PATHOLOGICAL PHYSIOLOGY AND GENERAL PATHOLOGY

CEREBRAL OXYGEN TENSION AND HEMODYNAMICS DURING EXPERIMENTAL LETHAL BLOOD LOSS AND SUBSEQUENT RESUSCITATION

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The object of this investigation was to study the concentration of free oxygen (the partial pressure of oxygen – P_{O_2}) and the velocity of the blood flow in the vessels of the cerebral cortex of animals during lethal blood loss and after resuscitation.

METHOD

Under ether anesthesia the skull of 27 cats was trephined. To determine the P_{O_2} a platinum electrode, 0.3 mm in diameter, was introduced into the motor area of the cortex [7, 10]. In 12 experiments the blood flow in the same area was measured with Gibbs's thermoneedles [2]. In 8 animals the cardiac output was determined (by means of a bubble flowmeter) in the pulmonary trunk, in 8 cats the oxygen saturation of the blood was measured (with an oxyhemometer), and in 10 cats the velocity of the blood flow (thermometrically) and the oxygen tension in the liver were determined. The arterial pressure and respiration of all the animals were recorded. The values of the velocity of the blood flow, P_{O_2}, and arterial pressure were calculated as percentages. The lowest recorded level was taken as zero.

The animals were bled from the femoral or carotid artery. They were resuscitated 3-5 min after the onset of clinical death by the method of V. A. Negovskii and co-workers [4], but without the addition of adrenalin, glucose, or other substances which might possibly influence the dynamics of the indices under scrutiny, to the blood.

RESULTS

Acute blood loss led to a slowing of the cerebral blood flow and to a fall in the oxygen pressure. Comparison of these indices showed that their changes were not parallel (Fig. 1, 2). The general arterial pressure fell most rapidly, reaching 20-30% of its initial level after 1-2 min, and zero after 6-8 min. The cardiac output fell still more rapidly at the beginning of bleeding, and later the degree of the lowering of this index diminished. The velocity of the cerebral blood flow during the first 60-80 sec was maintained at the level of 90-80%, after which it fell rapidly. By the 3rd minute the cerebral blood flow was 50%, and by the 4th minute about 35% of the initial value. Hence, the cessation of the blood flow, as recorded thermometrically, took place later than the fall of arterial pressure, a finding in agreement with those of other workers [3]. On the average 5 min after the beginning of bleeding the intensity of the blood flow in the cortex was below 10%, and at the beginning or during the first 1-2 min of clinical death it was about zero.

The oxygen tension fell more slowly during the first 2 min than the blood pressure, but more rapidly than the cerebral blood flow. At the beginning of "agonal respiration" the rate of fall of P_{O_2} was slowed abruptly. The general arterial pressure in these circumstances was 20-15 mm Hg. The cerebral blood flow fell steadily. At this period three types of change in P_{O_2} were observed (Fig. 2). The first type (13 animals) was characterized by a temporary, but fairly considerable, rise of oxygen pressure: from 35 to 60%. The increase in P_{O_2} lasted for 3-6 min and in nine animals it was present during part of the period of clinical death.

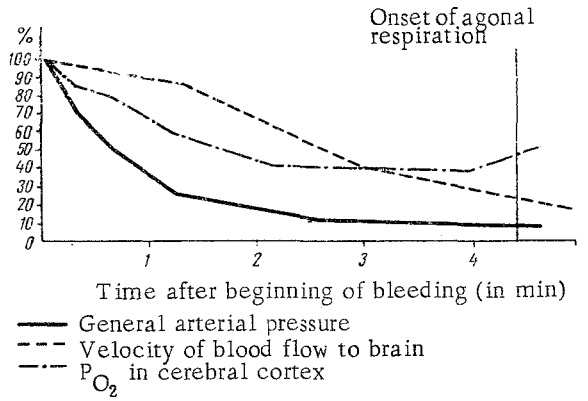

Fig. 1. Changes in the general arterial pressure, velocity of the cerebral blood flow, and oxygen tension in the cerebral cortex during acute blood loss (mean data).

