Clinical Biomechanics 29 (2014) 636–642

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Increased range of motion after static stretching is not due to changes in muscle and tendon structures

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ARTICLE INFO

Article history:
Received 23 January 2014
Accepted 28 April 2014

Keywords:
Stiffness
Ultrasound
Static
Passive resistive torque
Maximum voluntary contraction
Range of motion

ABSTRACT

Background: It is known that static stretching is an appropriate means of increasing the range of motion, but information in the literature about the mechanical adaptation of the muscle–tendon unit is scarce. Therefore, the purpose of this study was to investigate the influence of a six-week static stretching training program on the structural and functional parameters of the human gastrocnemius medialis muscle and the Achilles tendon.
Methods: A total of 49 volunteers were randomly assigned into static stretching and control groups. Before and following the stretching intervention, we determined the maximum dorsiflexion range of motion with the corresponding fascicle length and pennation angle. Passive resistive torque and maximum voluntary contraction were measured with a dynamometer. Muscle–tendon junction displacement allowed us to determine the length changes in tendon and muscle, and hence to calculate stiffness. Fascicle length, pennation angle, and muscle tendon junction displacement were measured with ultrasound.
Findings: Mean range of motion increased significantly from 30.9 (5.3) to 36.3 (6.1) in the intervention group, but other functional (passive resistive torque, maximum voluntary contraction) and structural (fascicle length, pennation angle, muscle stiffness, tendon stiffness) parameters were unaltered.
Interpretation: The increased range of motion could not be explained by the structural changes in the muscle–tendon unit, and was likely due to increased stretch tolerance possibly due to adaptations of nociceptive nerve endings.

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1. Introduction

The three most common stretching methods are static, ballistic, and proprioceptive neuromuscular facilitation (PNF) stretching (Magnusson et al., 1996a). All the methods are used for both acute (a single stretching training) and short-term (repeated stretching training for three to eight weeks) stretching and are able to increase the range of motion (RoM) (Magnusson, 1998; Mahieu et al., 2007, 2009; Nakamura et al., 2012). Various authors have reported that short-term static stretching training does not affect the passive torque–angle curve (Gajdosik et al., 2005; Magnusson et al., 1996b; Weppler and Magnusson, 2010) or the joint angle at the same, standardized passive torque (Ben and Harvey, 2010; Folpp et al., 2006; Law et al., 2009; Weppler and Magnusson, 2010) in the pre- and post-intervention. Others, however, have identified decreased PRT, and therefore changes in the torque–angle curve, after a prolonged static stretching regime (Guissard and Duchateau, 2004; Kubo et al., 2002; Mahieu et al., 2007; Nakamura et al., 2012). Furthermore, there is some evidence that short-term static stretching does not alter maximal isometric torque (MVC, Kubo et al., 2002) or tendon stiffness (defined as force-length relationship during an isometric ramp contraction with maximal voluntary effort (Kubo et al., 2002; Mahieu et al., 2007)) following a three- to six-week training period. However, several structural parameters which might affect and explain RoM changes, such as muscle and tendon stiffness during passive movements (Konrad et al., 2014), as well as fascicle length and pennation angle (Konrad et al., 2014; Morse et al., 2008), were not analyzed by these authors (Kubo et al., 2002; Mahieu et al., 2007; Nakamura et al., 2012).

Therefore, the objective of this study was to analyze the effects of a short-term static stretching program on the functional and structural parameters of the plantar flexor muscle–tendon unit. Since tendon, like muscle tissue, undergoes substantial structural changes as a result of a number of chronic processes, such as aging (Narici et al., 2008), chronic use (Csapo et al., 2010), disuse (Reeves et al., 2003), exercise (Kubo et al., 2002), and PNF stretching (Konrad et al., 2014), we also expected changes as a result of the static stretching training.

Due to the findings in the literature, we hypothesized to observe a gain in RoM, a decrease in PRT, but no change in MVC following a six-week static stretching training program. Moreover, we expected that the static stretching training would also result in structural changes, i.e. more compliant muscle or tendon tissue, as well as longer fascicle length and/or smaller pennation angles.

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http://dx.doi.org/10.1016/j.clinbiomech.2014.04.013
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2. Methods

2.1. Experimental design

A total of 49 police cadets participated in the study, and they were randomly assigned to a static stretching group ($N = 25$) and a control group ($N = 24$). All the subjects were asked to maintain their normal physical activities during the study. Teachers of the police school were informed about the study and were asked to maintain the intensity and extent of physical activities during their lessons (two per week). The static stretching group undertook a collective static stretching training program five times a week for six weeks, in the morning before education in the police school started. Investigators controlled the stretching training at least once a week by random and unannounced visits to ensure the accomplishment of the stretching training. Since the static stretching exercise (standing wall push) is rather simple and due to the observations during the visits we can assume a proper execution of the program in non-monitored sessions. Furthermore, subjects were asked to keep a diary of their stretching performance, which was collected at the end of the study. All measures were taken before and after the six-week static stretching intervention.

2.2. Subjects

Thirty-five healthy male (mean (SD): 23.3 (2.9) years, 178.6 (5.5) cm, 76.1 (7.2) kg) and 14 healthy female (mean (SD): 22.5 (2.5) years, 171.8 (4.2) cm, 61.8 (5.6) kg) police cadets participated in this study. Each subject was informed about the testing procedure but not about our hypotheses, and they each gave written consent to participate in the study. Competitive athletes and participants with a history of lower-leg injuries were excluded. The Ethical Committee of the University of Graz approved the study.

