The article is admitted to the International Scientific Conference “Fundamental and applied research in medicine”, China (Beijing), 26 November - 4 December, 2007, came to the editorial office on 09.11.07.

ULTRASOUND IMAGING DISTINGUISHES BETWEEN NORMAL AND WEAK MUSCLE

Koryak Yu. A.
Department of Neurophysiology & Countermeasures, State Scientific Center – Institute of Biomedical Problems RAS, Moscow, RUSSIA

Introduction

A number of studies have documented that the microgravity environment encountered during spaceflight or simulated by using models of weightlessness induces alterations in skeletal muscle function [3, 10, 14]. In the absence of weight-bearing activity, strength loss is the most evident consequence of atrophy. Moreover, showed that muscle strength decreased during bed-rest or immersion and suggested that the loss of strength [11, 13] was due primary to muscle atrophy [4, 15]. Muscle atrophy has been shown to be pronounced in the lower limb muscles [17], and it has often been observed that the reduction of strength is greater than that of muscle size [17, 19]. Therefore, these observed changes following a period of immobilization may cause changes in fascicle length.

Most skeletal muscles in humans are more or less pennated [8], in which muscle fibres are arranged at an angle with respect to the line of action of the muscle The angle of muscle fibres with respect to the tendon action line is an important functional characteristic of the muscle. A large pennation angle allows more contractile material to be placed along the tendon increasing the muscle's force generating capacity, results in a less efficient force transmission through the tendon and results in a reduced fibre length, compromising shortening velocity and excursion range [7]. Pennation angle changes proportionally as a function of isometric contraction intensity.

Muscle architecture, i.e. geometrical arrangement of fibres within a muscle, has been shown to have a substantial influence on the force-generating capabilities of the muscle [9]. This angulation (pennation angle) has been shown to affect force transmission from muscle fibres to tendon, and hence muscle force generation [8, 9]. The architecture of a skeletal muscle is an important determinant of its functional characteristics [8]. Human muscle architecture may be studied noninvasively *in vivo* both at rest and during muscle contraction, by using real-time ultrasonography [9]. Indeed, several investigators [5] have demonstrated that during isometric contractions muscle architecture undergoes remarkable changes. Changes in fiber length by contraction are thus expressed as fascicle length changes

In an attempt to improve our understanding of *in vivo* changes of muscle architecture, modern imaging techniques have been used [5, 9, 18]. Real-time ultrasonography enables *in vivo* muscle scanning and offers promise for a realistic determination of changes in muscle architecture [9]. Real-time ultrasonic (US) measurements were taken in the present study in the triceps surae (TS) muscle in healthy man and patients. In this report, we have studied by means of ultrasonography the relationships between architectural parameters [lengths fascicles (L), and pennation angles (Θ) of fascicles, and muscle thickness (H)] and level of force exerted in highly-subjects and patient with consequences of cerebral palsy. The purpose of our research work was to determine *in vivo* changes in pennation angle and fibre length in each muscle of the triceps surae complex [gastrocnemius medialis (GM), gastrocnemius lateralis (GL) and soleus (SOL)], both at rest and moment produced voluntarily during an isometric ankle plantarflexion. We employed real-time ultrasonography to visualize fascicles *in vivo.*

Methods

Subjects

Thirty subjects participated in this study. These subjects were assigned to two groups. The first group of subjects consisted of 8 healthy men (avg. age = 52±3.6 years), and the second group of subjects was composed of 22 patients men and women (avg. age = 55±3.4 years). Prior to the experiment, the details and possible risks of the protocols were explained to the subjects and written informed consent was obtained from each of them.

Ultrasound scanning

The longitudinal US images of the medial (MG) and lateral (LG) gastrocnemius muscles were obtained at 30% proximal level of lower leg (the distance between the lateral malleolus of the fibula and the lateral condyle of the tibia), and soleus (SOL) muscles were obtained at 50% of the distance between the poplitealcrease and the center of the lateral malleolus the using the B-mode ultrasound apparatus (Sonoline Elegra, Siemens, Germany). Briefly, the measurements were carried out while the subjects stood with their weight evenly distributed between both legs. The mediolateral widths of the MG and LG muscles were determined by ultrasound over the skin surface, and the position of one-half of the width was used as a measurement site. The echoes from interspaces of fascicles and from the superficial and deep aponeurosis were visualized [16].

