THE BLOOD SUPPLY OF THE BRAIN UNDER CONDITIONS OF CRANIOCEREBRAL HYPOTHERMIA

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The state of the brain's blood supply under conditions of craniocerebral hypothermia [3, 4, 6, 8, 9, 10, 11] is of unquestionable interest. Nevertheless, there are no data in the literature on this question. We undertood an experimental investigation of the volumetric blood flow rate in the brain, as one of the most important indices characterizing its blood supply.

EXPERIMENTAL METHOD

In the experiment we used 24 essentially healthy, nonpedigreed dogs, weighing from 12 to 23 kg. The brain of the animals was chilled in a hypothermic apparatus utilizing freon refrigerant. In the experiments, we determined the volume of blood flowing out of the brain, the arterial pressure, the frequency of cardiac contractions, the rectal temperature, and the temperature of the cerebral cortex.

In order to measure the volumetric blood flow rate, we used a pump-flow meter [2] in our modification. The water heating system is refined and the construction of the functioning ends and the relay is changed. This made it possible to regulate the water temperature rapidly and accurately, to maintain it at a low level, and to adjust the relay time according to the magnitude of blood flow.

Under light ether-oxygen intubation narcosis, following injected narcosis (20-22 mg/kg of thiopental-sodium intravenously), the femoral artery was prepared for recording of the arterial pressure,and the internal jugular vein for registering the amount of blood flowing out of the brain. The flowmeter was connected to the vein with the aid of polyethylene catheters or glass canulas. In the latter case, all branches and anastomoses of the cranial segment of the vein were ligated prior to its entrance into the jugular foramen of the skull. After recording the base line data, narcosis was intensified and the head of the animal was placed in the hypothermic apparatus. "Richter" brand heparin was injected intravenously in order to prevent blood clotting within the apparatus (500 ME per kg of weight of the dog).

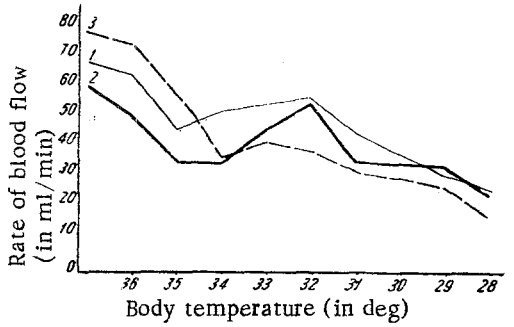

Fig. 1. Changes in the rate of blood flow within the internal jugular vein with deepening of hypothermia. 1) Trial No. 240; 2) trial No. 242; 3) trial No. 250.

The state of the brain's blood supply can be appraised not only from the magnitude of the arterial blood flow, but also from the amount of blood flowing out of that organ. Observations [15] on adult humans showed that the blood entering the brain via the internal carotid artery is almost entirely distributed within the hemisphere of the same side, and flows out via the jugular vein of that side. These conclusions are confirmed by other investigators [1, 14], who studied cerebral blood flow in animals, using radioactive isotopes. Thus, it may be assumed that the cerebral hemispheres, both in man and in animals, are supplied with blood separately, but at the same rate. Hence, in our experiments we always used only one of the internal jugular veins (left or right).

The temperature in the animals was controlled with a universal electrothermometer: in the rectum – by the usual method, and in the area of the cerebral cortex (in 8 animals) – using a

TABLE 1. Volumetric Rate of Blood Flow in the Jugular Vein with Deepening of Hypothermia (Mean Data)

Body temperature	Rate of blood (in ml/min)
Original	77.3
34°	39.2
32°	39.6
30°	30.6
28°	24.3

TABLE 2. Temperature of the Body and Cerebral Cortex (in Degrees) during Cerebral Chilling

Body temperature	Temperature of the cerebral cortex
36.0	35.1
34.0	31.9
32.0	28.7
30.0	25.6
28.0	22.4

needle element through a trephinated opening in the frontal portion of the skull. In the remaining experiments, the temperature of the cortex was calculated according to the linear formula:

$$t^{o}_{к} = 1{,}59 \cdot t^{o}_{p} - 22{,}1,$$

obtained by the method of least quadratics [5], where t^{0}_{k} – temperature of the cortex, t^{0}_{p} – rectal temperature, and 1.59 and 22.1 – constants. Comparison of the calculated figures with the actual ones showed that they reflected the temperature change dynamics in the brain with sufficient accuracy, deviating within the range of $\pm 0.4°$.

