Structural and Functional Rearrangement of Muscle Spindles in Rats under Conditions or Zero Gravity

A. V. Volodina and O. M. Pozdnyakov

Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 137, No. 1, pp. 106-111, January, 2004
Original article submitted July 28, 2003

Electron microscopy of muscle spindles in *m. extensor halucis longus* of rats 14 days after space mission on board SLS-2 space laboratory (USA) showed structural rearrangement in the receptors. The number of intrafusal fibers increased, but some fibers developed degenerative changes. The changes were also seen in the spindle capsule, but its integrity was not impaired. Vascularization of the spindle capsule was impaired as a result of necrobiotic changes in capillary endotheliocytes. Sensory nerve endings were the most sensitive structures of the receptor. Destructive changes in various structures of the muscle spindles were paralleled by regenerative processes.

Key Words: *muscle spindles; intrafusal spindles; zero gravity*

The interactions between various analyzers are discoordinated under conditions of space missions because of lack of functional loading of the locomotor system and changes in sensory input into CNS compartments. These changes lead to motor discoordination in humans and animals and are paralleled by metabolic and structural rearrangement in the whole organism and tissues [1,4-6]. Muscle spindles, as highly differentiated structures regulating spontaneous and reflex activity of muscles, occupy an important place in this process [8]. The data on the role of muscle spindle components in receptor intactness in general and recovery of receptor activity in various pathologies are contradictory [2,3,7]. The state of muscle spindles under conditions of space flights is poorly studied.

We investigated the structural and functional changes in muscle spindles under conditions of a space mission in rats.

MATERIALS AND METHODS

The muscle elevating the forefinger (*m. extensor halucis longus*) in Spraig—Dowley rats was examined. The animals spent 14 days on board the SLS-2 space laboratory (USA). The material for ultrastructural analysis was collected from experimental animals on the orbit and from control and synchronous rats on the Earth.

Muscle fragments were fixed during the mission on board the space laboratory in 4% paraformaldehyde solution in 0.1 M phosphate buffer (pH 7.2) with 2.5% sucrose and after landing they were postfixed in 1% OSO_4 and embedded in araldite. The material was examined and photographed under a JEM-100S electron microscope. Semithin sections were stained in toluidine blue for spot ultratomy. The blocks were ultratomied at levels 5-6, because of anatomical characteristics of the receptor (sensory nerve endings are situated in the central part and motor endings in opposite poles of intrafusal fibers).

RESULTS

Photooptic examination showed that muscle spindles are usually located in the immediate vicinity to the intramuscular nerves. The immediate transition of the epineural membranes into external leaflets of the receptor capsules was detected. Normally, the spindle capsule consists of 3-4 cells of epineural epithelium.

Institute of Pathology and Pathophysiology, Russian Academy of Medical Sciences, Moscow

0007-4888/04/1371-0092

Solitary axons and capillaries were seen on cross-sections of the capsule. Three-four intrafusal fibers inside the capsule occupied virtually the entire intracapsular space (Fig. 1, *a*).

The capsule remained intact in the majority of receptors under conditions of space flight. However, plasma membranes of the capsular epineural epithelial cells were destroyed because of edema and hydropic swelling, which led to focal cytolysis. On the other hand, multiple layers of the spindle capsule ensured its anatomical integrity and intactness of individual receptors (Fig. 1, *b*; 2, *a*). Collagen fibrils strictly delineating the capsular membrane were seen between the capsular layers (Fig. 2, *a*).

Pronounced destructive changes were seen in some receptors. Epithelial cells formed numerous interdigitating processes, the capsular leaflet borders were undetectable. Lumpy degradation of the cytoplasm was seen, the structure of the capsule was impaired (Fig. 2, *b*, *c*).

In axons lying in deep layers of the capsule we observed detachment and vacuolation of the axoplasm, impaired structure of myelin sheath, and hyperplasia of neurofilaments. These changes are morphological signs of axonal transport disorders. The type and degree of morphological changes in axons varied in different spindles; the signs of Woller degeneration were seen in some of them (Fig. 1, *b*, *c*), endoneurium sclerosis was observed.

Destructive degenerative changes were seen in the capsular capillaries and arterioles. Destroyed membranes of cell organelles were seen in endotheliocytes; finely grained lumpy degeneration of the cytoplasm was paralleled by increase of its electron density. The thickness of capillary basal membranes increased, endotheliocyte surface was activated (villus formation, bay-like prolapsed areas), which led in many cases to disintegration of the plasma membranes and was accompanied by cytoclasmatosis and formation of microclots (Fig. 2, *c*, *d*).

