Quantitative MR T2 and T1ρ Mapping of Cartilage and Meniscus at 7 Tesla – Data Reproducibility and Management of Magnetic Field Inhomogeneities

Stefan Zbyn[1,2,3] *, Richard Lartey[1,2], Ahmet H. Ok[1,3], Jeehun Kim[1,2], Carl S. Winalski[1,2,3], Xiaojuan Li[1,2,3]

[1]Program of Advanced Musculoskeletal Imaging (PAMI), [2]Department of Biomedical Engineering, [3]Department of Diagnostic Radiology, Cleveland Clinic, Cleveland, OH. *zbyns@ccf.org

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INTRODUCTION: Cartilage and meniscus degeneration are characteristic manifestations of knee osteoarthritis (OA). MR T2 and T1ρ mapping of cartilage showed great potential for the early OA detection and for the prediction of OA progression **[1]**. Additionally, T2 values were correlated with histological degree of meniscal degeneration in OA patients **[2]**. Unfortunately, clinical application of T2 and T1ρ mapping is often limited by suboptimal reproducibility and long scan times. Although 7T MRI offers increased signal-to-noise ratio and higher acceleration factors when compared to 3T, the management of B0 and $B1^+$ inhomogeneities at 7T remains challenging **[3]**. One approach is to place high-permittivity dielectric padding near the region with low $B1^+$ to increase the $B1^+$ magnitude **[4]**. Thus, the aim of this 7T *in vivo* study was to i) calculate scan-rescan repeatability of T2 and T1ρ quantification in knee cartilage and meniscus, and ii) evaluate the effect of adding dielectric pads inside the knee coil on B0 and $B1^+$ inhomogeneities and on T2 and T1ρ values.

METHODS: The institutional review board approved this ongoing study and informed consent was obtained from all participants. Seven subjects (age range= 18-48 years; 5 females; 2 right knees) with knee pain were imaged at 7T Terra MRI (Siemens) using a 1-Tx/28-Rx knee coil (QED). Morphological turbo-spin echo sequences and 3D DESS were acquired for clinical evaluation and for cartilage and meniscus segmentations, respectively. Four subjects were scanned twice (10-15 minutes break) without dielectric pads to evaluate scan-rescan reproducibility of MAPSS T2 and T1ρ (spin-lock frequency= 500 Hz) **[5]**. In other 3 subjects, B0, $B1^+$, MAPSS T2, MAPSS T1ρ (spin-lock frequency: 500 Hz), and multi-echo spin echo (MESE) T2 maps were acquired during the scan with and without dielectric pads on the same day. Two dielectric pads were placed anteriorly over tibia and over either side of the knee. Nine cartilage and meniscus compartments were automatically segmented on DESS images using an in-house deep learning algorithm **[6]**, followed by manual corrections in ITK-SNAP as needed. In order to evaluate the same location with respect to its position within the magnet, all medial compartments in right knees were assigned as left (i.e. medial meniscus = left meniscus), and all medial compartments in left knees were assigned as right. $B1^+$ inhomogeneities ($\Delta B1^+$) maps were calculated as the ratio between the measured and prescribed flip angles. All T2 and T1ρ maps were calculated voxel-wise by fitting a mono-exponential decay to the data using a two-parametric least-square fitting routine. Segmented regions were transformed and overlaid onto the parameter maps to obtain mean ΔB0, $\Delta B1^+$, T2 and T1ρ values in each compartment. Coefficients of variation (CVs) were calculated to evaluate the T2 and T1ρ scan-rescan repeatability in each compartment.

RESULTS: Morphological images showed multiple chondral and meniscal defects in this cohort. ***Reproducibility:*** Scan-rescan repeatability of MAPSS in cartilage and meniscus at 7T showed the mean CVs from 2.4% to 7.0% for T2 and from 1.9% to 5.5% for T1ρ (**Table 1**). MAPSS T2 showed higher CVs than T1ρ in all compartments. Furthermore, the highest CVs were observed in Right Tibia and Right Meniscus compartments. ***Dielectric Pads:*** Examples of morphological TSE images and $B1^+$ maps acquired from the right knee side of the same subject with and without dielectric pads are shown in **Figure 1**. Left Trochlea and Patella demonstrated the largest B0 inhomogeneities (ΔB0) while Right Meniscus and Right Tibia compartments showed the largest $\Delta B1^+$ (**Table 2**). Dielectric pads helped decrease ΔB0 and $\Delta B1^+$ (i.e., $\Delta B1^+$ closer to 1) in most compartments. Right Tibia and Right Meniscus showed the largest improvement in $\Delta B1^+$ after application of dielectric pads as well as the largest decrease in MAPSS T2, T1ρ and MESE T2 values. MAPSS T1ρ values were the least sensitive while MESE T2 were the most sensitive to $\Delta B1^+$ changes. The largest decrease in ΔB0 did not result in large changes in T2 and T1ρ values.

