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Effects of percutaneous acupuncture stimulation on the viscoelastic properties of tendon during isometric contraction

Toshiyuki Fukushima [a,*], Shuichirou Kawamura [b], Hidenori Horiuti [c], Masanori Nagaoka [a]

[a] Department of Rehabilitation Medicine, Juntendo University Graduate School, Tokyo, Japan
[b] Department of Medicine, Shin-Tokyo Hospital, Tokyo, Japan
[c] National Association of Speed and Explosion, Tokyo, Japan

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ABSTRACT

This study aimed to investigate the effects of percutaneous acupuncture stimulation on the viscoelasticity of human tendon structures during isometric contraction. Nine healthy men participated. The experimental order was pre-test, acupuncture stimulation, and post-test. Real and sham acupuncture applications were used at the stimulus site of the medial gastrocnemius muscle (MG), and a crossover trial was performed on the same subjects at a later date. Before and after acupuncture stimulation, tendon elongation and MG aponeurosis were directly measured by ultrasonography while the subjects performed isometric plantar flexions up to the maximum voluntary contraction (MVC) followed by relaxation. The relationship between the estimated MG muscle force (Fm) and tendon elongation (L) during the ascending phase was fitted to a linear regression, the slope of which was defined as the stiffness of the tendon structures. Additionally, the ratio (%) of the area within the Fm–L loop to the area under the curve during contraction and relaxation was calculated and defined as hysteresis. Stiffness rate of change (RC) in real and sham acupuncture was 137.5 ± 116.5% and 55.0 ± 10.4%, respectively ($p < 0.05$). Thus, real acupuncture demonstrated significantly higher values than sham acupuncture. The hysteresis measurement results in real acupuncture indicated a downward tendency (pre-treatment: 25.6 ± 5.1%, post-treatment: 16.1 ± 13.0%), while sham acupuncture indicated an upward tendency (pre-treatment: 26.5 ± 10.9%, post-treatment: 28.4 ± 6.9%). These results indicated that percutaneous acupuncture stimulation reduces hysteresis, enhances stiffness, and improves the viscoelasticity of tendon structures.

1. Introduction

Acupuncture has been used in various fields with an expectation of efficacy. The primary purpose of using acupuncture in the sports field is conditioning, such as the prevention of disorders, relieving muscle tension and fatigue, relaxation, and health management.

Improving sports performance is such an important issue for all athletes that many of them would employ every available means to realize this purpose, including acupuncture, even if the scientific validation of its effect is not yet fully established.

The U.S. National Institutes of Health (NIH) 1997 consensus statement pointed out that it is necessary to for the effects of acupuncture to be researched and evaluated based on scientific evidence, rather than by ambiguous experiential evaluation [1]. Some of the physiological mechanisms and scientific explanations of acupuncture have gradually become clear, such as the sensory receptors that become activated in response to acupuncture stimulation [2], the reflection and communication mechanisms [3], and its impact on endocrine regulation and the autonomic nervous system [4]. However, very little research can be found that has verified how acupuncture stimulation acts upon exertions during actual physical exercises [5].

Every movement the human body performs, including during sports, is comprised of joint motions and achieved through skeletal muscle contractions [6]. The skeletal muscles are attached to bones by tendon structures, and move joints by exerting contractile forces. This function is finely controlled by the nervous system, and allows the performance of physical movements. Skeletal muscles comprise the muscle-tendon complex (MTC), which includes muscle and tendon structures with contractile and elastic forces, respectively [7]. The MTC enables us to perform various physical movements.

* Corresponding author at: Department of Rehabilitation Medicine, Juntendo University Graduate School 2-1-1, Hongo, Bunkyo-Ku, Tokyo 113-8421, Japan. Tel.: +81 3 3813 3111; fax: +81 3 5684 1861.
E-mail address: tfukushi@icloud.com (T. Fukushima).

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Therapies such as tack needles are used in percutaneous acupuncture for sports conditioning, and are expected to attain sustained stimulation of the low-invasive plaster type. The mechanism by which acupuncture acts upon MTC activities and regulates the smoothness of physical movements has yet to be fully elucidated.

Recently, the use of ultrasonography has enabled direct observations of muscle-tendon activities *in vivo*. It has also made it possible to determine MTC functions with clues to the dynamics of tendon structures during muscle contraction. Using ultrasonography, previous research has observed the dynamic states of tendon structures during isometric contraction and investigated the dynamic properties of the MTC [8–10]. By utilizing the same method, we aimed to observe biological tendon and muscle responses to acupuncture stimulation and to clarify its effects on the viscoelasticity of human tendon structures.

Acupuncture has been experientially applied for releasing stiffness. If the mechanism by which acupuncture influences MTCs could be clarified, it could be used more appropriately for sports conditioning and could contribute to sports performance improvements. Therefore, by using tack needles that provide sustained stimulation, even during physical movements, we attempted to elucidate the effects of acupuncture on the viscoelastic properties of tendon structures that significantly contribute to MTC exertion.

