UNEQUAL COOLING AND WARMING OF TISSUES DURING HYPOTHERMIC PERFUSION

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Perfusion of an animal with cooled blood is accompanied by unequal cooling of the body tissues, due to distrubances of the regional blood flow, which of necessity leads to metabolic acidosis.

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Many studies of the hypothermic perfusion have now been published [1-9, 11-15]. They give details of changes in biochemical reactions [1, 10, 11] and in the body temperature [1, 3, 4, 11] under artificial circulation conditions in conjunction with hypothermia. Many workers have observed the appearance of temperature gradients under these conditions, but the reason for their appearance, as well as the connection between the dynamics of body temperature and various reactions of the organism, particularly biochemical changes during hypothermic perfusion, have been inadequately studied.

The object of the present investigation was to compare changes in the temperature in different parts of the body with some biochemical changes associated with an artificial circulation combined with hypothermia.

EXPERIMENTAL METHOD*

The temperature was recorded in various parts of the body in dogs (gray and white matter of the brain, heart, liver, esophagus, rectum, skeletal muscles, and blood in various vessels) every minute during hypothermic perfusion. A T-59 thermograph designed by the Research Institute of Experimental Surgical Apparatus and Instruments (NIIÉKhAI), equipped with a series of thermistors in a special selector attachment [4] was used. The artificial circulation was maintained by Crafoord–Senning and Lillehei apparatuses. The volume velocities of perfusion varied from 70 to 125 ml/min/kg body weight. The Crafoord-Senning apparatus was supplied with pure oxygen at the rate of 10-15 liters/min, and the Lillehei apparatus at the rate of 6-12 liters/min. Carbon dioxide was added in a proportion of 2-3% of the oxygen.

During the experiment the degree of oxygen saturation of the blood was determined with an oxyhemometer and the following indices of acid-base balance were studied: pH, CO_2, BE (excess of acids or bases).† Blood samples were taken before perfusion, at the lowest depth of cooling (10° in the myocardium), at the end of the period of circulatory arrest against the background of deep hypothermia, and at the climax of reheating.

EXPERIMENTAL RESULTS

During sudden cooling of the animal (20 experiments) with blood at a temperature of 3-5°, after the first minute of perfusion large temperature gradients developed (25-35°) between the blood and the body tissue, indicating unequal cooling. In the first 5-8 min of hypothermic perfusion (the phase of active cooling) the temperature in the skeletal muscles (thigh and shoulder groups) and in the rectum fell slowly, while that in the heart muscle, esophagus, liver, cerebral cortex, and blood fell rapidly and by a large

*Experimental material collected at the A. N. Bakulev Institute of Cardiovascular Surgery, Academy of Medical Sciences of the USSR.

†The biochemical tests were carried out by E. N. Ashcheulova.

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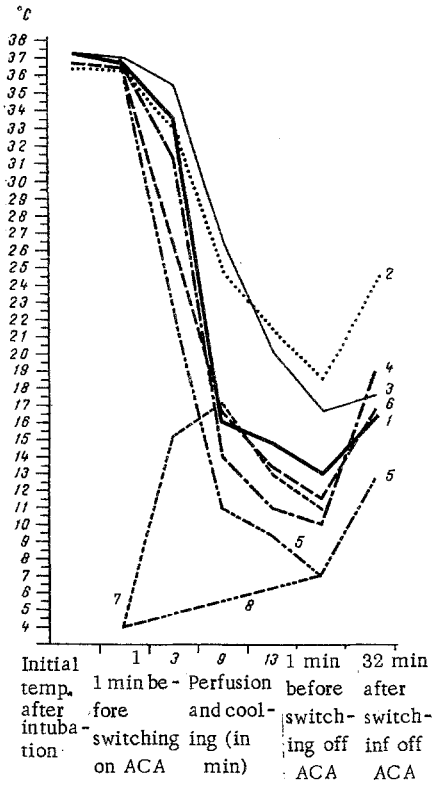

Fig. 1. Changes in body and blood temperatures in dogs under conditions of hypothermic perfusion (period of cooling) and circulatory arrest against the background of deep hypothermia. 1) Temperature of cerebral cortex; 2) of skeletal muscles; 3) of rectum; 4) of myocardium; 5) of liver; 6) of esophagus; 7) of arterial blood; 8) of venous blood in artificial circulation apparatus (ACA).

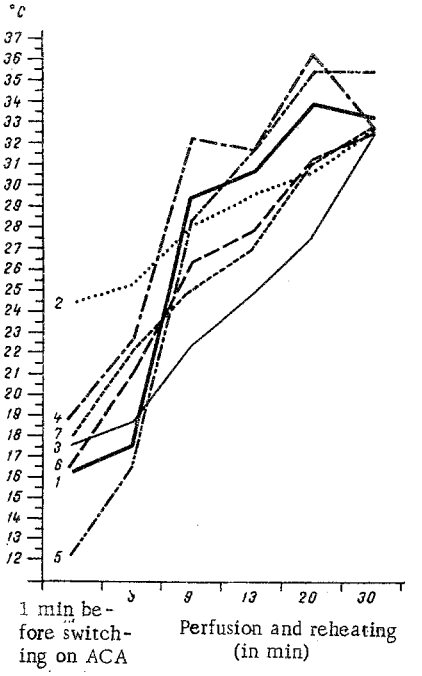

Fig. 2. Changes in body and blood temperature of dogs during hypothermic perfusion (period of reheating). Legend as in Fig. 1.

absolute amount (20-25°). Differences between the rate of change of temperature in these parts of the body were statistically significant ($P < 0.02$; Fig. 1). The temperature gradients began to diminish only after active cooling had ceased or after arrest of the circulation and discontinuation of the artificial circulation against the background of hypothermia (10° in the myocardium).

