ULTRASTRUCTURE OF MYOCARDIAL CELLS OF YAKS PERMANENTLY LIVING AT HIGH ALTITUDES

B. Zhaparov and Academician M. M. Mirrakhimov*

UDC 599.735.5-141.2

The ultrastructure of the myocardial cells of the left and right ventricles and of the interventricular septum of Altai and Pamir yaks, permanently living at altitudes of 3000-3600 m above sea level, was studied. Electron-microscopic investigation of the myocardial cells revealed myocardia with a special ultrastructure of their cristae as well as ordinary mitochondria. In some groups of mitochondria the cristae consisted of polyhedral undulating membranes, and in other groups as polyhedral reticular structures. A large accumulation of glycogen granules was discovered beneath the sarcolemma, in the perinuclear zone of the crytoplasm, and between the myofibrils. The results indicate that mitochondrial cristae, twisted into a certain structural orderliness, leading to an increase in their number and useful area, ensures the working efficiency of the mitochondria. The large accumulation of glycogen granules in most of the myocardial cells evidently helps to maintain the energy potential of the myocardium and prevents it from developing hypoxia.

KEY WORDS: high altitudes; ultrastructure of the myocardium; mitochondrial cristae; glycogen.

Adaptation to high-mountain hypoxia is a topical problem [1]. A certain proportion of mankind and of his livestock lives permanently in the high mountain regions. The study of functional and structural mechanisms of adaptation to extremal high-altitude conditions, which may help to reveal the most effective elements in the mechanism of myocardial adaptation, is therefore important. It was therefore decided to investigate the myocardium of high-mountain yaks, well adapted to conditions of high-mountain hypoxia. There are only isolated reports in the literature on the ultrastructure of the myocardial cells of yaks [3].

EXPERIMENTAL METHOD

The myocardium from 23 yaks was studied. Material from 20 yaks (living at 3200-3500 m) was obtained at slaughter in the town of Osh (altitude 1150 m). Three yaks were killed by decapitation in the village of Murgab (3600 m). The total weight of the animals, the weight of the heart, the thickness of the walls of the right and left ventricles, and the thickness of the interventricular septum were determined. Pieces were taken from the various parts of the heart for light microscopy, fixed in 10-12% neutral formalin solution, and embedded in paraffin wax. The sections were stained with hematoxylin and eosin.

For electron microscopy, the pieces were fixed in 3-6% glutaraldehyde solution in phosphate buffer, pH 7.4, then postfixed for 2 h in 1% osmium tetroxide solution in veronal–acetate buffer, pH 7.4. The material was dehydrated in alcohols of increasing concentration and embedded in a mixture of Epon-812 and Araldite. Ultrathin sections were examined in the JEM-100B electron microscope.†

*Academy of Sciences of the Kirghiz SSR.

†The authors are grateful to Professor V. A. Shakhlamov (Institute of Human Morphology, Academy of Medical Sciences of the USSR) for advice and for giving permission for the work to be done on the JEM-100B electron microscope.

Department of Internal Medicine and Department of Electron Microscopy, Central Research Laboratory, Kirghiz Medical Institute. Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 81, No. 6, pp. 729-732, June, 1976. Original article submitted December 30, 1975.

