CHANGES IN PARTIAL PRESSURE OF OXYGEN IN THE CEREBRAL CORTEX DURING HEMODILUTION

A. L. Stolbov

UDC 615.384.015.4:[612.825:612.262

KEY WORDS: Hemodilution; hematocrit; partial pressure of oxygen; cerebral cortex; polarography.

Two aspects can be distinguished in the problem of hemodilution: physiological, namely the optimal hematocrit (HC) level for supplying the tissues with oxygen, and medical, namely the limits of application of this procedure in surgical practice. Changes (for example, a decrease) in the blood hematocrit signify changes also in some of its parameters, such as oxygen capacity and viscosity. Whereas a decrease in viscosity improves the rheologic properties of the blood and facilitates the work of the heart (which benefits the microcirculation), a fall in the oxygen capacity, on the other hand, worsens the conditions of oxygen supply to the tissues. The optimal HC value is thus determined by interaction between these two opposite processes. According to some workers [6, 12], this optimum is HC = 30%, but most workers [5, 10, 13] consider that the normal hematocrit of 40-45% creates the best conditions for oxygen transport. If the oxygen supply is disturbed, the myocardium and cerebral cortex are the first to suffer.

In the investigation described below the partial pressure of oxygen (pO_2) was determined in the cerebral cortex when the hematocrit fell to 5%, for this is one of the most important parameters reflecting the oxygen supply to the organ.

EXPERIMENTAL METHODS

Wistar rats weighing 290-310 g were anesthetized with pentobarbital sodium (40 mg/kg, intraperitoneally). Blood replacement was carried out through catheters introduced into the femoral vein and artery, the arterial pressure (BP) was measured and samples were taken. Heparin (1-2 units/g body weight) was injected intravenously. The exchange transfusion was carried out with a peristaltic micropump (type 304) by removing blood from the artery and simultaneously injecting a 7% solution of placental albumin into the vein at the rate of 0.6 ml/min. Blood samples were taken for determination of the hematocrit periodically by means of an MGTs-8 microcentrifuge. BP was recorded by means of a mercury manometer while the pump was stopped. To prevent a rapid fall of BP, hypervolemic hemodilution was created (15-20% more solution was injected than blood was withdrawn). Throughout the experiment the animals breathed atmospheric air unaided. To measure pO_2 in the brain an opening measuring 1 × 3 mm was made in the parietal zone of the skull, the dura was removed, and by means of a step motor a polarographic microelectrode was inserted into the cerebral cortex: This was an electrochemically pointed platinum wire, soldered into a No. 29 glass capillary tube with an overall diameter of 3-8 μ. To test the quality and stability of operation of the electrodes, the LP 7e polarograph was used. The electrodes were calibrated both immediately before and immediately after the experiment. Continuous measurements of tissue pO_2 were carried out with the F 128/2 nanovoltammeter. For this purpose, microzones with low (up to 30 mm Hg) and relatively stable (spontaneous variations not more than 1-1.5 mm Hg) values of pO_2 were selected in the cerebral cortex at depths of between 1000 and 1500 μ. The initial values and their change during blood replacement until death of the animal were recorded.

The animals as a whole were divided into two groups depending on their initial pO_2 value at the point of measurement: Group 1) initial pO_2 23-27 mm Hg (8 experiments); group 2) pO_2

Laboratory of Temperature Regulation and Bioenergetics, I. P. Pavlov Institute of Physiology, Academy of Sciences of the USSR, Leningrad. (Presented by Academician of the Academy of Medical Sciences of the USSR P. N. Veselkin.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 96, No. 9, pp. 18-20, September, 1983. Original article submitted February 1, 1983.

0007-4888/83/9609-1209$07.50

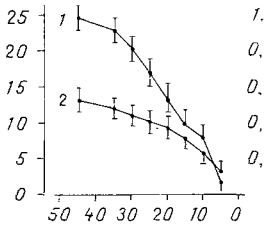

Fig. 1

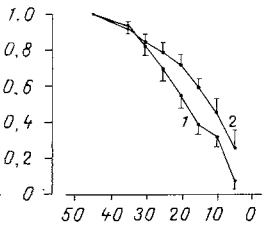

Fig. 2

Fig. 1. pO_2 in cerebral cortex at different hematocrit levels. 1) Points of brain with relatively high initial pO_2 (24.5 ± 1.7 mm Hg), 2) brain points with relatively low initial pO_2 (13.1 ± 1.7 mm Hg). Abscissa, hematocrit (in %); ordinate, partial pressure of oxygen (in mm Hg).

Fig. 2. Relative changes in pO_2 in cerebral cortex during hemodilution. Ordinate, ratio of pO_2 at the given hematocrit level to initial pO_2. Remainder of legend as to Fig. 1.

in the test zone normally 7-17 mm Hg (7 experiments). Changes in the tissue pO_2 during hemodilution were analyzed statistically in each group.

