During the action of the conditioned visual stimulus (white target) the different responses of somatosensory cortical neurons of the intact and commissurotomized animals were much less marked than during the action of diffuse photic stimulation (Table 1). The percentage of neurons responding to exposure of the target in commissurotomized animals differed only a little from the control and was almost identical for both hemispheres. However, neurons of the left somatosensory cortex of the cats in group 2 responded much more frequently to exposure of the conditioned stimulus by a tonic decrease in the mean firing rate (Fig. 1b). The response of ECoG desynchronization to presentation of the conditioned stimulus was well marked in both control and commissurotomized animals (Fig. 1c).

Changes observed in the character of unit activity and the ECoG in response to the action of visual stimuli in the somatosensory cortex of the visually "deafferented" hemisphere of the animals of group 2 are evidence that commissural structures in the floor of the third ventricle and mesencephalic reticular formation are concerned in transhemispheric transmission of visual information into this projection region. The mainly inhibitory type of neuronal responses in the visually "deafferented" somatosensory cortex is evidently due to the greater relative contribution of commissural channels of the mesencephalic reticular formation. The ECoG desynchronization reaction is also evidently connected with these systems. Comparison of somatosensory cortical neuronal responses to the action of diffuse and conditioned visual stimuli in the animals of groups 1 and 2 demonstrates that the efficiency of transmission of visual information along diencephalic and mesencephalic commissural channels can be made more efficient if the biological importance of peripheral stimulation is enhanced.

LITERATURE CITED

1. S. B. Dzugaeva, Conducting Pathways of the Human Brain [in Russian], Moscow (1975).
2. N. N. Lyubimov, Zh. Vyssh. Nervn. Deyat., No. 2, 287 (1964).
3. V. F. Fokin, Zh. Vyssh. Nervn. Deyat., No. 3, 752 (1975).
4. V. Yu. Urbakh, Statistical Analysis in Biological and Medical Research [in Russian], Moscow (1975).
5. K. E. Bignall, M. Imbert, and P. Buser, J. Neurophysiol., 29, 396 (1966).
6. V. A. Fedan and N. N. Lyubimov, Neurosci. Lett., Suppl. No. 5, 481 (1980).
7. N. N. Lyubimov, Iugosl. Physiol. Pharmacol. Acta, 6, 157 (1970).
8. V. B. Mountcastle, J. Neurophysiol., 20, 408 (1957).
9. J. M. Sprague, J. Berlucchi, and J. Rizzolati, in: Handbook of Sensory Physiology, Vol. 7/3, Berlin (1973), Part B, p. 23.

PHYSIOLOGICAL MECHANISM OF STABILIZATION OF THE PARTIAL OXYGEN PRESSURE IN CAPILLARY BLOOD

E. P. Vovenko

UDC 612.127.2:612.135

KEY WORDS: fluctuations in partial oxygen pressure (pO_2) of arterial blood; pial microvessels; stabilization of pO_2 in capillary blood.

Establishment of the fact that oxygen diffuses through the wall of arterial microvessels introduced an essential correction into ideas on the principles governing oxygen transport from blood to tissue [2, 6, 7]. In particular, it was explained that under normoxemic conditions, with a decrease in diameter of arterioles, the partial oxygen pressure (pO_2) falls in blood flowing along them [3, 5, 7, 8]. As a result blood with its pO_2 considerably reduced compared with that in the aorta flows toward the capillaries. For instance, in the arterial portion of capillaries in the cerebral cortex it is 43 ± 3 mm Hg [5]. On this basis it has

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 A. P. Veselkin.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 97, No. 1, pp. 8-11, January, 1984. Original article submitted February 1, 1983.

