Correlation Between T1ρ MRI and Arthroscopy in Adults with Chondromalacia

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Introduction: The need to detect the earliest changes in cartilage degeneration in order to both use and validate disease modifiying osteoarthric drugs, as well as with the rather poor accuracy of conventional MR sequences for the detection of these changes, has stimulated considerable interest in the development of techniques that can directly probe the macromolecular structure. In addition to direct sodium MRI and dGEMRIC, T1ρ was used previously to explore proteoglycan loss in patients with confirmed cartilage loss, but without exogenous contrast agent. A study of two patients with arthroscopically confirmed posttraumatic cartilage injury found increased T1ρ compared to the healthy compartments in both patients (1). T1ρ was increased ($p<0.002$) in six subjects with OA scored using a WOMAC (2) and KL scores (3). We hypothesize that chondromalacia observed during arthroscopy should correlate with lesions detected by T1ρ MRI. To test this hypothesis, in a blinded, retrospective study, we investigated whether T1ρ MRI can reliably detect chondromalacia at arthroscopy.

Materials and Methods: ***Recruitment and Arthroscopy.*** 9 asymptomatic subjects (2 men and 7 women) and 6 patients (3 men and 3 women) in whom one or more regions of chondromalacia, defined as grade I or II cartilage damage, had been demonstrated at arthroscopy were recruited for this study. Cartilage grading was performed according to the classification of Outerbridge modified to include the femorotibial joint and was as follows: Grade I: Softening and swelling of the cartilage; Grade II: Early superficial fibrillation, which does not reach the subchondral bone, and is less than 0.5 inch in diameter; Grade III: Fissuring that reaches the subchondral bone, which is not exposed, and greater than 0.5 inch in diameter; Grade IV: Exposed subchondral bone of any diameter. ***MRI.*** MRI was performed 2-3 months post-arthroscopy using T1-weighted and T1ρ MRI from which spatial T1ρ relaxation maps were calculated. ***Image Processing.*** T1-weighted images were interpolated to 0.5 mm^3 and resliced along coronal and axial aspects and interpolated again along each aspect to 0.5 mm x 0.54 mm^2 to match the resolution of T1ρ-weighted images. Patient motion during image acquisition was found to be problematic for T1ρ quantification, especially in axial views where non rigid body rotation of the leg was observed. An initial manual alignment of the axial T1ρ-weighted images to the resliced axial T1-weighted image was performed by in-plane rotation and translation after which a region of interest containing cartilage and bone was selected. Masked, axial T1ρ-weighted images were exported to 3DVIEWNIX (MIPG, University of Pennsylvania, Philadelphia, Pennsylvania) where T1ρ-weighted images were registered to T1-weighted images. The cartilage was semi-automatically segmented from the T1-weighted images using a LiveWire algorithm (21) and masks were applied to all T1ρ-weighted images. Masked, coregistered T1ρ-weighted images were fit pixelwise to the linearized, monoexponential signal decay equation $\ln(S) = -TSL/T1\rho + \ln(S_0)$. T1ρ relaxation maps were viewed by two of the authors, who characterized lesions as either diffuse or focal in patients only. While diffuse lesions were quantified by the average compartment T1ρ (Table 1), focal lesions were quantified by mean T1ρ in an ROI drawn at the site of the lesion and possibly extending across multiple slices. ***Data Analysis.*** The difference between subjects and patients was performed using multivariate ANOVA and bootstrap confidence interval tests. Correlation between arthroscopy and T1ρ MRI was determined by calculating mean compartment T1ρ or calculating T1ρ mean of a large focally elevated region in a compartment.

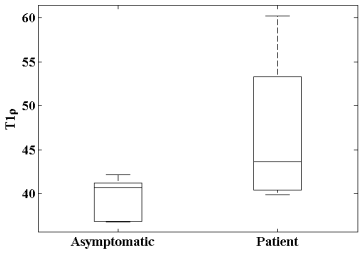

Figure 1: Boxplots of T1ρ among asymptomatic subjects and patients. Median T1ρ was significantly different by a nonparametric Wilcoxon rank sum test ($p<0.001$).

