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# MORPHOMETRIC CHARACTERISTICS OF NEUROMUSCULAR SPINDLES OF HYPERTROPHIED SKELETAL MUSCLE

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The principal function of neuromuscular spindles (NMS) is to regulate muscle stretching and contraction through spinal reflex arcs [6, 8]. The use of horseradish peroxidase [7] has revealed a specialized microcirculatory bed in the region where NMS and axo-muscular synapses are located [4], which maintains their nutrition.

Investigations [1, 5] have shown that NMS possess considerable reactivity in response to measured physical exercise. However, to determine morphological equivalents of strengthening of the functional potential of NMS during hypertrophy of skeletal muscle arising under the influence of repeated physical exercises, objective quantitative information is needed on the degree of adaptive reorganization of all components of proprioceptors.

The aim of this investigation was a quantitative study of changes in NMS and the components of their microcirculatory bed arising during hypertrophy of skeletal muscles.

## EXPERIMENTAL METHOD

Experiments were carried out on 20 male rats aged 1 month and weighing 62.4 ± 2.7 g, five of which served as the control. Skeletal muscular hypertrophy was produced by regular measured physical exercises of submaximal intensity (daily running on a treadmill at a speed of 35-65 m/min for 4 months). Blood vessels were injected and material collected under ether anesthesia. The rectus femoris muscle was the test object. Injection of the vessels with 0.25% silver nitrate solution, or a suspension of Paris green, combined with staining of sections by the Bielschowsky–Gros and Kupriyanov [2, 3] methods were used to reveal the microvessels and individual components of NMS. The MVO-1-15* screw-adjusted ocular micrometer was used for the morphometric investigation. The results were subjected to statistical analysis by Student's test.

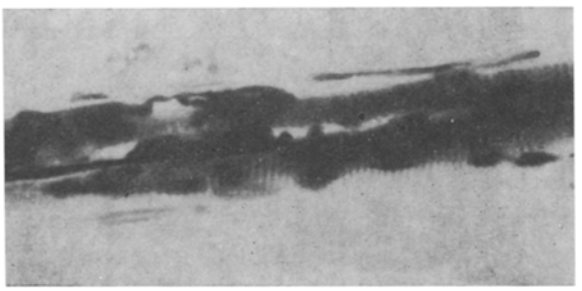

Fig. 1. IFMF of hypertrophied rectus femoris muscle. Impregnation by Bielschowsky-Gros method, stained with Ehrlich's hematoxylin and eosin. 600×.

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TABLE 1. Quantitative Characteristics of Structural Components of NMS of Albino Rat Rectus Femoris Muscle ($X \pm S_X$, n = 10)

| Parameter | Control | Experiment | P |
|---|---|---|---|
| Thickness of connective-tissue capsule, μ | 5,63±0,19 | 7,94±0,21 | <0,001 |
| Diameter of NMS in equatorial zone, μ | 147,62±3,11 | 182,34±3,76 | <0,001 |
| Width of subcapsular space, μ | 15,51±2,82 | 22,54±3,42 | <0,001 |
| Diameter of IFMF, μ | 10,81±0,55 | 12,92±0,11 | <0,02 |
| Area of annulo-spiral afferent nerve endings, $\mu^2$ | 455,02±7,65 | 635,31±17,55 | <0,001 |
| Area of flower-spray afferent nerve endings, $\mu^2$ | 241,73±10,25 | 388,08±9,99 | <0,001 |
| Area of motor end-plates, $\mu^2$ | 98,36±15,24 | 126,41±18,35 | <0,05 |
| Diameter of lumen of terminal artericle of NMS, μ | 22,02±1,15 | 26,73±0,44 | <0,05 |
| Diameter of blood capillaries, μ | 6,24±0,34 | 8,03±0,36 | <0,02 |

