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Achilles tendon morphology, plantar flexors torque and passive ankle stiffness in spastic hemiparetic stroke survivors

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A B S T R A C T

Background: The present study compared the Achilles tendon morphological characteristics, plantar flexor toque and passive ankle stiffness between hemiparetic spastic stroke survivors and healthy subjects.
Methods: The Achilles tendon length was measured at the affected and contralateral limbs of twelve hemiparetic stroke survivors with ankle spasticity and twelve healthy subjects. The ankle was held at three different angles (20° plantar flexion, 0° and maximum dorsiflexion) while an ultrasound system was used to capture images from the Achilles tendon. Active and passive plantar flexor torque production was measured using an isokinetic dynamometer.
Findings: There was no significant difference in tendon length and Achilles tendon complacency between stroke survivors [affected limb: 20.8 (1.59) cm at 0° and 0.11 (0.09) cm/N; contralateral limb: 20.8 (1.7) cm at 0° and 0.12 (0.08) cm/N] and healthy subjects [20 (2.78) cm at 0° and 0.15 (0.1) cm/N]. The contralateral limb was stronger than the affected limb, while healthy participants presented larger active torque in relation to stroke survivors. There was no significant difference in passive ankle stiffness between the affected [0.43 (0.08) N/°] and the contralateral limb [0.40 (0.11) N/°], but affected limb was significantly stiffer than the healthy subjects [0.32 (0.07) N/°].
Interpretation: The larger passive torque and ankle joint stiffness from stroke survivors with similar Achilles tendon length compared to healthy subjects seem to be unrelated to tendon extensibility.

1. Introduction

Spasticity is defined as a velocity-dependent resistance to stretch, in which there is no inhibition from the antagonistic muscles, followed by an increased resistance to movement and enhanced contraction from the agonist muscles at a given joint (Lance, 1980). This mechanism leads to an increase in tonic stretch reflexes resulting from a hyperexcitability of the upper motor neuron and it is observed in approximately 66% of chronic stroke survivors (Arene and Hidler, 2009). Substantial evidence suggests muscle adaptations from spasticity as the percentage increase in Type I fibers, extracellular matrix proliferation and increases in muscle cells stiffness secondary to abnormalities in motor neuron excitability (Lieber et al., 2004). Studies also observed that spastic muscles have shorter fascicle length and reduced muscle cross-section area (Gao et al., 2009; Kwah et al., 2012; Dias et al., 2016), followed by muscle atrophy (Triandafilou and Kamper, 2012). These changes in mechanical properties of muscle may enforce tendon adaptations.

The mechanical properties of tendons is determined from important elastic and time-dependant characteristics which can influence force transmission, energy storage and return during locomotion, spinal reflexes responses and the way that joint position and movement accuracy are controlled (Magnusson et al., 2008). The plasticity of tendon properties (i.e. stiffness, hystheresis) has been assessed in many studies that observed the adaptations in exercise conditions (Kubo et al., 2010; Urlando and Hawkins, 2007), joint immobilization (Yasuda and Hayashi, 1999; Couppé et al., 2012), tendinopathy (Maffulli et al., 2000; Chimenti et al., 2014), and aging (Kohler et al., 2013; Stenroth et al., 2012). In all these conditions, a high tendon adaptation capacity has been demonstrated.

Recent studies using ultrasonography reported changes in mechanical properties of the Achilles tendon in stroke survivors. Two studies

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(Zhao et al., 2009, 2015) found increased tendon length, decreased stiffness and increased hysteresis for the affected compared to the contralateral limb. These authors suggest that the Achilles tendon is more compliant in the impaired side and it may shift proximally the muscle-tendon junction (Zhao et al., 2009, 2015). On the other hand, another study investigated mechanical properties of calf muscle-tendon unit before and after a passive ankle stretching protocol and observed no significant difference in Achilles tendon length for the affected limb of stroke survivors compared to healthy subjects (Gao et al., 2011). However, we were unable to find studies comparing passive tendon complacency at different joint angles and passive ankle stiffness, which allows the knowledge extent on tendon properties in spastic stroke survivors.

To address the aforementioned gaps, the aim of the present study was to compare the Achilles tendon morphological properties along with the torque production from plantar flexors and passive ankle stiffness between stroke survivors with ankle spasticity and healthy subjects. Comparison to healthy subjects was performed to enhance the knowledge on tendon adaptation in stroke survivors. Based on muscle adaptation and decreased range of motion due to spasticity, our hypotheses were that spastic stroke survivors should have longer Achilles tendon, suggesting a lower resistance of the Achilles tendon to passive stretch related to higher ankle joint stiffness and lower active torque production compared to healthy subjects.

