Ultrashort Echo Imaging (UTE) of Rotator Cuff Repair in an Ovine Model

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Introduction. Intact rotator cuff musculature and the associated tendons are required to transmit forces to the proximal humerus during activities of daily living. Postoperative assessment of surgically repaired tissue has largely relied upon qualitative assessment of tendon signal intensity and morphology (1).Ultra-short echo imaging is capable of displaying signal from tendons (2) and from knee meniscus (3) and may provide a method to quantitatively assess the state of repair in the rotator cuff. The purpose of this pilot study was to assess the feasibility of UTE imaging to evaluate the repair of the infraspinatus tendon in a pre-clinical ovine model.

Materials and Methods. Six adult sheep were used in the current pilot study. The central third of the infraspinatus tendon was resected from its insertion site and reattached using suture anchors. A proprietary scaffold spanning the full tendon width was sutured along the operative site to augment tendon to bone healing. Animals were euthanized at 8 weeks and the shoulders were immediately prepared for MR imaging. Image Acquisition: All scanning was performed using a 3T clinical MRI system and an 8-channel phased array knee coil. Morphologic axial and sagittal PD FSE images were acquired with the parameters: TE: 36 ms, TR: 4700 ms, ETL: 20, BW: ±62.5 kHz, Matrix: 512x416, FOV: 13 cm, slice thickness: 1.2-3.2 mm, slice spacing: 0 mm. The axial images were oriented to display the full extent of the supraspinatus tendon from the muscle-tendon junction to the enthesis. Axial UTE images were acquired for T2* analysis. Scanning parameters were: TE: 0.3, 5.4, 10.7, 16.0 ms, TR: 350, flip angle: 45°, slice thickness: 2.0 mm, slice spacing: 0.4 mm, FOV:13cm, BW: ±125 kHz, Freq: 512, Phase:1201, NEX: 2. All scanning of an individual specimen required approximately 1 hour. The contralateral shoulder of one sheep was also scanned and considered as a control specimen for T2* calculations. Image Analysis: The signal intensity of morphologic images was evaluated at 7 anatomic locations: normal tendon, reattachment point of tendon (lateral, central, medial) and of the tendon repair (medial, central, lateral) and at the enthesis in control shoulders. Images were also evaluated for formation of gap, synovitis and bone marrow edema. Custom written software (Matlab, Mathworks, Natick, MA USA) was used to calculate T2* values on a pixel-by-pixel basis by fitting the echo time to the corresponding signal intensity data using a monoexponential offset equation: $SI(TE) = So*exp(-TE/T2*)+C$. The tendon was divided into three equally sized regions of interest (ROIs): enthesis, mid-tendon and muscle-tendon junction regions. A bulk average T2* value was calculated from all pixels within each ROI and used for subsequent analysis. Statistical Analysis: One-way repeated measures ANOVAs were performed to detect differences of signal intensity from FSE images across the examined tendinous regions and to detect differences of T2* values across the three defined ROIs. A Student-Newman-Keuls (SNK) post hoc test was performed when statistical significance was found. A one sample T-test was performed to evaluate differences of T2* between the test and control shoulders across the three ROIs. Statistical significant was set at $p<0.05$.

Results. A significant difference was found in average signal intensity in the PD FSE images, p=0.0002. All surgically involved ROIs had significantly higher signal intensity than the normal tendon. All surgically repaired shoulders had a gap formation, 17.8±8.1 mm (mean ±std.dev.). Bone marrow edema was evaluated as mild (< 1cm^2) in three shoulders and as moderate (1-2 cm^2) in one shoulder. Synovitis was also present in the shoulders with bone marrow edema. Significant differences of T2* values were found at the enthesis (p=0.0006), mid-tendon (p=0.045) and muscle-tendon junction (p=0.007). The T2* values reduced in magnitude from the enthesis to the mid-tendon region to the muscle-tendon junction (Figure 1), but the changes in T2* were not significant along the length of the tendon, p=0.06. Representative FSE images and T2* maps of supraspinatus tendons are shown in Figure 2.

Discussion. Recent studies have focused on imaging intact tendons and have not used UTE for quantitative assessment of surgical repair. This pilot study used UTE and T2* mapping to quantitatively evaluate rotator cuff repair in an ovine model. The repaired supraspinatus tendons had longer T2* values than normal tendon and the results indicated a trend of decreasing T2* values away from the primary site of repair. The low power of this pilot study and the heterogeneity of T2* values within the biologically-active scaffold and across the ROIs (Figure 2) may have prevented significant T2* differences from being detected. The FSE PD images were interpreted for qualitative gap formation and remodeling, but the T2* maps were effective at providing quantitative evaluation of the repair interface. This study highlights the potential use of UTE for quantitative evaluation of soft tissue repair, and may aid in establishing a method for clinical investigation of soft tissue repairs. Future studies will correlate T2* values with the histological, biochemical and mechanical integrity of the repair.

Figure 1. T2* values (mean ± std.dev.) of normal and reparative infraspinatus tendon for the ROIs evaluated.
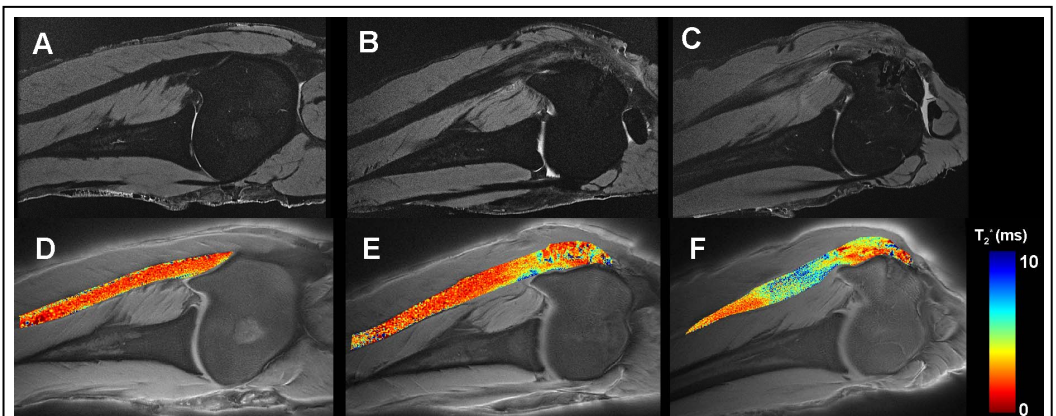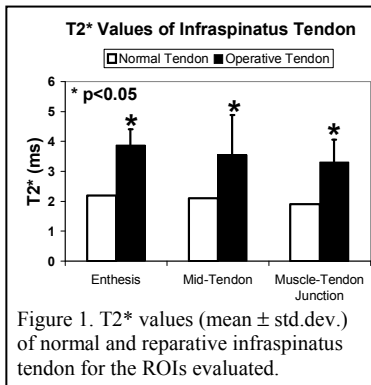

Figure 2. (A,B,C) FSE images of control (A) and operative (B, C) sheep shoulders. (D, E, F) T2* maps of control (D) and operative (E, F) sheep shoulders. Elevated T2* values were seen 8 weeks post operatively, however, the distribution of T2* values was not consistent. Increased T2* values tended to be seen found in focal regions (E – Enthesis region) or in the mid-tendon (F).

References
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