Ultrashort and Short T2 signal detection in cartilage and meniscus: How low do we need to go?

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Introduction: Ultrashort echo-time (UTE) imaging methods, designed to capture T2 signals less than a millisecond, offer the ability to visualize deep cartilage layers and internal meniscus structure that are otherwise invisible by standard T2 mapping and conventional musculoskeletal imaging sequences[1,2]. UTE-enhanced T2* (UTE-T2*) maps, acquired with the 3D AWSOS sequence (acquisition-weighted stack of spirals)[3], have detected significant differences in the deep cartilage of ACL-injured subjects with arthroscopically normal cartilage and cartilage of healthy controls[4], and have also demonstrated significant differences between menisci of ACL-injured subjects without clinical evidence of meniscal pathology and the menisci of healthy controls[5].Yet quantitation of cartilage and meniscus T2* values by UTE-T2* mapping and other techniques have reported mean UTE-T2* or T2* relaxation values in the range of 1-30ms for cartilage[4,6,7] and 4-13ms for meniscus[5,6,8,9] begging the question is UTE required to study these tissues? This study examines the range of echo times (TEs) required to detect significant T2* differences between clinically distinct cohorts: ACL-injured subjects without arthroscopic evidence of damage to medial femoral cartilage (MFC) or medial meniscus, and uninjured controls.

Methods: MRI data from 32 subjects selected from established cohorts[4,5] was used for this analysis: 11 uninjured control subjects (5 female, 28±4 yrs; BMI 25±4) with no known or suspected knee pathology and 21 subjects with ACL injury requiring ligament reconstruction surgery (12 female, 29±9 yrs; BMI 28±6). ACL-injured subjects (ACLT) were included in this re-evaluation on the basis of their arthroscopic findings: only subjects with firm, intact cartilage (arthroscopic grade 0) to the central medial femoral condyle (cMFC, n=12) and/or no arthroscopic or MRI evidence of tear to the medial meniscus (n=15) were included. Six ALCT subjects met both criteria (cMFC scope grade 0 and no medial meniscus tear). All subjects provided informed consent; all studies procedures were IRB-approved. Arthroscopic exams of cartilage and meniscus were previously conducted on the ACLT subjects during ACL-reconstruction surgery. Arthroscopic grades were assigned by the surgeon using a modified Outerbridge scale (0-normal 'firm'; 1-softening; 2- partial thickness defect, superficial fissures; 3-fissuring to subchondral bone; 4-exposed subchondral bone). During surgery, the medial meniscus was examined for tears. Uninjured controls did not undergo surgery. 3-D AWSOS[3] images were acquired on all subjects on a 3T Siemens Tim Trio scanner with an 8-channel knee coil. ACLT subjects were scanned prior to reconstruction surgery. Eleven images at TE= 0.6, 1, 2, 3, 4, 5, 7, 10, 20, 30, and 40ms were collected with FOV=140mm, matrix size=256, and in-plane resolution=0.55mm at 2mm slice thickness. Other acquisition parameters were: 60 slices, 24 in-plane spirals, 11.52ms spiral readout time, 5µs data sampling interval, and FA/TR 30°/80ms. Scan time was 1.92 min per TE-image. TE-images were linearly interpolated to matrix size 512^2 prior to T2*-curve fitting. The cMFC cartilage was manually segmented from a mid-sagittal medial section; the full-thickness cartilage region of interest (ROI) was further segmented to separately evaluate the deep portion of the cMFC cartilage. The posterior horn of the medial meniscus was manually segmented from a different, more central, sagittal section. T2* maps were generated with a mono-exponential pixel-by-pixel T2-fit routine using MRIMapper software (© Beth Israel Deaconess and MIT 2006) using all or a subset of acquired TE-images as detailed in Table 1. T2* maps were regenerated for the same ROIs 8 times, iteratively dropping the shortest TE for each new map. The distributions of calculated UTE-T2* mean values were assessed for normality using Shapiro Wilks tests. Two-tailed t-tests assessed differences between ACLT and uninjured control's mean UTE-T2* value for each ROI, except in cases where the data was not found to meet the assumptions of a normal distribution and non-parametric Mann-Whitney U Tests (MWUT) were used instead. All statistical analyses were performed with IBM SPSS. Statistical significance was accepted for $p<0.05$.