0007-4888/84/9701-0006$08.50

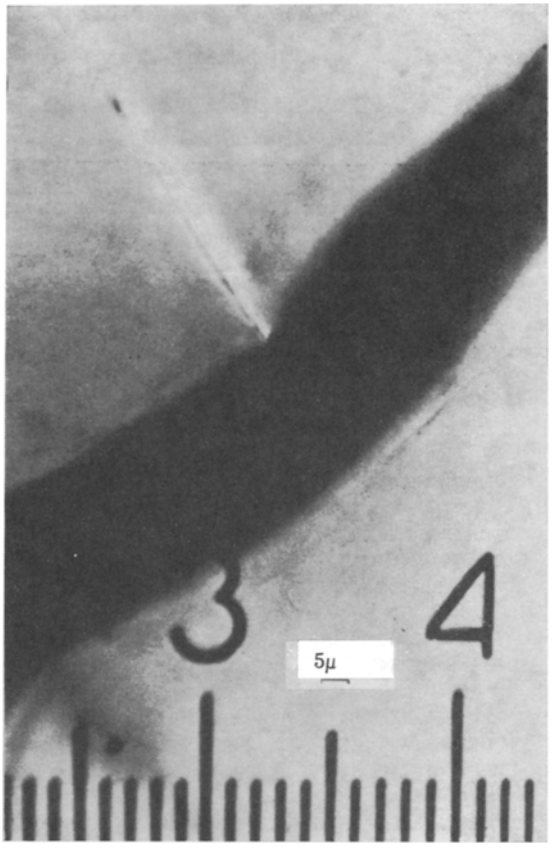

Fig. 1. Microelectrode tip brought up to lumen of a pial arteriole 30 μ in diameter.

been suggested that the arrival of blood in the capillaries with relatively low pO_2 values facilitates stabilization of the intracapillary pO_2 [5].

The aim of this investigation was to test this hypothesis and to continue the analysis of the effects of permeability of the arteriolar wall for oxygen. The investigation comprised measurement of the pO_2 values in blood from arterioles and capillaries of the pia mater during fluctuations of pO_2 in the blood of the large arteries (p_aO_2) between 60 and 150 mm Hg.

EXPERIMENTAL METHOD

Female rabbits weighing 2.7-3.2 kg were anesthetized with pentobarbital (30 mg/kg) and immobilized with diplacin (8-10 mg/kg). A hole 2 cm in diameter was drilled in the parietal region of the skull and the dura removed in that area. The brain surface was continually irrigated with Krebs—Ringer solution with bicarbonate buffer (pH 7.4, 37°C), through which a gas mixture of 5% CO_2 in oxygen was bubbled. The animal's body temperature was kept at 37 ± 0.5°C. The arterial pressure was monitored by means of a mercury manometer. Values of pH, pCO_2, and pO_2 in blood samples from the femoral artery were determined on the BME-3 instrument (Radiometer, Denmark) and oxyhemoglobin (HbO_2) dissociation curves were plotted (Hem-o-Scan, from Aminco, USA). With the optical system used (LYUMAM-K1 contact microscope), microvessels on the surface of the pia mater and in the depth of the tissue down to 60 μ could be observed under a magnification of 150-300. The internal diameter of the vessels (the diameter of the flow of moving erythrocytes) was measured by an ocular micrometer with an accuracy of 2 μ.

Platinum polarographic microelectrodes, insulated with glass and covered by a styrene membrane (tip 2-4 μ) were used to measure pO_2. The microelectrodes were calibrated in physiological saline saturated with air before and after each measurement. To reduce induction, the Ag—AgCl reference electrode was made in the shape of a ring, arranged around the frontal lens of the objective. During measurements the frontal lens was in direct contact with brain tissue, which prevented exchange of gases between the region of pO_2 measurements and

TABLE 1. Coefficients of Correlation and Regression between p_aO_2 and $p_{mv}O_2$ for Different Groups of Microvessels (M ± m)

Parameter studied	Capillaries 3-5 μ in diameter (n = 62)	Arterioles with a diameter of			
		5–10 μ (n = 57)	10–30 μ (n = 201)	30–60 μ (n = 83)	60–100 μ (n = 24)
Coefficient of correlation	0,266	0,880*	0,850*	0,904*	0,946*
Coefficient of regression	0,09±0,1	0,48±0,07	0,64±0,05	0,78±0,08	0,9±0,1

Legend. *P < 0.001; n) number of measurements.

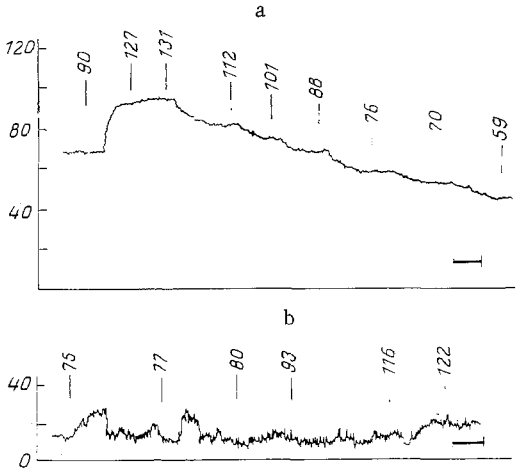

Fig. 2. Changes in pO_2 in blood of arteriole 30 μ in diameter (a) and in blood of venous portion of capillary 4 μ in diameter (b). Abscissa, time (in min); ordinate, pO_2 in blood of microvessels (in mm Hg). Numbers by vertical lines denote values of p_aO_2 (in mm Hg). Calibration: 1 min.

the external medium. To determine pO_2 in blood from the arterioles the microelectrode tip was introduced into the tissue of the vessel wall under microscopic control (by partial puncture) up to a distance of 2-3 μ from its lumen (Fig. 1). A special test showed that the values of pO_2 recorded under these conditions ($p_{mv}O_2$) were virtually identical with the values of pO_2 in the blood of these microvessels.

