PHYSIOLOGY

Cardiodynamics and Pumping Function of the Heart under Conditions of Hyperthermia

V. F. Sagach and T. V. Shimanskaya

UDC 612.17+612+591.128

Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 116, № 8, pp. 115-116, August, 1993
Original article submitted February 23, 1993

Key Words: *myocardium; hyperthermia; loads*

There is a large body of investigations concerning the effect of overheating on the function of the cardiovascular system [4,9,12]. However, the mechanisms underlying the disturbances of cardiodynamics and contractile function of the myocardium under conditions of hyperthermia remain poorly understood. At a temperature of the organism above 40°C the development of systemic hypotension is known to occur due to a drop of cardiac output. Restricted venous inflow of the blood to the heart was recently shown to be partially responsible for a reduced minute heart volume [6]. Prevention of a considerable drop of the venous inflow in hyperthermia in experimental studies by blocking the biosynthesis of prostanoids [2] did not affect the cardiac output, thus prompting us to seek the mechanism of hypotension in decreased functional reserves of the heart itself.

The objective of the present study was to investigate the cardiodynamics and pumping function of the myocardium under conditions of intense overheating.

MATERIALS AND METHODS

The experiments were performed on 10 mongrel dogs weighing 15-25 kg under chloralose-urethane narcosis (0.05 and 0.5 g/kg). After operative manipulations and catheterization of vessels the animals were placed in a heating chamber, in which the temperature was maintained at 50°C. The temperature of the blood was recorded with an MT-54 thermistor, inserted into the aorta. The parameters of cardiodynamics were redetermined with every degree of the temperature rise. The systemic arterial pressure (SAP), cardiac output (CO, by thermodilution and rheographically), heart rate (HR), pressure in the left ventricle ($P_{l.v.}$) and its first derivative (dP/dt), and end-systolic (ESP) and end-diastolic (EDP) pressures were recorded. The recording of all the parameters was performed with electromanometers (Elema, Sweden) hooked up to a Minograf-82 8-channel direct writer (Simens-Elema, Germany-Sweden).

For determination of blood volumes in the left ventricle at the end of diastole and systole (ESV and EDV) the method of indicator (cold physiological saline) wash-out was employed [13].

For estimating the reserve capacity of the myocardium volume and pressure loads were applied. The pressure load was produced by pulsed infusion of a plasma substitute, polyglucin, through the jugular vein so as to increase the end-diastolic pressure (EDP) by 2-3 mm Hg. The load curves were constructed by plotting the stroke volume to EDP ratio against the load, and then the tangents of their slope were calculated. The pressure load

Department of Circulation Physiology, A. A. Bogomol'ts Research Institute of Physiology, Ukrainian Academy of Medical Sciences. (Presented by B. I. Tkachenko, Member of the Russian Academy of Medical Sciences)

0007-4888/93/0008-0893$12.50

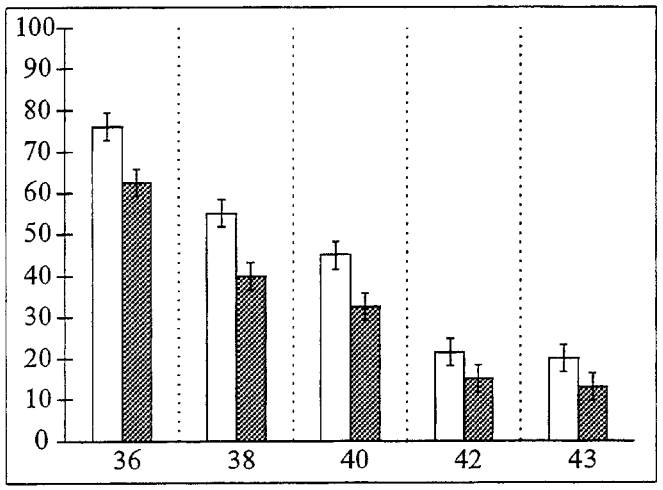

Fig. 1. Effect of hyperthermia on end-diastolic (light bars) and end-systolic (hatched bars) volumes of the left ventricle.

was produced by occlusion of the aorta with an inflatable rubber balloon to a rise of SAP by 10-15 mm Hg. The load-dependent curve of the $\Delta(dP/dt_{max})/\Delta SAP$ was constructed [5].

