ACHILLES TENDON ADAPTATION
DURING STRENGTH TRAINING IN YOUNG ADULTS

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INTRODUCTION

Skeletal muscle strength (Weiss, et al., 1988) and tendon properties (Józsa and Kannus, 1997) change in response to new physical demands. However, little is known about the interactions between muscle strength changes and tendon property changes in functional muscle-tendon units in-vivo. The purpose of this study was to investigate human muscle-tendon units in-vivo and to test the hypothesis that tendons adapt to muscle strength training to maintain strains within a preferred operating range.

METHODS

The Gastrocnemius/Soleus-Achilles tendon complexes of 11 male subjects, age 24.8 ± 3.2 years (mean ± SD), mass 78.5 ± 9.3 kg and height 177.7 ± 8.0 cm, were studied. Subjects performed an eight-week strength-training program consisting of three weekly sessions separated by at least one day of rest. The strength-training sessions consisted of three sets of ten heel-raising lifts involving 70% of the subject’s maximum effort.

Subjects were tested before and at the end of the first, second, fourth, sixth and eighth week of the strength training program. Lower leg volume was measured by water immersion at the start of each testing session. Subjects kneeled on a custom bench and performed isometric plantar flexion efforts (Figure 1). Plantar flexion force was quantified using a load cell secured to the custom bench on one side and attached to a foot jig on the other. A Hitachi EUB 405 PLUS Ultrasound system, with a 64 mm-7.5 MHz linear probe was used to obtain images of the Achilles tendon, defined as the region between the calcaneus bone-Achilles tendon junction or notch and the Achilles tendon-soleus muscle junction (MTJ).

Figure 1. The basic setup used to quantify tendon length during isometric muscle efforts.

The ultrasound probe length limited the portion of Achilles tendon that could be imaged at one time to about 60 mm. A hollow one millimeter diameter plastic rod was secured to the subject’s skin with tape and spray adhesive. Proximal and distal Achilles tendon images were obtained by placing the ultrasound probe between the calcaneus bone and the plastic rod (REF) and by placing the ultrasound probe between the plastic rod and the MTJ respectively (Figure 2). Subjects performed six isometric plantar flexion efforts ranging from rest to their maximum voluntary contraction. Each section of the Achilles tendon (i.e. proximal and distal) was imaged three times during the six isometric plantar flexion efforts.
Tendon length and strain were determined from the ultrasound images. Snappy™ 4.0 (by Play®) was used to capture and digitize ultrasound video images that corresponded to the specified effort levels. Scion Image, an image analysis program, was used to digitize these images and quantify Achilles tendon lengths and cross sectional areas. The lengths of the Achilles tendons during the various plantar flexion efforts were obtained by combining images of the proximal (D2) and distal (D1) sections (Figure 2). Strain was calculated from these lengths.

**Figure 2.** Longitudinal images of the Soleus muscle-Achilles tendon-Calcaneus bone created from proximal and distal ultrasound images.

### RESULTS AND DISCUSSION

The group’s average percent increase in maximum Achilles tendon force from baseline to the eighth week of training was statistically significant and equal to 22.4%. The group’s average percent increase in soleus volume from baseline to the eighth week of training was also statistically significant, equal to 7.7%. Maximum Achilles tendon strain ($\varepsilon_{\text{max}}$) values ranged between 0.006 mm/mm and 0.135 mm/mm throughout the study. Six of the eleven subjects had an initial increase in $\varepsilon_{\text{max}}$ followed by a return to baseline by week 8. The remaining five subjects had an initial decrease in $\varepsilon_{\text{max}}$ followed by a return to baseline in two subjects. Average stress-strain curves were computed for the entire group (Figure 3). Stress-strain curves shifted to the left initially and then back to the right from week 6 to week 8. Alterations in the initial non-linear portion rather than alterations in tendon stiffness appear responsible for shifts in the stress-strain curves.

On average, tendons appeared to have preferred strain limits that were maintained as muscle strength increased supporting the study’s hypothesis. The magnitude of these limits or “set-points” varied between individuals as did the initial tendon strain responses to strength training.

**Figure 3.** Average stress-strain curves showing the group’s response to the strength-training program.

### REFERENCES
