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# Acute effect of heel-drop exercise with varying ranges of motion on the gastrocnemius aponeurosis-tendon's mechanical properties

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ABSTRACT

The objectives of this study was to investigate the acute effects of various magnitudes of tendon strain on the mechanical properties of the human medial gastrocnemius (MG) in vivo during controlled heel-drop exercises. Seven male and seven female volunteers performed two different exercises executed one month apart: one was a heel-drop exercise on a block (HDB), and the other was a heel-drop exercise on level floor (HDL). In each regimen, the subjects completed a session of 150 heel-drop exercises (15 repetitions × 10 sets; with a 30 s rest following each set). Before and immediately after the heel-drop exercise, the ankle plantar flexor torque and elongation of the MG were measured using a combined measurement system of dynamometry and ultrasonography and then the MG tendon strain and stiffness were evaluated in each subject. The tendon stiffness measured prior to the exercises was not significantly different between the two groups 23.7 ± 10.6 N/mm and 24.1 ± 10.0 N/mm for the HDB and HDL, respectively ($p > .05$). During the heel-drop exercise, it was found that the tendon strain during the heel-drop exercise on a block (8.4 ± 3.7%) was significantly higher than the strain measured on the level floor (5.4 ± 3.8%) ($p < .05$). In addition, the tendon stiffness following the heel-drop exercise on a block (32.3 ± 12.2 N/mm) was significantly greater than the tendon stiffness measured following the heel-drop exercise on the level floor (25.4 ± 11.4 N/mm) ($p < .05$). The results of this study suggest that tendon stiffness immediately following a heel-drop exercise depends on the magnitude of tendon strain.

## 1. Introduction

Tendons serve as the elastic linkage between bone and muscle. Due to the elasticity of tendons, the dynamic interaction between muscle and tendons has been known to influence the functions of the muscle as well as the muscle–tendon complex as a whole (Alexander, 2002; Alexander and Bennet Clark, 1977; Roberts et al., 1997; Roberts and Azizi, 2011).

Considering the functional importance of tendon elasticity, researchers have studied how tendons adapt to an altered loading environment. Previous studies examining the effect of long term exercise on tendon property have demonstrated an increase in the degree of tendon stiffness regardless of the type of exercise; whether it be isometric (Kubo et al., 2001a), eccentric (Duclay et al., 2009; Mahieu et al., 2008), concentric (Morrissey et al., 2011) or plyometric exercise (Fouré et al., 2010). In studies examining acute effects on tendon stiffness, MVICs (Kay and Blazevich, 2009), passive stretching (Kubo et al., 2001b) and isometric leg press (Kubo et al., 2005) all were shown to decrease Achilles tendon stiffness. However, repetitive drop jumps (Kubo et al., 2005) and submaximal voluntary contractions (Mademli et al., 2006) caused no change. These studies have shown that tendon stiffness would decrease after contractions of longer duration and when greater amounts of strain were induced by maximal voluntary contractions. Based on these findings, it is plausible that the magnitude of the tendon strain and the exercise duration are important to alter the stiffness of a tendon.

From a mechanical viewpoint, it has been suggested that the strain magnitude, frequency and duration are critical factors influencing tendon cell functions (Arnoczky et al., 2002; Lavagnino et al., 2003). These studies suggested the existence of a threshold at the applied strain magnitude at which the transduction of the mechanical stimulus may influence the tensional homeostasis of the tendon's extracellular matrix in vitro. Furthermore, an in vivo study by Arampatzis et al. (2007) provided evidence of the existence of a threshold showing that the tendon stiffness only

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increased following a six-week MVIC exercise regimen under high-magnitude tendon strain (4.6%).

Considering the fact that tendon connects with muscle and works as a muscle–tendon complex, tendon stiffness would be an important factor determining the muscle–tendon complex's functions. For examples, changes in tendon stiffness would affect the working range of muscle (Maganaris, 2001) and the transmission of muscle force (Reeves et al., 2003). Studies examining tendon stiffness immediately after stretching and resting have shown a decrease in the tendon stiffness or no change (Kay and Blazevich, 2009; Mademli et al., 2006). However, studies examining how the strain magnitude induces alterations in the tendon stiffness immediately after exercise are scarce.

To investigate the effects of the magnitude of tendon strain on the properties of tendon, we chose two types of heel drop exercises which have different exercise ranges. The aim of the study was to investigate changes in the MG (medial gastrocnemius) tendon stiffness immediately after the two types of heel drop exercises. Based on previous studies, we hypothesized that a greater exercise range during the heel-drop exercises will result in a change in the tendon stiffness immediately after the heel-drop exercises.