A real-time B-mode US apparatus (Sonoline Elegra, Siemens, Germany) with a 7.5-MHz linear-array probe (with 80-mm scanning length) 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. A transducer with a 7.5-MHz scanning head was placed perpendicular to the tissue interface. The scanning head was coated with water-soluble transmission gel, which provided acoustic contact without depressing the dermal surface. The subcutaneous adipose tissue-muscle interface and the muscle-bone interface were identified from the ultrasonic image, and the distance from the adipose tissue-muscle interface to the muscle-bone interface was adopted as representative of muscle thickness. All measurements were performed on the right leg. During all measurements, subjects were instructed to relax their leg muscles. Each subject's right foot was firmly attached to an dynamometer (Cybex® II, USA). The subjects were verbally encouraged to perform static contractions with the ankle plantarflexor with a maximum possible effort. Three contractions were performed by a 1 min rest interval between bouts and the highest value was considered the maximum voluntary contraction (MVC). US images were obtained during the experimental trial on the previously determined stronger leg. Each subject was then asked to maintain the stronger leg contractions for at least 2-3 s 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 [5, 9]. The length of fascicles across the deep and superficial aponeurosis was measured as a straight line between the insertion points of the fascicle, onto the aponeurosis of the muscle (1, 16). Muscle thickness (*H*) was measured as the distance between the superficial and the deep aponeuroses echoes, and *L* at rest was measured as the length of the line drawn along the echoes parallel to the fascicles from the deep up to the superficial [5]. US images were calculated by US-system, using program Magic View 300 (Siemens) with archiving the data by Sienet (Siemens, Germany). In each muscle the average of the five images was used for data analysis.

Statistical Methods

Standard procedures were used to calculate means and standard deviations (± SD). The statistical significance of the differences between the two groups of subjects were calculated by Student's *t* test for independent samples and between groups of subjects.

Results

The US findings in the patient groups were compared to of a control group. From the US image, it was observed that *L* and Θ changed during in the passive condition and specially the active condition. The degree of *L* change was not identical for the three muscles The effects relaxation and an isometric contraction of the triceps surae muscle (50 % MVC) on *L* were significant for MG and LG and there was also a significant interaction between control and patients in these muscles. In other words, in MG and LG, changes in *L* changes were larger with the SOL. In the active condition, *L* of MG were not different between control and patients, although in the passive condition the difference was significant. The *L* of SOL were not different.

From the US image, it was observed that and Θ changed during an isometric contraction of the TS muscle. Changes in *L*, and were expressed as a function of relative torque. The Θ change was not identical for the three muscles. The fascicle Θ of MG demonstrated the greatest variation in three muscles. The effects of activation and relaxation positions were significant in all three muscles. The differences in MG fascicle Θ because of changes in ankle positions were significant among control and patients both in the passive and active conditions. Fascicle Θ of LG and SOL not differed among control and patient in the relaxation condition but not in the activation condition. For LG, and Sol fascicle Θ were changes were larger in control with the patients. The mean values fascicle Θ of MG, LG, and SOL an isometric contraction (50 % MVC) in the control groups increased by 60 %, 41 %, and 41 %, respectively; in the patient groups were a smaller increase, by 28 %, 26 %, and 36 %, respectively.

H of MG and LG were not significantly greater in control than in patients, but in SOL were loss than in control. Changes in *H* were expressed as a function of relative torque. *H* of MG at was no significantly different between rest and 50 % MVC. In contrast, *H* of LG and SOL increased from rest to MVC by 21.9 % ($p < 0.05$) and 17.9 % ($p < 0.05$), respectively. In MG and SOL patients was not significantly different either between different imaged. *H* LG and SOL were not significantly greater in patients by 10.7 % and 3.6 %, respectively, but MG was decreased by 3.6 %.

Discussion

Our results show that the US image method applied is valid and reliable for assessing the size of a large, individual, human locomotor muscle. This method can provide information on cross-section area changes along the entire muscle length in response to training, disuse or as a spaceflights.

Internal architecture of the TS complex (MG) was altered. Both fascicle length and pennation angle were reduced after in patients groups, this strongly suggests a loss of both in-series and in-parallel sarcomeres, respectively. This observation is in agreement with previous findings in disuse conditions [19]. The functional consequence of the decreased fascicle length was a reduced shortening during contraction. It is necessary to note, that at some patients with motor disorders, having restriction of mobility, the normal ultrasonic architecture of muscles was marked. It is possible to assume, that disuse of a muscle is not the unique factor influencing on the ultrasonic architecture of muscles. Studying of architecture of muscles at patients with various motor disorders allows to understand better the intimate processes in healthy persons under influence of various factors, including microgravitation, long space flights, where restriction of impellent activity takes place, despite of using preventive measures, and experiments on animals demonstrate the development of a muscular atrophy in conditions of microgravitation.

