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Muscle Spindles in Elongation of the Extremity: Proprioceptive Conflict or Activity Deficit?

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Comparison of electrophysiological and morphological parameters of shin muscles of experimental animals during shin elongation by Ilizarov's method indicates involvement of muscle spindles into reconstruction of the skeletal muscular tissue in response to its dosed distraction, which results in temporary deficit of specific somatosensory afferentation.

Key Words: *muscle spindles; electromyography; somatosensory analyzer*

Reaction of muscle spindles (MS) to long-term dosed distraction of tissues in elongated limb remains the object of research. Distraction of the elongated segment muscles is expected to cause MS activation leading (through the reflex ring) to an increase in the tone of extrafusal fibers [1]; in other words, the muscle actively resists the distraction. Moreover, simultaneous tension of antagonist muscles located on the elongated segment leads to proprioceptive conflict, which serves as the mechanism triggering the formation of post-distraction contractures [1]. Activity of motor units (MU) increases in muscles of the elongated segment during the first weeks of distraction [5]. These concepts suggest injections of myorelaxants into muscles [3] and using relaxation exercises on the basis of biological feedback by the EMG signal [1,5].

An alternative viewpoint is based on the fact that muscle effort of a preset level remains difficult for orthopedic patients even in delayed periods after elongation of the lower limbs by distraction osteosynthesis [4]. This suggests that long-term dosed distraction of the limb tissues during correction of its length largely involves the proprioceptor system of the muscles. In addition, it is known that limb distraction in experimental animals is associated with reactive changes primarily in some thick myelinated fibers and spinal sensory ganglion neurons [2]. Hence, deficit of specific somatosensory information forms in the motor analyzer segment responsible for afferent support of motor function of the elongated limb [6], preventing effective regulation of accurate movements. Suppression of H-response of the crural tricipital muscle of the elongated limb [5] and reduced amplitude of early components of somatosensory evoked potentials [6] indirectly confirm this hypothesis.

We studied changes in the shin muscle MS in experimental animals during elongation of the shin by distraction osteosynthesis.

MATERIALS AND METHODS

The study was carried out on 10 adult mongrel dogs aged 1-3 years. The shins were elongated using an Ilizarov's device, consisting of 2 arches and 2 rings. All animals were subjected to closed flexion osteoclasia of the tibial bones in the middle third of the diaphysis. Distraction in the manual mode (1 mm/day by 4 steps) was started 5 days

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after surgery. Experiments were carried out in animal clinic of National Research Center for Reconstructive Traumatology and Orthopedics by A. A. Shreiner, Cand. Med. Sci., and S. A. Erofeev, Doct. Med. Sci. Handling of animals, surgical interventions, and sacrifice were carried out in accordance with the Order of the Ministry of Health of the USSR No. 755, 1977. Elongation (15% of the initial length of the segment) was carried out over 4 weeks. After 30 and 60 days of fixation and 30 days after removal of the device, the animals were sacrificed by barbiturate overdose. Spontaneous bioelectrical activity was recorded during the same periods through a 13K13 bipolar needle electrode using a DISA-1500 digital EMG system (Dantec).

The morphology of the anterior tibia and gastrocnemius were studied after sacrifice. For histological studies, paraffin sections (3-5 μ) were sliced from fragments of the upper, middle, and lower thirds of the muscles, stained with hematoxylin and eosin and by van Gieson method.

RESULTS

No morphological signs of structural changes were detected in MS at the beginning of distraction, when the external distracting forces are compensated for by active resistance of extrafusal muscle fibers. The MS capsules were represented by two connective tissue plates (internal and external), which suggests that they retained their capacity to function as a mechanical and chemical barrier providing permanent ionic composition of the inner media essential for normal functioning of this receptor organ.

The appearance of MU action potentials (AP) in the elongated limb segment muscles at rest during the first days of distraction [9] can be regarded as a result of hyperactivity of MS with reduced (at the expense of primary tension of extrafusal muscle fibers) stimulation thresholds. Another source of MU AP is increased intensity of interoreceptive (including the nociceptive) afferentation from the zone of application of the distraction device at the expense of mechanisms of somatovisceral reflexes increasing the tonic strain of slow MU in the presence of potent central inhibition of the greater part of fast α-motoneurons of the respective spinal motor centers [5]. Due to this, the greater part of afferent flow, generated by MS, is blocked by the presynaptic inhibition mechanism and does not lead to sharp increase in tonic activity of MU. As a result, EMG amplitude at rest in distracted muscles during this period represents a sum of asynchronic discharges of a small part of slow MU not surpassing 30-40 μV [5].