DISCUSSION: *In vivo* scan-rescan repeatability of MAPSS T2 and T1ρ quantification in cartilage at 7T showed CVs similar to previously reported CVs of 1.4-4.1% for T2 and 1.6-3.9% for T1ρ mapping of cartilage in volunteers at 3T **[7]**. Interestingly, while Right Tibia and Right Meniscus compartments demonstrated the lowest reproducibility, they also showed the largest increase in $B1^+$ when placing dielectric pads over tibia. Dielectric pads improve T2 and T1ρ quantification in cartilage and menisci at 7T when using a 28-channel knee coil. Our results agree with findings of Fagan and colleagues reporting increase of $B1^+$ in the right knee side after using dielectric pads with the same knee coil type **[4]**. MAPSS T1ρ sequence was the most robust to $B1^+$ inhomogeneities.

SIGNIFICANCE/CLINICAL RELEVANCE: Ten minutes T2 and T1ρ mapping with MAPSS sequence have great potential for *in vivo* evaluation of cartilage and meniscus degeneration and regeneration at 7T. Dielectric pads have potential to reduce B0 and $B1^+$ inhomogeneities and thus improve the quality of morphological images and the quantification of T2 and T1ρ in cartilage and meniscus, however, future studies are needed to determine the effect of pads on T2 and T1ρ reproducibility.

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TABLE 1: Reproducibility

(n=4)		CV (%) MAPSS T2	CV (%) MAPSS T1ρ
Femoral Condyle	Left	2.4	2.3
	Right	2.8	1.9
Trochlea	Left	4.3	3.7
	Right	5.7	4.5
Tibia	Left	3.6	2.2
	Right	7.0	5.0
Patella		4.4	3.2
Meniscus	Left	5.8	4.1
	Right	6.7	5.5

IMAGES AND TABLES:

FIGURE 1: Morphological TSE images (left) & $B1^+$ maps (right) with & w/o pads. Using dielectric pads significantly reduced $B1^+$ inhomogeneity (magenta circles).

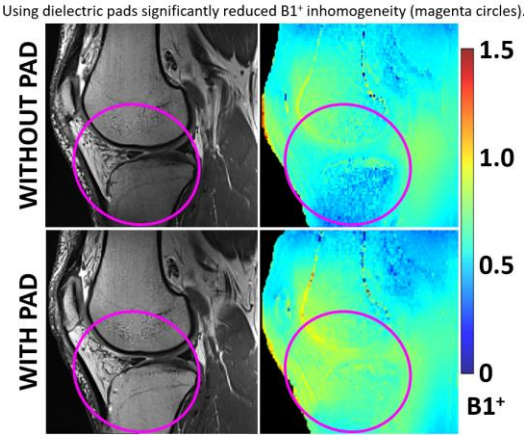

TABLE 2: Magnetic fields and relaxation times measured with and without dielectric pads

(n=3)		Fem. Condyle Left	Fem. Condyle Right	Trochlea Left	Trochlea Right	Tibia Left	Tibia Right	Patella	Meniscus Left	Meniscus Right
ΔB0 (Hz)	No Pad	39.4	26.0	**111.4**	75.2	38.3	24.4	**123.1**	44.2	31.6
	With Pad	27.5	22.1	**93.4**	60.3	19.9	24.4	**124.5**	26.0	28.7
	Change (%)	-30.2	-14.9	-16.2	-19.8	**-48.1**	-0.3	1.1	**-41.1**	-9.0
$\Delta B1^+$ (%)	No Pad	0.96	0.68	0.88	0.86	0.90	**0.65**	0.87	0.90	**0.64**
	With Pad	1.00	0.71	0.90	0.90	1.00	**0.76**	0.84	0.97	**0.71**
	Change (%)	3.5	4.8	2.7	4.5	11.5	**16.3**	-3.2	7.9	**12.3**
MAPSS T2 (ms)	No Pad	36.1	38.1	38.2	39.0	33.8	36.1	36.5	18.3	22.2
	With Pad	36.0	36.7	39.0	38.5	32.4	32.7	34.6	16.6	18.1
	Change (%)	-0.2	-3.6	2.2	-1.4	-4.2	**-9.5**	-5.2	-9.4	**-18.4**
MAPSS T1ρ (ms)	No Pad	39.4	46.6	40.1	42.4	37.3	41.9	38.6	19.8	23.1
	With Pad	39.3	44.5	39.9	41.5	35.5	38.5	37.7	19.1	20.4
	Change (%)	-0.1	-4.5	-0.6	-2.2	-4.8	**-7.9**	-2.3	-3.6	**-11.9**
MESE T2 (ms)	No Pad	37.5	43.9	39.8	39.3	31.4	38.4	37.0	N/A	N/A
	With Pad	36.2	42.0	38.4	38.5	30.3	31.7	36.2	N/A	N/A
	Change (%)	-3.4	-4.4	-3.4	-2.1	-3.7	**-17.4**	-2.3	N/A	N/A