Using the Ratio of T1ρ and T2 MR Parameters to Examine the Relationship Between Anterior Cruciate Ligament (ACL) Abnormalities and Patellofemoral Cartilage Integrity

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Target audience: Clinicians working with the lower extremities and developers of quantitative MR sequences.

Purpose: $T_{1\rho}$ and T_2 MR relaxation time mapping techniques have shown to be effective, non-invasive metrics for quantitative assessment of cartilage in osteoarthritis (OA) [1-2]. Since hydration of the cartilage contributes to $T_{1\rho}$ and T_2 relaxation times [3], taking the ratio of $T_{1\rho}$ to T_2 would adjust for potential hydration effects, yielding a single metric better indicative of macromolecular integrity. The purpose of the study was to evaluate the $T_{1\rho}/T_2$ ratio as a metric to explain macromolecular differences in patellofemoral joint (PFJ) cartilage between subjects with and without structural abnormalities in the anterior cruciate ligament (ACL).

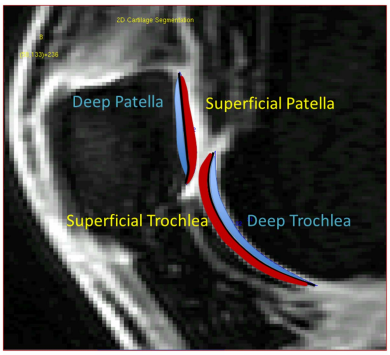

Figure 1: Patellofemoral cartilage compartments and laminar layers.

Methods: Subjects recruited from the community underwent 3-Tesla MRI. Three MR sequences were acquired: 1) a sagittal 3D high-resolution T_2-weighted isotropic fast spin echo sequence (3D FSE CUBE) for segmentation and clinical grading 2) a sagittal $T_{1\rho}$-mapping sequence and 3) a sagittal T_2-mapping sequence for quantitative assessment. The ACL and PFJ cartilage (patella and trochlea compartments) were graded on the 3D FSE images using modified Whole Organ MRI Score (mWORMS) scales [4]. Thirty subjects were identified as having structural abnormalities within the ACL such as mucoid degeneration and/or tears (mWORMS ≥ 2). Thirty subjects with no focal PFJ cartilage defects or ACL lesions (mWORMS < 2) were selected for comparison, matching age, gender, and BMI of those with ACL lesions. Of those with ACL abnormalities, 11 subjects had no focal PFJ cartilage defects and were compared with 11 other subjects without abnormalities of the patella, trochlea, or ACL and matched for age, gender, and BMI. Cartilage regions of interest (ROIs) were semi-automatically segmented on 3D FSE CUBE images using in-house software then overlaid onto $T_{1\rho}$ and T_2 images for quality control; cartilage ROIs were also automatically divided into deep and superficial layers (Figure 1). $T_{1\rho}$ and T_2 relaxation times were calculated for whole cartilage ROIs as well as laminar layers. $T_{1\rho}$ values were then divided by the T_2 values to yield the $T_{1\rho}/T_2$ ratio. Student's t-test was used to compare $T_{1\rho}$ and T_2 relaxation times and $T_{1\rho}/T_2$ ratios between subjects with and without ACL lesions, using an alpha level of $P < 0.05$.

Results: Individuals with ACL lesions had significantly higher T_2 relaxation times compared to those without in the whole trochlea (p=0.039) as well as the superficial layer of the trochlea (p=0.008, Figure 2). Those with ACL abnormalities also had a significantly lower $T_{1\rho}/T_2$ ratio in the trochlea superficial layer (p=0.019, Figure 3). No significant differences were observed in $T_{1\rho}$ between those with and without ACL pathology. In the cohort of subjects with no focal abnormalities in PFJ cartilage, those with ACL lesions had significantly lower $T_{1\rho}/T_2$ in the deep layer of the patella (p=0.049) and whole trochlea (p=0.033, Figure 4) than those with healthy ACLs. These $T_{1\rho}/T_2$ differences approached significance in the whole patella (p=0.062) and the trochlea superficial layer (p=0.10, Figure 4). There were no significant differences in $T_{1\rho}$ or T_2 relaxation times between those with and without ACL abnormalities in this sub-cohort.