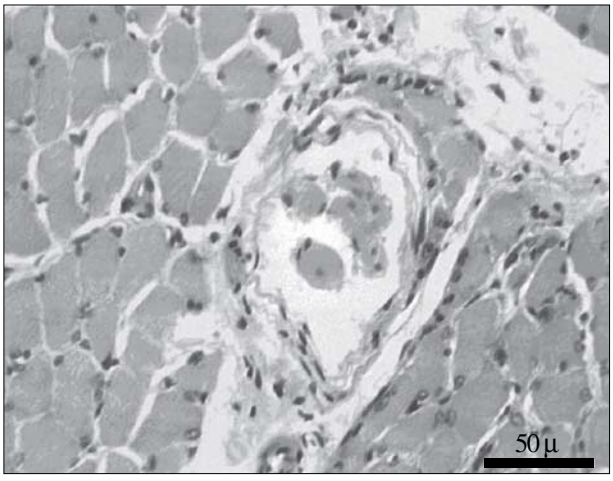

Fig. 1. Histological structure of tibia fragment from adult dog collected at the level of bone regenerate after 21 days of distraction. Edema and loss of fibers in the exterior plate, intracapsular edema and compression of MS intrafusal fibers. Cross-section, hematoxylin and eosin staining.

With prolongation of distraction, histological studies showed mucoid swelling and loss of fibers in the connective tissue structures of the internal plate of the capsule, development of intracapsular edema (Fig. 1) indicating tension, and impairment of the barrier function of their capsules at later stages. This event destabilized ionic composition of the internal medium of the receptor and caused compression of intrafusal muscle fibers (Fig. 1). All this caused subsequent reactive changes in the MS structure and in the system of their afferent and efferent innervation.

On day 28 of distraction, spontaneous bioelectrical activity of the elongated shin muscles was

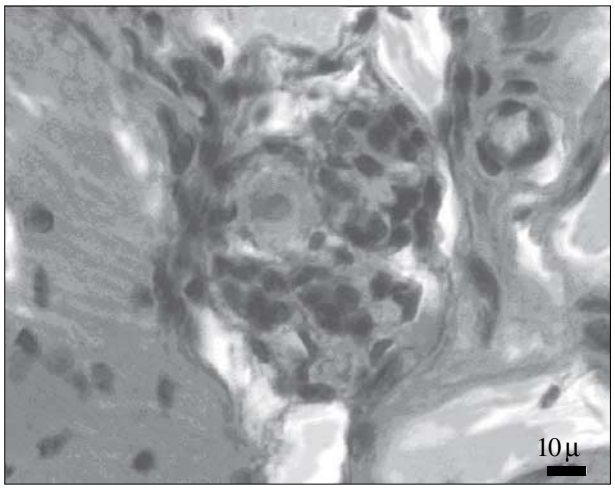

Fig. 2. Histology of the gastrocnemius MS in an adult dog after 30 days of the shin fixation in the device. Densely packed intrafusal fibers occupied by numerous nuclei. Cross-section, hematoxylin and eosin staining.

Fig. 3. Histology of the MS terminal portion of the tibia in an adult dog after removal of the device. Densely packed intrafusal fibers with nuclear sacs and nuclear chains. Cross-section, hematoxylin and eosin staining.

characterized by high intensity and was presented by numerous fibrillation potentials and various rhythmic graphoelements: fasciculation potentials and pseudomyotonic discharges. The intensity of individual constituents of bioelectrical basal level was extremely heterogeneous and varied greatly in different animals. These data coincide with clinical picture of EMG at rest in patients [5]. Despite the appearance of denervation activity, the intensity of spontaneous EMG was retained, which indirectly indicated lesser contribution of tonic discharges of MU.

A decrease in the intensity of fibrillation potentials in experimental animals and their partial replacement by various forms of spontaneous rhythmic activity can be explained by restoration of the appreciable part of neuromuscular synapses [3]. The presence of fasciculation potentials can be explained by high trophic loading of motoneurons, which regulates differentiation of new muscle fibers; to a certain extent it reflects activity of MS with intrafusal fibers occupied by the nuclei (Fig. 2). Gradual recovery of MS structure was observed after removal of the device. Muscle spindles enclosed in the capsule with inner and outer plates were fully represented by myocytes with nuclear sacs and nuclear chains (Fig. 3).

Hence, the data indicate that at least some MS are gradually involved in reactive reparative restructuring under the effect of long-term dosed distraction of the elongated limb tissues. The MS proprioceptive function is switched off for some time during this process. In combination with the block of stimulation conduction through some thick myelinated nerve conductors, this leads to the formation of specific somatosensory afferentation deficiency. Therefore, the development of high tonic activity in a negligible part of slow MU can result from somatovisceral reflexes similar to the defense strain of skeletal muscles in response to appearance of a focus of nociceptive afferentation.

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