Increased electron density of intracapsular space and appearance of finely dispersed material probably result from impaired permeability of capsular microvessels, which can be paralleled by an increase in intracapsular pressure (Fig. 1, *b*). Intracapsular space of some muscle spindles was filled with collagen fibrils, somewhere fragments of degenerative receptors were seen between these fibers. In these cases the receptor can be identified only by multilayer capsular membrane.

The number of intrafusal fibers in the receptors increased to 5-6 under conditions of space flight. Intrafusal fibers lay loosely in the receptors. Fibers with signs of intracellular myofibril regeneration were seen in one receptor (Fig. 3, *a*, *d*), other fibers were completely destroyed, with membrane fragments occupying their place. Some fibers were necrotic (Fig. 1, *b*, *d*). Myofibrillar atrophy was detected on longitudinal sections of intrafusal fibers.

Ultrastructural signs of adaptive type were detected in the motor nerve endings in polar areas of intact intrafusal fibers. The zone of synaptic contact was extended and included 3-4 axon terminals, filled with synaptic vesicles and small mitochondria. Accumulations of finely dispersed floccular material and fragments of membrane structures were seen in some terminals. The type of postsynaptic folds is worthy of note. Some presented as shallow finger-shaped prolapsed areas, others were well expressed and by their structural organization resembled synaptic folds of synapses on extrafusal muscle spindles (Fig. 3, *b*). Structural organization of the motor-terminal endings indicates that the efferent component of the receptor remained intact.

It is noteworthy that sensory nerve endings exhibited pronounced destructive changes. The greater part was completely destroyed, others contained fragments of destroyed organelle membranes (Fig. 3, *c*). Presumably, this was caused by inadequate intensification of the functional activity of sensory nerve endings of the receptor under conditions of zero gravity because of constant correction of the motor function and intense afferent impulsation. One more proof of this hypothesis is relaxation of extra- and intrafusal fibers. It is known that a pause in the receptor work is associated with contraction of extrafusal fibers.

Hence, space mission leads to structural reorganization of muscle spindles. Signs of structural overstrain of receptors are seen, leading to destructive degenerative changes in its components, as well as structural signs of compensatory and regeneratory processes. On the other hand, the detected ultrastructural changes in the receptor components under conditions of space mission indicate the possibility of their adequate functioning and the intactness of some receptors in general. Sensory nerve endings are the most vulnerable structures of the receptor.

It can be hypothesized that damage to microvessels associated with thrombosis is a key component in the development and progress of degenerative processes in the receptor. This assumption is in line with the data of D. Barker and S. S. A. Scott [8] an J. Kucera and I. M. Walro [10], who showed that devascularization of muscle spindles in the presence of intact innervation leads to disappearance of the receptor after 21 days. The receptor appeared again after 3.5 months. At the same time, denervation of skeletal muscles in 90% cases is associated with a decrease in the number of intrafusal fibers in the receptor [11].