2.3. Measures

To ensure a high scientific standard, all measurements were undertaken by the same investigator. Pre- and post-training tests were executed at the same time of day, and the temperature in the laboratory was kept constant at around 20.5 °C. Measurements were performed without any warm-up and in the following order: 1. range of motion (10-min break); 2. passive resistive torque (1-min break); and 3. maximum voluntary contraction (see Fig. 1).

2.3.1. Range of motion (RoM) measurement

Dorsiflexion RoM was measured with an electronic goniometer (Biovision, Wehrheim, Germany) fixed to the foot and shank with Leukotape® (BSN medical S.A.S., Vibraye, France). The axis of the goniometer was aligned with the estimated axis of rotation of the ankle at the malleolus lateralis. The shanks of the goniometer were carefully fixed to the foot (from the axis of rotation to the metatarsophalangeal joint) and the shank (from the axis of rotation alongside the fibula). Participants were first instructed to stay upright in a neutral position, with the ankle joint angle at 90°. They were then asked to step back with one leg and bring the ankle joint to maximum dorsiflexion, keeping their heel on the ground. The knee of the testing leg had to remain fully extended, and the knee of the opposite leg flexed. Both feet were kept in a parallel position, and hands could be placed on a wall to ensure balance. Special attention was paid to the appropriate position of the stretched leg during the measurement, to avoid any pronation of the foot. If some pronation was visually observed, the measurement was repeated. The difference between the maximum dorsiflexion and the position in rest (neutral position) was the dorsiflexion RoM.

2.3.2. Passive resistive torque (PRT) measurement

To investigate PRT, an isokinetic dynamometer (CON-TREX MJ, CMV AG, Duebendorf, Switzerland) was used, and the standard setup for ankle joint movement of the dynamometer was adjusted to the subjects. Subjects lay prone with their knee fully extended on a bench, and were secured with a strap on the upper body to exclude any evasive movement. The foot was fixed barefooted with a strap to the foot plate of the dynamometer. The ankle joint was carefully aligned with the axis of the dynamometer to avoid any heel displacement. The dynamometer moved the ankle joint from a 10° plantar flexion to a dorsiflexion position, which corresponded to 95% of the individual maximum dorsiflexion RoM previously measured in the RoM measurement. Since maximum dorsiflexion positions differed between pre- and post-intervention, we compared PRT at the smaller of these two positions. The ankle joint was moved passively for three cycles. During pilot measurements, we recognized a conditioning effect during the first two passive movements, similar to the active conditioning reported by Maganaris (2003). Therefore, measurements were taken during the third cycle to avoid the conditioning effect. Similar to the studies by Kubo et al. (2002) and Mahieu et al. (2009), the velocity of the dynamometer was set at 5°/s to exclude any reflexive muscle activity. Participants were asked to relax during the measurements.

2.3.3. Maximum voluntary contraction (MVC) measurement

MVC measurements were performed with the dynamometer at a neutral ankle position (90°). Participants were instructed to perform three isometric MVCs of the plantar flexors for 5 s, with rest periods of at least 1 min between the measurements, to avoid any fatigue. The attempt with the highest MVC value was used for the further analysis.

2.3.4. Electromyography (EMG)

Muscular activity was monitored by EMG (myon 320, myon AG, Zurich, Switzerland) during PRT and MVC measurements. Surface electrodes (Blue Sensor N, Ambu A/S, Ballerup, Denmark) were placed on the muscle bellies of the GM and the tibialis anterior. In the PRT measurements, the EMG (normalized to plantar flexor MVC) was monitored post hoc to ensure that the subject was relaxed, i.e. did not show any EMG activity. Sample rate was 2000 Hz. The EMG signals were high-pass filtered (10 Hz, Butterworth) and root-mean-square (RMS, 50 ms window) values were calculated.

2.3.5. Measurement of elongation of the muscle–tendon structures

A real-time ultrasound apparatus (mylab 60, Esaote S.p.A., Genova, Italy) with a 10 cm B-mode linear-array probe (LA 923, Esaote S.p.A., Genova, Italy) was used to obtain a longitudinal ultrasound image of the GM.

During the PRT and MVC measurement, the ultrasound probe was placed on the distal end of the GM (Fig. 2), where the muscle is connected to the Achilles tendon, i.e. the muscle–tendon junction (MTJ, Kato et al., 2010). The ultrasound probe was secured with a standard orthopedic stocking to prevent a displacement of the probe. To determine the muscle displacement during PRT measurement, the echoes of the MTJ in the ultrasound videos were manually tracked (Kato et al., 2010). In some cases during MVC measurements the ultrasound probe lost skin contact above the MTJ due to the deformation of the muscle which led to minor quality of this area in the videos. Thus, the muscle displacement was determined by manually tracking the echoes of a fascicle insertion at the deep aponeurosis near the MTJ (Kubo et al., 2002). Similar to the approach used by other authors (Kato et al., 2010; Morse et al., 2008), the cadaveric regression model of Grieve et al. (1978) was used to obtain the percentage length changes of the MTU of the GM during passive movements. Original total MTU lengths were measured with a tape measure according to Grieve et al. (1978) to calculate absolute length changes of the MTU. The difference between the MTU length change and the displacement of the muscle was defined as the tendon displacement.

During RoM measurement, the length of the GM fascicle and its pennation angle with the deep aponeurosis were determined from the

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