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EFFECT OF ELECTRICAL STIMULATION OF LOW FREQUENCY ON ARCHITECTURE AND SOME CONTRACTILE CHARACTERISTICS IN MEN

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Introduction

Gravitational loading appears to be necessary for the maintenance of human lower limb skeletal muscle size and force [Kubo et al., 2000; Shenkman et al., 2003; Koryak, 2001-2003]. Studies simulating microgravity have shown that exercise countermeasures can attenuate, but not completely prevent the loss of muscle mass and force [Koryak, 2000; Kawakami et al., 2001]. The muscle groups most affected by exposure to microgravity appear to be the antigravity extensors of the knee and ankle [Akima et al., 2001]. Among these, the plantarflexors seem to be the most affected [LeBlanc et al., 1998], likely due to their greater mechanical loading under normal gravitational conditions. Most notable after exposure to microgravity is a disproportionate loss of force as compared to that of muscle size [Kawakami et al., 2001], indicating that factors other than atrophy contribute to muscle weakness. The internal architecture of a muscle is an important determinant of its functional characteristics. There is a paucity of studies on the effects of disuse [Maganaris et al., 1998] or simulated microgravity [Kubo et al., 2000; Kawakami et al., 2000] on muscle architecture.

Purpose

The purpose of the present study was to investigate the internal architecture of the triceps surae [medial (GM) and lateral (LG) and soleus (SOL) muscles] in relation to the functional characteristics of the plantarflexors after 7-days of "*dry*" water immersion (DI) with exercise countermeasures [term-long low-frequency functional electrical stimulation (FES) trainings].

Methods

To simulate microgravity the DI model has been used [Shulzhenko, Vil-Villiams, 1976]. Six subjects (men-volunteers; 22.8 ± 0.8 yr, 1.84 ± 0.1 m, and 79.3 ± 4.2 kg) gave their written, informed consent to participate in this study, after the ethics committee of the SSC – Institute of Biomedical Problems of the RAS had approved the procedures involved. All the experimental procedures were performed in accordance with the Declaration of Helsinki. FES is applied to 4 muscle groups of both lower extremities. "*Dry*" electrodes (Ltd. «*Axelgaard*», USA) are placed on the skin above the quadriceps femoris muscles, the hamstrings, the tibialis anterior, the peroneal, and the triceps surae muscles. The synchronous stimulation of antagonistic muscle groups prevents unwanted joint movements. The FES-training is performed during 3 hours per day with 1 s « *on* » and 2 s « *off* » trains at intensity levels of 20-30 % of maximum tetanic force and a frequency of 25 Hz. The electrical stimulus was provided by the «STIMUL LF-1» stimulator (RUSSIA). The technical equipment consists of electrode trousers carrying stimulation electrodes for the 12-channels, and 2 interconnected 6-channel stimulators caned on a belt. Subjects performed a series of isometric plantarflexion contractions on an isokinetic dynamometer (Biodex, USA) at ankle angles of 0° (neutral ankle position: the foot plate of the dynamometer perpendicular to the longitudinal axis of the tibia). All measurements were carried out with the knee joint flexed at 90°. A real-time B-mode ultrasound apparatus ("SonoSite MicroMaxx", USA) with a 7.5 MHz linear-array probe, and length of a scanning surface 60 mm and thickness of 10 mm was used to obtain sagittal images of the GM, GL and Sol at rest and at 50 % of plantarflexor MVC at the neutral ankle position. The fascicle pennation angle (Θ) was measured from the angles between the echo of the deep aponeurosis of each muscle and interspaces among the fascicles of that muscle. The length of fascicles (L) across the deep and superficial aponeurosis was measured as a straight line (Abe et al., 2000). Shorter fascicle L fibres (ΔL_{muscle}) was determined as a delta between L and cos Θ fibres in the active comparison with the passive condition. All ultrasonic images were processed with use of the software package «Dr. ReallyVision» (Ltd. "Alliance – Holding", RUSSIA).

Results

After the 7-day DI with application by FES-training, maximal plantar flexion torque increased on the average by 11.3 % (150 ± 17.3 *vs* 167 ± 6.7 H). After DI, in the passive condition, L fibres in the MG, and LG, and SOL has decreased for 12 % (from 32 ± 2 to 28 ± 1 mm), 13 % (from 36 ± 2 to 31 ± 2 mm), and 13 % (from 36 ± 3 to 32 ± 2 mm) but in the active condition by 18 % (from 26 ± 3 to 22 ± 2 mm), 22 % (from 36 ± 3 to 28 ± 2 mm), and 21 % (from 32 ± 2 to 26 ± 2 mm), respectively. The fascicle angles, in the passive condition, was decreased by 22, 20 and 16%; but in the active condition by 17, 22 and 17 %, respectively. Shorter fascicle lengths and steeper fascicle angles in the active compared with the passive condition show internal shortening of fascicles by contraction. Before DI $\triangle L_{muscle}$ the MG has found 7.9 mm after has decreased and has made 7.8 mm, and in Sol 5.9 *vs* 5.6 mm. Significant increased in $\triangle L_{muscle}$ from 0.9 to 3.3 mm were found by LG.

Discussion

After 7-days of DI a considerable increased of force, was observed in the exercise (+11 %) groups whereas absence of preventive actions results in reduction in MVC more than on 50 % [Grogor'eva, Kozlovskaya, 1987; Koryak, 2001—2006], and in Po more than on 30 % [Koryak, 1998, 2001, 2992, 2003]. Efficacy of FES-training for increased the contractile properties of skeletal muscles has been suggested in previous studies (Koryak, 1995; Mayr et al., 2000; Koryak et al., 2002). The insignificant increase in force of contraction in the present study can be assumed it is defined by slack intensity impulses. Internal architecture of the GM, LG, and Sol muscle was altered and this was only partially prevented by exercise countermeasures. Both fascicle length and pennation angle were reduced after DI with FES, this strongly suggests a loss of both in-series and in-parallel sarcomeres, respectively. The functional consequence of the decreased fascicle length was a reduced shortening during contraction. The loss of in-series sarcomeres would mean that this is likely to have implications both on the *force-length* and *force-velocity* relationships of the muscle. The observation of a smaller pennation angle during contraction after DI with FES will partially compensate for the loss of force, because of a more efficient force transmission to the tendon. The reduced initial resting Θ probably, grows out reduction decreased tendon stiffness or of the muscle-tendon complex that finds confirmation in substantial growth ΔL_{muscle} of LG (with 0.9 up to 3.3 mm after DI) during contraction. This observation is consistent with the findings of Kubo et al. [2000]. In conclusion, FES-training was partially successful in mitigating the loss of function and architecture induced by prolonged DI. Apparently, by ascending during FES-trained a flow muscular afferentation (Gazenko et al., 1987).

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