The data were processed statistically using the Student test of variational statistics.

RESULTS

In our previous studies it was shown that long-term exposure to 50°C led to the development of pronounced hyperthermia, accompanied by marked alterations in the hemodynamics, manifested primary in a decrease of the cardiac output and the development of systemic hypotension.

The observed cardiac output dynamics was similar to that of SAP: initially (below 40°C), the CO had a tendency to rise (by 16%), but with the rise of body temperature above 40°C CO dropped dramatically and reached 587±66 ml at 43°C (initial value was 1316±98 ml). These results are in conformity with published data [1,3,11], also obtained from experiments on dogs.

A rise of HR during the overall heating period (from the initial value of 150±14 beats/min to 247±11 beats/min at 42°C) was registered in parallel with a substantial reduction of SV, the latter being responsible for considerable drop of CO.

The systolic pressure in the left ventricle did not change significantly during the development of hyperthermia; however, the end-systolic and end-diastolic pressures dropped reliably in hyperthermia in comparison with the initial values (from 100±5.0 to 40±5.4 mm Hg, $p<0.001$, and from 6.3±1.1 to 0.2±1.4 mm Hg, respectively).

Measurements of the left ventricle volumes in different phases of the heart cycle showed a marked decrease of EDV and ESV in hyperthermia (Fig. 1).

The marked decrease of ESV, EDV, and SV during the heating period suggests impairment of the pumping function of the heart. This is confirmed by experiments evaluating the functional reserves of the myocardium under conditions of hyperthermia using the pressure and resistance load tests. The slope of the functional curves of the heart (CO-EDV) in the pressure load test was shown to decrease gradually with the temperature rise, and at T=42°C it was 22°20' (initial value 50°40') (Fig. 2). Thus, the changes in slope of the curves suggest that the functional reserves of the myocardium decrease considerably with increasing depth of hyperthermia due to a reduced efficiency of the Frank-Starling mechanism under these conditions.

In the study of the functional capacity of the myocardium in the pressure load test under moderate hyperthermia (below 40°C), it was found that the heart compensated for the imposed load by responding with enhanced contractile activity. Then, with further overheating, the pumping capacity of the myocardium under the load decreased markedly, and at t=42°C constituted 62% of the initial value (Fig. 3).

The data suggest that along with the development of hyperthermia the pumping function of the heart decreased not only due to restriction of the venous inflow to the heart, as was previously

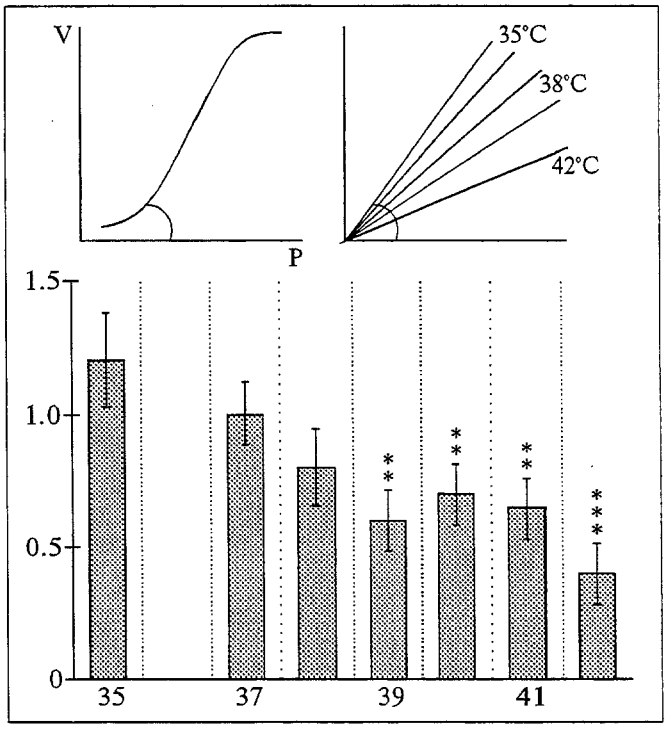

Fig. 2. Changes in tangents of slope of CO-EDP functional curves in hyperthermia (pressure load).