References:

1. Abe T., Kumagai K., Brechue W.F. Fascicle length of leg muscle is greater in sprinters than distance runners. *Med. Sci. Sports Exerc*., 2000, v. 32, pp. 1125-1129
2. Akima H, Kubo K, Kanehisa H, et al. Leg-press resistance training during 20 days of 6° head-down-tilt bed rest prevents muscle deconditioning. *Eur. J. Appl. Physiol*., 2000, v. 82, pp. 30–38.
3. Cavagna G.A., Heglund N.C., Taylor C.R. Mechanical work in terrestrial locomotion: two basic mechanisms for minimizing energy expenditure. *Am. J. Physiol*., 1977, v. 233, pp. R243–R261.
4. Duchateau J, Hainaut K. Electrical and mechanical changes in immobilized human muscle. *J. Appl. Physiol.*, 1987, v. 62, pp. 2168–2173.
5. Fukunaga T., Ichinose Y., Ito M. et al. Determination of fascicle length and pennation in a contracting human muscle in vivo. *J. Appl. Physiol*., 1997, v. 82, pp. 354-358.
6. Fukunaga T., Roy R.R., Shellock F.G. et al. Physiological cross-sectional area of human leg muscles based on magnetic resonance imaging. *Orthop. Res*., 1992, v. 10, pp. 928-934.
7. Gans C. Fiber architecture and muscle function. *Exer. Sport Sci. Rev*., (Teijung R.T., ed.), Franklin Institute Press< Phuladelphia, 1982, v. 10, pp. 160-207
8. Gans C., Bock W.J. The functional significance of muscle architecture—a theoretical analysis. *Ergeb. Anat. Entwicklungsgesch*., 1965, v. 38, pp. 115-142.
9. Kawakami Y., Abe T., Fukunaga T. Muscle-fiber pennation angles are greater in hypertrophied than in normal muscles. *J. Appl. Physiol*., 1993, v. 74, pp. 2740-2744.
10. Koryak Yu. Electrically evoked and voluntary properties of the human triceps surae muscle: effects of long-term spaceflights. *Acta Physiol. Pharmacol. Bulg*., 2001, v. 26, pp. 21-27.
11. Koryak Yu. Surface action potential and contractile properties of the human triceps surae muscle: effect of “dry” water immersion. *Exp. Physiolog*., 2002, v. 87, pp. 101-111
12. Koryak Yu. “Dry” immersion induces neural and contractile adaptations in the human triceps surae muscle. *Environ. Med*., 2002, v. 46, pp. 17-27
13. Koryak Yu. Contractile properties and fatiguability of the human triceps surae muscle after exposure to simulated weightlessness. Basic Motor Control to Functional Recovery III. (ed. N. Gantchev), Varna, Univ. Press, 2003, pp. 369-380.
14. Koryak Yu., Siconolfi S.F., Kozlovskaya I.B. et al. Maximal voluntary (MVC), tetanic (P_o) and single twitch (P_t) contractions before & after space flight. *FASEB J*., 1997, p. A1408
15. Kubo K., Akima H., Kouzaki M. et al. Changes in the elastic properties of tendon structures following 20 days bed-rest in humans. Eur. J. Appl. Physiol., 2000, v. 83, pp. 463–468.
16. Kumagi K., Abe T., Brechue W.E. et al. Sprint performance is related to muscle fascicle length in male 100-m sprints. *J. Appl. Physiol.,* 2000, v. 88, pp. 811-816
17. LeBlanc A., Gogia P., Schneider V. et al. Calf muscle area and strength changes after five weeks of horizontal bed rest. *Am. J. Sports Med*., 1988, v. 16, pp. 624-629
18. Narici M.V., Binzoni T., Hiltbrand E. et al. In vivo human gastrocnemius architecture with changing joint angle at rest and during graded isometric contraction. *J. Physiol*., 1996, v. 496, pp. 287-297.
19. Suzuki Y., Murakami T., Haruna Y. et al. Effects of 10 and 20 days bed rest on leg muscle mass and strength in young subjects. *Acta Physiol. Scand*., 1994, v. 150, pp. 5-18.

The article is admitted to the International Scientific Conference “Fundamental and applied problems of medicine and biology”, Tunis (Suss), 10-17th June, 2007г., came to the editorial office on 09.11.07.

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

Koryak Yu.A.
State Scientific Center — Institute of Biomedical Problems of the RAS, Moscow, Russia

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