The animals were brought out of the hypothermic state by warming with reflectors to a body temperature of 31-32°, with subsequent self-recovery.

EXPERIMENTAL RESULTS

Under normothermic conditions, the rate of blood flow in the internal jugular vein of the dogs ranged from 50 to 80 ml/min, with an average of 77.3 ml/min. An exception was observed in only one experiment, where this index was equal to 134 ml/min under the normal conditions. Deepening the hypothermis always decreased the magnitude of the volumetric blood flow (Fig. 1). In the initial stage of chilling, with a body temperature of 35-34° (33.5-31.9° in the region of the cortex), the amount of blood flowing out of the brain, as a rule, decreased by 1½-2 times. Thus, in trial No. 242 at the level of 35° (33.5° in the region of the cortex), the rate of blood flow was equal to 37 ml/min in place of 62 ml/min seen under normal conditions, and in trial No. 250 – 38 and 80 ml/min, respectively.

In certain animals, with lowering of the temperature in the body and the brain, the rate of blood flow increased. The duration and degree of this increase were not always the same. The latter is apparently explained by a number of factors, all based on the state of the central nervous system during this period. Low temperature (−16-20°) in the hypothermic apparatus and narcosis of the proper depth (III_{2-3}) cause a relatively profound inhibition of the cortex, and defense reactions under these conditions are weakly manifested. In this case, cerebral blood flow does not intensify, or else a minimal increase is noted. In trial No. 250 (see Fig. 1), at a body temperature of 34°, blood flow began to increase, but it quickly fell again. On the other hand with an insufficiently energetic chilling during the period of intermediate hypothermia [7], one frequently observes rather vigorous defense reactions in the organism directed toward the support of a high body temperature: the arterial pressure is elevated, tachycardia arises, and blood flow increases in the regional vessels of the brain. A marked increase in the latter (by 32%) may be observed in trial No. 242, and prolonged in trial No. 240.

Mean data on the rate of blood flow show that during the period of change in the body temperature from 34 to 32° (cerebral cortex from 31.9 to 28.7°), the minute volume in the jugular veins did not decrease (Table 1).

The subsequent state of the cerebral blood flow was determined, in our experiments, by the level of hypothermia and the rate at which the animals' temperature was lowered; the more profound was the chilling, and the faster was the temperature drop, the greater and the faster did the rate of blood flow decrease. As a rule, energetic chilling caused an intense drop in the body temperature and especially in the brain. The difference between these two temperatures gradually increased as the organism was increasingly chilled, and reached several degrees by the time of the intermediate hypothermia period (Table 2).

However, despite this character of temperature change, the volumetric blood flow in the jugular veins, during marked deepening of the hypothermia, changed within smaller limits than at the beginning of the chilling (Fig. 2). While up to 34° the rate of blood flow decreased by an average of 19 ml/min for each degree, from 32 to 28° it fell by an average of 3.1 ml/min for each degree. The data of the experiments presented in Fig. 2 illustrate this characteristic. It was noted above that, at 34°, the amount of blood flowing out of the brain via the internal jugular vein decreased from 77.3 ml/min (under the starting conditions) to 39.2 ml/min, i.e. by almost 50%. At the same time, at the level of 28° (brain temperature of 22.4°), the minute blood flow was equal to an average of 24.3 ml, i.e., 31% of the original level.

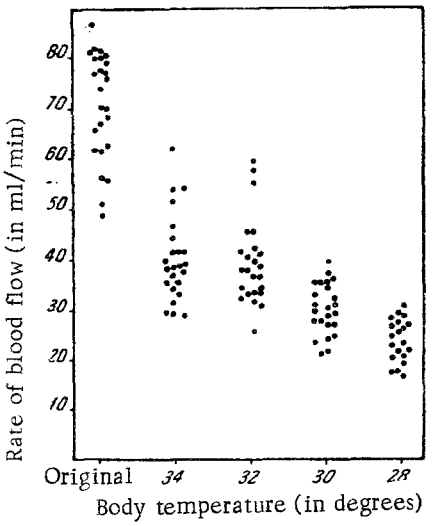

Fig. 2. Minute blood volume flowing out of the brain via the internal jugular vein at different levels of hypothermia.