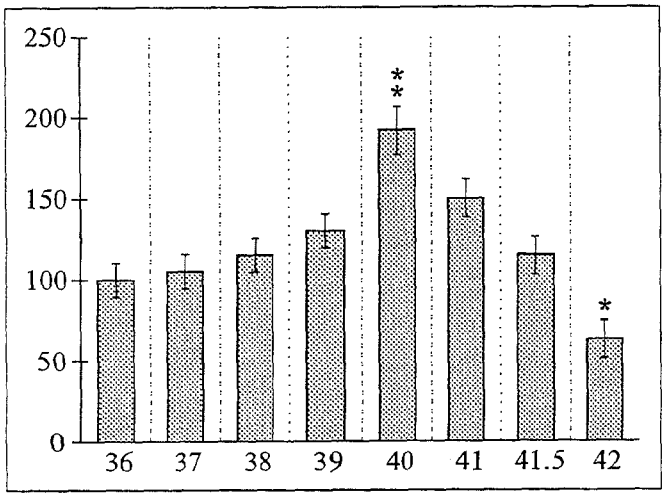

Fig. 3. Changes of $\Delta(dP/dt_{max})/\Delta SAP$ in resistance load test under heating.

shown by us [6], but also due to impaired function of the myocardium under these conditions. This is in conformity with earlier investigations on the isolated heart, which demonstrated a considerable weaking of contractions and impairment of the heart function [7,10] in hyperthermia. Analogous changes in the function of the left ventricle were reported in a later paper [8].

Thus, the reported data on changes in the pumping function of the left ventricle in hyperthermia obtained from the analysis of the heart function in the pressure and volume load tests are in conformity with previously published data and suggest impairment of the pumping function of the heart under conditions of intensive overheating due to restricted functioning of the mechanisms of heterometric regulation of myocardial function.

REFERENCES

1. A. A. Moibenko, L. A. Grabovskii, L. F. Potapovich, and E. G. Bidkov, *Fiziol. Zh.*, **34**, № 1, 17 (1988).
2. V. F. Sagach and T. V. Shimanskaya, *Dokl. Akad. Nauk Ukrainy*, № 11, 182 (1991).
3. M. M. Seredenko, V. P. Pozharov, T. D. Minyailenko, *et al.*, *Fiziol. Zh.*, **35**, № 1, 21 (1989).
4. F. F. Sultanov, B. I. Tkachenko, and G. F. Sultanov, *Circulation under Conditions of Hyperthermia* [in Russian], Ashkhabad (1988).
5. A. V. Trubetskoi, M. P. Sakharov, Ts. R. Orlova, *et al.*, *Cor et Vasa* (Prague), **25**, № 5, 384 (1983).
6. T. V. Shimanskaya, M. I. Gurevich, V. F. Sagach, and V. I. Boiko, *Fiziol. Zh.*, **36**, № 3, 14 (1990).
7. R. S. Berkowitz and W. C. Ullrick, *Experientia*, **28**, № 6, 664 (1972).
8. M. N. D'Ambra, P. Magrassi, E. Lowenstein, *et al.*, *Amer. J. Physiol.*, **252**, № 2, Pt. 2, H448 (1987).
9. J. R. S. Hales and R. A. Z. Dampney, *J. Therm. Biol.*, **1**, № 1, 29 (1975).
10. P. B. Hollander and J. L. Webb, *Circulat. Res.*, **3**, № 5, 604 (1955).
11. K. Miki, T. Morimoto, H. Nose, *et al.*, *J. Appl. Physiol.*, **55**, № 2, 300 (1983).
12. E. L. Rollet, H. Sherman, and R. Gorlin, *Ibid*, **19**, № 6, 1164 (1964).
13. L. B. Rowell, *Physiol. Rev.*, **54**, № 1, 75 (1974).