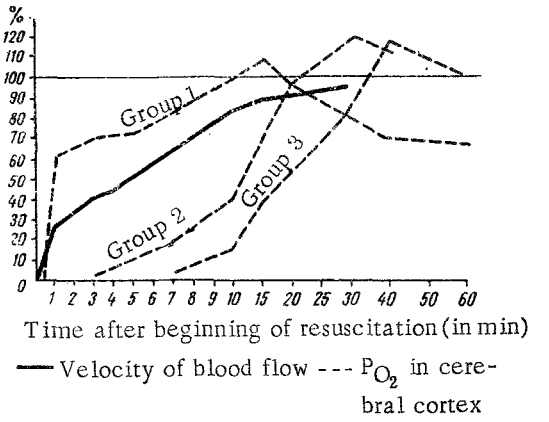

Fig. 2. Types of change in oxygen tension in the cerebral cortex in the resuscitation period (mean data).

In the second type of change (7 animals) only a temporary delay (for about 3 min) of the fall in P_{O_2} was observed, while in the third type (7 animals) the free oxygen concentration fell without any visible delay. After respiratory arrest (the beginning of clinical death) the free oxygen concentration in the cerebral cortex remained above zero for a short time. Only in 9 animals was the zero level reached during clinical death. In 18 cats the level of P_{O_2} continued to fall after resuscitation had begun, and reached its minimal value between 1 and 5 min after the restoration of the independent circulation. The changes observed in the value of P_{O_2} in the brain differed from the dynamics of this index in the other organs. For instance, in the liver the fall in the oxygen tension was more closely related to the circulatory changes.

In the period of resuscitation a rise of P_{O_2} took place simultaneously with restoration of the arterial pressure in the cerebral cortex in only three animals. The zero level was maintained for different times in 6 cats after being reached during the period of clinical death. In 18 cats, as previously mentioned, the oxygen tension continued to fall for a short time. The fact that zero had been reached did not foretell an early onset of a rise in P_{O_2}. For a certain length of time the free oxygen concentration did not rise. This delay in the rise of P_{O_2} was not due to the slow cerebral blood flow: it also occurred when the cardiac output, the arterial pressure, and the cerebral (and general) blood flow were high. The blood supply to the brain, recorded by the thermoneedles, also reached high values in such cases. Meanwhile, in some experiments with a comparatively low level of the general and cerebral hemodynamics, there was no delay in the recovery of the P_{O_2}.

The time of onset of the rise in P_{O_2} after resuscitation varied considerably. The oxygen tension began to rise in 3 animals 10 sec after the beginning of resuscitation, in 3 animals after 1 min, in 4 after 3 min, in 2 after 4 min, in 4 after 5 min, in 2 after 7 min, and in 9 animals after 10-40 min.

In accordance with this index, the animals as a whole could be divided into 3 groups (Fig. 3). Five animals in which the rise in P_{O_2} began 15-40 min after resuscitation are not shown in Fig. 3 because of the great variation in the time at which this index was restored.

In the animals of group I the rise in oxygen tension was most rapid. By the 10th minute the mean value of P_{O_2} was 100%, and by the 15th minute 110% of normal. A slow fall in this index then followed, lasting for 1 h or more. The cerebral blood flow and the blood oxygen concentration were more stable.

In the animals of group II the rise in P_{O_2} during the first few minutes of the change was slower. After about 5-7 min this index began to rise more rapidly, and by 20-25 min it had reached 100%, and after 30 min—120% of normal. A gradual fall then began. In these animals the cerebral blood flow fluctuated to some extent.

In the animals of group III the free oxygen concentration rose steadily. It reached 100% after approximately 30 min and its maximal increase (mean 120%) took place 35 min after the beginning of the change in P_{O_2}. Although in group III, as in group II, the cerebral blood flow showed some degree of fluctuation in the course of the recovery period, this was not visibly reflected in the recovery of P_{O_2}. The dependence of the value of P_{O_2} on the intensity of the cerebral blood flow usually became apparent later, when the oxygen tension had become more or less stabilized.

