Mechanical Changes of Soleus Muscle Fascicles and Achilles Tendon Post Stroke

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ABSTRACT INTRODUCTION:
Triceps surae muscle tendon complex plays an important role in physical activities such as walking and running. Calf muscle spasticity, contracture, and weakness are commonly observed following stroke (Harlaar et al. 2000), which can be partially attributed to the changes of mechanical properties of soleus muscle fascicles and/or Achilles tendon. Recent studies have shown metabolic activity in human tendon is remarkably high which affords the tendon the ability to adapt to changing demands (Magnusson et al. 2008). It is not clear how calf muscle fascicles change biomechanically and how Achilles tendon responds to the muscle fascicular changes. The purpose of this study was to investigate mechanical changes of the soleus muscle fascicles and the Achilles tendon in stroke survivors using ultrasonography and biomechanical measurements.

METHODS:
Subjects
Six hemiparetic stroke survivors with mean age of 56.3±3.0 years, mean stroke duration of 11.1±6.0 years, mean height of 168.7±12.4 cm, mean body mass of 79.8±19.5 kg, mean modified Ashworth scale 0.8±1.1, participated in the study. Each participant gave written informed consent approved by the Institution Review Board.

Experimental setup
The setup was comprised of a custom knee-ankle joint device, a LOGIQ-9 (GE Waukesha, WI) ultrasound imaging system, an EMG system, and a personal computer. The knee-ankle joint device can fix the knee and the ankle at various positions when ankle joint torque was recorded. The ultrasound video data collection was synchronized with torque and electromyography (EMG) data acquisition by using an analogue trigger.

Experimental design
The study was composed of two visits for each participant, with one visit for each side of the lower limbs in random sequence, following the same protocol. First the subject was seated upright relaxed with knee fixed at 90° flexion. The ankle joint torque was measured across the ankle range of motion and the ultrasound images of the soleus muscle in the sagittal plane at corresponding ankle angles were recorded using an extended field of view technique called LOGIQView™. Then the ankle was fixed at 0° dorsiflexion and the subject performed an isometric plantar flexion effort following the slowly ramping up torque target displayed on the screen. The ankle joint torque signals, EMG signals from tibialis anterior (TA) muscle and the ultrasound video data were recorded.

Soleus muscle mechanical properties evaluation
The Achilles tendon moment arm was calculated by subtracting the distance between the skin and the tendon line-of-action (LOA), from the distance between the skin and the center of rotation (inferior tip of malleolus) measured in sagittal plane. Achilles tendon force was calculated by dividing the ankle joint torque with tendon moment arm. Since the knee was flexed, the Achilles tendon force was considered equal to the soleus muscle force. The length of the soleus fascicle half way between the muscle belly and at the distal end was measured and defined as the average fascicle length. Then the relation between the soleus muscle force and soleus fascicle length was determined. The fascicle stiffness was calculated at 0° dorsiflexion based on the force and length data.

Achilles tendon mechanical properties evaluation
The Achilles tendon resting length was measured using LOGIQView™, and average tendon cross-sectional area (CSA) was measured by scanning the transverse plane. As the subject performed the isometric plantar flexion effort, the movement of soleus-Achilles muscle tendon junction (MTJ) was recorded using ultrasound. An automated block-matching method based on minimum sum of absolute differences (MSAD) (Li et al 2007) was used to track the MTJ displacement. The EMG signals from TA muscle and the heel motion were monitored to make sure no co-contraction and heel motion happened during the plantar flexion effort. The force-displacement relation curve, as well as the stress-strain relation curve was calculated. The tendon stiffness and Young’s modulus were defined as the slope of force-displacement curve and the slope of stress-strain curve at 3% strain, respectively.

RESULTS SECTION:
The mean fascicle length from 6 stroke survivors’ impaired and unimpaired sides at different ankle angles is displayed in Fig. 1. Statistical significance was observed in all ankle joint angles.

DISCUSSION:
According to the results, soleus muscle fascicles became shorter and stiffer post stroke. Probably as adaptation to these changes, Achilles tendon became longer and more compliant, so that less force was needed to elongate the tendon which might help to prevent falls or fatigue in slow movements (Svantesson et al. 2000). Even at a flexed knee position (90°), there still might be a fraction of ankle joint torque attributed to the gastrocnemius (GS) muscle. How GS muscle mechanical properties changes contribute to passive ankle joint stiffness change needs to be further investigated.

The passive Achilles tendon force could be estimated from the ankle joint torque only from the ankle neutral position to the maximum dorsiflexion, because the dorsiflexors would be stretched and contribute to the joint torque when the ankle was moved to plantar flexion. The Achilles tendon Young’s moduli calculated in this study were lower than the values reported in some other studies with muscles under maximal voluntary contraction (Magnusson et al. 2003). This may be related to the sub-maximal contractions within the comfortable torque-generation range for stroke survivors in this study, in which tendon was evaluated near the toe region of the stress-strain curve.

A better understanding of the simultaneous biomechanical changes of the calf muscle fascicles and Achilles tendon will help us gain insight into the mechanisms underlying spasticity and motor impairment post stroke and facilitates development of more effective treatment.

REFERENCES:

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