after the fall in CP a decrease in the ATP concentration and disturbance of the permeability of the sarcolemma and other organs are observed; these are the morphological reflections of the inadequacy of the energy supply to these membranes.

Permeability of the sarcolemma for the ^{99m}Tc-Sn-pyrophosphate complex in the early, reversible stages of hypoxia suggest that, in principle, it is possible for other substances, whose administration could lead to improvement in the state of the heart, to be introduced into the cardiomyocytes under these conditions also.

The results show that the radioactive complex ^{99m}Tc-Sn-pyrophosphate can be used to study permeability of the membranes of cardiomyocytes, especially in the early stages of hypoxic damage.

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ULTRASTRUCTURE OF THE MYOCARDIUM IN YAKS LIVING AT ALTITUDES OF OVER 3000 m ABOVE SEA LEVEL

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The ultrastructure of the myocardium was studied in yaks living constantly at an altitude of over 3000 m above sea level. The pattern of Z lines in semithin and ultrathin sections was sharply defined and produced distinct cross-striation of the myofibrils. Numerous lipid granules were seen in the cytoplasm of the cardiomyocytes. An increase in the number of intercalated disks was found in many zones of the myocardium. The results are discussed from the point of view of increased activity of yak heart muscle and its hyperfunction at high altitudes in the mountains.

KEY WORDS: high mountains; yaks; myocardium; intercalated disks; lipids.

Yaks are typical representatives of high-mountain animals. They have great powers of endurance, can work satisfactorily all the year round, and can be found in the open air whatever the weather. The study of the structure of the myocardium of these animals from the standpoint of adaptation is therefore particularly

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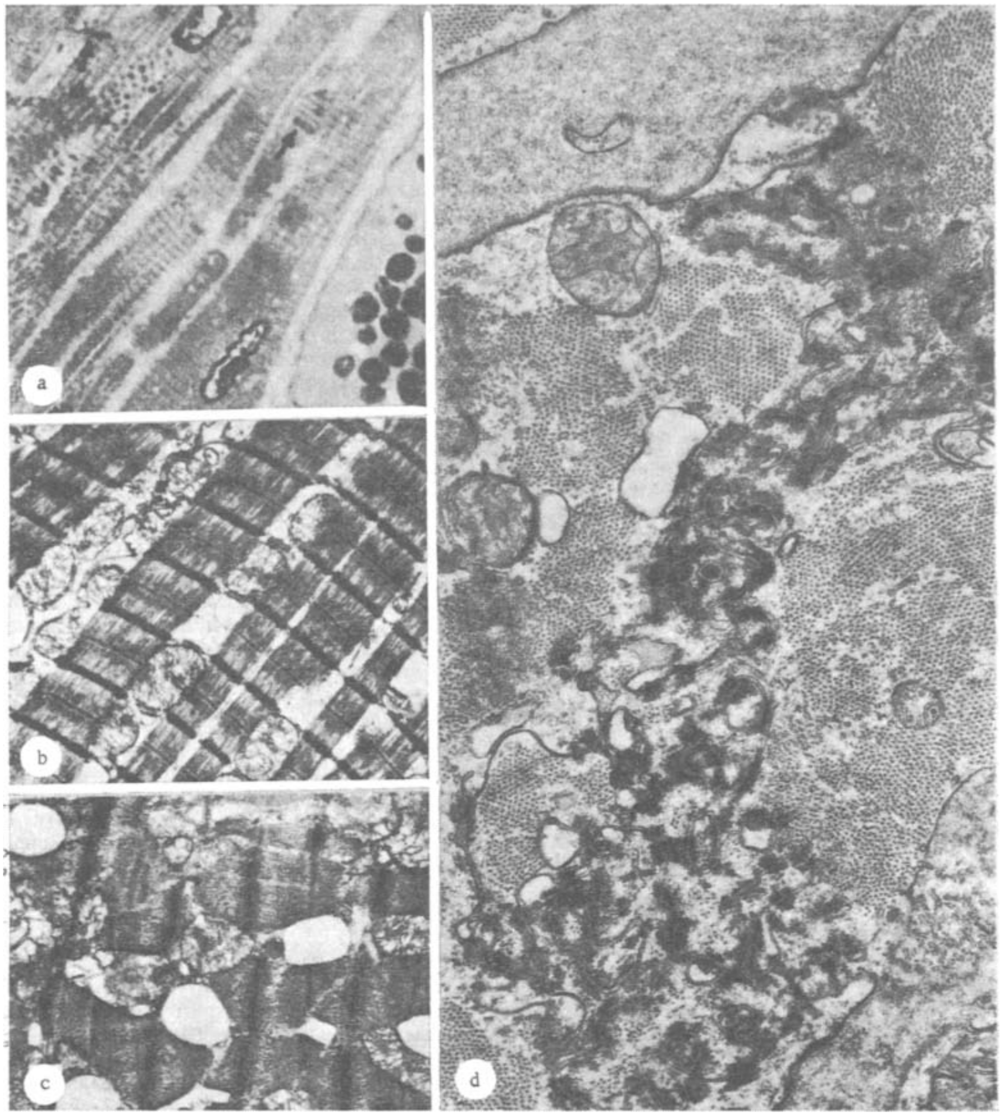

Fig. 1. Photomicrograph of yak myocardium. a) Semithin longitudinal section through myocardium of right ventricle: distinct cross-striation of myofibrils can be seen, intercalated disks appear as zigzag dense lines (indicated by arrows, 1200 ×); b) myocardium of left ventricle: Z lines of myofibrils thickened (9000 ×); c) myocardium of left ventricle: many lipid granules present in sarcoplasm of myocyte (10,000 ×); d) transverse section through myocardium of right ventricle: numerous intercalated disks can be traced throughout the cell from one inner layer of the sarcolemma to the opposite (24,000 ×).

interesting. However, only a few papers on the morphology of the yak myocardium have been published [2, 5, 15]. In a previous investigation the present writer found certain features which distinguished the ultrastructure of the mitochondria in the yak myocardium [2].