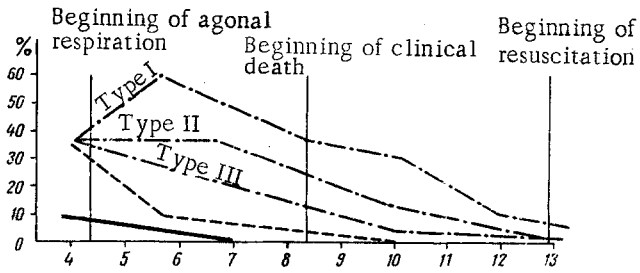

Fig. 3. Types of change in oxygen tension in the cerebral cortex during acute blood loss (mean data). Legend as in Fig. 1.

In five animals in which the beginning of the rise of oxygen tension took place later still, the periods of return to normal of the indices were correspondingly later.

The duration of the rise in oxygen tension above 100% varied from one animal to another. The degree of its increase also varied. For instance, whereas in 8 cats the value of P_{O_2} was considerably higher than initially, reaching 150-350% of normal, in 6 animals (with a sufficiently high cerebral blood flow) it did not exceed 70-90%.

In contrast to the brain, in the liver the increase in the oxygen tension during resuscitation took place at the same time as the circulation was restored. If the course of the recovery period was satisfactory, the value of P_{O_2} in the liver was established at a higher level than initially after a few minutes.

The circulation and metabolism of the brain in terminal states have received inadequate study [3, 4, 5]. The oxygen tension in the tissues is determined by two principle factors: the supply of oxygen and the activity of its utilization [6, 7, 9].

During the first 1.5-2 min of blood loss, the value of P_{O_2} fell faster than the cerebral blood flow. The oxygen saturation of the arterial blood then showed no significant change. The arterio-venous difference of oxygen rose. It may be assumed that, besides the reduction in the supply of oxygen, the oxygen consumption of the brain cells was increased. A similar phenomenon has been described [9] during the initial period of cerebral anemia after compression of the carotid arteries. The temporary increase in the oxygen tension or the delay in its fall in some of the experiments could be attributed to several factors, of which one of the most important was evidently the revival of the failing blood flow frequently observed in the agonal period, which may lead to an improvement in the oxygen transportation and to opening of the capillaries. The increase in P_{O_2} or the delay in its fall may also have been determined by a decrease in the utilization of oxygen. The distance of the platinum electrode from the nearest functioning vessel may also have had some bearing on the situation [8].

The decrease or absence of increase in the value of P_{O_2} which was found in the initial period of resuscitation during the recovery of the general circulation and of spontaneous respiration was of considerable importance. Considering the lowered ability of the brain tissue at this time to utilize oxygen, it may be assumed that no blood flow was present in the small vessel nearest to the cathode. Although the thermometric method showed recovery of the cortical blood flow, cooling of the thermoelectrodes may result from movement of the blood in vessels next to the closed capillaries and in larger vessels. The polarographic electrode detects more local changes. The mechanism of the prolonged closure of the cerebral capillaries in the period of resuscitation is evidently associated with the intravascular coagulation of the blood or aggregation of erythrocytes [1].

In physiological conditions and in hypoxia the value of P_{O_2} is directly dependent on the distance between the vessel and the area under study [8, 9]. During lethal blood loss and subsequent resuscitation this relationship may persist.

The picture described above shows that even when the period of agony and clinical death is short, and respiration and the circulation are successfully restored, profound disturbances of the circulation and metabolism may persist for a time in certain capillary zones of the cerebral cortex. Investigations recently conducted in our laboratory have shown that this conclusion is valid for different levels of the brain. This phenomenon may be responsible for the development of focal necrosis and, in some cases, for the irreversibility of the process.

Analysis of the dynamics of the polarographic curve shows that the earlier the free oxygen concentration in the brain rises, the faster its utilization begins.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.