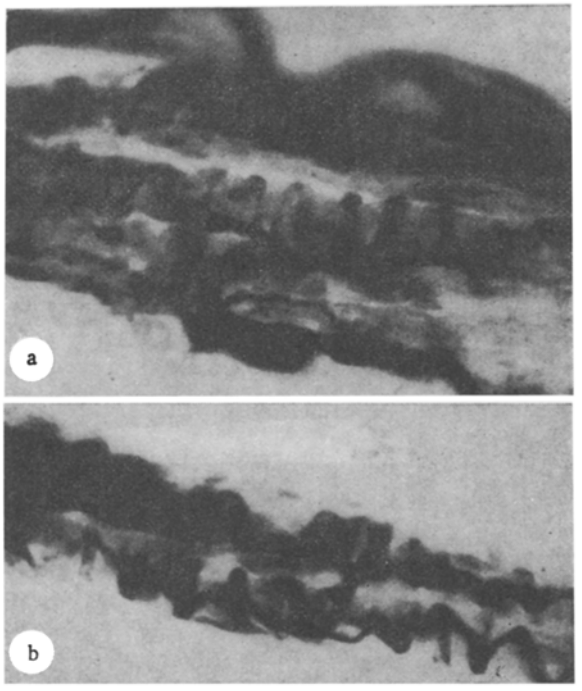


Fig. 2

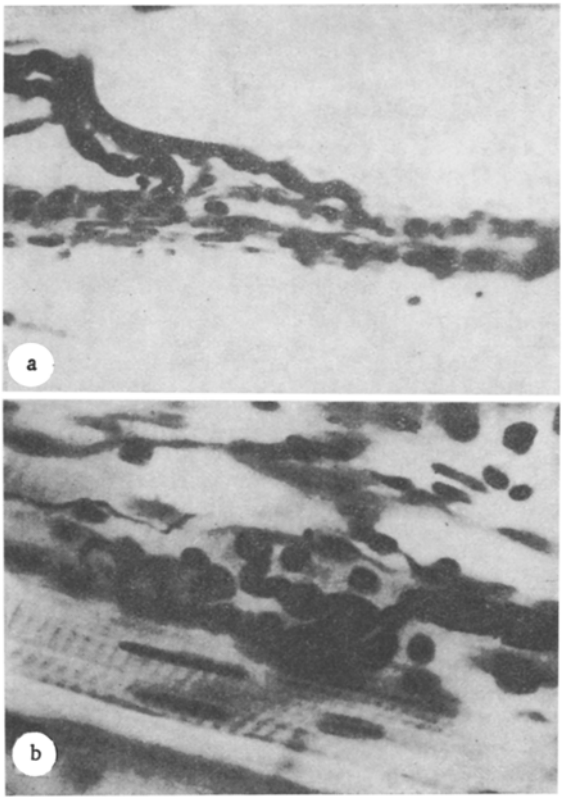


Fig. 3

Fig. 2. Primary annulo-spiral afferent nerve endings on NC fibers of albino rat rectus femoris muscle: a) intact rat; b) rat doing submaximal physical exercises. Impregnation by Bielschowsky—Gros method. 900×.

Fig. 3. Secondary flower-spray afferent nerve endings on NC fibers of NMS of albino rat rectus femoris muscle (600×). Legend as in Fig. 2.

## EXPERIMENTAL RESULTS

Changes in configuration of the connective-tissue capsule were observed in NMS of the hypertrophied rectus femoris muscle. Whereas in the control animals, in transverse sections in the equatorial zone it was oval in shape, in the hypertrophied skeletal muscle the capsule acquired the shape of an irregular polygon. At the same time, the number of laminae formed by fibroblast-like cells was increased, causing an increase in its thickness by 41.0% (Table 1). The diameter of NMS in the equatorial zone was increased by 23.5%, due to widening of the subcapsular space by 45.3% with the accumulation of tissue fluid in it, surrounding the intrafusal muscle fibers (IFMF).

Characteristic features of NMS of hypertrophied skeletal muscle were an increase in the diameter and intensification of cross-striation of IFMF (Table 1, Fig. 1) and an increase in the number and size of the nuclei in both thick NB and thin NC fibers. Adaptive changes in the myogenic structures of NMS caused significant structural changes in their afferent nerve endings. For instance, the area occupied by primary (annulo-spiral) afferent nerve endings in the middle portions of NB and NC fibers was increased by 39.6%, whereas the area occupied by secondary (flower-spray) endings, located on NC fibers on both sides of the annulo-spiral, was increased by 60.5% (Table 1). These changes were due to thickening, growth, and the formation of additional branches of the terminal sensory fibers (Fig. 2b, Fig. 3b).

The efferent innervation of IFMF was characterized by an increased area of the motor end-plates, formed by terminal branches of thick efferent fibers (Table 1, Fig. 1). Thickening and increased argyrophilia of both preterminal and terminal divisions were characteristic of the thin motor fibers, forming dynamic and static $\gamma$-efferents on the contractile regions of IFMF.

Quantitative and qualitative reactive changes observed in IFMF and their nervous apparatus, arising as a result of their increased metabolic activity, were reflected in appropriate morphological and functional reorganization of the associated microvascular bed. For instance, the lumen of the terminal arteriole located beneath the capsule of NMS was dilated by 21.3%, and the diameter of the blood capillaries responsible for nutrition of IFMF was increased by 28.6% (Table 1). The increase in their diameter and number led to increased capillarization both of IFMF and of their sensory and motor endings. Whereas normally, for every 1 $\mu^2$ of area of IFMF there was 0.6 $\mu^2$ of area of cross section of blood capillaries, the corresponding ratio between the areas in NMS of the hypertrophied muscle was 1:0.9 ($P < 0.05$).

The results of these investigations showed that quantitative and qualitative changes in the myogenic and finished neural and vascular components of NMS, arising as a result of skeletal muscular hypertrophy, are an expression of their long-term adaptation to physical work of submaximal intensity. The level of correlation discovered between structural changes in NMS can serve as morphological equivalent of the intensification of their functional potential under conditions of increasing hypertrophy of skeletal muscle.

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