2. Material and methods

2.1. Subjects

Nine healthy volunteer men with no history of serious injuries to the lower limbs (age: 31.1 ± 8.7 years, height: 171.3 ± 5.6 cm, body mass: 66.8 ± 8.0 kg, mean ± SD) were enrolled. Prior to the experiment, the purpose, details, and potential risks of this study were explained to the subjects, and written, informed consent was obtained.

2.2. Experimental procedure

The experiment proceeded in the order of pre-measurement (pre-test), acupuncture stimulation (with tack needles), and post-measurement (post-test). Before and after acupuncture stimulation, the torque produced during isometric plantar flexion and elongation in the medial gastrocnemius muscle (MG) tendon structures were determined by a dynamometer (Cybex 770-NORM, Cybex International, Medway, MA, USA) and ultrasonography, respectively.

2.3. Acupuncture stimulation

During a 15-min break after the pre-task, real and sham acupuncture stimulation was applied by attaching tack needles (Pyonex) to the right leg.

In order to avoid placebo effects, both real and sham acupuncture needles were prepared with identical shapes; the needles were randomly chosen without informing the subjects, and applied to the stimulus site (the middle of the gastrocnemius muscle belly) (Fig. 1). Furthermore, as a crossover experiment, a second trial was performed on each subject by replacing the needle with the needle type not used during the first trial, i.e., real to sham, or vice versa. To ensure the effects from the first trial would not interfere, a sufficient interval was arranged between the trials.

To ensure the validity of the blinded test, subjects were asked about sensations from acupuncture stimulation during each trial. The results of the inquiries were as follows. After each trial, all were asked if they felt the sensation of a needle being inserted. During real acupuncture, five replied "yes" and four replied "no;" during sham acupuncture, six replied "yes" and three replied "no" (kappa coefficient [κ] = −0.11). Thus, it was concluded that the blinded test was valid.

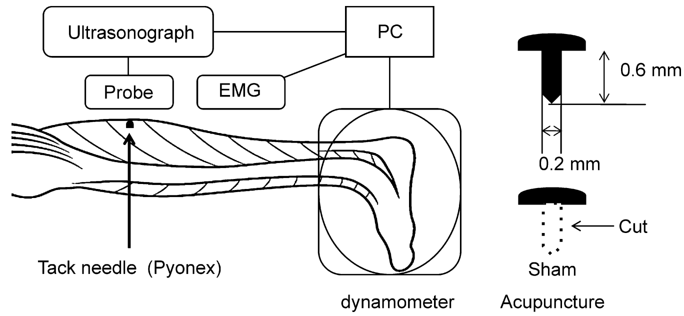

Fig. 1. A schematic representation of the experimental setup. A dynamometer was used to fix the ankle joint angle at 0° plantar flexion from the anatomical position and to measure torque. The right foot was firmly attached to the footplate of the dynamometer with a strap. An ultrasonography apparatus with an electronic linear-array probe was used to obtain sectional images of the medial gastrocnemius muscle (MG). Sonograms, torque, and EMG data were synchronized by a timer in the PC.

2.4. Measurement of the viscoelastic properties of tendon structures

2.4.1. Measurement of torque

Each subject lay prone on a bed and his right ankle joint was fixed to the dynamometer pedal. The pelvis and thighs were both fixed to the bed of the Cybex with suitable belts. The knee of the tested leg (the right) was fully extended, and the ankle joint was placed in a neutral anatomical position on a footplate and firmly fixed with a strap (Fig. 1).

Firstly, to measure maximum voluntary contraction (MVC), the subjects were instructed to exert plantar flexion MVC torque and hold it for 3 s. Measurements of each task were performed at least twice. To detect accidental errors of greater than 5%, one more trial was added, and the maximum value was determined as the MVC torque. Secondly, after being provided ample time to rest after the MVC task, each subject was instructed to develop a gradually increasing force from relaxation to MVC for 3 s, hold it for 1 s, and release back to a relaxed state for 3 s. Measurements of each task were performed at least three times. To detect accidental errors of greater than 5%, one more trial was added, and the maximum torque value was used for the analysis. At least a 3-min interval was provided between trials. The torque signals were converted from analog to digital at a sampling rate of 1 kHz (Contac ADA16-32/2(CB)F) and analyzed by a personal computer. Then, the measurements, along with the post-task, were performed in the same manner as the pre-task.

2.4.2. Electromyogram (EMG) measurements

The electromagnetic activities of the tibialis anterior (TA), MG, lateral gastrocnemius (LG), and soleus (SOL) muscles were recorded during isometric plantar flexion. Then, Ag/AgCl electrodes with a built-in preamplifier (DE-2.3 10, Delsys, Boston, MA, USA) were placed over the bellies of the respective muscles. The obtained EMG signals were amplified by an EMG amplifier (Bagnoli Desktop EMG systems, Delsys, Boston, MA, USA; filtering frequency: 50 Hz), analog-to-digital converted, and transmitted to a computer at a sampling rate of 1 kHz. EMG signals were amplified with band-pass filtering from 15.92 Hz to 600 Hz. The maximal and mean EMG signal values were computed after full-wave rectification. The mean values used for the analysis were those of maximum torque for the MVC.