PHYSIOLOGY

Cardiodynamics and Pumping Function of the Heart during Hyperthermia

V. F. Sagach and T. V. Shimanskaya

UDC 612.17+612.591+591.128

Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 115, № 6, pp. 563–564, June, 1993
Original article submitted February 2, 1993

Key Words: *myocardium; hyperthermia; loads*

Numerous publications have been devoted to the effect of hyperthermia on the activity of the cardiovascular system [4,9,12]. However, the mechanisms underlying the disturbances of heart activity and myocardial contractility during hyperthermia remain unclear. The development of systemic hypotension resulting from a drop of the cardiac output is observed when the body temperature rise above 40°C. It was established previously [6] that limited venous return to the heart is one of the causes of the drop of the minute volume flow rate. Preventing a significant decrease in the blood supply to the heart during hyperthermia produced no pronounced effect on the changes of the cardiac output in experiments with blocked synthesis of prostanoids [2]; this pursuaded us to seek the cause of the development of hypotension in the lowered functional activity of the heart itself.

The aim of the present study was to investigate the cardiodynamics and pumping function of the myocardium under conditions of profound hyperthermia.

MATERIALS AND METHODS

The experiments were carried out on 10 mongrel dogs weighing 15-25 kg under chloralose-urethane anesthesia. After surgical pretreatment and catetherizing of the vessels, the animals were placed in a heat chamber where the air temperature was maintained at 50°C. The blood temperature of the dogs was recorded with the aid of an MT-54 thermistor inserted in the aorta. The parameters of the cardiodynamics were registered while raising the blood temperature of the dogs by each degree. The systemic arterial pressure (SAP), cardiac output (CO) (by methods of thermodilution and rheography), heart rate (HR), pressure in the left ventricle of the myocardium (P_{lv}) and its first derivative (dp/dt), end-systolic pressure (P_{cs}), and end-diastolic pressure (P_{cd}) were determined, all the parameters being recorded with the aid of an electromanometer (Elema, Sweden) on an 8-channel recorder (Mingograf-82, Siemens-Elema, Germany -Sweden). For assessing the left ventricular end-systolic and end-diastolic blood volumes (V_{cs} and V_{cd}, respectively), the method of washing the indicator (cooled physiological saline) out of the ventricular cavity was used [12]. The reserve capabilities of the myocardium were studied during volume and pressure loading tests. The volume load was created by a short-term injection of a blood substitute (rheopolyglucin) via the jugular vein at a P_{cd} increased by 2-3 mm Hg. The loading curves (relationship between the increment of relative volume (RV) and P_{cd}) were plotted and the tangent of their slope was calculated. The pressure load was created by occluding the lumen of the

Department of Circulation Physiology, A. A. Bogomolets Institute of Physiology, Ukraine Academy of Sciences, Kiev. (Presented by A. D. Ado, Member of the Russian Academy of Medical Sciences)

0007-4888/93/0005-0617$12.50

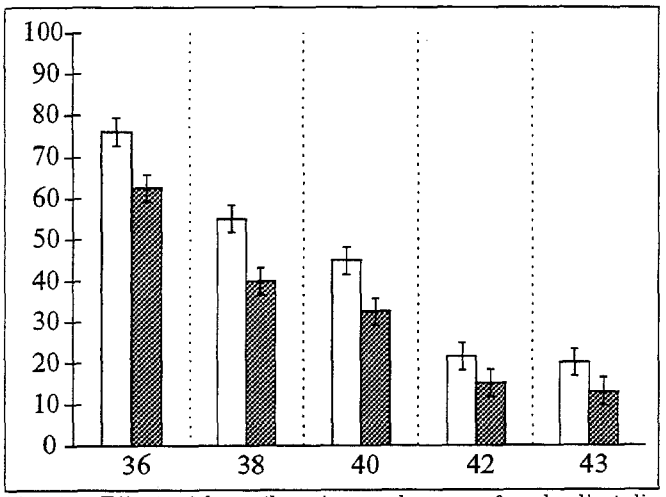

Fig. 1. Effect of hyperthermia on changes of end-diastolic (V_{ed}) and end-systolic (V_{es}) left ventricular blood volumes. Unhatched columns: V_{ed}; hatched columns: V_{es}.

aorta by means of an inflatable latex balloon until SAP rose by 10-15 mm Hg. The afterload curves of the ratio $\Delta dp/dt_{max}$/dSAP were plotted [5]. The results were statistically processed using the methods of variational statistics after Student.

RESULTS

As was shown by our results, the prolonged effect of heating at 50°C led to the development of pronounced hyperthermia associated with significant changes of the hemodynamics, manifested primarily in a drop of the cardiac output and the development of systemic hypotension.

The changes of cardiac output observed were similar to those of SAP; initially (below 40°C), CO tended to increase (by 16%); when the body temperature rose above 40°C, we registered its sharp decrease, and at t=43°C it dropped to 587±66 ml (vs. 1316±98 ml in the initial state). These results are in line with published data [1,3,11] also obtained in experiments with dogs.

Over the whole period of exposure to heating, an increase in HR (from 150±14 beats per minute at the initial level to 247±11 beats per minute at 42°C) was registered against the background of a significant decrease of RV, a marked drop of CO being predetermined by the latter. The level of the left ventricular systolic pressure did not undergo any pronounced changes during the development of hyperthermia; however, the end-systolic and end-diastolic pressure reliably dropped (from 100±5.0 mm Hg in the initial state to 40±5.4 mm Hg at t=43°C, p<0.001, and from 6.3±1.1 mm Hg at t=36°C to 0.2±1.4 mm Hg at t=43°C, respectively).