To reduce the amplitude of respiratory movements of the brain during artificial ventilation of the lungs, the method of high-frequency oscillations [14] was used. In this method of ventilation, oscillations of gas with a frequency of 5 Hz during a total gas flow of 1.3-1.5 liters/min were created in the upper respiratory tract under low positive pressure (5-6 cm water). This technique ensured practically complete immobility of the brain surface and allowed values of pO_2 and pCO_2 of the arterial blood to be kept within the desired range.

Isocapnic (p_aCO_2 = 35 ± 4 mm Hg) shifts of pO_2 of the arterial blood were produced by changing the oxygen concentration in the inspired gas. From the initial state of normoxemia p_aO_2 was raised (by adding measured quantities of O_2 to the inspired gas) with steps of 10-20 mm Hg up to 150 mm Hg. After this, p_aO_2 was reduced with the same steps to 60 mm Hg (by adding nitrogen to the inspired gas), after which the original normoxemic state was restored. The whole cycle of changes in p_aO_2 lasted on average 30-40 min. A blood sample was taken from the femoral artery 2-3 min after each change of composition of the inspired gas for analysis of the gas composition. The values of p_aO_2 obtained were compared with the values of $p_{mv}O_2$ measured simultaneously with the microelectrode.

In 20 experiments on 61 microvessels 427 paired measurements of p_aO_2 and $p_{mv}O_2$ were obtained.

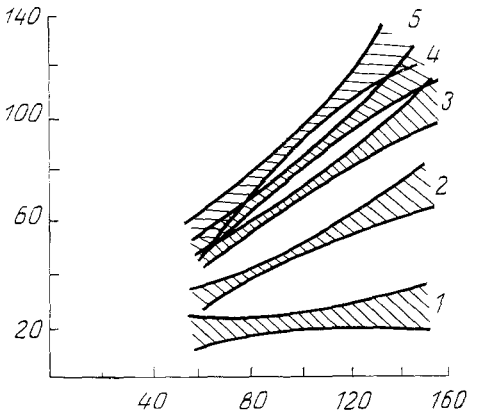

Fig. 3. Confidence zones of regression between $p_{mv}O_2$ and p_aO_2 for different groups of microvessels. Abscissa, pO_2 in blood from femoral artery (in mm Hg); ordinate, pO_2 in blood of microvessels (in mm Hg). 1) Capillaries 3-5 μ in diameter; 2-5) arterioles 5-10, 10-30, 30-60, and 60-100 μ in diameter respectively.

EXPERIMENTAL RESULTS

All microvessels tested, depending on the diameter of their lumen, were divided into five groups. Group 1 consisted of capillaries of the pia mater 3-5 μ in diameter. It was possible to measure pO_2 only in the venous portion of the capillaries, because their arterial ends were outside the optical depth of examination. Single erythrocytes moving in a row one after the other could be distinguished in the capillaries. Microvessels of group 2 consisted of the smallest arterioles 5-10 μ in diameter. A strong blood flow was observed in these microvessels, in which single erythrocytes could not be distinguished. The remaining three groups consisted of pial and precortical arterioles 10-30, 30-60, and 60-100 μ in diameter respectively.

During shifts of p_aO_2 corresponding changes in pO_2 in blood of the arterioles differed significantly from changes in pO_2 in capillary blood (Fig. 2). Incidentally, fluctuations of pO_2 observed in the capillaries were not associated with changes in p_aO_2.

On the basis of the set of pairs of measurements of p_aO_2 and $p_{mv}O_2$, coefficients of correlation were calculated and regression lines plotted for each group of microvessels (Table 1; Fig. 3). The coefficient of correlation for capillaries, assessed by the Z statistic, did not differ significantly from zero ($P > 0.05$). For the other microvessels, correlation between p_aO_2 and $p_{mv}O_2$ was significant ($P < 0.01$). Comparison of regression lines using the t test showed a significant difference between coefficients of correlation for lines 5, 3, and 2 ($P < 0.01$). The regression coefficient for line 1 did not differ significantly from zero ($P > 0.05$).

