EFFECT OF ARTIFICIAL HYPOTHERMIA ON THE CARDIO- AND HEMODYNAMICS

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To study the direct effect of hypothermia on electrical activity of the brain the writers previously [4] used the principle of comparison of two forms of hypothermia in experiments on animals. In that way the erroneousness of the view that hypothermia inhibits predominantly high-frequency bands of the electroencephalogram (EEG) was proved. By using the same method in the present investigation, the aim was to study the effect of different forms of hypothermia on cardiac activity and on the basic parameters of the hemodynamics. Three forms of hypothermia were studied: in the experiments of series I – deep general hypothermia with immersion (external) cooling to 18-20°C (120 experiments); series II – deep general hypothermia with combined cooling to 26°C in the same way as series I, and then to 18-20°C by means of an artificial circulation (six experiments); series III – isolated hypothermia of the head to a brain temperature of 18-20°C with maintenance of stable normothermia (43 experiments) by means or an original method [3, 4]. In 104 of 120 experiments in series I the whole body including the heart was cooled (group A), but in 16 experiments selective normothermia of the heart was maintained by an original method of cardiosynchronized direct coronary perfusion with warm blood [2].

EXPERIMENTAL METHOD

Experiments were carried out on mongrel dogs of both sexes weighing from 5-7 kg (series I, group A) to 18-20 kg (in the remaining experiments). For premedication, promedol (trimeperidine) was injected subcutaneously in a dose of 5-6 mg/kg of the 2% solution, anesthesia was induced by intravenous injection of hexobarbital in a dose of 20-25 mg/kg of the 2.5% solution, and anesthesia was maintained by inhalation of a mixture of ether and air to a depth of level II-III of the surgical stage as shown by the EEG [1]. The state of the animals was assessed from the EEG, ECG, arterial and central venous pressure, cardiac output determined by the thermodilution method, phase analysis of the cardiac cycle, the rate of rise of the intraventricular pressure (dp/dt), the circulating volume of blood (CBV) and its components, namely plasma and erythrocytes, and the volumes of intracellular and extracellular fluids by means of a combined method [5]. The hemoglobin concentration in the blood, the oxygen saturation of the blood, the oxygen demand, and the state of the acid–base balance and other indices also were determined.

EXPERIMENTAL RESULTS

The effect of general hypothermia with external cooling was expressed primarily as inhibition of automatic activity of the animals' heart. During the period of cooling there was a progressive fall in cardiac frequency and a corresponding lengthening of the cardiac cycle. The cardiac frequency per minute at the beginning of the experiments (during normothermia) averaged 148 ± 12 beats/min, but when the body temperature fell to 20°C the cardiac frequency averaged 38 ± 7. In series III, with isolated hypothermia of the head, when the brain temperature was 20°C the cardiac frequency was virtually unchanged at 129 ± 8. The duration of electrical systole of the left ventricle (the Q-T interval on the ECG) in the experiments of series I also increased from 0.217 sec during normothermia to 0.659 sec at 20°C. The duration of the Q-T interval on the ECG reflects polarization and depolarization processes in the heart muscle during cooling and it is connected with changes in its metab-

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olism. In the series with isolated hypothermia of the head, no changes therefore were found in this interval. The changes in mechanical systole were similar in the forms of hypothermia studied.

During general hypothermia, as it deepened the difference increased between electrical and mechanical systoles (Hegglin's index) by more than 14 times, evidence of worsening of the ability of the left ventricle to maintain a pressure higher than that in the aorta (what Hegglin calls energetic-dynamic insufficiency); under these circumstances premature closing of the semilunar cups of the aortic valve took place. In isolated hypothermia of the head the variations in this index were small, but when the brain temperature was 20°C, this index was actually reduced a little. This was a sign of functional integrity of the myocardium. An early manifestation of the decrease in myocardial contractility in the experiments of series I was lengthening of the period of contraction from 0.092 at 36°C to 0.146 sec when the body temperature was 20°C. No significant change in this index was observed in the experiments with isolated hypothermia of the head. The situation was the same in experiments with selective normothermia of the heart combined with deep hypothermia of the rest of the body. Further evidence of worsening of myocardial contractility in general deep hypothermia was a twofold or greater increase in the duration of the phase of isometric contraction. A characteristic feature of the cardio-

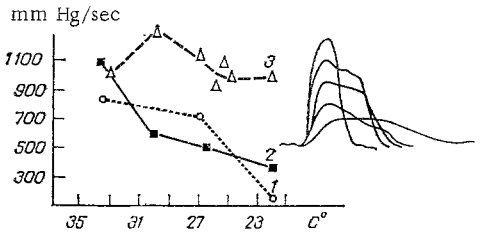

Fig. 1. Rate of rise of pressure in right ventricle in dogs exposed to different depths of hypothermia in experiments with general hypothermia, including the heart, with immersion cooling (1); in experiments with combined cooling (2), and in experiments with general immersion cooling of the body combined with selective normothermia of the heart (3). An example of the character of the changes in the curve of the rate of rise of intraventricular pressure during deepening of hypothermia is given on the right. The extreme values of the temperature in this experiment were 35-20°C.

