QUANTITATIVE CHANGES IN MYONEURAL SYNAPSES AND CAPILLARIES FOLLOWING PHYSICAL EXERTION

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Experiments on young male rats showed that graded muscular exercises of gradually increasing amount in the course of 1 month led to an increase in area both of the neuromuscular synapses and of the exchange surface of the capillaries in the region occupied by them. These quantitative changes are the morphological equivalent of the increased activity of the neuromuscular apparatus during physical exertion.

KEY WORDS: graded muscular exercises; neuromuscular synapses; capillaries; morphological equivalent.

Changes developing regularly in the neuromuscular apparatus during various types of physical exertion have been demonstrated experimentally [1, 3, 7, 8]. Meanwhile, the histometric relations of efferent nerve endings of skeletal muscles and the microvessels surrounding them have not been studied in the course of graded muscular exercises.

The object of this investigation was the quantitative assessment of changes in the myoneural synapses and capillaries close to motor nerve endings during repetitive motor training with a gradual increase in the volume of muscular work.

EXPERIMENTAL METHOD

Experiments were carried out on 30 male rats aged 1 month and weighing 62.4 ± 2.7 g. Muscular exercises consisted of graded running on a treadmill in accordance with a schedule worked out previously (from 5 to 60 min, distance from 130 to 1560 m). During the month of training exercises the work done by the animals was equivalent to running a distance of 22,620 m at an intensity of 1560 m/h. The test material consisted of muscles of the forelimbs (biceps and triceps brachii) and hind limbs (biceps and rectus femoris muscles). Capillaries and myoneural synapses were both demonstrated by injecting the vessels with a suspension of Paris green and then impregnating the sections by Bielschowsky–Gros method. The motor nerve endings were measured by Glagolev's method [2] using a morphometric grid designed by Stefanov [6]. The area of the motor end plates was calculated by the equation $S_x = N_x \cdot \Delta^2$, where S is the mean area of cross section of the motor end plate (based on the results of several measurements), N_x the mean number of junctions of the morphometric grid lying within the cross section during several random applications of the grid to the cross section; and Δ the step of the grid (the distance between junctions, in cm).

The area of the exchange surface of the capillaries in the region of the motor nerve endings was calculated by the method suggested by Mel'man et al. [5]. Capillaries within a radius of 25 μ were studied.

EXPERIMENTAL RESULTS

The experiments showed that the neural elements of the skeletal muscles of young animals, especially the neuromuscular synapses, are highly sensitive to the action of muscular exertion. The afferent nerve fibers, their branches, and their terminal structures all showed changes. Differences in the response of myoneural

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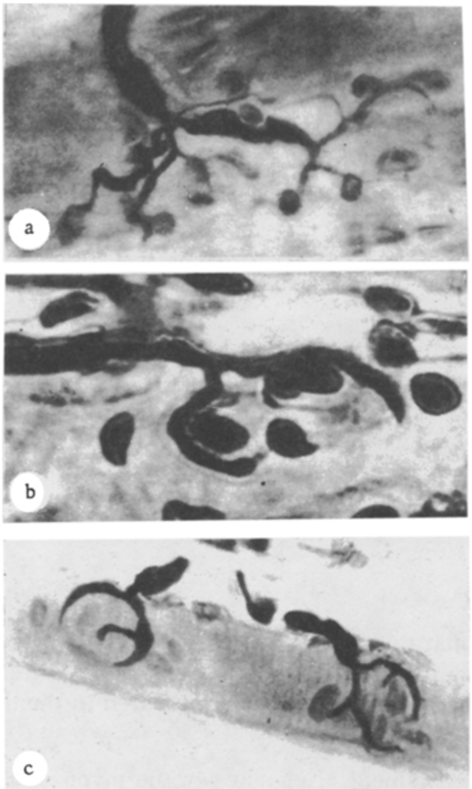

Fig. 1

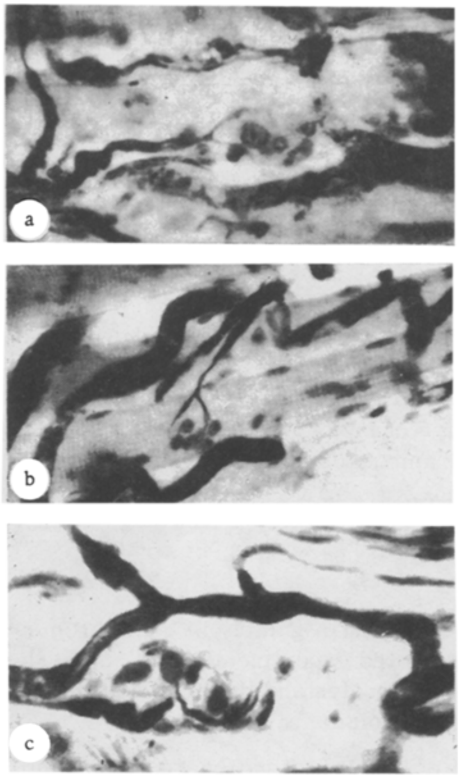

Fig. 2

Fig. 1. Myoneural synapses of albino rats after experimental muscular training: a) motor nerve ending from biceps brachii muscle showing different stages of changes in terminal structures, 600×; b) neuromuscular synapse with very coarse neurofibrillary skeleton, 600×; c) two end plates on same muscle fiber from biceps femoris muscle, 300×. Impregnation by Bielschowsky–Gros method.

