CHANGES IN THE MICROCIRCULATION IN THE BRAIN FOLLOWING ACUTE BLOOD LOSS AND PROLONGED HYPOTENSION

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The microcirculation of the brain was studied in dogs after acute blood loss and subsequent prolonged hypotension reproduced by Wiggers' method. After massive blood loss (mean 41.3±2.2 ml/kg body weight) and subsequent hypotension (40 mm Hg), dilatation of the pial arteries is observed, its relative degree depending on their caliber. Dilatation of the pial arteries does not compensate for the disorders of the cerebral circulation, as is shown by the marked disturbances of carbohydrate metabolism and slowing of the EEG rhythm, which do not disappear even after adequate replacement of the lost blood and restoration of the morphological picture of the microcirculation.

Dilatation of the blood vessels of the brain occurring after massive blood loss and severe hypotension is regarded by many authorities as a compensatory reaction [3, 6-8]. The most marked dilatation is observed in the pial arteries, while the diameter of the larger vessels usually remains unchanged [3]. Marked disturbances of the cerebral blood flow have been recorded during lowering of the systolic pressure in the central end of the divided carotid artery to 40 mm Hg [1], i.e., to one third of the normal level [6], and in the peripheral end to one half its normal level [2]. The rate of blood loss also plays an important role. After a rapid fall of arterial pressure to 40 mm Hg, marked disturbances of the blood supply to the brain begin to be observed in 27 min [5]. Compensatory dilatation of the vessels is evidently able to maintain an adequate blood flow into the brain and to prevent the development of metabolic disturbances only up to certain limits.

The simultaneous use of morphological, physiological, and biochemical research methods can make a contribution to the further study of this complex problem.

EXPERIMENTAL METHOD

Acute blood loss, followed by prolonged hypotension, was reproduced in dogs by Wiggers' method. In series I (21 dogs) the microcirculation in the brain was studied intravitally, and several physiological and biochemical indices were recorded simultaneously. In identical experiments of series II (10 dogs) only physiological and biochemical tests were carried out. The microcirculation was studied through a burr hole (2 cm) in the parietal region of the skull, by means of a type MBS-2 stereoscopic microscope in incident light (magnifications 16×, 32×, 56×). The dura was removed beneath the burr hole but the subarachnoid space was not opened. Many measurements were made of the lumen of the vessels and the thickness of their wall, and they were drawn and photographed. The brain surface was continuously irrigated with physiological saline. Similar pictures of the microcirculation were obtained also in control experiments, using a transparent plastic window to close the opening in the skull hermetically. The brains of five animals were fixed supravitally [4]. The vessels were investigated in total specimens of the meninges and in brain sections

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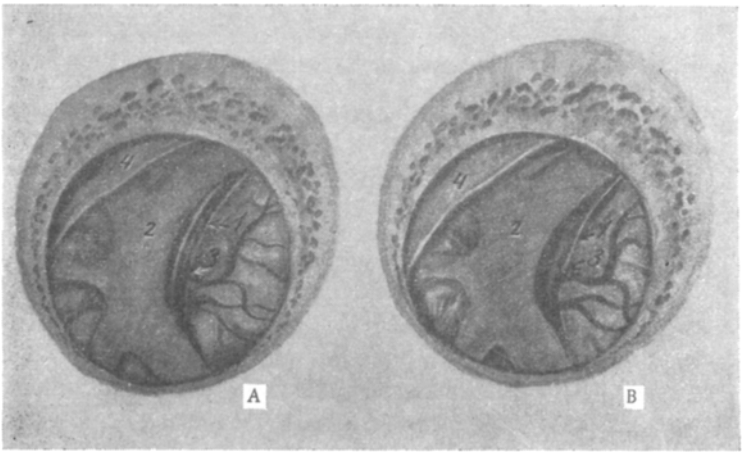

Fig. 1. Pial vessels of a dog's brain: A) before blood loss (background); B) at period of most marked hypotension; 1) artery; 2) vein; 3) region of branching of arteries; 4) dura. Drawing made in course of experiment by means of MBS-2 microscope. 16×.

cut to a thickness of 30-60 μ, which were stained by the usual methods and also impregnated with silver by the Bielschowsky-Gros method. Simultaneous recordings were made of the extent of the blood loss, the return flow of blood from the reservoir into the body (this was regarded as an index of vascular tone), blood pressure in the femoral artery, and the EEG (by a bipolar method using needle electrodes fixed into the cranial bones over the premotor cortex). Blood was investigated separately from the femoral artery and jugular vein for its content of lactic and pyruvic acids. The arterial pressure was lowered to 40 mm Hg by rapid exsanguination and maintained at that level for 1.5 h, after which the lost blood was replaced, and observations continued for a further 2 h.

