Submaximal physical exericse thus causes moderately severe dystrophic changes in the cardiomyocytes and capillaries of the left ventricle. Maximal physical exercise, especially when integrative nervous influences are disturbed, leads to the development of focal destructive changes in the myocardium.

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ULTRASTRUCTURE OF DISTRIBUTION SPHINCTERS AND PROCORTICAL ARTERIES IN THE PIAL ARTERIAL SYSTEM IN RABBITS

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The local blood flow in the cerebral cortex can be changed independently in a small volume of tissue measuring about 0.5-1 mm^3 [3, 5, 9]. Analysis of control of the blood flow in the cerebral cortex has shown that it can take place on account of specific microvascular segments, or distribution sphincters of the pial artery and precortical arteries [2, 6, 10]. However, it was not known whether the walls of these microvessels have any distinguishing structural features responsible for the character of their function.

The aim of this investigation was to study, with the light and electron microscopes, the structure of the walls of the distribution sphincters and precortical arteries, which play an important role in the control of local blood flow in the cerebral cortex.

EXPERIMENTAL METHOD

Experiments were carried out on 19 adult rabbits weighing 2.5-3 kg anesthetized with urethane (1 g/kg, intravenously). The preliminary operations included tracheotomy,

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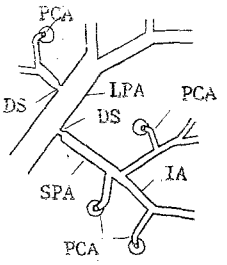

Fig. 1. Diagram of pial arterial network in the rabbit. LPA) Large pial arteries; SPA) small pial arteries; PCA) precortical arteries; DS) distribution sphincters; IA) interarterial microanastromoses.

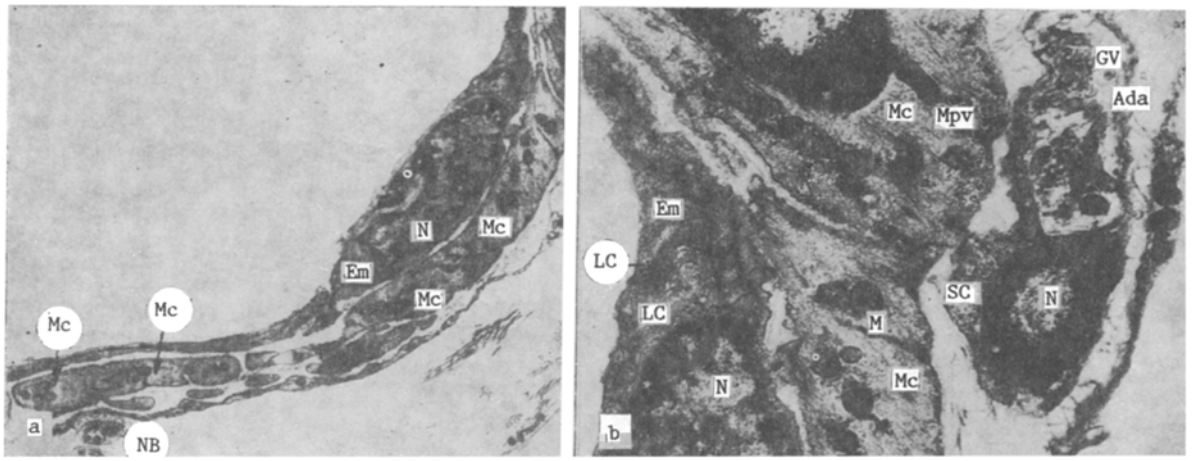

Fig. 2. Structure of a sphincter of a pial artery: a) region of distribution sphincter of a small pial artery. Arrows indicate myoendothelial junctions. 14,000 ×; b) fragment of part of sphincter region illustrated in Fig. 2a. Single arrow indicates myoendothelial junction, double arrow — myoneural junction 33,000 ×. N) Nucleus, Mc) myocyte, NB) nerve bundle, M) mitochondria, LC) lamellar complex, En) endotheliocyte, MpV) micropinocytotic vesicles; SC) Schwann cell. AdA) adrenergic axons, GV) granular vesicles.

isolation of the carotid artery, and ligation of the external carotid artery (so that fixing fluid could be injected into the cerebral vessels) and wide trephining in the parietal region. The fixing solution was injected under pressure (which was monitored) simultaneously with withdrawal of blood from the aorta through the thoracic portion of the carotoid artery [2, 10].

