# Changes in Structure-Function Characteristics of the Human Soleus Muscle-Tendon Complex from Atrophy Induced by Limb Suspension – a MR Phase Contrast Study at 3T

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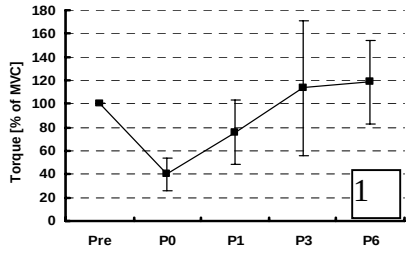
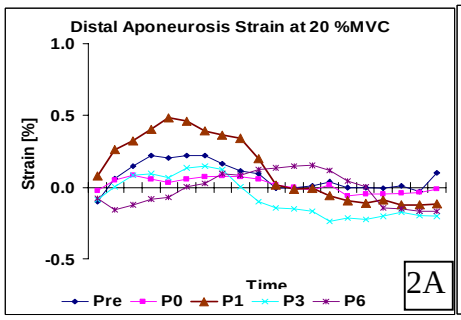
**Introduction:** In most skeletal muscles, muscle fibers connect to bones via aponeurosis and tendon. It has been well established that the tendinous structures play important roles in the muscuoskeletal system in terms of their elastic and viscoelastic properties. However, the functional implications of these tendinous structures with respect to human muscles, has not been investigated before in vivo in either normal or atrophied muscles. MRI, particularly with the recent enhancements in performance, provides a powerful tool to map the structure and characterize the function non-invasively with a resolution hitherto not possible. Our objective in this study was to determine, in a cohort of normal subjects, the effects of atrophy induced by unilateral limb suspension (ULLS), and subsequent rehabilitation. The changes investigated included muscle volume, the torque levels using MR compatible dynamometry, and strain characteristics of aponeurosis, tendon and muscle in human soleus muscle using velocity encoded phase contrast imaging at 3T.

**Methods:** Four healthy subjects (3 men and 1 woman; 28 ± 4 yr.; 79.3 ± 7.2 kg; 174.7 ± 8.1 cm) were subjected to 4-week of ULLS (after IRB approval) followed by 6-week rehabilitation. During the suspension period, one of their legs was lifted above the ground level by means of a Velcro strap, going around their waist, and an elevated heel on the other leg. Compliance (even to the extent of not driving a stick-shift car) was confirmed daily by telephone and clinical condition was monitored weekly. Before and after the ULLS and during the subsequent rehabilitation period, the maximum isometric ankle plantarflexion torque (MVC) and strain was determined along the posterior aponeurosis of the soleus at constant torque levels of 10 and 20 % pre-ULLS MVC. Using the combined method of velocity-encoded phase contrast magnetic resonance imaging (PC-MRI) and a MR-compatible dynamometry, described previously[1,2], velocity at each pixel point in a sagittal image through the ridge in the aponeurosis bisecting the soleus was determined. A turboFLASH sequence with TR/TE/FA: 61ms/7.6ms/30°, 5 PE levels/view, 3 Avg, 256x144 matrix, with pixel resolution of 1.25 x1.25mm, 320mm FOV, was used in the prospectively gated mode to acquire 20 phases during the isometric contraction cycles. The force exerted on the foot of the cast, sensed by an optical Fabry-Perot interferometer, was (i) used for triggering (ii) digitized and stored for subsequent force-strain analysis and (iii) digital video-projected to the face of the magnet as a feedback to the subject to maintain consistent force levels during the ~90 contraction cycles. Extensive calibration was performed to validate the accuracy of the velocity quantification[2].

**Results** Following the ULLS, ankle plantarflexion torque decreased almost 60 % (39.8 ± 13.6 % MVC) (Fig. 1). Muscle strength gradually increased and fully recovered (118.5 ± 35.8 % MVC) at the end of resistance-based rehabilitation therapy (Fig. 1). Muscle atrophy was limited to about ~8~10%. However, strain characteristics of the proximal and distal soleus posterior aponeurosis during an ankle plantarflexion at 10 and 20 % MVC were altered following the ULLS and did not recover to those obtained before the ULLS (Fig. 2).



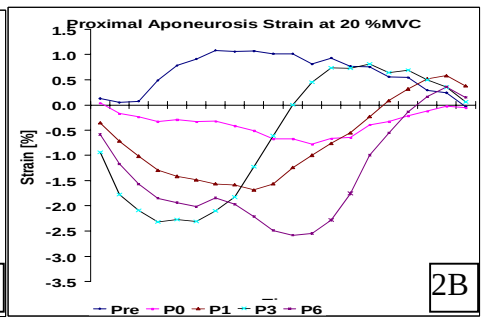




**Fig. 1. Maximum isometric ankle plantarflexion torque (Mean ± 1SD) before (Pre) and after (P0) and during 1, 3, and 6th week of rehabilitation (P1, P3 and P6). Figure 2. Strain of the distal (a) and proximal (b) soleus posterior aponeurosis during isometric plantarflexion at 20 % of MVC before (Pre) and after (P0) and during 1, 3, and 6th week of rehabilitation (P1, P3 and P6)**

**Discussion:** This study showed that the maximum excursion and distribution of strain of the soleus aponeurosis changed following the 4-week ULLS and although strength recovered fully following 6-week rehabilitation, strain characteristics did not, suggesting that changes in strain distribution of the SOL aponeurosis following ULLS was probably due to altered stiffness of aponeurosis in combination with altered muscle activation pattern. The decrease in muscle force was out of proportion to the amount of atrophy suggesting that other factors such as recruitment were affected by 4 weeks of unloading. Knowledge about how the muscle velocity changes as atrophied muscle recovers may be a valuable clinical parameter to quantify the progress of recovery and efficacy of different therapeutic strategies for recuperation

**References**

1. Drace JE, Pelc NJ. JMRI 4:157-163, 1994
2. Sinha, S., Hodgson, J.A., Finni, T., Lai, A.M., Grinstead, J., Edgerton, V.R. JMRI Dec. 2004.

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