RESPONSES OF PIAL MICROVASCULAR EFFECTORS REGULATING THE ADEQUATE BLOOD SUPPLY OF THE NEURONALLY ISOLATED CEREBRAL CORTEX

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The phenomenon of regulation of an adequate blood supply even in very small areas of brain tissue, to correspond to the metabolic demands of its structural elements, is well known [4, 7-9, 13]. Available experimental data demonstrate the important role of the small pial arteries and their active segments, i.e., sphincters of their branches, of precortical arteries, and of interarterial microanastomoses in the regulation of an adequate blood supply to the cerebral cortex [1, 4, 12]. A task for further research was the elucidation of the physiological mechanism (neurogenic, metabolic) of control of the lumen of these microvessels when the normal relations between the blood supply and metabolic requirements of the brain tissue are disturbed.

The object of the present investigation was to study responses of these regulation effectors when cortical activity was intensified as a result of neuronal isolation [5].

EXPERIMENTAL METHOD

Experiments were carried out on 17 rabbits of both sexes weighing 2-3 kg and anesthetized with hexobarbital or pentobarbital (about 30 mg/kg body weight). The responses of the pial arteries and of the special effectors located there (sphincters of their branches, precortical arteries, and microanastomoses) were investigated intravitally when activity of the cortex (identified regularly on the electrocorticogram) was intensified as a result of local application of 0.5% strychnine to the brain surface. The vasodilatation arising under these circumstances depended on influences from the cerebral cortex and not on the direct action of strychnine on the vessel walls [3].

Serial intravital photomicrography (magnification 80 times) of the system of pial arteries in the parietal region was carried out through a wide burr-hole in the parietal region of the skull. Brain pulsation during the experiment was considerably reduced by drainage of the 4th ventricle. To prevent paroxysmal contraction of the skeletal muscles after application of strychnine, the muscle relaxant diplacin dichloride was injected intravenously (about 1 mg/kg body weight) and the lungs were artificially ventilated with a mechanical ventilator; the frequency and depth of respiration were about the same as before injection of the relaxant. Measurements of the general arterial pressure in preliminary experiments (through a catheter inserted into the common carotid artery) showed that under the conditions used it was unchanged, so that there was no need to record it.

The investigations were carried out on the segment of the pial arterial system where all types of microvascular effectors are represented. These vessels were photographed for the first 10-30 min (control), after which strychnine was applied to that same region as a drop beneath a coverslip for 3 min, during which the photomicrography continued. The strychnine was then washed off and applied again after an interval of not less than 30-60 min, when the vessels had returned to their original state.

Neuronal isolation of the cortex was carried out by the method described in detail in [5]: A narrow strip (3 × 8 mm) was cut out of the skull by means of a saw to provide access to

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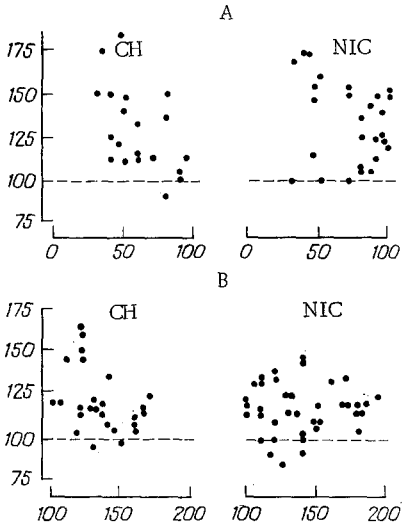

Fig. 1

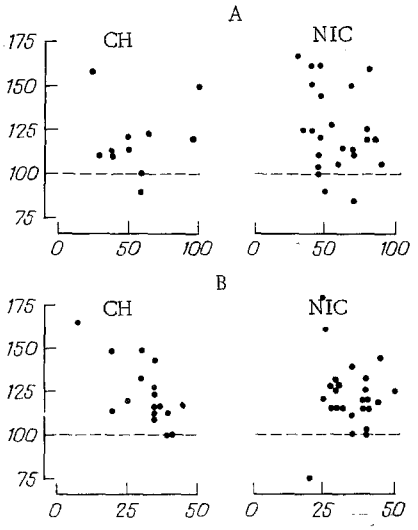

Fig. 2

Fig. 1. Changes in diameter of pial arteries with caliber over 100 μ (A) and under 100 μ (B) with stimulation of cortical activity by application of 0.5% strychnine in rabbits. Initial (control) diameter of vessels taken as 100%; CH) control hemisphere, NIC) neuronally isolated cortex. Abscissa, diameter of arteries (in μ), ordinate, change in diameter (in % of control).

Fig. 2. Changes in diameter of sphincters of branches of pial arteries (A) and of precortical arteries (B) during stimulation of cortical activity by application of 0.5% strychnine in rabbits. Legend as to Fig. 1.

the anterior temporal region of the cortex; the dura was then divided and an incision made in the cortex to expose the lateral ventricle. A thin spatula was introduced into the slit thus formed, by movement of which in an anteroposterior direction all the cortical projection pathways were divided, thus producing complete neuronal isolation from the deep brain formations. In the chronic experiments the integrity of the skull was restored by replacing the excised piece of bone.