EXPERIMENTAL RESULTS

In the initial state the brain arteries twisted and turned lengthwise with each pulse wave. The veins changed in volume mainly under the influence of respiratory movements. Mechanical stimulation of the arterial wall caused constriction of these vessels, and their lumen was restored after 5-8 min. The ratio between the lumen of the intracerebral arteries and their external diameter average 0.7 ± 0.17. The veins hardly responded at all to mechanical stimulation. During hypotension a regular dilatation of the lumen of the arteries took place, especially of those of medium and small caliber (by 50-75%), and less marked in the case of the larger arteries (by 20%). The arterial walls became thin, their pulsation ceased, and the muscle sphincter at points of branching disappeared. The over-all volume of the brain and subarachnoid space was reduced. The reaction to mechanical stimulation was very sluggish. The ratio between the lumen of the intracerebral arteries and their external diameter was appreciably increased (0.82 ± 0.008; $P = 0.01$). The volume of blood in the veins was reduced, but the thickness of their walls remained unchanged. Two principal types of reaction of the brain vessels were observed during hypotension: either a transient constriction followed by moderate dilatation, or constriction followed by marked dilatation, lasting until replacement of the lost blood.

During the 5-10 min after replacement of the lost blood the arteries of the brain became constricted to their original size. The ratio between the lumen of the intracerebral arteries and their external diameter at this stage of the experiment averaged 0.69 ± 0.02, i.e., its initial value was restored. The walls of the arteries were thickened and their pulsation had returned, and the veins were filled with blood. At the same time the volume of the brain and the amplitude of its movements were increased. The constricted arteries responded to mechanical stimulation by definite segmental spasm. Replacement of the lost blood was less effective in restoring the picture of the microcirculation in those experiments in which progressive dilatation of the arteries was observed in the period of hypotension. Drawings of the brain vessels in the principal stages of the experiment are shown in Fig. 1.

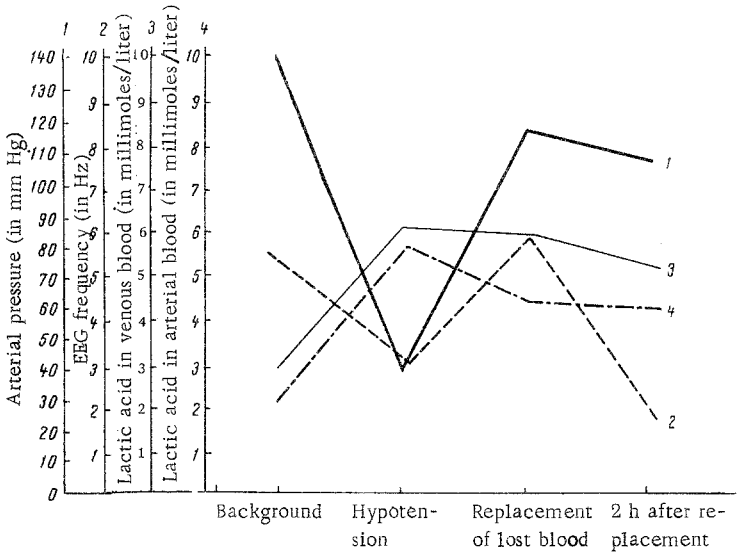

Fig. 2. Dynamics of certain functional and biochemical indices during prolonged hypotension followed by restoration of blood volume: 1) arterial pressure; 2) frequency of EEG rhythms; 3) lactic acid concentration in blood from jugular vein; 4) lactic acid concentration in arterial blood.

These experiments indicated that the vasodilatation occurring during 90-minute hypotension is evidently paralytic in character, and could not keep the blood supply to the brain at its initial level. This was confirmed also by the results of physiological and biochemical tests (Fig. 2), which reflected the state of metabolism of the brain.

The results given in Fig. 2 show that despite dilatation of the pial arteries, severe disturbances of carbohydrate metabolism developed in the brain. Evidence of these disturbances is given by biochemical tests, especially on blood draining from the brain, and also by the EEG. Blood transfusion and restoration of the morphological picture of the microcirculation did not, however, restore normal brain metabolism, for the high blood lactic acid level persisted, and the EEG rhythms became progressively slower.

In these experiments, acute massive blood loss followed by hypotension to the level of 40 mm Hg for a period of 90 min thus caused dilatation of the pial arteries, the relative degree of which depended on their caliber. This dilatation could not compensate the disturbances of the cerebral circulation causing metabolic disorders. Nor were these metabolic disorders abolished even after restoration of the morphological picture of the microcirculation. In other words, dilatation of the pial vessels during prolonged hypotension and restoration of the normal blood volume cannot compensate disturbances of the cerebral blood flow and cannot prevent damage to the nerve cells.

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