$T_1\rho$ MRI QUANTIFICATION OF ARTHROSCOPICALLY CONFIRMED CARTILAGE FOCAL LESIONS IN KNEES WITH ACUTE ACL INJURIES

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INTRODUCTION Knees with acute injuries, such as anterior cruciate ligament (ACL) tears, have a high risk of developing post-traumatic OA (1). Quantitative MRI $T_1\rho$ mapping has been suggested as a promising tool to detect early biochemical changes in cartilage matrix during degeneration. Although many studies in literature show that $T_1\rho$ could potentially detect cartilage degeneration non-invasively (2,3), few studies have correlated quantitative MRI measures with clinical evaluation of cartilage degeneration using arthroscopy (4). The purpose of this study was to evaluate the capability of MR $T_1\rho$ to detect cartilage lesions as evaluated by arthroscopy in acutely ACL-injured knees, and to compare with clinical standard MRI. Our hypothesis is that cartilage $T_1\rho$ will be significantly elevated in regions with arthroscopically confirmed lesions.

METHODS Ten subjects with acute ACL injuries (5 male, 5 female, mean age=39 years, range=28-51 years) and ten healthy control subjects (8 male, 2 female, mean age=35 years, range=29-53 years) were scanned with a 3T MR scanner (HDx, GE Healthcare) using an 8-channel phased array knee coil. Patients were scanned after ACL injuries and prior to ACL reconstruction. The imaging protocol included: sagittal fat-saturated T2-weighted fast spin-echo (FSE) images (TR/TE = 4300/51 ms, FOV = 14 cm, matrix size = 512 x 256 slice thickness = 2.5 mm, gap = 0.5 mm), sagittal 3D water excitation high-resolution spoiled gradient-echo (SPGR) images (TR/TE = 15/6.7 ms, flip angle = 12°, FOV = 14 cm, matrix = 512 x 512, slice thickness = 1 mm), 3D $T_1\rho$ based on spin-lock and SPGR sequences (TR/TE = 9.3/3.7 ms; FOV = 14 cm, matrix size = 256 x 128, slice thickness = 4 mm, view per segment = 64, time of recovery = 1.5 s, time of spin-lock (TSL)= 0, 10, 40, 80 ms, frequency of spin-lock = 500 Hz), and T2 quantification based on non-selective T2 preparation and SPGR sequences (TE = 3.1/13.5/23.9/44.8 ms and all other parameters were the same as the $T_1\rho$ sequence).

During ACL reconstruction, the cartilage was evaluated using arthroscopy by an orthopedic surgeon. The Outerbridge grading score was used to grade the cartilage in each defined subcompartment (Fig 1): Grade 0 – normal, Grade I - cartilage with softening and swelling, Grade II - a partial-thickness defect with fissures on the surface that do not reach subchondral bone or exceed 1.5 cm in diameter, Grade III - fissuring to the level of subchondral bone in an area with a diameter more than 1.5 cm, Grade IV - exposed subchondral bone.

During image analysis, cartilage of the lateral/medial femoral condyles (LFC/MFC), lateral/medial tibia (LT/MT), and the patella were segmented using high resolution SPGR images and then divided into sub-compartments in a manner analogous to the Outerbridge compartments, resulting of a total of 49 subcompartments for each subject. Each sub-compartment was labeled according to facet (LFC, MFC, LT, MT, or Patella), side (lateral, central, medial), and orientation (anterior, central, posterior) (Fig 2). $T_1\rho$ maps were registered rigidly using VTK software to SPGR images and the generated ROIs for each subcompartment were overlaid to the aligned maps. The mean $T_1\rho$ values in each sub-compartment for full thickness, superficial and deep layers were calculated and normalized to remove spatial variation between sub-compartments with Z-scores using the equation: $Z_{i,\, T_1\rho} = (T_1\rho_i - Mean_i)/SD_i$, where Z_i, where $T_1\rho$ is the mean value of $T_1\rho$ in compartment i, $mean_i$ and SD_i is the mean and standard deviation of $T_1\rho$ of controls in compartment i. Using T2-weighted FSE, modified WORMS (5) cartilage subscoring was performed in each defined subcompartment.