In the experiments now described, neuronal isolation of the cortex was carried out unilaterally, either in acute experiments when responses of the same pial arteries were studied before and after the operation (five animals), or in chronic experiments, when the pial arteries were investigated 1-2 weeks (five animals) or 1-2 months (seven animals) after the operation. In chronic experiments the responses of the pial arteries of the contralateral (intact) hemisphere served as the control. The results described in this paper were obtained in experiments in which successful neuronal isolation of the cortex was verified at autopsy. The experimental results were subjected to statistical analysis, data of the acute and chronic experiments being pooled, for their separate statistical analysis revealed no difference in the results in the two hemispheres.

EXPERIMENTAL RESULTS

Serial photomicrography of the branching and anastomosing system of pial arteries at the beginning of the experiments showed that their diameter as a rule did not change. Only infrequent (twice or three times per hour) and small changes in the diameter of the pial arteries, the sphincters of their branches, and the precortical arteries were observed. The direction of the blood flow in the interarterial microanastomoses changed periodically and from time to time they were shut off from the circulation.

After local application of strychnine the characteristic response of the pial arteries and of the active segments in that region, namely sphincters of the branches of the pial arteries, precortical arteries, and microanastomoses, was their dilation; the degree of dilatation differed for different microvessels (Figs. 1 and 2). The differences in the degree of dilatation were regular only in the relatively large and small pial arteries (over and

under 100 μ), which dilated by 18 ± 2.4 and 32 ± 4.2%, respectively ($P < 0.001$). Meanwhile, no general rule could be found as regards the dependence of dilatation of the sphincters of branches of the pial arteries and precortical arteries on their initial caliber (Fig. 2).

Comparison of the responses of the various microvessels in the neuronally isolated and control hemispheres revealed no regular differences between them. This applied both to the large and small pial arteries and to their active segments — sphincters of the branches and precortical arteries (Figs. 1 and 2).

Division of the connections between cortex and basal ganglia thus does not abolish functional dilatation of the pial arteries, an important element in the system of effectors regulating the cortical microcirculation and responsible for the appearance of hyperemia in the cortex when its activity is intensified [1]. It can accordingly be concluded that the mechanism of these vascular responses may be either metabolic (direct action of certain metabolites formed in the cortex on smooth muscles of the effector vessels tested, namely the small pial arteries, sphincters of their branches, precortical arteries, and pial arterial microanastomoses), or neurogenic, but in this case the reflex arc may be closed locally and not at the level of any general center.

The following facts are evidence in support of a metabolic mechanism: Metabolic changes arising in the brain tissue during stimulation of its activity (an increase in the K^+ or H^+ concentration, etc.) are factors producing dilatation of the pial arteries through their direct action [10]. However, these metabolic factors evidently cannot reach the wall of the pial arteries within the very short time after which their functional dilatation takes place [2, 11].

Meanwhile there is the following evidence that the appearance of this vascular response may depend on a neurogenic mechanism: a) The response of the pial arteries is not the same all along their length, but there is a relatively independent response of some segments: sphincters of branches of the pial arteries, and precortical arteries, in the walls of which an abundant innervation exists [6]; b) there is a short latent period, measuring a few seconds, before the vascular responses to stimulation of cortical activity take place [2, 11].

It can be concluded from the results obtained in this investigation that if functional vasodilatation does in fact arise through a neurogenic mechanism, the reflex arc must be closed locally, within the area of cortex supplied with blood by the same effector arteries.

LITERATURE CITED

1. D. G. Baramidze and G. I. Mchedlishvili, Fiziol. Zh. SSSR, 61, 1493 (1975).
2. Yu. E. Moskalenko, I. T. Demchenko, A. A. Savich, et al., in: Correlation of Blood Supply with Metabolism and Function, edited by G. I. Mchedlishvili [in Russian], Tbilisi (1969), pp. 154-166.
3. G. I. Mchedlishvili, Tr. Inst. Fiziol. Akad. Nauk Gruz. SSR, 13, 147 (1963).
4. G. I. Mchedlishvili, Function of the Vascular Mechanisms of the Brain [in Russian], Leningrad (1968).
5. M. Khananashvili, The Neuronally Isolated Cortex [in Russian], Leningrad (1971).
6. D. G. Baramidze, R. Gadamski, and G. Szumanska, in: Third Symposium on Cerebral Hypoxia, Warsaw (1979), p. 2.
7. C. W. Darrow and C. G. Graf, J. Neurophysiol., 8, 449 (1945).
8. D. H. Ingvar and U. Söderberg, Acta Physiol. Scand., 42, 130 (1958).
9. D. H. Ingvar and N. A. Lassen (editors), Cerebral Function, Metabolism and Circulation, Copenhagen (1977).
10. W. Kuschinsky and M. Wahl, Physiol. Rev., 58, 656 (1978).
11. E. Leninger-Follert and D. W. Lübbers, Bibl. Anat. (Basel), 15, 345 (1977).
12. G. I. Mchedlishvili, D. G. Baramidze, L. S. Nikolaishvili, et al., Biochem. Exp. Biol., 11, 113 (1974-1975).
13. L. Sokoloff, in: Regional Neurochemistry, S. S. Kety and J. Elkes, eds., Oxford (1961), pp. 107-117.