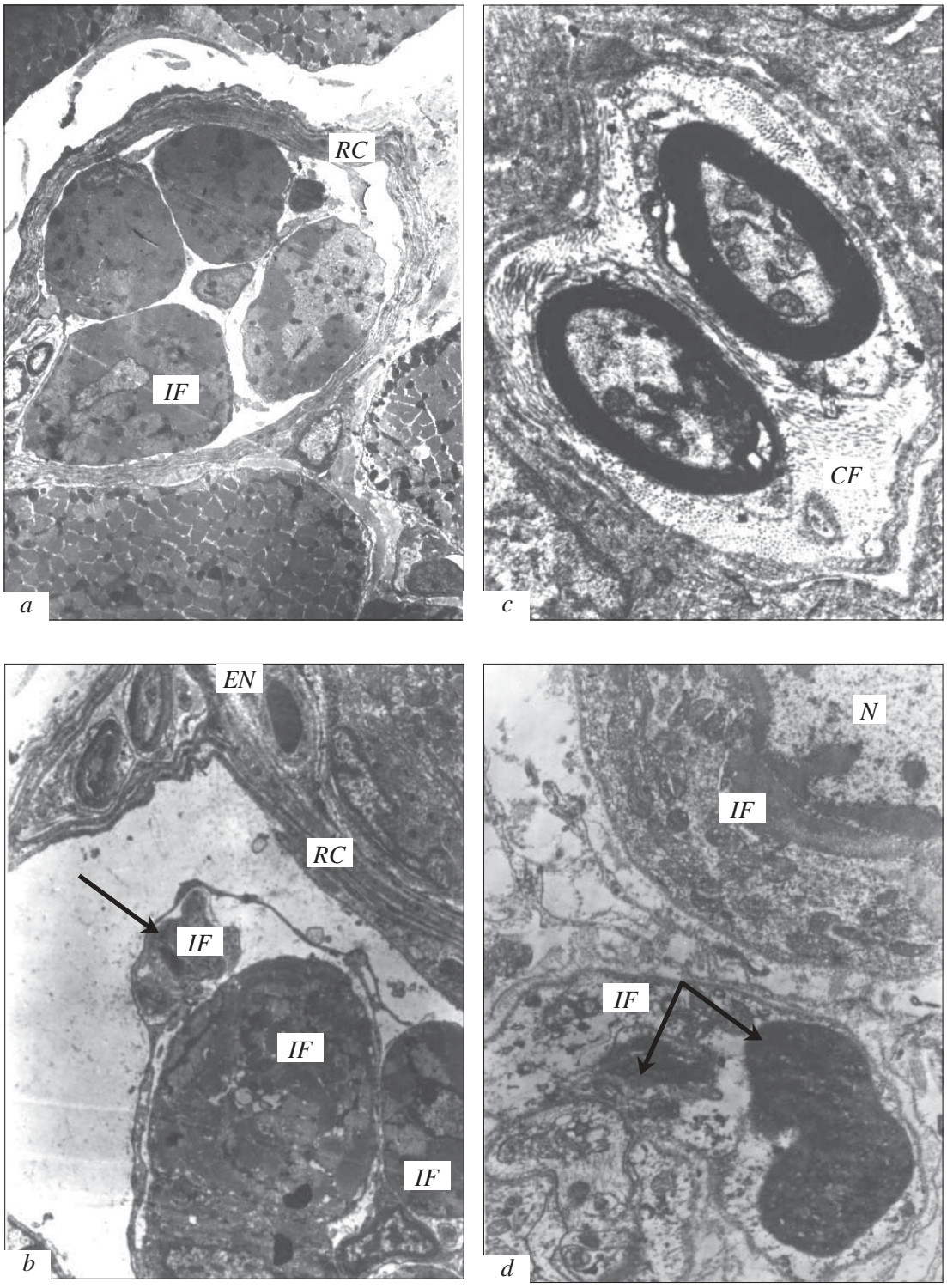

Fig. 1. Destructive degenerative changes in the intrafusal fibers under conditions of space flight. *a*) muscle spindle (control, ×5600); *b*) receptor fragment on day 14 of flight, ×5600; *c*) sclerosed nerve fiber in receptor capsule, ×11,200; *d*) degenerative intrafusal fibers, ×5600: coagulation necrosis, intracellular edema (arrow); normal intrafusal fiber. Here and in Figs. 2-3: *IF*: intrafusal muscle fiber; *C*; capillary; *CF*: collagen fibers; *RC*: receptor capsule; *NF*: nerve fibers; *T1*, *T2*, *T3*: terminals; *SNE*: sensory nerve endings; *EN*: microvessel endothelium; *E*: erythrocyte; *N*: nucleus.

