Ultra-short Echo Imaging of Cyclically Loaded Rabbit Patellar Tendon

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Target Audience: Clinician scientists, radiologists, and orthopaedic surgeons with an interest in the effect of mechanical loading on quantitative magnetic resonance imaging of tendons.

Purpose: 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 in 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 fibrocartilagenous structure. Few studies have evaluated changes of tendon MR parameters (e.g. T_1, T_2, diffusion coefficients) in a *loaded* environment[5] or to determine the effects of a freeze-thaw cycle. The purpose of this study was to determine the effect of cyclic loading of tendon on corresponding T_2^* values.

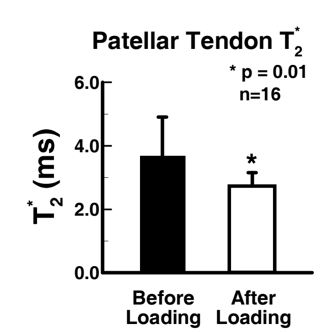

Figure 1. Rabbit patellar tendon T_2* values before and after cyclic loading.

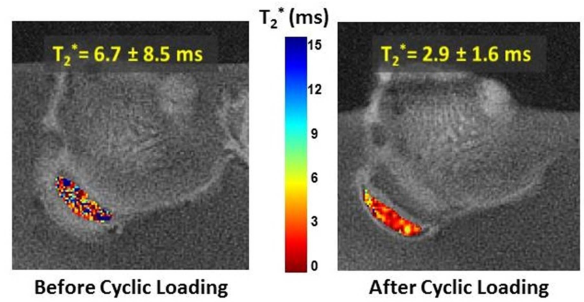

Figure 2. T_2^* maps of rabbit patellar tendon. A – T_2^* values prior to loading are elevated and have high variability. B – T_2^* values after loading are shorter and have reduced variability.

Methods: Eight frozen and 8 fresh rabbits were obtained from a local abattoir. The frozen specimens (4°C) were thawed at room temperature for 12 hours prior to preparation. The quadriceps, patellar tendon and proximal portion of the tibia were prepared en block 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_o 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. <u>Image Analysis</u>: T_2^* values were calculated from the UTE images by fitting the TE to the corresponding signal intensity: $SI(TE)=S_o*e^{(-TE/T_2^*)}+C$, where *SI (TE)* is the signal intensity at *TE*, *So* is proportional to proton density, T_2^* is the time constant, and *C* is a constant to account for image noise. Regions of interest were placed in the center of the mid-substance portion of the tendon. <u>Statistical Analysis</u>: An independent two-sample t-test was performed (SAS v9.3, Cary, NC) to detect differences of tendon T_2^* values between fresh and frozen samples prior to loading. A paired t-test was performed to detect differences of tendon T_2^* values between the between the loaded and loaded configurations. Significance was set at $p<0.05$.

Results: No difference of T_2* was found between the fresh and frozen samples prior to loading, p=0.85, and the two groups were combined for further analysis. The tendons had significantly shorter T_2^* values after cyclic loading, p=0.011. The variability of T_2^* also reduced due to the imposed loading (Figs 1 & 2). A majority (69%, 11/16) of the tendons had shorter patellar tendon T_2^* values after cyclic loading with the remaining tendons experiencing limited T_2^* prolongation of ~0.5 ms. One sample had bony failure at the patella after 88 cycles due to friction by the load application method. Repeat occurrences were minimized by using fishing line from a different manufacturer.

Discussion: This study evaluated the effects of a single freeze-thaw cycle and 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]. Four 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.

Conclusion: 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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