$T_1\rho$ Z-scores were compared between cartilage with Outerbridge score = 0 and score > 0 using a rank test. Receiver operating characteristic (ROC) analysis was also performed to assess diagnostic performance of $T_1\rho$ and WORMS scores from standard MRI to detect arthroscopically confirmed cartilage lesions.
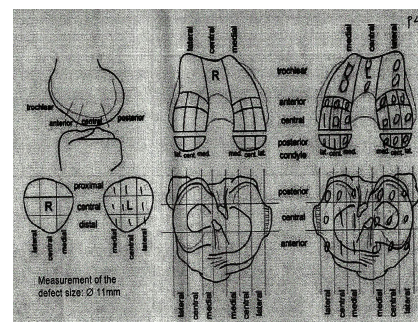

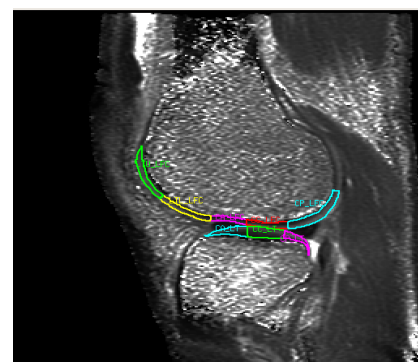**Figure 1**. Outerbridge grading score sheet

Figure 2. Subcompartmentalization of cartilage in a manner analogous to the Outerbridge compartments shown in Figure 1. LFC and LT are shown as examples

RESULTS Out of the ten ACL patients, nine showed cartilage lesions during arthroscopic evaluation, resulting in a total number of 62 lesions (Outerbridge Grade I: 54; Grade II: 6; Grade III: 2), while all ten patients showed cartilage lesions in the FSE image (cartilage WORMS>0) with a total number of 24 lesions (WORMS Grade 1: 18, Grade 2: 4, Grade 2.5: 1; Grade 3: 1), . Table 1 shows the number of lesions within each compartment for both the Outerbridge and WORMS scoring. The $T_1\rho$ Z-score for full thickness and superficial layer of cartilage with lesions were significantly higher compared to those without lesions (normal), which were identified using arthroscopy (Table 2). No significant elevation of $T_1\rho$ Z-scores was found in the deep layer of the cartilage. In the LT, where the most lesions were found with the Outerbridge scoring, the area under the ROC curve was 0.6990, 0.7007, 0.6873, and 0.5655 for $T_1\rho$ Z-scores of full thickness, $T_1\rho$ Z-scores of superficial layer, $T_1\rho$ Z-score for deep layer, and WORMS scores, respectively.

Table 1. Number of focal lesions in each compartment

	LFC	LT	MFC	MT	Patella
Outerbridge	1	23	12	6	20
WORMS	1	7	3	2	11

Table 2. $T_1\rho$ Z-scores (Mean ± SD) of normal cartilage and cartilage with lesions

	Normal	Lesion	p-value
Full	0.176 ± 1.314	0.641 ± 1.317	0.01
Superficial	0.314 ± 1.194	0.692 ± 1.158	0.02
Deep	0.045 ± 1.061	0.202 ± 1.169	0.07

CONCLUSIONS AND DISCUSSION Subjects with acute ACL injuries showed arthroscopically confirmed lesions mostly in the LT. Surprisingly, only one lesion was found in the LFC, although bone bruises after acute ACL injuries are commonly seen in both LT and LFC. Quantitative MRI $T_1\rho$, particularly in the superficial layer of cartilage, provided better diagnostic capability than standard clinical MR images (such as FSE images) to detect cartilage lesions after acute ACL injuries. Quantitative MRI has great potential to detect early degeneration in cartilage non-invasively.

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