force as an index of contractility is integral in character. Meanwhile the velocity of contractions reached optimal values under normothermic conditions for frogs (20°C), in agreement with data showing maximal values of many physiological functions of cold-blooded animals at the normal ambient temperatures of the animals [7]. Furthermore, with a decrease of temperature from 10 to 0°C the velocity of contraction changed significantly, whereas the changes in force were not significant. This indicates that velocity of contractions is a more appropriate and more sensitive criteria of the effect of cold on contractility.

Quantitative evaluation of contractility of the cooled myocardium on the basis of force per unit time, i.e., of the velocity of contractions, is thus a more soundly based procedure, as Pokrovskii [4] and Sheikh-Zade [5] also have stated. In that case, the question of the effect of cold on contractility of the myocardium can be unambiguously answered: Contractility is depressed during cooling as a result of impairment of the general functional state of the myocardium when the temperature falls [4, 5], which is reflected in a decrease in the velocity of contractions. This conclusion is also confirmed by the behavior of V_{max} (maximal velocity of shortening), a velocity index of the relationship between force and velocity, characterizing the contractile state of muscle [1], which also decreases with cooling [8, 11].

LITERATURE CITED

1. E. Braunwald, J. Ross, and E. H. Sonnenblick, Mechanisms of Contraction in the Normal and Failing Heart, Little (1975).
2. O. A. Zhigal'skii and V. Ya. Izakov, Izvest. Akad. Nauk SSSR, Ser. Biol., No. 2, 281 (1977).
3. V. S. Kruglov, Theoretical Problems in the Action of Low Temperatures on the Organism [in Russian], Vladimir (1972), p. 315.
4. V. M. Pokrovskii, in: Hypothermia and the Local Action of Cold on the Brain and Heart [in Russian], Krasnodar (1968), p. 301.
5. Yu. R. Sheikh-Zade, in: Theoretical and Practical Problems in the Action of Low Temperatures on the Organism [in Russian], Leningrad (1975), p. 226.
6. H. Badeer, J. Thorac. Cardiovasc. Surg., 53, 651 (1967).
7. J. R. Brett, Am. Zool., 11, 99 (1971).
8. J. W. Covell, J. Ross, Jr., and E. H. Sonnenblick, Circulat. Res., 19, 364 (1966).
9. S. Garb and M. B. Chenoweth, Am. J. Physiol., 156, 27 (1949).
10. J. Koch-Weser and J. R. Blinks, Pharmacol. Rev., 15, 601 (1963).
11. H. Mashima and M. Matsumura, Jpn. J. Physiol., 14, 422 (1964).
12. Z. J. Penefsky, Am. J. Physiol., 214, 730 (1968).
13. J. Sumbera, P. Braveny, and V. Kruta, Arch. Int. Physiol., 75, 216 (1967).