Results: A significant difference in deep cMFC cartilage T2* values between ACLT subjects with firm, intact articular cartilage (arthroscopic grade 0, n=12) and uninjured controls (n=11) was detected when the T2*-weighted images at TE= 0.6 or 1 ms were included in the T2* curve fit ($p\leq0.006$). When the first TE in the fit was increased to 2 ms or longer, no significant difference between these clinically distinct cohorts was detected ($p>0.09$), Figure 1. In meniscus, a significant difference in meniscal T2* values between ACLT subjects without clinical evidence of meniscal pathology and uninjured controls was maintained for the first TE as long as 5 ms ($p\leq0.01$). When the first TE in the fit was 7ms or longer, no significant difference was detected between the cohorts ($p>0.13$), Figure 2.

Conclusions: These results show that inclusion of an echo image with TE ~1ms provided sensitivity to detect subtle differences in the deep cartilage matrix between ACL injured subjects with arthroscopically intact articular cartilage and menisci, a population known to be at risk of OA (and therefore a target population for early OA detection), and uninjured controls. The inclusion of the UTE (0.6ms) acquisition improved the stability of the mean cMFC T2* value in the differentiation between the two cohorts (p-value = 0.006 vs. 0.002 for the first TE at 0.6 vs. 1.0 ms). For the meniscus, the inclusion of the UTE (0.6ms) or short TE (1ms) had the same impact on the stability of the mean T2* value ($p<0.0005$) although TEs as long as 5ms detected significance differences between the cohorts. Further work in larger clinical cohorts is needed to consolidate these findings in the detection of the earliest signs of cartilage and meniscus matrix degeneration with UTE-T2* mapping. **Acknowledgments:** NIH RO1 AR052784 (CRC). Yongxian Qian, PhD, University of Pittsburgh.

Table 1. Echo images included in T2*-curve fit

# of TEs	*TE times, ms*
11	0.6, 1, 2, 3, 4, 5, 7, 10, 20, 30, 40
10	1, 2, 3, 4, 5, 7, 10, 20, 30, 40
9	2, 3, 4, 5, 7, 10, 20, 30, 40
8	3, 4, 5, 7, 10, 20, 30, 40
7	4, 5, 7, 10, 20, 30, 40
6	5, 7, 10, 20, 30, 40
5	7, 10, 20, 30, 40
4	10, 20, 30, 40

References: **[1]** Gatehouse, Clin Radiol, 2003;58:1. **[2]** Robson, NMR Biomed, 2006;19:765. **[3]** Qian, MRM, 2008;60(1):135 **[4]** Williams, #0049, 20th Annual Meeting ISMRM, Melbourne May 5-11, 2012. **[5]** Williams, OACart, 2012;20(6):486. **[6]** Du, JMRI, 2009;29:412. **[7]** Du, OACart, 2013;21:77. **[8]** Gatehouse, B J Radiol, 2004;77:641. **[9]** Du, MRM, 2010;64:834.

Figure 1

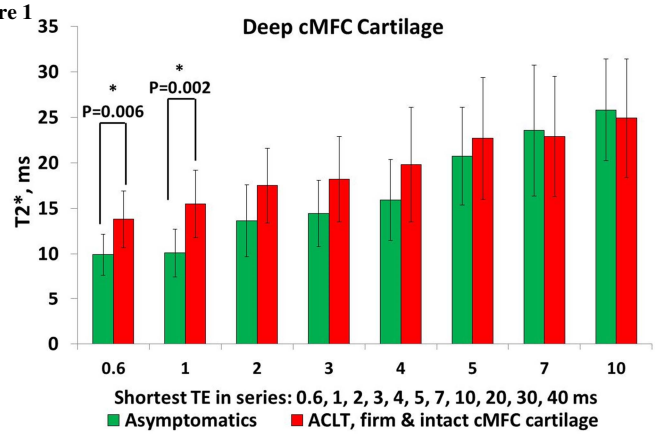

Figure 2