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, 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 T2* 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 T2* calculation. Previous studies have found prolonged T2* in the presence of tendinopathy, and T2* has been correlated to the structure and composition of the knee meniscus, also a highly ordered fibrocartilagenous structure. Few studies have evaluated changes of tendon MR parameters (e.g., T1, T2, diffusion coefficients) in a loaded environment 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 T2* values.

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 in 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 B0 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): 8 cm, slice thickness (SL): 1.7 mm. Axial multi-slice multi-echo 2D UTE images were acquired: TEs=0.05, 5, 10, 15 ms, RBW=±62.5 kHz, AM=512x701, NEX=2, flip angle = 45°, ST=3 mm, slice spacing = 1 mm. 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: T2* values were calculated from the UTE images by fitting the TE to the corresponding signal intensity: $SI(TE) = S_0 e^{-T2* TE / T1} / C$, where SI (TE) is the signal intensity at TE, $S_0$ is proportional to proton density, $T2*$ 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. Statistical Analysis: An independent two-sample t-test was performed (SAS v9.3, Cary, NC) to detect differences of tendon T2* values between fresh and frozen samples prior to loading. A paired t-test was performed to detect differences of tendon T2* values between the loaded and unloaded configurations. Significance was set at p<0.05.

Results: No difference of T2* 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 T2* values after cyclic loading, p=0.011. The variability of T2* also reduced due to the imposed loading (Figs 1 & 2). A majority (69%, 11/16) of the tendons had shorter patellar tendon T2* values after cyclic loading with the remaining tendons experiencing limited T2* 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 T2* values. Most tendons experienced shortening of T2* and T2* 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 T2* values due to collagen organization has been seen in compressed articular cartilage. Four tendons experienced prolongation of T2*, even though the loading was under 10% of the monotonic failure strength of rabbit patellar tendon, 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. Limited damage from the imposed loading may have prolonged the T2* values. 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 T2* as well as the change of local water content.

Conclusion: Changes of tendon T2* values due to loading may indicate level of tissue organization and the presence of collagen fibril disruption.


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