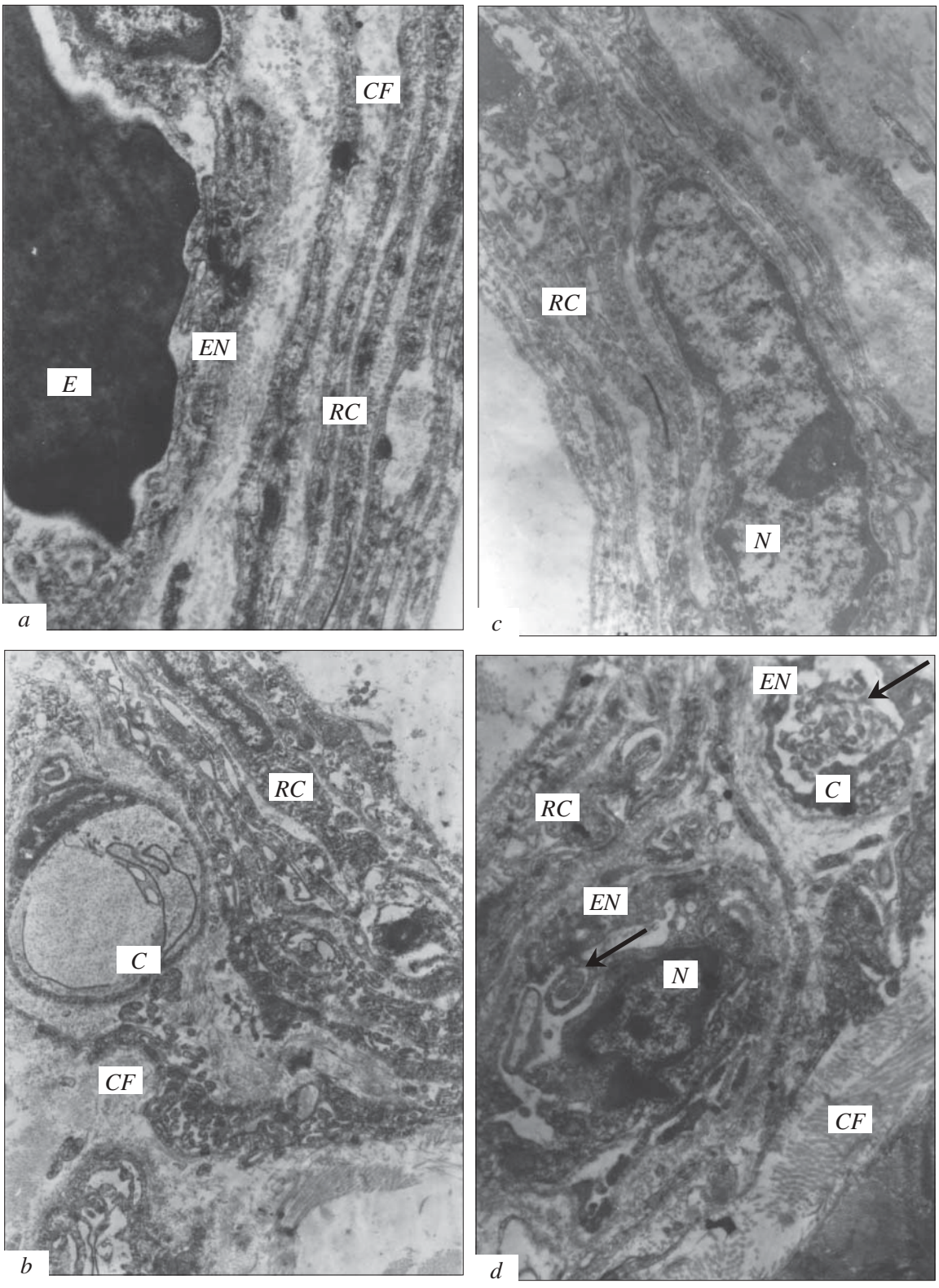

Fig. 2. Disintegration of the external capsule of receptor and destructive changes in capsular microvessels. *a*) collagen fibrils between receptor capsule epithelial cell layers, ×11,900; *b*) blurred interface between capsular epithelial cells, signs of intracellular edema, ×12,750; *c*) formation of interdigitating processes between epithelial layers; cell degradation into fragments, ×4930; *d*) destructive degenerative changes in receptor capsule. Thrombosis and destruction of capillary wall (arrow), ×8500.