Fig. 2. Arrangement of vessels in vicinity of myoneural synapses: a) forked capillary loop from biceps femoris of experimental rat; b) closed capillary loop with vascular anastomotic bridge from rectus femoris muscle of control rat; c) arcuate capillary in region of neuromuscular synapse from biceps brachii muscle of experimental rat. Injection with suspension of Paris green. Impregnation by Bielschowsky–Gros method, 300×.

synapses not only some distance apart, but also situated close together, was an interesting fact. Whereas in some neuromuscular synapses reactive changes were observed both in the afferent nerve fiber and in the terminal structures, in others the response to muscular exertion was limited to changes in the afferent nerve fiber. In some places, especially in the preterminal regions, very slight thickening of the myelinated nerve fibers was observed. Many of the terminals were seen more clearly than normally. The terminal portions of the myoneural synapses did not at all react at the same time to the motor load, but within the same motor nerve apparatus the changes in the terminal structures could be in different stages (Fig. 1a). The initial stage of the reactive state was manifested as coarsening of the neurofibrillary skeleton, with the result that the delicate terminals and, in particular, those that are normally difficult to see, became strongly argyrophilic and clearly distinguishable (Fig. 1b).

In some motor nerve endings, besides the neurofibrillary skeleton, the sarcoplasm, the amount of which was increased, also was impregnated. No appreciable change could be observed in the number of nuclei in the foot of the motor end plates, but the nucleoli were increased in volume and occupied almost the whole nucleus (Fig. 1b).

The reactive changes in the myoneural synapses were accompanied by changes in their quantitative indices (Table 1). As Table 1 shows, the area of the neuromuscular synapses in the rectus femoris muscle was

TABLE 1. Changes in Area of Myoneural Synapses in Skeletal Muscles during Graded Motor Training

Muscle	Statistical index	Area of myoneural synapses, μ^2	
		normal	experiment
Biceps femoris	$M \pm m$	348,1±13,5	359,4±2,6
	P	—	0,2
Rectus femoris	$M \pm m$	246,8±3,2	355,8±7,6
	P	—	0,01
Biceps brachii	$M \pm m$	210,1±3,9	236,3±2,7
	P	—	0,001
Triceps brachii	$M \pm m$	191,5±4,9	249,2±5,0
	P	—	0,001

TABLE 2. Change in Area of Exchange Surface of Capillaries in Microregion of Myoneural Synapses

Muscle	Statistical index	Area of exchange surface of capillaries	
		normal	experiment
Biceps femoris	$M \pm m$	202,1±5,5	341,9±7,6
	P	—	0,001
Rectus femoris	$M \pm m$	337,4±3,3	426,9±25,9
	P	—	0,001
Biceps brachii	$M \pm m$	206,3±5,4	216,8±2,2
	P	—	0,05
Triceps brachii	$M \pm m$	213,4±2,1	334,0±4,4
	P	—	0,001

increased by 44.1%. The increase in area of the myoneural synapses for the biceps brachii muscle was 12.4% and for the triceps brachii 30.4%. It was due to branching and the formation of new terminals. At the same time end plates appeared, so that two or three myoneural synapses could be seen on one muscle fiber (Fig. 1c). Since the impulse in a myelinated motor nerve spreads much faster than the subsequent action potential in the muscle fiber, the presence of several end plates results in greater synchronization of contraction [9].

Myoneural synapses were found to be in close contact with vessels of capillary type (Fig. 2). Where they were present the capillaries formed oval, circular, horseshoe-shaped, and forked loops. Closed capillary loops were formed by fusion of dichotomously dividing capillaries or with the aid of capillary anastomotic bridges. If the functional activity of the myoneural synapses was depressed, one of the microvessels of the loop consisted of a plasmatic capillary (2.5-3.0 μ in diameter) and the anastomosis was open. The existence of closed capillary loops evidently ensures optimal opportunities for a regular circulation of the blood and transport exchange in the microregion of the myoneural synapses [4].

A histometric analysis showed that under the influence of muscular exertion the area of the exchange surface of the capillaries close to the motor end plate of the biceps femoris muscle increased by 69.1% (Table 2), in the rectus femoris muscle by 26.5%, in the biceps brachii by 5.1%, and in the triceps brachii by 56.5%. No significant difference could be found between the area of the exchange surface of the capillaries in 1 μ^2 of area of the neuromuscular synapse of the control and experimental animals (normal 0.9 μ^2, experiment 1.1 μ^2). These indices are evidence of the adequate response of the microvessels in the microregion of the motor nerve endings to repeated graded muscular exertion.

The results of this investigation showed that graded muscular exertion with a gradual increase in its volume for a period of 1 month leads to an increase in area both of the neuromuscular synapses and of the exchange surface of the capillaries in the microregion occupied by them. These quantitative changes are the morphological equivalents of the increased activity of the neuromuscular apparatus during physical exertion.

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