Changes in Achilles Tendon Compliance from 30 Days of Chronic Unloading and Subsequent 3 Weeks of Rehabilitation – An MR Phase Contrast Study at 3T

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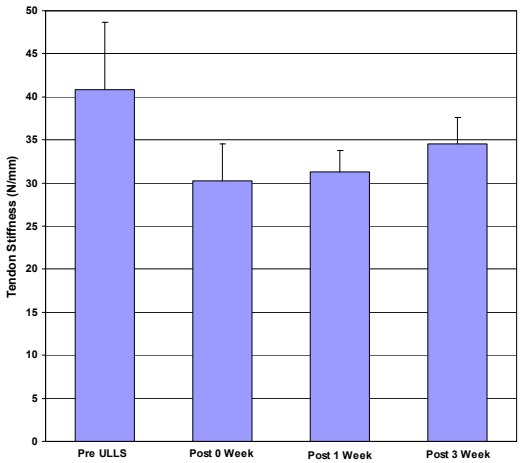
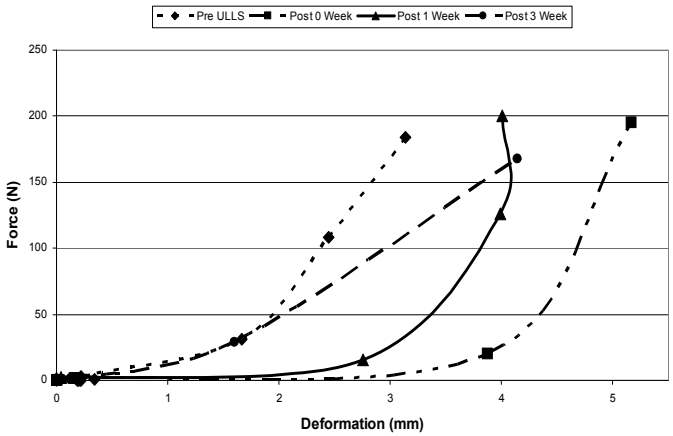
Introduction: Muscle atrophy induced by chronic unloading is associated with a number of musculoskeletal changes. Our group previously[1] reported significant reduction in muscle strength and volume, which are well studied because of their obvious clinical relevance. Passive structures such as the tendon are of considerable significance in their role as components that transmit force from the activated muscle to the skeletal system to produce motion. The structural and mechanical changes from chronic unloading of the tendon are likely translated to overall deterioration of function of the musculo-skeletal system.

Objective: To use phase contrast cine magnetic resonance imaging (PC MRI) to monitor the changes in the compliance factor of the Achilles tendon, between the normal state, immediately after 30 days of unloading and subsequently during 3 weeks of physical rehabilitation.

Materials and Methods: Six subjects were recruited for this study after Institutional approval. One leg was subjected to chronic unloading from 30 days of unilateral lower limb suspension (ULLS) to induce muscle atrophy. Immediately after ULLS, the subjects were given weekly physical rehabilitation for 3 weeks. MRI was performed using a multi-channel, phased array torso coil inside a 3.0T Siemens Trio scanner with a FLASH 2D PC sequence (VENC: 10 cm/s, TR/TE/FA: 13.3 ms/7.5 ms/20^o, 3 mm slice thickness, 290 Hz receiver BW/pixel, 3 segments, 2 averages, 128x256 matrix, 160 mm x 320 mm FOV in the retrospective gated mode to acquire 80 ms temporal resolution 22 phases during 86 isometric contraction cycles). Plantar flexor force was recorded during the repetitive isometric contractions using a pre-calibrated strain transducer located under the sole of the cast, synchronized with an audio cue. Its output was also used to gate the PC cine acquisition, and to provide a visual feedback to the subject for consistent force level exerted. The same scan protocol was repeated for each subject at 10%, 20% and 40% MVC levels per session repeated at different time periods, i.e. before ULLS, immediately after ULLS, 1, 2, 4, 6 weeks after physical rehabilitation. Exactly the same sagittal oblique slice orientation was used to visualize the tendon from the calcaneous to the insertion of the medial gastrocnemious to monitor the Achilles tendon stiffness changes. Achilles tendon force was estimated by multiplying the force measured at the sole of the foot to the previously published ratio[2] of 2.67. Displacement was calculated by placing two pixels (on the calcaneous and at the Soleus insertion point) and tracking their trajectories during the plantar flexion. For stiffness calculation, force and displacement pairs were plotted and the linear regression was used for slope estimation, i.e. stiffness.

Results and Discussion: Using the PC MR technique, the pre ULLS average tendon stiffness was determined to be 42.33 (19.28) N/mm. 26% reduction ($P < 0.01$) in tendon stiffness was observed following unloading (post 0 week). The stiffness gradually increased toward the pre ULLS level, though still 10% below the pre ULLS level. Figure 2 shows representative Achilles tendon force-deformation relation for one subject. The stiffness value is smaller than literature findings, partially because tendon stiffness was estimated over a small force interval (0 to 250 N). Repeatability of stiffness measurement using PC MR was confirmed by getting the same value at different force levels (% MVC).





Conclusion: The PC MR technique in conjunction with the developed algorithm was successful in quantifying the changes in Achilles tendon compliance from 30 days of chronic unloading. This resulted in a reduction of the Achilles tendon stiffness possibly due to changes in the material properties of the tendon in combination with altered muscle activation pattern. The stiffness gradually recovered near pre ULLS level over time as the homeostatic mechanism of the body was instigated.

References: [1]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

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