Quantitative Magnetic Resonance Imaging for Evaluation of ACL Injuries: a pilot multicenter study

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Purpose:

Acute anterior cruciate ligament (ACL) injuries can lead to early cartilage degeneration despite surgical reconstruction. Quantitative magnetic resonance imaging (MRI) techniques using $T_{1\rho}$ and T_2 can identify early signs of cartilage degeneration. Previous studies have shown elevation in $T_{1\rho}$ and T_2 in osteoarthritic cartilage by detecting changes in proteoglycan/collagen and water content.[1–3] $T_{1\rho}$ and T_2 is also elevated in ACL injured knees.[4–7] In this study, we present the feasibility of detecting cartilage degeneration using quantitative MRI in ACL-injured patients in a multicenter study.

Materials and Methods:

<u>*Subjects*</u>: Bilateral knees of 37 patients (21 males, 29.1 ± 12.8 years, BMI 24.6 ± 3.16) with isolated acute ACL injuries were scanned using a 3 Tesla MRI scanner (GE Healthcare, Milwaukee, WI, USA) with an 8-channel phased array knee coil (Invivo, Orlando, FL, USA) at three institutions (17, 9, 11 patients respectively) after injury and prior to surgery. Two volunteers with healthy knees were scanned and re-scanned at all three sites for reliability testing at different time points.

<u>*MRI protocol:*</u> MRI imaging protocol: (1) high-resolution 3D FSE (CUBE), TR/TE = 1500/26.69 ms, field of view 16 cm, 384 x 384 matrix size, slice thickness 0.5 mm, echo train length 32; (2) quantitative combined $T_{1\rho}/T_2$: $T_{1\rho}$ TSL= 0/10/40/80 ms, spin-lock frequency = 500 Hz, field of view 14 cm, 256 × 128 matrix size, slice thickness 4 mm, T2 preparation TE= 0/12.87/25.69/51.39ms.[8]

<u>*Image Post-Processing*</u>: Post-processing was performed with an in-house Matlab program. Sagittal CUBE images were rigidly registered on the first $T_{1\rho}$-weighed image (TSL=0) and used for cartilage segmentation. Using a semiautomatic edge based strategy, six compartments were identified: medial femoral condyle (MFC), medial tibia (MT), lateral femoral condyle (LFC), lateral tibia (LT), patella (PAT), and trochlea (TRO). $T_{1\rho}$ and T_2 relaxation times were determined with a pixel-by-pixel, two-parameter exponential fit. The $T_{1\rho}$ and T_2 values of each compartment were computed as the mean of all pixels belonging to the ROI.

<u>*Statistical Analysis:*</u> Inter- and intra-variability were considered to assess for the reproducibility across the three sites. Paired t-test was performed to evaluate the $T_{1\rho}$ and T_2 difference between injured and non-injured knee with significance defined as $p < 0.05$. Analyses were performed again on patient data after age stratification (< or ≥ 20 years).

Results:

<u>*Volunteer data:*</u> Mean inter-site differences (repeat scans) at baseline and 1 year were 1.3ms and 1.6ms for $T_{1\rho}$, 0.8ms and 1.1 ms for T_2 (Figure 1).

<u>*Patient data*</u>: Mean $T_{1\rho}$ relaxation times were significantly higher on the injured side in the MFC, LFC, MT, and LT compartments, and in the MFC, LFC, and LT for T_2 (Table 1, Figure 2). $T_{1\rho}$ relaxation times were also significantly higher in the non-injured trochlea. After age stratification, the younger group (N=12) showed elevation on the injured side in LT only, while the older group maintained elevations in the MFC, LFC, MT, and LT. Posterolateral tibia, a subcompartment of LT, showed elevations ($p \leq 0.0001$ for N=37) at all sites and age groups. ANOVA showed no significant difference between sites (p>0.05).

Discussion and Conclusion:

Both volunteer and patient data indicate good reproducibility across the three sites, and demonstrates the feasibility of expanding this technology to multiple institutions. $T_{1\rho}/T_2$ relaxation times are elevated in ACL injured knees, and while damage to the LT, especially in the posterior aspect, is consistent with the pivoting mechanism of the injury, older patients tend to have cartilage injuries in other parts of the knee. MRIs obtained at 6 and 12 month post-surgical follow-up as part of this study may shed more light into the correlation between relaxation times and clinical findings.

References:

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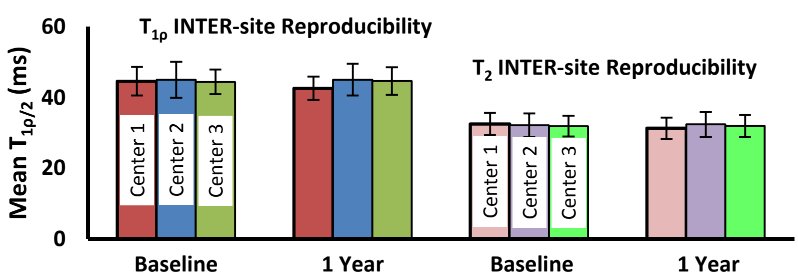

Figure 1. Mean $T_{1\rho}/T_2$ relaxation times of all compartments for two traveling volunteers at two time points show good reliability and reproducibility between the three institutions involved in the study.

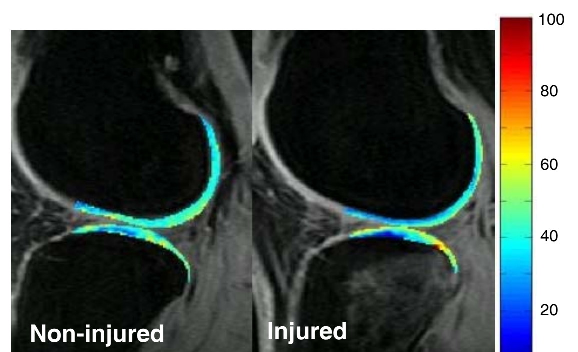

Figure 2. The color maps demonstrate higher $T_{1\rho}$ relaxation times in the lateral tibia cartilage, especially in the posterior aspect, of a single patient.

(N=37)	Medial Femur		Lateral Femur		Medial Tibia		Lateral Tibia*		Patella		Trochlea	
Sequence	T1ρ	T2	T1ρ	T2	T1ρ	T2	T1ρ	T2	T1ρ	T2	T1ρ	T2
Injured mean (ms)	45.23	34.02	45.45	33.57	39.75	28.74	39.53	28.41	45.75	34.04	43.72	34.57
Non-injured mean (ms)	43.53	32.32	43.41	32.19	38.15	27.77	37.69	26.20	46.48	33.40	45.48	35.75
P -value (paired t-test)	0.0078	0.0023	0.0013	0.0157	0.0364	0.1073	0.0094	0.0003	0.4459	0.4740	0.0374	0.1178

Table 1. Mean $T_{1\rho}$ and T_2 relaxation times for the six compartments of the knee. A paired t-test shows how relaxation times are significantly elevated (highlighted) in the femur and tibia cartilages regions.*Posterior part of lateral tibia showed elevation in injured side for all age groups and sites.