The results of the measurements were thus as follows. With a decrease in diameter of the lumen of the arterioles pO_2 falls in the blood flowing along them (Fig. 3). With a decrease in diameter of the microvessels changes in $p_{mv}O_2$ in response to shifts of p_aO_2 become smaller (the corresponding regression coefficients decrease). In the venous part of the capillary system there is no significant correlation between p_aO_2 and $p_{mv}O_2$ (within limits of change of p_aO_2 from 60 to 150 mm Hg).

Fluctuations of p_aO_2 have been shown to lead to various changes in local values of pO_2 in cerebral cortical tissues [1, 10, 12, 13]. For instance, the most marked changes in the values of the tissue pO_2 as a rule were observed when its values were initially high, whereas low values (5-10 mm Hg) showed no significant change [1, 12]. It must be pointed out that in all these investigations tissue pO_2 values were measured "blind," i.e., without identifying the position of the microelectrode tip relative to the blood vessels.

The writer's previous investigations [2, 5] and others [8] in which the position of the electrode tip was determined visually, showed that the highest values of tissue pO_2 are observed, not along the arterial limb of the capillaries, as was hitherto considered, but close to arterioles. Correspondingly, low values of pO_2 (compared with p_aO_2) are recorded as a rule in capillary blood and in the intercapillary space [3, 5].

The results of the present investigation are evidence that during changes in p_aO_2 the most marked changes in pO_2 are observed in blood in arterioles 30-100 μ in diameter. With a decrease in diameter of the microvessels, correlation between p_aO_2 and $p_{mv}O_2$ weakens (Fig. 3). Values of pO_2 in blood from the venous part of capillaries are virtually independent of changes in p_aO_2 between limits of 60 and 150 mm Hg. It can be tentatively suggested that these differences are due to the S-shaped course of the HbO_2 dissociation curve. Actually values of pO_2 in blood from arterioles 10-100 μ in diameter correspond to the sloping region of the curve, within which a fall of blood O_2 concentration by 1 vol. % is accompanied by a fall of pO_2 on average by 20-25 mm Hg. Values of capillary pO_2 correspond to the steep part of the HbO_2 dissociation curve, within which a fall of O_2 concentration by 1 vol. % is accompanied by a fall of pO_2 by only 2 mm Hg. The local blood flow in cerebral cortical tissue, incidentally, does not depend significantly on changes in p_aO_2 between 60 and 150 mm Hg [9]. For that reason, stabilization of the values of p_aO_2 observed in the capillary blood cannot be due to changes in the velocity of the blood flow. We know, however, that the linear velocity of the blood flow in cerebral microvessels [4] and oxygen consumption by microregions of brain tissue [11] fluctuate around certain mean values, and this is evidently responsible for fluctuations of pO_2 in capillary blood which are independent of changes in p_aO_2 (Fig. 2b).

The results of this investigation thus show that values of pO_2 of blood in the venous part of capillaries are virtually independent of changes in p_aO_2 between limits of 60 and 150 mm Hg. The observed stabilization of the values of pO_2 is due to diffusion of O_2 through the wall of arterioles and to the steepness of the part of the HbO_2 dissociation curve in the region of capillary pO_2 values.

LITERATURE CITED

1. I. T. Demchenko and A. E. Chuikin, Fiziol. Zh. SSSR, 61, No. 9, 1310 (1975).
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, E. P. Vovenko, and A. N. Derii, Dokl. Akad. Nauk SSSR, 265, No. 2, 494 (1982).
4. K. P. Ivanov, M. K. Kalinina, and Yu. J. Levkovich, Microvasc. Res., 22, 143 (1981).
5. K. P. Ivanov, A. N. Derii (A. N. Derry), E. P. Vovenko, et al., Pflüg. Arch. Ges. Physiol., 393, 118 (1982).
6. P. W. Davies and D. W. Bronk, Fed. Proc., 16, 689 (1957).
7. B. R. Duling and R. M. Berne, Circ. Res., 27, 669 (1970).
8. B. R. Duling, W. Kushinsky, and M. Wahl, Pflüg. Arch. Ges. Physiol., 383, 29 (1979).
9. J. Grote and R. Schubert, Arzneimittel-Forsch., 30, 2219 (1980).
10. E. Leniger-Follert, D. W. Lübbers, and W. Wrabetz, Pflüg. Arch. Ges. Physiol., 359, 81 (1975).
11. E. Leniger-Follert and D. W. Lübbers, Pflüg. Arch. Ges. Physiol., 366, 39 (1976).
12. H. Metzger, W. Erdmann, and G. Thews, J. Appl. Physiol., 31, 751 (1971).
13. P. Nair, W. J. Whalen, and D. Buerk, Microvasc. Res., 9, 158 (1975).
14. M. M. Todd, S. M. Toutant, and H. M. Shapiro, Anesthesiology, 54, 496 (1981).