It will be clear that when different "temperature levels" were present, the corresponding parts of the body had different levels of metabolism. With a myocardial temperature of 10° (temperature of the skeletal muscles 19-31°), the arteriovenous oxygen difference was 0.4-6% HbO_2, the pH fell to 7.3-7.0, the concentration of standard bicarbonates fell to 9-10 meq/liter, and the concentration of incompletely oxidized metabolic products was increased (BE = −16, −20 meq/liter). Circulatory arrest against the background of deep hypothermia (10° in the myocardium) caused an increase in the arteriovenous oxygen difference to 10-20% HbO_2 after 30 min and to 40-50% HbO_2 after 60 min, together with a further increase in the concentration of incompletely oxidized metabolic products (BE > −22). In this period an increase in temperature of the myocardium, brain, liver, esophagus, and blood (by 2-10° in the first 30 min) was observed. The temperature of the skeletal muscles and intestine in the first 15 min of this period fell by 1-3°, and then rose by 5-8° toward the beginning of reheating. In the period of circulatory arrest, the heart as a rule fibrillated slowly. At the climax of reheating (temperature of the myocardium 35-37°) the arteriovenous oxygen difference was 20% higher than initially (Fig. 2). An increase in the concentration of standard bicarbonates to 12-13 meq/liter and a slight decrease in the concentration of incompletely oxidized metabolic products (BE = −14, −16 meq/liter) were observed, and the pH rose slightly.

Hence, during sudden cooling of an animal with blood at 3-5° the body tissues are cooled unequally, leading to the appearance of foci of anoxia, resulting in metabolic acidosis. Following injection of cold blood into the arterial system, intense vasoconstriction develops, and the mechanism producing it is a reflex vascular response. In the first stages of cooling, some parts of the body are in fact cut off from the circulation as a result of closure of the capillaries and arterioles, while the arteriovenous anastomoses evidently begin to function. This is confirmed by our own observations [3] and by published data [1, 8, 9, 11]. Changes in the regional blood flow are accompanied by the development of temperature gradients. Under these conditions a rapid fall in the temperature of the myocardium, esophagus, liver, and cerebral cortex and a slow fall in the temperature of the skeletal muscles and intestine are observed. This distinctive pattern of the temperature dynamics in areas "isolated" from the artificial circulation, the increase in temperature gradients between the body tissues and also between the blood and the tissues—these are all evidence of inadequacy of hypothermic perfusion from the point of view of temperature control. The inadequate blood supply to body tissues at a relatively high temperature is unquestionably accompanied by anoxia. Under these conditions, the hypothermic perfusion loses its principal function, that of protecting the tissues against anoxia.

LITERATURE CITED

1. A. A. Bunyatyan, Hypothermic Perfusion and Anesthesia in Surgery of Congenital and Acquired Defects of the Heart, Doctoral Dissertation, Moscow (1965).
2. V. I. Burakovskii, M. V. Murav'ev, and G. G. Gel'shtein, Grudnaya Khir., No. 3, 3 (1961).
3. I. Yu. Vinokurova, A. G. Bukhtiyarov, R. Z. Amirov, et al., Abstracts of Proceedings of the 6th Scientific Session of the Institute of Cardiovascular Surgery of the AMN SSSR [in Russian], Moscow (1962), p. 31.
4. I. Yu. Vinokurova, in: Problems in Clinical Physiology [in Russian], Moscow (1963), p. 378.
5. I. Yu. Vinokurova, Pat. Fiziol., No. 1, 60 (1965).
6. A. A. Vishnevskii, T. M. Darbinyan, and S. Sh. Kharnas, in: Experience of Clinical Use of New Surgical Apparatuses and Instruments [in Russian], Moscow (1964), p. 39.
7. T. M. Darbinyan, Modern Anesthesia and Hypothermia in Surgery of Congenital Heart Defects [in Russian], Moscow (1964).
8. P. A. Kupriyanov (editor), Artificial Circulation in Surgery of the Heart and Great Vessels [in Russian], Leningrad (1962).
9. A. P. Parfenov, in: Problems in Clinical Physiology [in Russian], Moscow (1963), p. 205.
10. E. P. Stepanyan, E. P. Pospelova, E. L. Geselevich, et al., in: Surgery of the Heart and Vessels [in Russian], Moscow (1963), p. 251.
11. F. Gollan et al., J. Thorac. Surg., 30, 626 (1955).
12. H. Harms, Arch. Klin. Chir., 301, 698 (1962).
13. A. Senning, Acta Chir. Scand., 107, 516 (1954).
14. A. Senning, Thoraxchirurgie, 8, 382 (1960).
15. S. K. J. Wolfson, E. Yalav, and S. Eisenstat, J. Thorac. Cardiovasc. Surg., 45, 466 (1963).