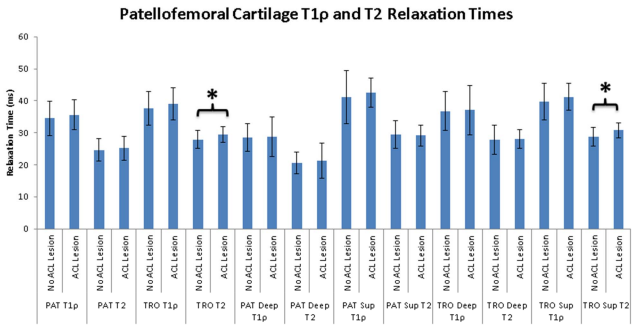

Figure 2: $T_{1\rho}$ and T_2 relaxation times in whole and laminar patellofemoral cartilage of subjects with and without structural abnormalities of the ACL.
* signifies $p < 0.05$.

Discussion: Though $T_{1\rho}$ and T_2 have shown strong associations with proteoglycan and collagen content in articular cartilage, respectively, hydration also influences the calculated values. We propose that normalizing $T_{1\rho}$ by T_2 could eliminate the effects of hydration and provide a more appropriate metric for measuring cartilage quality at the macromolecular level. This study employed this $T_{1\rho}/T_2$ ratio to investigate the relationship between ACL abnormalities and cartilage degradation in the patellofemoral joint. Subjects with ACL lesions showed elevated T_2 relaxation times as well as reduced $T_{1\rho}/T_2$ ratio in trochlear cartilage relative to those without, suggesting compromised collagen structure and diminished cartilage integrity. In subjects without PFJ cartilage lesions, the $T_{1\rho}/T_2$ ratio was significantly lower in the PFJ cartilage of those with ACL lesions compared to those without; no significant differences were observed with $T_{1\rho}$ or T_2 individually. The results from this cohort may indicate some degree of degradation in macroscopically healthy PFJ cartilage, marking the earliest changes in the OA disease process [5]. The results of this study demonstrate the potential of the $T_{1\rho}/T_2$ ratio as a tool for quantitative MR; however, the results must be considered in light of the relatively small cohort sizes. Further imaging and specimen studies are necessary to precisely understand the efficacy of the $T_{1\rho}/T_2$ ratio as a viable research and diagnostic tool.

Conclusion: The $T_{1\rho}/T_2$ MR relaxation time ratio may be useful for quantitative assessment of cartilage, as it potentially adjusts for hydration effects. ACL pathology has previously been associated with PFJOA; in this study, ACL abnormalities were associated with decreased $T_{1\rho}/T_2$ ratios in PFJ articular cartilage. Furthermore, degenerative change in the ACL may alter loading biomechanics of the PFJ, leading to the increase in relaxation time and the changes in the extra-cellular matrix.

References:

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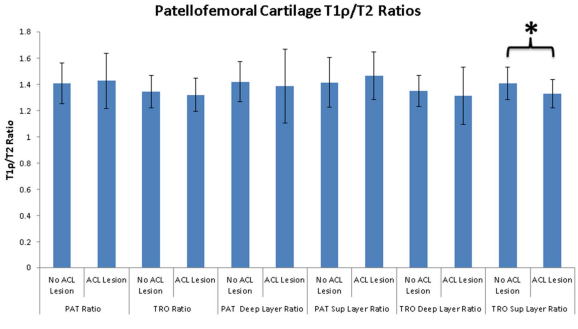

Figure 3: $T_{1\rho}/T_2$ relaxation time ratios in whole and laminar patellofemoral cartilage of subjects with and without structural ACL abnormalities.
* signifies $p < 0.05$.

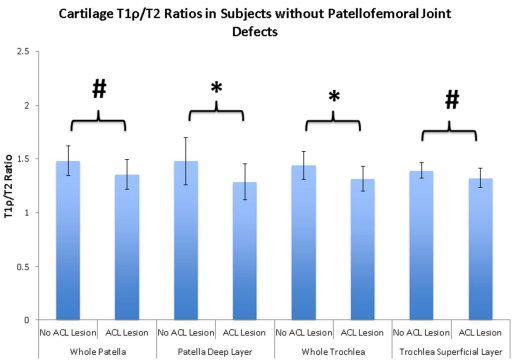

Figure 4: $T_{1\rho}/T_2$ ratios in subjects with healthy patellofemoral cartilage with and without structural ACL abnormalities.
* signifies $p < 0.05$, # signifies $0.05 < p \leq 0.10$.