Ultrashort TE enhanced T_2^* mapping of cartilage: A Pilot Clinical Study

A. Williams[1], Y. Qian[2], and C. R. Chu[1]

[1]Cartilage Restoration Laboratory, University of Pittsburgh, Pittsburgh, PA, United States, [2]Magnetic Resonance Research Center, University of Pittsburgh, Pittsburgh, PA, United States

Introduction This clinical report assesses the feasibility of 3-D ultrashort echo time enhanced T_2* (UTE-T_2*) mapping of cartilage *in vivo* and examines the sensitivity of UTE-T_2* to early cartilage degeneration compared to arthroscopic grading as the standard. UTE-T_2* mapping is sensitive to changes in short-T_2 signal (T_2 <10ms) and may provide improved sensitivity to subtle matrix alterations, particularly in deep layers, that are not well captured by standard T_2 mapping[1,2]. A previous *in vitro* study indicated that UTE-T_2* values reflect cartilage collagen matrix structural integrity as determined by polarized light microscopy[3]. We hypothesize that UTE-T_2* mapping *in vivo* is sensitive to earlier degenerative changes of articular cartilage than can be detected with standard T_2.

Methods UTE-T_2* and standard T_2 images were acquired on the knees of 10 human subjects on a clinical 3T MRI scanner (MAGNETOM Trio TIM 3T, Siemens Medical Solutions, Erlangen, Germany) using an 8-channel knee coil (In vivo Inc., Gainesville, Florida, USA). Subjects had either degenerative meniscal tear (n=5) or patellofemoral joint degeneration (n=5). All subjects provided informed consent; all studies were IRB approved. Standard T_2 and UTE-T_2* maps in the sagittal plane and centered on the femorotibial joint were acquired in the 5 subjects with meniscal tears (4 left knees, 1 right). Axial images centered on the patellofemoral joint were acquired in the 5 subjects with patellofemoral disease (5 right knees). UTE-T_2* mapping images were acquired with AWSOS sequence (acquisition-weighted stack of spirals)[4]. Eleven echo images, TE ranging 0.6 – 40ms, were collected with 547μm^2 resolution in-plane, and 2mm section thickness; FA/TR = 30º/80ms. Scan time was 1.92 minutes per TE-image. Standard T2 mapping images were acquired using a 2-D FSE sequence with seven TEs ranging from 10-80ms, TR 2700ms, BW 250 Hz/pix. The 30 2-D slices were collected with a 384x384 matrix in a 14cm FOV and down-sampled to create an effective resolution of 486μm^2 in-plane and 3mm section thickness. Total T_2 scan time was 12 minutes. UTE-T_2* and standard T_2 maps were generated with a mono-exponential fitting routine using MRIMapper software (© Beth Israel Deaconess and MIT 2006). Regions of interest (ROIs) were manually segmented from a single section from each knee: on sagittal scans, 3 full-thickness ROIs were segmented in the anterior, central and posterior weight-bearing zones, respectively, from a slice from the center of the medial condyle; on axial scans, 1 full-thickness ROI in the lateral facet was segmented from a slice in the center of patella. Zonal T2 variations were examined by further segmenting and separately evaluating the superficial and deep halves of each full-thickness ROI. UTE-T_2* and standard T_2 'lesions', identified on the medial facet or central ridge of the patella were separately segmented. Following MRI, the 5 subjects with meniscal tears underwent arthroscopic surgery. Targeted exams were conducted on the central weight-bearing zone of the medial femoral condyle in areas corresponding to MRI ROIs and were evaluated using a modified Outerbridge scale: (0-normal; 1-softening; 2- partial thickness defect, superficial fissures; 3-fissuring to subchondral bone; 4-exposed subchondral bone). Superficial and deep UTE-T_2* and standard T_2 values were compared to the surgeon's arthroscopic grade as the standard. MRI values were binned according to arthroscopic grade, and mean UTE-T_2* and standard T_2 values calculated. 2-tailed t-tests were performed to assess UTE-T_2* and standard T_2 differences between arthroscopic grades.