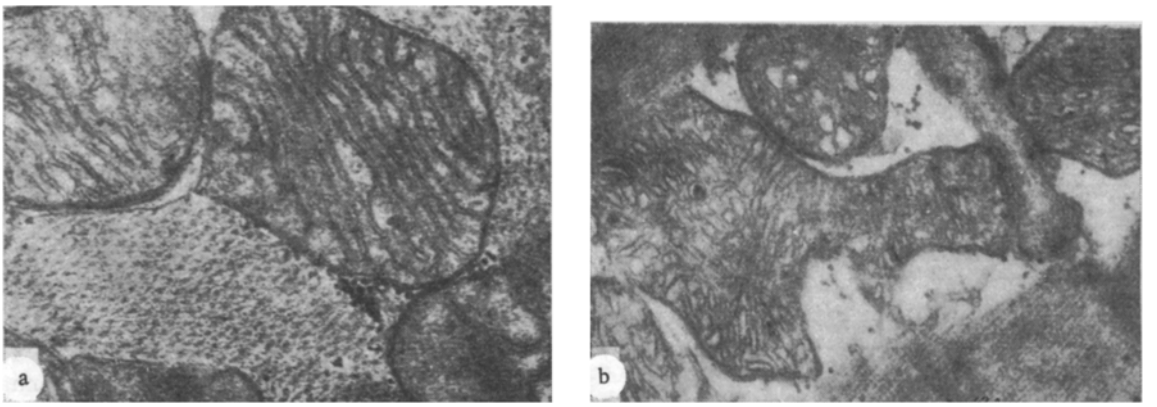

Fig. 1. Electron micrograph of myocardium of right ventricle of Pamir yaks permanently living at altitudes of 3600 m or more. a) Mitochondrial cristae mainly run parallel to each other, 60,000 ×; b) cristae resemble round oval vesicles and saccules, 60,000 ×.

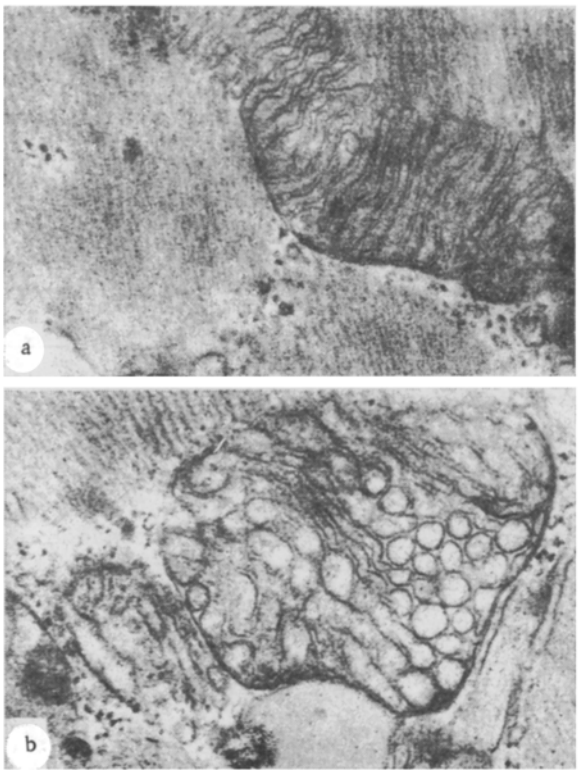

Fig. 2. Electromyogram of myocardium of right venticle of the same yaks: a) cristae with polyhedral undulating structure, 42,000 ×; b) cristae with polyhedral reticular structure resembling honeycombs, 42,000 ×.

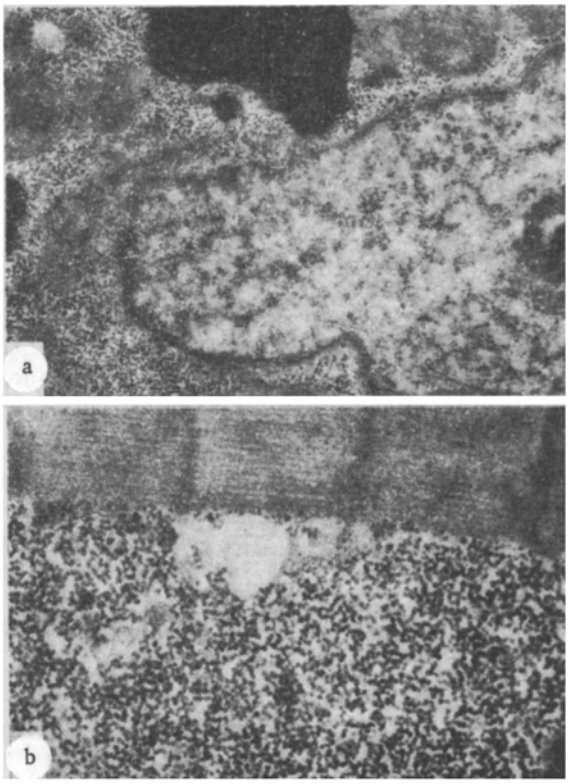

Fig. 3. Electron micrograph of myocardium of right (a) and left (b) ventricles of the same yaks. Many glycogen granules in different parts of myocardial cells: a) in perinuclear zone, 16,000 ×; b) between myofibrils in depth of cell, 30,000 ×.

