Effects of Muscle Atrophy on the Heterogeneity of Strain Distribution and Other Characteristics of the Human Triceps Surae Muscle-Tendon Complex

D. Shin[1], H. Lee[2], S. Ahn[1], J. Hodgson[3], T. Finni[2], R. Edgerton[1,3], S. Sinha[1,2]

[1]Biomedical Engineering, University of California, Los Angeles, CA, United States, [2]Radiological Sciences, University of California, Los Angeles, CA, United States, [3]Physiological Sciences, University of California, Los Angeles, CA, United States

Objectives: PC MRI has proven to be an invaluable tool for quantitative measurement of velocity of skeletal muscle motion in vivo. Our group previously has reported[1] heterogeneous strain distribution in the human soleus aponeurosis-tendon complex during sub-maximal voluntary contractions. The objective of this study was to further examine the effects of unilateral lower limb suspension (ULLS) and subsequent rehabilitation on the strain dynamics of the posterior soleus aponeurosis-tendon complex, as well as volume and strength of the triceps surae muscles (medial gastrocnemius, lateral gastrocnemius, and soleus). The former is analyzed by velocity encoded phase contrast imaging technique while the latter is analyzed by 3D volume rendering and torque analysis.

Materials and Methods: Atrophy was induced by chronically unloading of one lower leg with 4 weeks of unilateral limb suspension in twelve healthy volunteers (after IRB approval). Strain was determined along the aponeurosis-tendon complex at torque levels approximating 10, 20 and 40% of pre ULLS MVC, using an in-house developed algorithm (MATLAB) after acquisition of velocity-encoded (VENC = 10 cm/s) phase contrast cine images. Sobel edge detection scheme was used to identify and track ROIs along the entire aponeurosis. A standard FLASH 2D PC sequence with TR/TE/FA: 10.2ms/7.6ms/30^{o}, 5 mm slice thickness, 199 kHz receiver bandwidth, 3 segments, 3 averages, 144x256 matrix, 240x320mm FOV, was used in the prospectively gated mode to acquire 20 phases during the isometric contraction cycles. For the measure of volume of different muscle groups, a stack of axial slices, 7 mm think, were acquired using a proton density weighted TSE sequence across the entire length. Muscle volumes were calculated with commercial image analysis software (Vitrea). MVC, PC and morphological axial image acquisition, were repeated for each subject before and after the ULLS and during the subsequent rehabilitation period (0, 1, 3, 6 weeks).

Results and Discussion: All subjects involved in the study showed positive strain in the Achilles tendon and negative strain in the posterior aponeurosis during the plantar flexion (Figure 1). Positive strain implies elongation in reference to initial length while negative strain implies shortening. Maximum strain at the Achilles tendon ranged from 4% to 8% with increasing peak strain observed at higher MVC. Differentiating the maximum displacement revealed that the spatial strain distribution in soleus aponeurosis and Achilles tendon was inhomogeneous (Figure 2). Segments with positive slope imply compression (negative strain) while those with negative slope imply elongation (positive strain). Strain dynamics along aponeurosis-tendon complex changed among 60% of the subject population before and after ULLS and during subsequent rehabilitation (Figure 2). 40% of the subjects, on the other hand, didn't exhibit significant change in the strain dynamics. Possible sources of this variability include varying degree of activity among subjects after ULLS (different muscle adaptation rate) and inherent individual difference in muscle recruiting pattern.

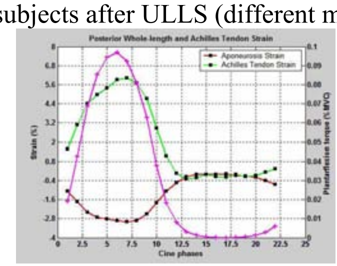


Fig. 1: Aponeurosis and Achilles tendon strain during one plantar flexion cycle.

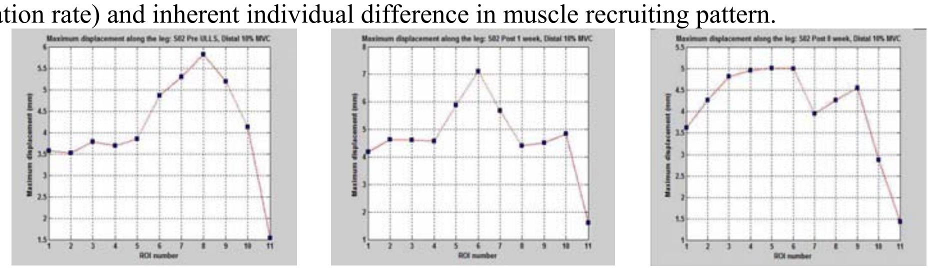
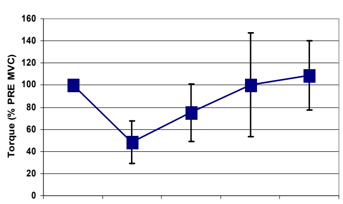
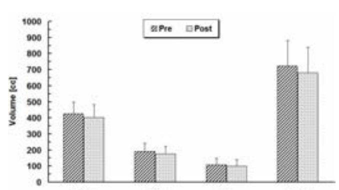


Figure 2: Maximum displacement along the aponeurosis-tendon complex. Representative data from one subject at 10% MVC.





Following the ULLS, MVC ankle plantarflexion torque decreased by almost 60 % (39.8 ± 13.6 % MVC). Muscle strength gradually increased and fully recovered (118.5 ± 35.8 % MVC) at the end of resistance-based rehabilitation therapy. The relative volume of each muscle compartment to the total volume (SOL+MG+LG) remained constant following the ULLS. For individual muscles, the soleus volume decreased from 425.7 ± 26.5 to 403.8 ± 27.9 cc ($p < 0.05$: 5.5 % loss) and the medial gastrocnemius decreased from 191.1 ± 17.9 to 175.8 ± 16.7 cc ($p < 0.05$: 7.5 % loss), but the lateral gastrocnemius volume did not change significantly.

Conclusion: This noninvasive methodology shows the potential to quantify functional and anatomical changes in tissue and distinct components of the triceps surae complex in response to chronic unloading. The implications of these marked changes in tissue function depending on the adaptive state has clear applications regarding the potential use of dynamic in vivo imaging as a diagnostic tool for musculoskeletal injuries and in assessing functional recovery following prolonged unloading as occurs in the microgravity environment.

References: Finni T, Hodgson JA, Lai AM, Edgerton VR, Sinha S. Nonuniform strain of human soleus aponeurosis-tendon complex during submaximal voluntary contractions in vivo. J Appl Physiol. 2003 Aug; 95(2):829-37.