Results Comparison of MRI and arthroscopy in 15 study areas across the 5 meniscal injury patients found that UTE-T_2* values in deep cartilage layers were significantly higher in softened tissue (arthroscopic grade 1, 27±8ms) compared to firm (arthroscopic grade 0, 16±4ms), p<0.01, Figure 2. UTE-T_2* values in superficial cartilage showed a trend for higher values in softened compared to firm tissue (40±15ms *vs* 31±7ms, for scope grade 1 *vs* 0, p= 0.17). Standard T_2 values showed no differences between firm and softened cartilage in either superficial or deep zones. Both UTE-T_2* values and standard T_2 values demonstrated zonal differences. In the central weight bearing zone of the medial femoral condyle (n=5 study areas in 5 meniscal patients), UTE-T_2* values were 38% lower in deep tissue than in superficial, p=0.03; standard T_2 values were 37% lower, p=0.01. In 5 subjects with patellofemoral pain (n=5 axial scans), deep UTE-T_2* values in lateral facet patellar cartilage were 32% lower than superficial, p<0.01. While standard T_2 values in the deep zone of patellar cartilage tended to be lower than in the superficial zone (average 18%), the difference was not significant, p=0.16. Focal regions of relatively high or low UTE-T_2* and standard T_2 relaxation rates were identified in axial scans of the 5 patellofemoral subjects. In 2 cases, 'high' lesions on standard T_2 maps were found to correspond to 'high' lesions on UTE-T_2* maps. In 2 other cases, 'low' lesions on standard T_2 maps were found to correspond to 'low' lesions on UTE-T_2* maps. In 1 case, a 'high' lesion noted on the standard T_2 map corresponded to a 'low' lesion on the UTE-T_2* map.

Conclusion This human clinical study shows that 3-D UTE-T_2* mapping of articular cartilage is feasible in both axial and sagittal planes in imaging times well-tolerated by patients with knee pain. UTE-T_2* mapping captures signal from deep cartilage better than standard T_2 mapping, and UTE-T_2* values in deep cartilage discriminated between healthy and unhealthy tissue where standard T_2 values did not. UTE-T_2* mapping *in vivo* provides a quantitative measure of chondral degeneration that is sensitive to the short T_2 components not well captured by standard T_2 mapping. In this pilot study, UTE-T_2* mapping was found to be superior to standard T_2 mapping at detecting early cartilage degeneration.

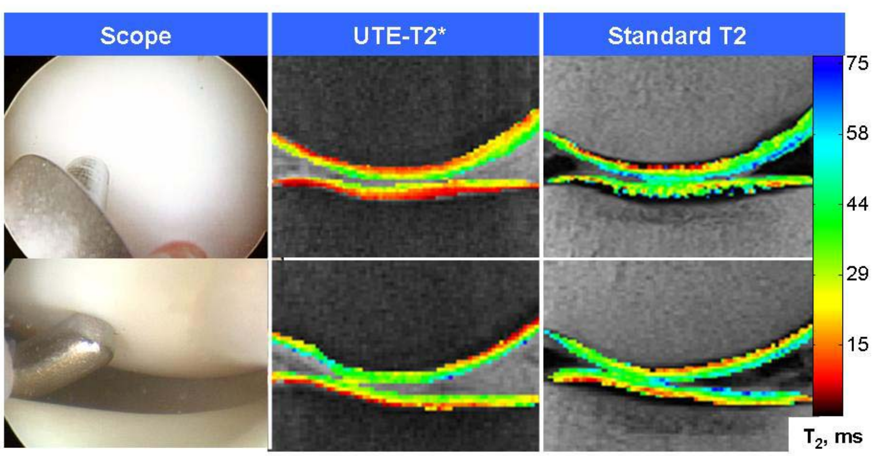
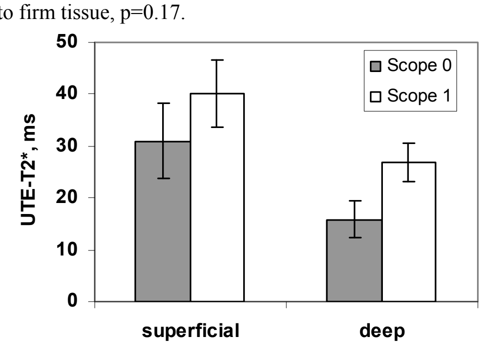


Figure 1 (above) – Example *in vivo* images. Top row: firm cartilage (scope 0) with low UTE-T_2* values in deep cartilage. Bottom row: softened cartilage (scope 1) with relatively high deep UTE-T_2* values. UTE-T2* maps show more robust signal and fits from deep cartilage than standard T2.

Figure 2 (below) – UTE-T_2* values in deep tissue detect early stages of articular cartilage degeneration assessed by arthroscopic evaluation, p<0.01. UTE-T_2* in superficial tissue shows a trend for higher values in softened compared to firm tissue, p=0.17.



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