Results: Median T1ρ relaxation times among symptomatic and asymptomatic subjects were significantly different ($p < 0.001$) and symptomatic T1ρ exceeded asymptomatic articular cartilage median T1ρ by 2.5 to 9.2 ms. Patellar T1ρ was 2.5-8.3 ms higher than the tibial compartment ($p < 0.01$). In 8 observations of mild (grade 1 and 2) osteoarthritis at arthroscopy, mean compartment T1ρ was elevated in 5, but in all cases, large foci of increased T1ρ were observed. In 6 cases of moderate or severe chondromalacia, compartment mean T1ρ was elevated.

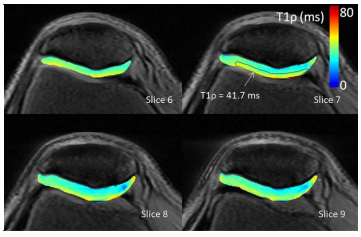

Figure 3: T1ρ relaxation maps from a 30 year old male with no previous history of knee injury and no knee pain. Patellar cartilage is homogenously, smoothly varying and has a characteristic increase in relaxation time from the deep cartilage adjacent to the subchondral bone to the superficial cartilage adjacent to the synovium.

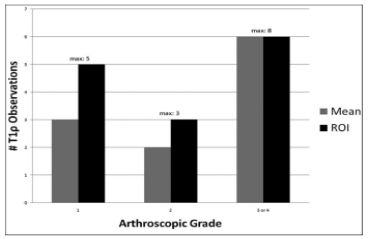

Figure 2: Correlation of arthroscopic grade with T1ρ MRI. 14 arthroscopic observations of chondromalacia were made among 6 patients. Mean compartment T1ρ was abnormal in all cases of grade 3 and 4 chondromalacia, but mixed for grades 1 and 2. ROI analysis of the individual patients resolves the inconsistency among grades 1 and 2, for which heterogeneous and focally increased T1ρ was observed and mischaracterized by the compartment average.

Discussion: Correlation between mean T1ρ for the entire compartment and arthroscopy was excellent in all cases where the patient had grade 3 or 4 chondromalacia at arthroscopy, however, in cases of mild chondromalacia, the correlation was much weaker when averaging over a compartment. It must be understood, however, that those facets labeled as diffuse grade I changes, demonstrated considerable heterogeneity at arthroscopy with normal and abnormal cartilage intermixed and that the grade is assigned on the basis of the highest grade of abnormality present, not on the basis of some type of average. Thus, a compartment average would underestimate the arthroscopic grade and the use of at least reasonably large foci of elevated T1ρ to compare to the arthroscopic grade is justified in that it better corresponds to how the arthroscopic grade is assigned. One potentially confounding variable is the presence of clinically occult osteoarthritic changes in asymptomatic subjects. This would artifactually elevate the mean T1ρ in the asymptomatic subjects, making it more difficult to discriminate between normal and abnormal values.

Conclusion: In conclusion, these results demonstrate that T1ρ relaxation mapping correlates with chondral lesions identified by arthroscopy. High correlation between T1ρ MRI and chondral damage was observed for grades 3 and 4 chondromalacia but correlation was only modest in the case of grade 1 or 2 damage when averaging across compartments.

References: (1) Lozano, et al. J. Bone. Joint Surg. (2006). (2) Regatte, et al. Acad. Radiol. (2004). (3) Li, et al. Osteoarthris Cartilage (2007).

Figure 4: Arthroscopic photographs and T1ρ relaxation maps from a 48 year old male (patient 3) diagnosed preoperatively with a torn left medial meniscus and chondromalacia. This patient was observed at arthroscopy to have grade 2 patellar chondromalacia and a torn left medial meniscus for which a partial medial meniscectomy was performed. Focal elevated medial patellar T1ρ was observed by MRI with a patellar ROI T1ρ = 49.2-62.7 ms, simultaneously with cartilage thinning.