Analysis of the nature of the changes of the left ventricular volumes measured during different phases of the heart cycle provided evidence of a significant decrease in V_{ed} and V_{es} (Fig. 1).

The pronounced decrease of the left ventricular volumes and of RV during the course of raising the body temperature of the animals spoke of a suppressed pumping function of the heart. This was confirmed by experimental findings on the reserve capabilities of the myocardium during the use of volume and resistance loads in hyperthermia. It was shown that the slope of the functional curves of the heart gradually decreased during the volume loading test and constituted 22°20' at t=42°C (vs. 50°40' in the initial state) (Fig. 2). Hence, the data on the changes of the slope of functional curves of the heart in profound hyperthermia suggest that the reserve capabilities of the myocardium in the course of deepening hyperthermia markedly drop due to a functionally reduced efficacy of the Frank-Starling mechanism under these conditions.

When the reserve capabilities of the myocardium were studied during the resistance loading test, the heart managed to deal with the imposed load (at a body temperature of no more than 40°C) by responding with an increased contractility. During the subsequent exacerbation of hyperthermia, the pumping function of the myocardium markedly dropped at t=42°C and constituted 62% of the initial level (Fig. 3).

The results presented here are evidence that during the development of hyperthermia the pump-

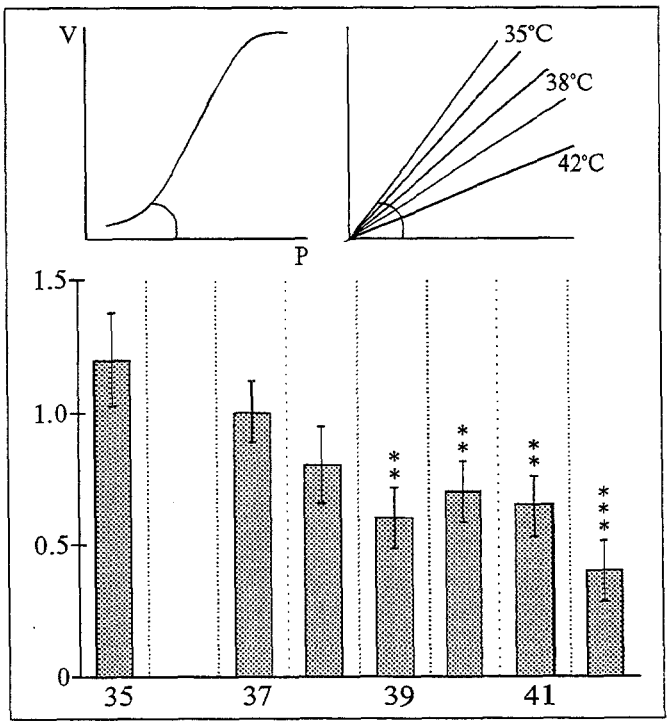

Fig. 2. Changes of tangent of slope of RV-P_{ed} functional curves in hyperthermia (volume load).

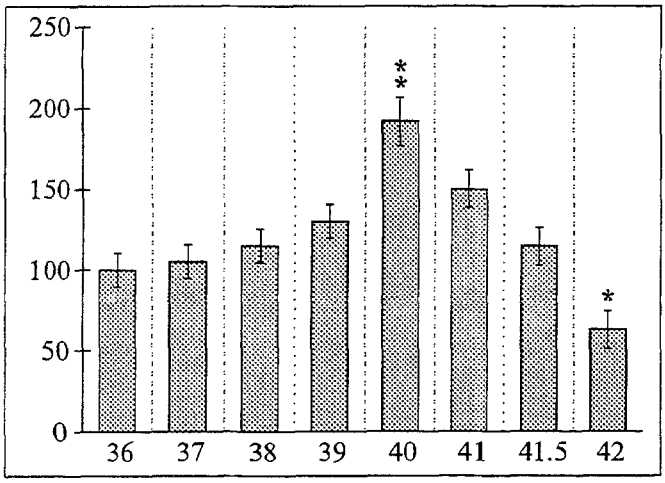

Fig. 3. Changes of $\Delta dp/dt_{max}$/dSAP under conditions of resistance load during hyperthermia.

ing function of the myocardium decreases not only due to limited venous return to the heart, as was previously shown [6], but also due to weakened myocardial activity per se under these conditions. This is consistent with the experimental results obtained on the isolated heart muscle, which demonstrated a marked decrease of the force of contractions and of the myocardial activity during the development of hyperthermia [7,10]. Similar changes of the function of the left ventricle during hyperthermia have been shown in a more recent study [8].

Thus, the data on the changes of the pumping function of the left ventricle for volume and resistance loads, obtained by analysis of cardiac activity during hyperthermia, are in line with the very few data available in the literature and provide evidence of an impaired pumping function of the heart due to functional limitations of the mechanisms of heterometric regulation of the myocardial contractility during profound hyperthermia.

REFERENCES

1. A. A. Moibenko, L. A. Grabovskii, L. F. Popovich, 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, V. I. Tkachenko, and G. F. Sultanov, *Circulation during 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).