EXPERIMENTAL RESULTS

On histological examination of the myocardium of the yaks a well-defined structure of the muscle fibers could be seen. In longitudinal sections the cross striation of the myofibrils was clearly visible. The nucleus was elongated with well-defined nucleoli. In transverse sections the nuclei of the myocytes varied in size and were polygonal in shape.

The myocardium of the yaks in the ultrastructure of the various organelles differed to some degree from the myocardium of other, lowland animals described previously in the litera-

ture [2, 4]. The chief difference was in the ultrastructure of the mitochondria. Their shape, their transverse diameter, and also their internal structure varied exceedingly. In some cells they were elongated, in others they were round or oval. Cells with irregular outlines of mitochondria were seen. The membranes of the mitochondria studied consisted of three layers. The cristae had a special structure, uncharacteristic of myocardial cells described previously in other species of animals and in man. Besides ordinary cristae found in the mitochondria of the myocardium of all species of animals (Fig. 1a) several varieties of cristae were found. In some myocardial cells mitochondria of indeterminate shape were found. Characteristically the arrangement of their cristae was haphazard. They did not run across from one internal membrane of the mitochondria to the other but were broken off. The impression was therefore obtained that the cristae were round or oval vesicles and long saccules (Fig. 1b). In the long mitochondria found in another myocardial cell the cristae were arranged parallel to one another, and they crossed continuously from one end of the internal membrane to the other. Many of the cristae followed a zigzag course to produce a picture of a broken line. Other cristae were parallel to each other. As a result, polyhedral undulating membranes were obtained (Fig. 2a). Since this pattern of the mitochondria was observed for the first time, it was decided to call them "mitochondria with a polyhedral undulating structure of their cristae."

In the round-oval mitochondria, the cristae twisted and anastomosed with each other to form structures resembling polyhedral networks similar to honeycombs. The matrix had the usual electron density and occupied a space corresponding to the openings in the net (Fig. 2b). This variety was called "mitochondria with a polyhedral reticular structure of their cristae."

A large accumulation of glycogen granules was discovered in the myocardium of the yaks. They measured 300-400 Å in size. Round or polygonal glycogen granules were found everywhere: beneath the sarcolemma, in the perinuclear cytoplasm, and between the myofibrils in the depth of the cell (Fig. 3a). Glycogen granules in the depth of the cell were arranged as a chain along the whole length of the myofibrils (Fig. 3b). This feature could account for the maintenance of the energy potential of the heart during high-altitude hypoxia. Besides the accumulation of glycogen, many lipid granules and lysosomes were found in the myocardial cells. They were in direct contact with the mitochondria in the perinuclear zone (Fig. 3a). The nuclei of the myocardial cells, the contractile elements, the intercalated disks, tubules of the sarcoplasmic reticulum, and other organelles were indistinguishable in their ultrastructure from those of animals of other species.

The ultrastructural features of the myocardial cells of the yaks as described above thus reveal a definite structural orderliness, an increased number of cristae, and an increased useful area. In this way the high efficiency of work of the mitochondria is ensured. The presence of numerous glycogen granules in most of the myocardial cells is evidence of maintenance of the energy potential of the heart under extremal high-mountain conditions.

LITERATURE CITED

1. M. M. Mirrakhimov, Heart Diseases and Mountains [in Russian], Frunze (1971).
2. D. S. Sarkisov and B. V. Vtyurin, Electron-Microscopic Analysis of Increased Tolerance of the Heart [in Russian], Moscow (1969).
3. S. Kh. Khamitov, M. M. Mirrakhimov, I. T. Kalyuzhnyi, et al., in: Problems of Adaptation to High-Mountain Conditions [in Russian], Frunze (1973), p. 37.
4. G. P. Epling, Am. J. Vet. Res., 29, 97 (1968).