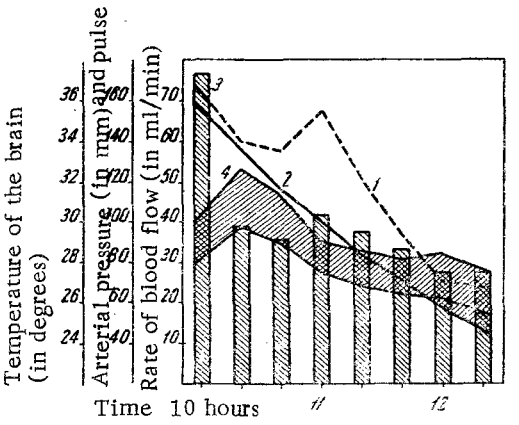

Fig. 3. Changes in the pulse (1), rate of blood flow in the jugular vein (3), and arterial pressure (4), with lowering of the temperature in the brain (2).

The volumetric rate of blood flow in the brain changed in correspondence with changes in the other hemodynamic indices. The most similar changes during the period of chilling were seen in the blood flow and the frequency of cardiac contractions. The link between blood flow and arterial pressure was more manifest during marked deepening of hypothermia. In the experiment illustrated in Fig. 3, as was observed in other animals, the rate of blood flow fell sharply in the beginning of the chilling – from 77 to 39.5 ml/min. The pulse also became slower, its frequency decreasing from 168 to 140 beats per minute. At this level of chilling the arterial pressure increased from 100/80 to 126/98. After a brief elevation in the rate of blood flow and frequency of cardiac contractions, there ensued a period of decreasing in the hemodynamic indices that were studied in this experiment. With lowering of the temperature from 30 to 24.5°, the volumetric rate of blood flow decreased from 42 to 24 ml/min, the pulse – from 156 to 66 beats per minute, and the arterial pressure – from 92/76 to 76/54 mm.

Thus, by the end of the chilling not only was the rate of blood flow characterized by a relatively high level, but also the arterial pressure testifying to a satisfactory functional state of the heart. Although the cardiac contractions became less frequent, they remained rhythmic and strong, and the pulse pressure – considerable. In these animals, as a rule, the hypothermia ran a smooth course, and function was restored sufficiently quickly.

The polarity of the changes in the rate of blood flow and the arterial pressure, observed in the analyzed experiment at the beginning of chilling (see Fig. 3), apparently indicate a specific characteristic of the cerebral blood circulation, which probably depends on the pressure in the aorta, but not always and not to the same degree. We noted this fact in many of the experiments.

Restoration of the blood supply to the brain usually occurred smoothly; it increased with progressive warming of the animals. Along with this, as the dogs were brought out of the hypothermic state, the volumetric blood flow (as well as the other hemodynamic indices) was lower than at the same temperature during the chilling. During warming, its magnitude in the internal jugular vein was usually 1.8-2.5 times smaller than during chilling. It must be noted that in certain animals, with restoration of the temperature in the body and the brain, the volumetric blood flow in the cervical vessels again began to fall soon after initiation of the warming and the brief increase in the rate of blood flow. In these cases, it was restored especially slowly. Usually, these changes, undesirable from our point of view, occurred in association with forced and very active warming of the body, and especially of the head.

One gets the impression that energetic warming causes a rapid decrease in the tonus of the vessels, as a result of which there arises a discrepancy between the volume of the vascular bed and the amount of circulating blood. Other investigators have also pointed this out [12, 13]. Apparently, such active warming primarily causes dilatation of the capillaries in the peripheral network, which leads to pooling of the blood in them and to a decrease in the circulating blood volume.

SUMMARY

Investigations were conducted on adult mongrel dogs. Hypothermia was created by chilling the brain through the surface coverings of the head, using a freon hypothermic apparatus. A pump-flow meter was used to record the amount of blood flowing out of the brain.

The cerebral blood supply dropped with reduction of the temperature of the animals. This reduction was more manifest (19 ml/min per degree, on the average) with decrease of the brain temperature to 31-30°C. Further changes in the jugular vein circulation were less significant (averaging 3.1 ml/min per degree). At a temperature of 23-22°C, the average volume of the blood flow constituted 30% of the initial value.

With normalization of the animals' temperature, the blood supply of the brain was restored.

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