The cerebral vessels for investigation in the light microscope were fixed with 6% formalin solution, made up in a mixture of equal parts of isotonic sodium chloride solution and ethyl alcohol. Total preparations of the pia mater were stained with hematoxylin and eosin. The ratio of the width of the myocyte nuclei to their length and the ratio of the thickness of the vessel walls to their lumen were used as criteria to assess the functional state of the vessels [2, 10].

For electron-microscopic investigation the pial vessels were perfused with a 2.5% solution of glutaraldehyde in phosphate buffer, pH 7.4, for 5 min. The pia mater was then detached from the cortex and fixation continued in the same solution in the cold for 3 h. The material was postfixed with 1% OsO_4 solution and stained with a 1.5% aqueous solution of uranyl acetate. Dehydrated fragments of the pia mater were embedded in Epon. Ultrathin sections of the points of branching of the pial arteries and of the precortical and pial arteries were examined under the JEM-100B electron microscope.

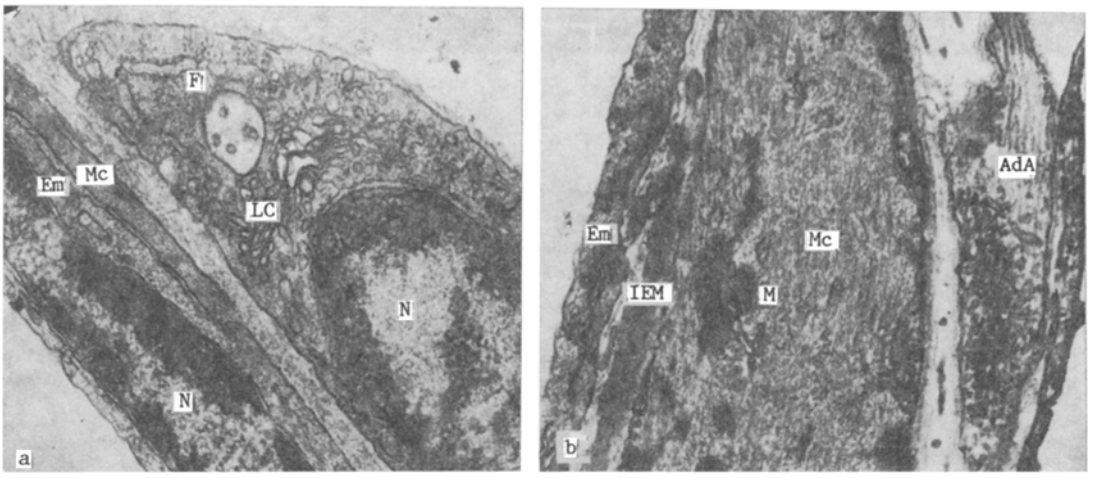

Fig. 3. Structure of precortical artery: a) segment of a precortical artery. Arrow indicates myoendothelial junctions. 34.000 ×; b) segment of precortical artery, adrenergic axon close to myocyte. 30,000 ×. IEM) Inner elastic membrane, F) fibroblast. Remainder of legend as to Fig. 2

EXPERIMENTAL RESULTS

In total preparations of the pia mater sphincters at sites of branching (at about a right angle) of the small from the larger pial arteries, in the absence of any experimental procedure, were found to be in different functional states (Fig. 1). The region of the sphincter, for a distance of 10-30 μ, was either constricted to a different degree from the branch at whose origin it was situated (60% of cases), or their diameters were equal (40% of cases). The terminal segments of the pial arteries and the precortical arteries buried in the thickness of the cerebral cortex also were in different functional states: their diameter was either equal to that of the corresponding radial artery (50%). or it was wider (38%) or narrower (12%) than the latter.