## 2. Methods

### 2.1. Participants

Seven male adults (25.0 ± 4.9 years old, 179.5 ± 6.1 cm body height, 75.4 ± 4.5 kg body mass) and seven female adults (24.3 ± 3.0 years old, 165.0 ± 3.3 cm body height, 51.5 ± 5.2 kg body mass) performed two separate exercises. Subjects did not have a history of performing resistance exercise, and written informed consent was obtained from all subjects prior to their participation in the study. This study conformed to the standards set by the Declaration of Helsinki and was approved by the local ethics committee.

### 2.2. Exercise protocols

Two exercises were completed in this study: (1) HDB (heel-drop exercise on a block) and (2) HDL (heel-drop exercise on a level floor). The two exercises were performed one month apart, and the order of the exercises was randomized. For each exercise, the subjects completed a session of 150 heel-drop exercises (15 repetitions × 10 sets; with a 30 s rest following each set). One leg (the dominant leg) was exercised only in the drop phase, with the other leg (non-dominant leg) used to raise the body back to the start position of the full plantar flexion of the dominant leg. The frequency of the heel-drop exercise was 0.5 Hz. It was necessary to use a set frequency for the exercise to ensure that the heel-drop motion applied an appropriate amount of load to the tendon. Therefore, we instructed subjects to maintain the frequency of the heel-drop exercise (0.5 Hz) by matching it to a metronome signal (Optimus LTE, LG, Korea). In the HDB, the exercise range was from full plantar flexion to the maximum possible dorsiflexion; in the HDL, the exercise range was from full plantar flexion to immediately before the heel touched the floor surface.

### 2.3. Tendon stiffness

The stiffness levels of the MG tendon were examined by measuring the ankle joint moments and the MG tendon elongation using a custom-built torque dynamometer and a linear array ultrasound probe (Aloka 7.5 MHz UST-5712 linear-array probe, Japan), respectively. Before and immediately after the heel-drop exercise, all subjects were seated on the dynamometer with their ankle angle at 10° plantar flexion, the knee fully extended and the hip flexed at 120°. In this position the subjects performed ramp contraction movements for 3 s and then maintained the maximum isometric contraction for 3 s. To avoid malalignment between the axis of the dynamometer and the ankle joint, the ankle was firmly attached to the dynamometer using a Velcro® strap. However, it was previously demonstrated that it is difficult to avoid joint rotation when performing isometric contractions and that the resulting ankle rotation may influence the results (Arampatzis et al., 2005a). Thus, to correct for ankle joint rotation, we used the method introduced by Fletcher et al. (2010). To avoid antagonistic contraction of the tibialis anterior muscle while performing ankle plantar flexion movements, we monitored the EMG amplitude of the tibialis anterior muscle as visual feedback. We instructed all subjects to contract with minimum co-contraction. If subjects performed co-contraction, they were re-examined after practicing ankle plantar flexion without co-contraction.

The stiffness of the medial gastrocnemius tendon was calculated based on the slope of the tendon force versus the tendon elongation curve measured above 50% of the maximum tendon force by means of linear regression (Kubo et al., 2001a). The medial gastrocnemius tendon force was estimated by dividing the plantar flexion moment by the portion of the MG physiological cross-sectional area (PCSA) about all plantar flexors PCSA (Fukunaga et al., 1996), and by the tendon moment arm, as obtained from a previous study (Maganaris, 2004). Although there are individual anatomical differences in the moment arm, these differences did not affect the findings because we compared the same leg in the HDB and HDL and in the pre and post-exercise tests.

### 2.4. Tendon strain

To determine the tendon length from the Achilles tendon insertion to the distal end of the MG, we used the method described by de Monte et al. (2006). Several 8 mm markers were placed along the Achilles tendon from the calcaneus to the distal end of a linear probe on the medial gastrocnemius; a linear probe was then used to measure the distance between the musculotendinous junction and a marker at the proximal end (Fig. 1). We calculated the tendon strain using the resting tendon length and the tendon length during the heel-drop exercise. The resting tendon length was measured in participants who were in a prone position on a bed with their ankle extending over the edge of the bed at an angle of 110°. Measurements of the tendon length during the heel-drop exercise were taken during five of the ten sets.

### 2.5. Statistical analyses

A two-way analysis of variance (ANOVA) with one-repeated-measurement factor and one between-group factor was used to analyze the effects of time (pre, post) and exercise protocols (HDL, HDB) of the tendon stiffness. In case of a significant interaction, paired and independent *t*-test were conducted to test the difference between before and after the heel-drop exercises and between exercise protocols, respectively. We assumed that if the comparison of the tendon stiffness between the HDB and the HDL at pre-exercise was not significant and the comparison between the HDB and the HDL at post-exercise was significant, then the heel-drop exercise modality had an effect on the tendon stiffness. A paired *t*-test was conducted to test the changes in the ankle moment between before and after the heel-drop exercises. An independent *t*-test was used to evaluate the differences in the tendon strain between the HDB and HDL. The level of significance was set to $\alpha = 0.05$. All data are presented as the mean ± SD (standard deviation). All statistical analyses were performed with SPSS software (SPSS version 16.0).