The object of this investigation was to study in greater detail the ultrastructure of the contractile and capillary systems of the yak myocardium.

EXPERIMENTAL METHODS

The structure of the cardiomyocytes of yaks living permanently at an altitude of over 3000 m above sea level was studied by light-optical and electron-microscopic methods. Material was taken from 15 yaks at the Rybach'e abattoir (altitude 1600 m above sea level). The mean weight of the yaks was 275.9 ± 16.5 kg. The measurements of the heart and its subdivisions were as follows: length of the heart (from base of aorta to

Fig. 2. Capillary of yak myocardium. Wall of capillary in transverse section consists of two endothelial cells, one dark and one pale (35,000×).

apex) 16.3 ± 0.2 cm, diameter (at the level of the base of the ventricles) 12.7 ± 0.6 cm, circumference (at the level of the base of the ventricles) 38.0 ± 0.7 cm. The thickness of the wall of the right ventricle was 1.65 ± 0.05 cm, of the left ventricle 2.9 ± 0.04 cm, and of the ventricular septum 2.6 ± 0.03 cm. The weight of the heart was 1.30 ± 0.05 kg, of the right ventricle 255.18 ± 2.4 g, of the left ventricle 445.2 ± 3.6 g, and of the ventricular septum 260.4 ± 2.5 g. Pieces of myocardium from the right and left ventricles were taken 5-6 min after electrocution of the animal. For electron-microscopic investigation the pieces were fixed and embedded in Araldite by the usual method. Ultrathin sections were stained by Reynolds' method and examined in the IEM-100B electron microscope. Material for light microscopy was fixed in 10% neutral formalin solution and embedded in paraffin wax. Sections were stained with hematoxylin-eosin. For preliminary survey, semithin sections through the myocardium, 1 μ thick, were cut on the LKB Ultrotome and stained with toluidine blue.

EXPERIMENTAL RESULTS

Examination of the histological sections revealed no special features distinguishing the structure of the myocardium in yaks from that of other mammals.

Cross-striation of the myofibrils, formed by distinct Z lines, was clearly visible in semithin longitudinal sections (Fig. 1a). The nuclei of the cardiomyocytes were oval in shape, with irregularly distributed chromatin of high optical density. The intercalated disks appeared as dense zigzag lines running perpendicularly to the myofibrils. Numerous dense granules, round or oval in shape and of various sizes, were located among the myofibrils and around the nuclei of the cardiomyocytes.

Electron-microscopic study of the yak myocardium revealed a very clear and distinct pattern of Z lines of the myofibrils (Fig. 1b). The thickness of the Z lines was 0.16-0.18 μ (the thickness of the Z lines in the dog myocardium, for example, is about 0.1 μ [10]). The nuclei of the cardiomyocytes in tangential sections were oval in shape, with chromatin of high electron density irregularly distributed in the karyoplasm. The mitochondria were usually arranged in one or two rows between the myofibrils, but in some parts in two or three rows. The cristae of the mitochondria were haphazardly arranged and the free ends of many cristae had pinhead expansions.

In many parts of the myocardium, especially from the right ventricle, the number of visible intercalated disks was increased. The characteristic structural components of the intercalated disks, described previously by many authors [1, 7-9, 11, 14], were well-defined in several animals and in man. In many zones of the myocardium the intercalated disks appeared as numerous zigzag lines of curious shapes. The intercalated disks could be traced throughout the cell from the inner layer of the sarcolemma on one side to the same layer on the opposite side (Fig. 1d). The nexus zones consisted of darker lines about 20 mm thick, formed by adjacent sarcolemmas of two neighboring myocytes. The spaces between the membranes were indistinguishable in the region of the nexus. These parts of the intercalated disk had low electrical resistance and they are the place through which excitation is transmitted from one myocardial cell to another, ensuring synchronization of their contractions. The increase observed in the number of intercalated disks in the yak myocardium could perhaps lead to stronger interlinking of the myocardiocytes and a more extensive zone of low electrical resistance, with consequent facilitation of the transmission of excitation from cell to cell.

Elements of the sarcoplasmic reticulum had the usual structure. The sarcoplasm of the cardiomyocytes contained numerous lipid granules (Fig. 1c). These were usually round or oval in shape and of low electron density and they were mainly located near to the mitochondria. The increase in the number of lipid granules can be regarded as a morphological expression of one stage of a nonspecific adaptive reaction aimed at providing the myocardium with a material that is the most effective source of energy required for the intensification of its function [4].

The capillaries supplying blood to the yak myocardium were similar in structure to those of other mammals and man. The walls of the capillaries in transverse section consisted of one, two or, less frequently, three endothelial cells. Numerous tiny micropinocytotic vesicles were present in their cytoplasm. More vesicles were seen on visual examination in pale than in dark cells (Fig. 2). Micropinocytotic vesicles are a transport system and their number reflects the activity of the endothelial cells. The existence of dark and pale endothelial cells probably reflects the principle of alternation of functional activity of the cells [6].

Under high mountain conditions man and experimental animals may develop pulmonary hypertension [3, 11, 12], leading to hyperfunction of the myocardium. The structural features distinguishing the yak myocardium, namely thickening of the Z lines, an increase in the number of visible lipid droplets and intercalated disks, probably reflect high functional activity of the myocardium of an animal adapted to high mountain conditions.

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