2. Methods

2.1. Subjects

Twelve hemiparetic stroke survivors with ankle spasticity and twelve healthy subjects participated in the study. The inclusion criteria for the stroke patients were the presence of hemiparesis with ankle spasticity confirmed by magnetic resonance imaging and clinical assessment, at least 1 year after the isquemic stroke, being able to walk without any assistance and ability to stay seated for a minimum of 1 h. Exclusion criteria included the history of orthopaedic surgery in any lower limb, musculoskeletal injury, medication treatment for spasticity or the use of orthoses. Ankle spasticity was measured by Modified Ashworth scale (Kulig et al., 1984). Twelve affected limbs and contralateral limbs from stroke survivors and the dominant limbs from healthy subjects were measured. All subjects signed an informed consent form to participate in the study and the experimental protocol was approved by the Universities' Ethics Committee in Human Research where the study was conducted.

2.2. Experimental setup

An isokinetic dynamometer (Biodex Medical System 3, Shirley – NY, USA) was used for position of the ankle joint at three different angles and for assessment of Achilles tendon length, passive and active isometric plantar flexor torques. Participants were seated on the dynamometer chair and were positioned with trunk and hips fixed by adjustable straps, with the knee joint fully extended (Mohagheghi et al., 2008) while the ankle angle was varied according to the protocol. The ankle joint axis of rotation (defined by the center of the medial/lateral malleolus) was aligned with the dynamometer axis and securely attached with Velcro straps at footplate of dynamometer to minimize rotations out of the intended motion plane (Geremia et al., 2015).

An ultrasound system (SSD 4000 – Aloka, Toquio, Japan) with a linear probe (60 mm, 7.5 MHz – Aloka, Toquio, Japan) was used to capture images from the Achilles tendon and soleus and gastrocnemius medialis muscle-tendon junction.

2.3. Experimental design

The experiment consisted of two sessions separated by one week for all participants. Each limb was tested in one session, following the same protocol. Only the dominant leg of healthy subjects was considered for analysis after all procedures. Dominance was determined using the Waterloo inventory (Elias et al., 1998). Full range of motion was measured followed by tendon length protocol and by passive and active torque production at three ankle joint angles.

2.4. Achilles tendon length and passive complacency measurements

The ankle joint was randomly positioned at 20° and 0° of plantar flexion (90° between foot and leg) and maximum dorsiflexion (MDF) for tendon images acquisition using ultrasound. For MDF position participants were instructed to say when the maximum dorsiflexion angle supported was obtained. The Achilles tendon length was obtained by an adaptation of the overlapping images method (Urlando and Hawkins, 2007; Geremia et al., 2015), which allows for the reconstruction of the whole tendon by superimposing partial images of the tendon. Ultrasound images were used to locate the Achilles tendon insertion at the calcaneus notch and muscle-tendon junction (MTJ) at the soleus muscles first and then at the gastrocnemius medialis. Adhesive markers were placed transversely on the leg skin surface at distances shorter than the length of the ultrasound probe (i.e. approximately 5 cm apart), with the first marker placed at the calcaneus notch. The probe was placed longitudinal to the skin surface and moved along the tendon length. The ultrasound technician ascertained that two skin markers were visualized at each image (Urlando and Hawkins, 2007), to enable proper matching of images for reconstruction of the full tendon length in the sagittal plane with muscles at rest. An image editing software (ImageJ, National Institutes of Health, Bethesda, MD, USA) was used to measure the distance between the MTJ of the gastrocnemius medialis and soleus muscles to the Achilles tendon attachment at the calcaneus notch (Fig. 1).

Passive complacency of Achilles tendon was obtained by the relationship between tendon length at the soleus muscle and gastrocnemius medialis, and passive torque. After measuring the tendon length difference between MDF and 20° of plantarflexion at each muscle, this difference was divided by passive torque variation (torque at MDF – torque at 20°). The result was considered passive Achilles tendon complacency.

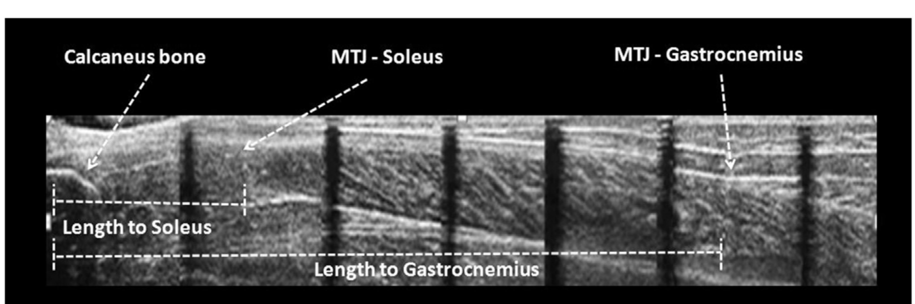

Fig. 1. Images overlapping method for measurement of the Achilles tendon length.