Ultra-short Echo Imaging of Cyclically Loaded Rabbit Patellar Tendon

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Introduction: Magnetic resonance imaging (MRI) is frequently used to detect tendon tears due to its high specificity and sensitivity (1), but standard MR evaluations use water-sensitive pulse sequences which require fluid imbibition at the tear site to generate differential contrast. Direct visualization of a tendon is challenging because the highly organized ultrastructure of the tissue produces strong dipole-dipole interactions resulting in very short $T_2$ values (~5 ms) and, in turn, limited signal intensity in generated images. Ultra-short echo (UTE) sequences acquire images at echo times of ~1ms to display contrast within a tendon, and allow for quantitative $T_2^*$ calculation (2). Previous studies have found prolonged $T_2^*$ in the presence of tendinopathy (3), and $T_2^*$ has been correlated to the structure and composition of the knee meniscus (4), also a highly ordered fibrocartilaginous structure. Few studies have evaluated changes of tendon MR parameters (e.g. $T_1$, $T_2$, diffusion coefficients) in a loaded environment (5). The purpose of this study was to determine the effect of cyclic loading of tendon on corresponding $T_2^*$ values.

Methods: Eight lower extremities from 4 rabbits were obtained from a local abattoir. The quadriceps, patellar tendon and proximal portion of the tibia were prepared en bloc and scanned on a 3T clinical system (GE Healthcare, Waukesha, WI) with an 8 channel wrist coil (Invivo, Gainesville, FL). The tendon was oriented parallel to $B_0$ to minimize magic angle effects. Two dimensional (2D) fast-spin-echo (FSE) images were acquired in the sagittal and coronal planes with parameters: echo time (TE): 24 ms, repetition time (TR): 4000 ms, receiver bandwidth (RBW): ±50 kHz, acquisition matrix (AM): 512x256, number of excitations (NEX): 2, field-of-view (FOV): 8cm, slice thickness (SL): 1.7mm. Axial multi-slice multi-echo 2D UTE images were acquired: TEs=0.05, 5, 10, 15 ms, TR=350 ms, RBW=±62.5 kHz, AM=512x701, NEX=2, flip angle = 45°, ST= 3mm, slice spacing = 1mm. Following UTE scanning, the tendons underwent manual loading to 45 N for 100 cycles at approximately 1Hz using a spring scale and fishing line secured through the patella and tibia. MR imaging was repeated. Tendons were kept moist throughout loading and imaging, with saline and a bathing solution, respectively. Image Analysis: $T_2^*$ values were calculated from the UTE images by fitting the TE to the corresponding signal intensity: $SI(TE)=S_0*e^{-TE/T_2^*}+C$, where $SI(TE)$ is the signal intensity at TE, $S_0$ is proportional to proton density, $T_2^*$ is the time constant, and $C$ is a constant to account for noise. Regions of interest were placed in the center of the mid-substance portion of the tendon.

Statistical Analysis: A Wilcoxon rank sum was performed (Mathworks, Natick, MA) to detect differences of tendon $T_2^*$ values between the between the loaded and unloaded configurations. Significance was set at p<0.05.

Results: A majority (75%, 6/8) of the tendons had significantly shorter patellar tendon $T_2^*$ values after cyclic loading, p=0.0004. The remaining tendons had prolonged $T_2^*$ values, but the difference was not significant (Fig 1).The variability of $T_2^*$ followed the trend of $T_2^*$ (Fig. 2). One sample had boney failure at the patella after 88 cycles due to friction by the load application method.

Discussion: This study evaluated the effects of cyclic loading on rabbit patellar tendon $T_2^*$ values. Most tendons experienced shortening of $T_2^*$ and $T_2^*$ variability following loading, indicating stronger proton spin-spin interactions due to greater tissue organization from the uncrimping of collagen fibrils and the lateral contraction of the tendon during loading. A similar effect of shortened $T_2^*$ values due to collagen organization has been seen in compressed articular cartilage (6). Two tendons experienced prolongation of $T_2^*$ even though the loading was under 10% of the monotonic failure strength of rabbit patellar tendon (7), and the ROIs were placed in the core of the tendon to prevent potential volume averaging from the external surface of the tendon from influencing the results (5). Limited damage from the imposed loading may have prolonged the $T_2^*$ values (4). The increase was found through the length of the tendon and not at any specific location. Future studies will continue to examine the effects of loading on tendon $T_2^*$ as well as the change of local water content.

Significance: Changes of tendon $T_2^*$ values due to loading may indicate level of tissue organization and the presence of collagen fibril disruption.

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Tendons With Decreased $T_2^*$

- Before Loading
- After Loading

* $p = 0.0004$

Tendons With Increased $T_2^*$

- Before Loading
- After Loading

Figure 1. Rabbit patellar tendon $T_2^*$ values before and after cyclic loading.

Figure 2. $T_2^*$ maps of rabbit patellar tendon. A – $T_2^*$ values prior to loading are elevated and have high variability. B – $T_2^*$ values after loading are shorter and have reduced variability.

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