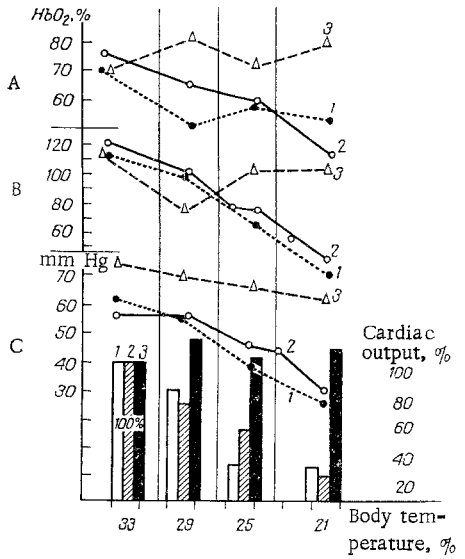

Fig. 2. Changes during deepening of hypothermia: oxygen saturation of venous blood (A), cardiac frequency in beats/min (B) and mean arterial pressure (C) in dogs during general hypothermia with immersion cooling of the whole body including the heart (1); in experiments with combined cooling of the body (2), and in experiments with immersion cooling of the body together with selective normothermia of the heart (3). Columns below represent changes in cardiac output at the same depth of hypothermia in the different variants of cooling.

dynamics during general hypothermia, including the heart, was thus an increase in the duration of all phases, and this was more marked as the hypothermia deepened.

Changes in the hemodynamic indices corresponded in character on the whole to results of phase analysis of the cardiac cycle. In particular, dp/dt in the experiments of series I, group A, before hypothermia averaged 1250 mm Hg/sec, at 25°C it fell to 600 mm Hg/sec, and at 20°C its mean value was 450 mm Hg/sec (Fig. 1). This was expressed graphically by the fact that the leading edge of the rise of the intraventricular pressure curve became less steep as hypothermia deepened. The changes in this index were similar in the experiments with combined hypothermia, but in the experiments with selective normothermia of the heart no decrease was observed. Selective normothermia of the heart also maintained an unchanged value of the principal hemodynamic index, the cardaic output (Fig. 2). In dogs with normothermia it averaged 118 ml/kg. If this value was taken as 100, at 25°C the cardiac output was reduced to 30%, and at 20°C to 23.5% of its initial value. As the writers showed previously [4], graphic comparison of the curves of change in cardiac frequency per minute and in cardiac output shows that in the initial stage of cooling of the body, including the heart, to a temperature of 26°C both values fell equally, but subsequent cooling of the body led to a more rapid decrease in cardiac output. This is evidence that down to this critical level of hypothermia of the body the decrease in cardiac output was due entirely to the developing bradycardia. In deeper hypothermia the stroke volume of the heart also was reduced, and this could be attributed only to changes in cardiac metabolism.

It can be suggested on the basis of these investigations that the decrease in cardiac output under the influence of deep general hypothermia is inadequate to satisfy the needs of the body, for the oxygen saturation of the venous blood fell gradually in the animals as their body temperature fell, i.e., the oxygen utilization increased in intensity. It can be concluded that the protective antihypoxic effect of hypothermia was less marked under these circumstances than the negative hemodynamic effect.

A definite role in the reduction in cardiac output may also be played by certain extracardiac factors: changes in CBV, the total peripheral vascular resistance (TPVR), etc. In the present experiments, however, their importance cannot be regarded as very substantial. In the experiments with deep general hypothermia a decrease in CBV occurred, but it was only moderate in degree. Not until 20°C did it reach 23%, i.e., CBV remained at the level of 77% of its initial value. During rewarming, CBV began to increase again and when normothermia was restored it exceeded its initial value by 12%. In experiments with isolated deep hypothermia of the head a decrease in CBV also was observed, to not less than 88% of its initial value, but in this series also CBV continued to fall during subsequent rewarming to 83% of its initial value. All changes in the experiments took place on account of TPVR to plasma, the level of which was obtained by calculation from the mean arterial pressure and cardiac output: In the experiments of series I at 25°C it was 127%, at 22°C 131%, and at 20°C 162% of its initial value. In the experiments with isolated deep hypothermia of the head TPVR was slightly reduced only at 20°C.

The results thus show that all cardio- and hemodynamic changes during hypothermia are due to the negative action of the low temperature directly on the heart muscle. In clinical practice it can therefore be recommended that deep hypothermia with immersion cooling of the body be combined with selective normothermia of the heart, or that when a temperature of 26°C is reached, further cooling be continued with the aid of an artificial circulation [7].

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