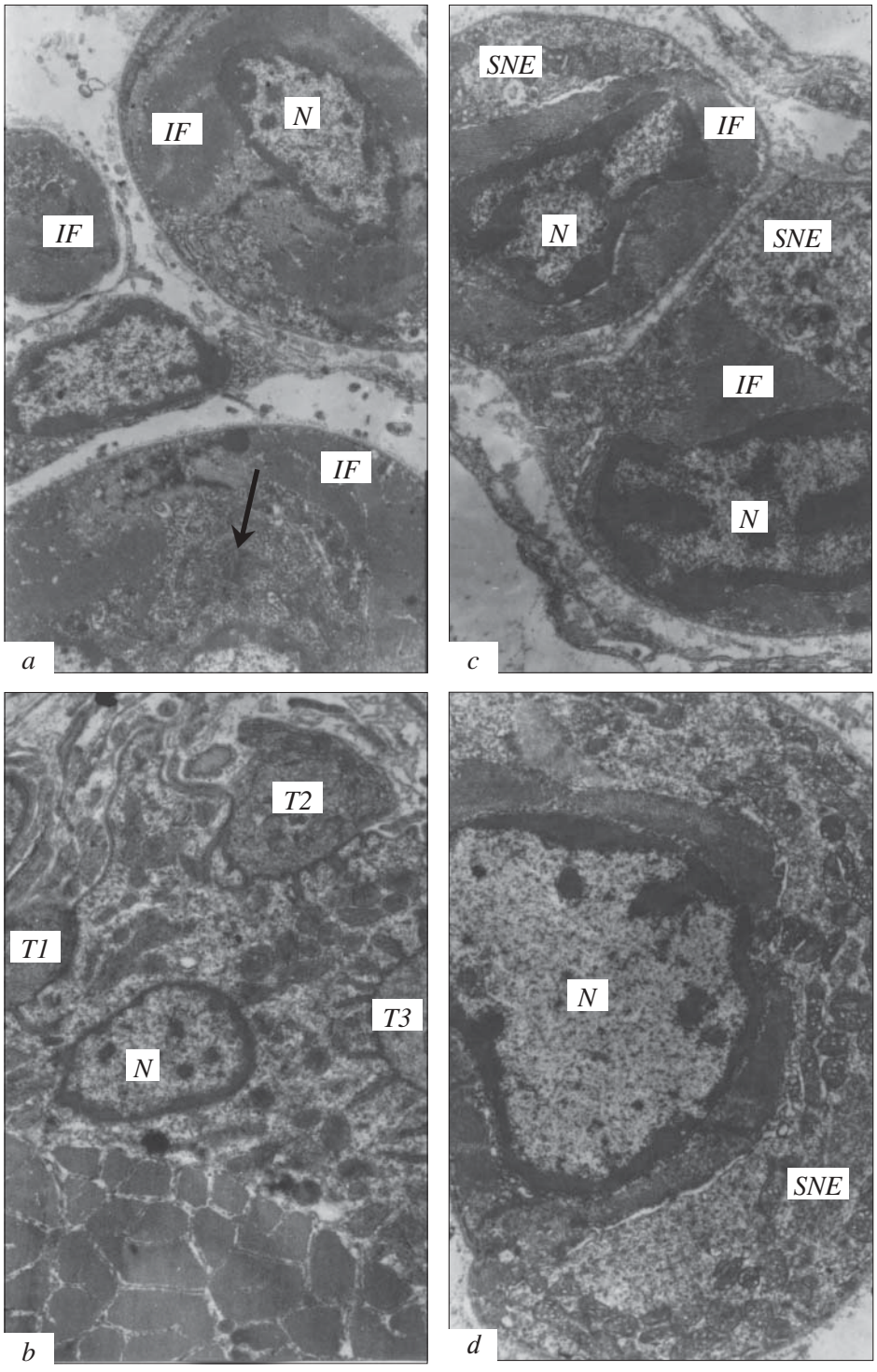

Fig. 3. Sensory and motor nerve endings on intrafusal fibers (day 14 of space flight). *a*) morphological signs of receptor strain, ×5760. Accumulation of ribosomes and polysomes in the intrafusal fiber (arrow); *b*) motor nerve ending consisting of 3 terminals, ×5760; *c*) synaptic vesicles of terminals are completely destroyed, individual mitochondria are seen, ×4800; *d*) sensory nerve ending surrounds the intrafusal fiber. Terminal is filled with mitochondria, solitary vesicles are seen, ×5760.

REFERENCES

1. L. L. Babakova, M. S. Demorzhi, and O. M. Pozdnyakov, *Byull. Eksp. Biol. Med.*, **116**, No. 11, 659-662 (1993).
2. A. V. Volodina, N. S. Gurko, and O. M. Pozdnyakov, *Ibid.*, **115**, No. 4, 432-443.
3. A. V. Volodina, V. N. Kiprenskaya, and O. M. Pozdnyakov, *Pathophysiology of Organs and Systems* [in Russian], Moscow (1996), P. 327.
4. A. M. Genina, *Effects of Dynamic Factors of a Space Mission on Animal Body* [in Russian], Moscow (1979), P. 121.
5. I. B. Kozlovskaya, *Pathophysiology of Organs and Systems* [in Russian], Moscow (1996), P. 329.
6. O. M. Pozdnyakov and L. L. Babakova, *Vestn. Rossiisk. Akad. Med. Nauk*, No. 8, 24-27 (1998).
7. T. P. Seene, M. M. Umnova, and I. L. Novoselova, *Functional Micromorphology of Skeletal Muscles* [in Russian], Tartu (1989), P. 373.

8. G. Tomar, *Fundamentals of Sensory Physiology* [in Russian], Moscow (1976), P. 520.
9. D. Barker and S. S. A. Scott, *J. Physiol.*, **424**, 27-29 (1990).
10. J. Kucera and I. M. Walro, *Nevrol. Sci.*, **98**, 47 (1990).
11. J. Palecek, J. Vejsadar, T. Soukup, and P. Hink, *Exp. Brain Res.*, **74**, 417-420 (1989).