EXPERIMENTAL RESULTS

In the animals of both groups a tendency for the tissue pO_2 to fall appeared in the first stages of hemodilution (Fig. 1), although a statistically significant difference from the initial values was found only at mean hematocrit levels (25-30%). During continued hemodilution the fall of pO_2 became more marked, so that at HC = 5% it averaged only 2-3 mm Hg. However, if the character of the change in pO_2 was compared in the animals of the two groups, it was clear that in rats with a relatively high initial pO_2 (group 1) this parameter fell faster, with a decrease in the hematocrit, than in the rats of group 2. For instance, in the rats of group 1 the tissue pO_2 differed from the initial value, when compared by the method of direct differences, with $P < 0.05$ at HC = 30%, whereas in group 2 it differed only at HC = 25%. The difference was particularly marked between the groups when relative changes in initial values were compared (Fig. 2): whereas down to HC = 35%, pO_2 changed in a similar manner in the animals of both groups, with a further fall in the hematocrit, their graphs diverge more and more, and at HC = 15% the mean value of pO_2 in group 1 was still 60.1% of the initial level whereas in group 2 it was only 39.3% (difference statistically significant, $P < 0.01$).

Despite the small degree of hypervolemia with the aim of preventing BP from falling, it was impossible to avoid this phenomenon completely. For instance, whereas under normal conditions the mean value of BP was 110-115 mm Hg, its mean value was 100 mm Hg at HC = 30%, 85 mm Hg at HC = 20%, and only about 70 mm Hg at HC = 10%. It must be pointed out that, however, the course of the changes in BP and pO_2 in the tissue in the course of the experiment was not always parallel, and in some cases pO_2 was observed to fall while BP rose. Evidently despite the generally similar direction of the changes in these two parameters, it must not be concluded that the fall of BP was the cause of the decrease in tissue pO_2, for in a given case the two processes share a common cause — hemodilution and changes in the rheologic and oxygen-transporting properties of the blood connected with it.

In the course of hemodilution, elevation of the tissue pO_2 level did not occur at any hematocrit levels. Moreover, at HC = 30%, it already began to fall in certain zones, even despite the hypervolemia which was present. Under the conditions used, not only was hypercompensation of the fall of oxygen capacity not observed, but the compensatory changes soon became inadequate for the brain tissue. This is evidence that the normal hematocrit is optimal, at least so far as the tissue pO_2 is concerned. Admittedly, one group of workers [8, 11, 14] investigated different organs (parts of the CNS were not included) during hemodilution and obtained different results: down to HC = 20% pO_2 did not decrease, and in some cases it actually increased a little. The dynamics of pO_2 in the cerebral cortex perhaps

differs in principle from that in the tissues of other organs; in addition, another cause of the disagreements may be a difference in the methods used. It will be recalled that in the investigations cited above multichannel surface electrodes were used, whereas we used single microelectrodes, which were inserted into the middle layers of the cerebral cortex.

At the same time, no significant decrease in pO_2 of the brain could be observed down to HC = 30%. This confirms the soundness of the clinical recommendations that during hemodilution the hematocrit should not be allowed to fall lower than 30%.

It will be clear from Fig. 1 that at points with different initial pO_2 values, they change in different ways with a fall of hematocrit. Let us try to explain this phenomenon. First, the difference in the initial pO_2 values may be caused by different positions of the points relative to the capillary network — points with higher pO_2 must be nearer to the nearest capillary and (or) nearer to its arterial end. Theoretically this could affect both the dynamics of pO_2 during a decrease in the oxygen capacity of the blood and the effectiveness of the compensatory reactions. However, calculations on a model of the capillary network of the brain show that during a change in these parameters pO_2 at different points changes by about the same amount [3, 4]. Admittedly, it must be stated that during these calculations the assumption was made that oxygen diffuses only from capillaries. It may be that if certain points lie close to arterioles, from which, as has been shown [1, 2, 7], oxygen also enters the tissues, the dynamics of pO_2 in them will differ during hemodilution. Second, the possibility cannot be ruled out that at points with low pO_2 (or next to them) the "critical threshold" is reached sooner, leading to a fall in the oxygen consumption in that region [9]. In this case the fall in the value of tissue pO_2, which reflects the local balance between the supply and utilization of oxygen, will take place more slowly here than in zones where the oxygen consumption remains at its initial level.

LITERATURE CITED

1. K. P. Ivanov, E. P. Vovenko, and A. N. Derii, Dokl. Akad. Nauk SSSR, 265, No. 2, 494 (1982).
2. K. P. Ivanov, A. N. Derii, M. O. Samoilov, et al., Dokl. Akad. Nauk SSSR, 244, No. 6, 1509 (1979).
3. K. P. Ivanov and Yu. Ya. Kislyakov, The Energy Demand and Oxygen Supply of the Brain [in Russian], Leningrad (1979).
4. K. P. Ivanov and Yu. Ya. Kislyakov, Fiziol. Zh. SSSR, No. 6, 783 (1980).
5. J. W. Crowell and E. E. Smith, J. Appl. Physiol., 22, 501 (1967).
6. H. Hint, Acta Anaesth. Belg., 2, 119 (1968).
7. K. P. Ivanov, A. N. Derii (A. N. Derry), E. P. Vovenko, et al., Pflüg. Arch. Ges. Physiol., 393, 118 (1982).
8. M. Kessler and K. Messmer, Bibl. Haematol., 41, 16 (1975).
9. D. W. Lübbers, Oxygen Transport to Tissue, Budapest (1981).
10. P. Lundsgaard-Hansen, Vox. Sang., 36, 321 (1979).
11. K. Messmer, J. Sunder-Plassmann, et al., Adv. Microcirc., 4, 1 (1972).
12. J. F. Murray, P. Gold, and B. L. Johnson, J. Clin. Invest., 42, 1150 (1963).
13. L. Sunder-Plassmann, M. Kessler, F. Jesch, et al., Bibl. Haematol., 41, 44 (1975).