Changes in the diameter of the two types of microvessels mentioned above were always connected with corresponding changes in the ratio of the width of the myocyte nuclei to their length, which averaged 0.09 during dilatation, 0.18 in the normal state, and 0.4 during constriction. Another criterion was the ratio of the thickness of the vessel walls to their lumen, which averaged 0.03 for the distribution sphincters during dilatation and 0.4 during constriction, whereas the corresponding values for precortical arteries were 0.07 and 1.4. This was undoubtedly evidence that changes in the diameter of these microvessels are related to functions. However, investigation with the light microscope revealed no differences in the structure of the walls of the distribution sphincters and precortical arteries compared with adjacent vascular segments.

The electron-microscopic investigations showed that endothelial cells of the pial arteries and of their specific active segments described above have basically the same structure: in the relaxed state they are flattened in shape, whereas when constricted they become spindle-shaped; their long processes, superposed one on another, sometimes form functions of nexus type. The cytoplasm of the endotheliocytes was permeated by bundles of filaments in no particular orientation, among which two or three lamellar complexes, mitochondria, smooth and rough endoplasmic reticulum, and intracellular vesicles could be clearly distinguished.

The thickness of the inner elastic membrane differed depending on the caliber of the vessel and its location: in the case of pial arteries 75-100 μ in diameter it averaged 400 nm, whereas in the region of the distribution sphincters of the same caliber it reached 2000 nm. In smaller pial arteries (under 75 μ in diameter) it was 500 nm, and in precortical arteries 18-20 μ in diameter it was 200-500 nm. In relatively wide distribution sphincters (50-75 μ) and in all the small pial arteries the inner elastic membrane was continuous throughout its extent. However, in the region of distribution sphincters with small diameter (18-20 μ) and in precortical arteries, it was always interrupted by myoendothelial junctions (Figs. 2a, b, 3a).

The media of the pial arteries 75-100 μ in diameter consisted of two or three layers of myocytes. By means of short cytoplasmic outgrowths they formed junctions with each other in a single row and also with the bodies and outgrowths of myocytes in neighboring roles, thereby forming a continuous syncytium. With a decrease in the diameter of the vessels the number of layers of myocytes also decreased. In the region of transition of a pial artery and its branch of much smaller diameter (i.e., in the region of the sphincter) the number of layers of myocytes remained the same as in the maternal artery, whereas in the wall of the daughter vessel the number of layers was reduced by one. In precortical arteries 15-18 μ in diameter there was only one layer of myocytes with a circular arrangement.

The adventitia of the pial vessels was very thin. Unmyelinated nerve fibers consisting of two to four axons ran in it. The nerve bundle contained both adrenergic axons with granular vesicles 30-60 nm in diameter and cholinergic axons, whose varicose expansions contained agranular vesicles. The distance between the nerve fibers and the muscular coat averaged 2000 nm, but in the region of the distribution sphincters and precortical arteries this could be reduced to 50-100 nm (Fig. 3b). This distance, in vascular myoneural complexes, is considered to be the tightest junction [11]. In sphincters with the smallest caliber single axons coming into close contact with myocytes also could be observed (Fig. 2b).

The electron-microscopic investigations thus revealed the following structural features in the region of functionally active segments of the pial arteries, namely distribution sphincters and precortical arteries: more numerous myocytes in the region of the sphincters myoendothelial junctions, regarded by some workers as specialized membrane mechanisms, by which humoral vasoactive substances act on the contractile elements of the vessel wall [4, 12], are always present, and very close relations exist between the vascular nerves and myocytes, so that the neurotransmitter can act quickly and locally [8]. Morphometric investigations conducted during recent years also have shown that the density of adrenergic and cholinergic fibers in the region of distribution sphincters and precortical arteries is significantly higher than in the neighboring pial arteries [7].

All these features of structure and innervation of the distribution sphincters and precortical arteries are combined with their active participation in regulation of the local blood flow in the cerebral cortex [1, 7] and they may provide the basis for their independent functioning.

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