In vivo MR $T_{1\rho}$ relaxation time in bone marrow edema overlying cartilage in knees with ACL injuries

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INTRODUCTION

Magnetic resonance imaging (MRI) is a useful diagnostic tool for anterior cruciate ligament (ACL) ruptures and related injuries. Bone marrow edema (BME) or microtrabecular fractures detected with MRI have been described previously with high frequency in patients with acute ACL lesions [1]. BME is indicated by focally increased signal in the marrow on fat-suppressed T2-weighted MR images due to multiple factors such as abnormal trabeculae, bone marrow necrosis, marrow hemorrhage, and marrow edema [2]. Despite the high prevalence of these so-called bone bruises with ACL ruptures, little is known about the clinical consequences of these findings or about their relationship with local and global cartilage degeneration. A number of studies have proposed that the BME-overlying cartilage may have sustained irreversible injury during impact of acute injuries [3]. $T_{1\rho}$ relaxation time mapping techniques have shown the potential of MRI to reflect changes in biochemical composition of cartilage with early OA [4]. The goal of this study was to assess the BME-overlying cartilage using $T_{1\rho}$ quantification and to study the spatial distribution of the $T_{1\rho}$ in patients with ACL tears.

MATERIALS AND METHODS

Eight healthy volunteers (3 female, 5 male, age = 19-34 years) without any clinical symptoms of OA or other knee injuries and fourteen patients (8 female, 6 male, age=21-56 years) with ACL tears who showed BME were studied using a 3T GE MR scanner and a quadrature knee coil. All ACL tear patients were imaged prior to surgery. Sagittal $T_{1\rho}$-weighted images were acquired using a previously developed sequence based on a 3D-SPGR sequence [5] (FOV=12cm, slice thickness = 3 mm, TR/TE = 10/5.8 ms, TSL = 0/10/40/80 ms, spin lock frequency = 500 Hz, total acquisition time approximately 13 mins). The protocol also included sagittal 3D water excitation high-resolution spoiled gradient-echo (SPGR) imaging, and fat-saturated T_2-weighted fast spin-echo (FSE) images. $T_{1\rho}$ maps were reconstructed by fitting the $T_{1\rho}$-weighted images $S(TSL) \propto \exp(-TSL/T_{1\rho})$ pixel-by-pixel. $T_{1\rho}$ maps and T2-weighted images were then aligned to SPGR images. The cartilage was segmented semi-automatically in SPGR images using a spline-based in-house developed program. Five compartments were defined: lateral and medial femur condyle (LFC and MFC), lateral and medial tibia (LT and MT), and patella. The LFC and MFC were further partitioned into weight-bearing and non weight-bearing anterior and posterior portions. Mean and SD of $T_{1\rho}$ values were calculated in each of these compartments in controls. $T_{1\rho}$ Z-score maps were generated pixel by pixel for all the patients as: $Z_I = (Voxel_I - Mean_{comparment}) / SD_{compartment}$, where $Voxel_I$ is the $T_{1\rho}$ in the voxel of interest, $Mean_{comparment}$ and $SD_{comparment}$ are the mean and SD of $T_{1\rho}$ values in each compartments derived from controls. In patients, 3D cartilage contours were overlaid to the aligned T2-weighted images and BME-overlying and surrounding cartilage were defined manually. These contours were then overlaid to $T_{1\rho}$ Z-score maps and mean, median, and SD of $T_{1\rho}$ Z-scores were next calculated in overlying vs. surrounding cartilage. A paired t-test was used to compare $T_{1\rho}$ Z-scores average between BME-overlying cartilage and surrounding cartilage.

RESULTS

Table 1 shows the mean and SD of $T_{1\rho}$ values in the nine compartments in controls which are significantly higher ($P<0.05$) in nwb than in wb portions. As shown in Table 2, the mean $T_{1\rho}$ Z-score in BME-overlying cartilage in LT was 2.23, indicating $T_{1\rho}$ values in these regions are significantly higher than the values in healthy controls. The mean and median $T_{1\rho}$ Z-scores are significantly higher than those in surrounding cartilage (2.23 ± 3.09 vs. 0.25 ± 2.26, P=0.00014 and 2.27 ± 3.04 vs. 0.18 ± 3.17, P=0.00016 respectively) in LT (Table 2). In LFC compartment, the mean and the median Z-scores for $T_{1\rho}$ in BME-overlying cartilage were not significantly different from those in surrounding cartilage (-0.77 ± 2.68 vs. -0.33 ± 1.08, and -0.78 ± 1.57 vs. -0.25 ± 0.81, respectively). Figure 1 shows a patient who had BME in both LT and LFC. $T_{1\rho}$ values are elevated in BME-overlying cartilage in LT (white arrow) but not in BME-overlying cartilage in LFC (yellow arrow).

Table 1 – Mean and standard deviations of $T_{1\rho}$ values (ms) in the nine compartments in controls; *P<0.05

	LFC-nwb-ant	LFC-nwb-post	LFC-wb	MFC-nwb-ant	MFC-nwb-post	MFC-wb	LT	MT
mean	46.96*	42.68*	38.44	41.15*	40.25*	36.92	36.02	34.89
SD	6.14	4.29	1.97	4.59	3.50	2.75	2.91	3.08

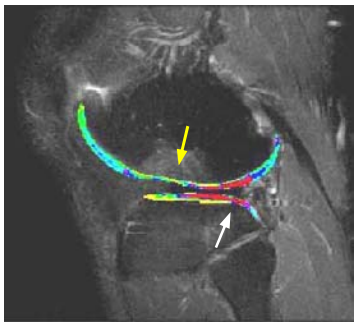

Figure 1 – $T_{1\rho}$ spatial distribution map (z-score) for an ACL tear patient: significant elevated values in BME-overlying cartilage in LT (white arrow) but not in BME overlying cartilage in LFC (yellow arrow).

Table 2 – Z-scores for $T_{1\rho}$ in BME-overlying cartilage compared to surrounding cartilage in lateral compartments; BME location: LFC (2 patients), LT (6 patients), and both in LFC and LT compartments (6 patients); ***P<0.0001

	Overlying (LT)			Surrounding (LT)		
	mean	median	SD	mean	median	SD
average	2.23***	2.27***	2.81	0.25***	0.18***	3.17
SD	3.09	3.04	1.53	2.26	2.16	1.91
	Overlying (LFC)			**Surrounding (LFC)**		
	mean	median	SD	mean	median	SD
average	-0.77	-0.78	5.42	-0.33	-0.25	3.02
SD	2.68	1.57	2.98	1.08	0.81	1.23

DISCUSSION

ACL patients tend to develop osteoarthritis even after ACL-reconstruction [6]. $T_{1\rho}$ quantification provided quantitative assessment of early cartilage changing in knee injuries. The Z-score conversion normalizes the $T_{1\rho}$ for each subject with the mean value of the control subjects in each defined compartment. In this way, differences between cartilage compartments, if exist, can be removed and compared on a common standard. Our data supported the findings in previous studies that BME in ACL tears were predominant in the lateral side of the joint [7]. BME-overlying cartilage showed significantly higher $T_{1\rho}$ values in LT, suggesting that early degeneration may take place at the time of injuries. This elevation, however, was not observed in LFC. These patients will be followed longitudinally to determine if there is any difference in cartilage degeneration in these different compartments post-surgery. Quantitative MRI will allow us to critically evaluate medical and surgical treatments for ligament and degenerative conditions of the knee.

REFERENCES

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