Multi-Component T2 Analysis of Articular Cartilage in Osteoarthritis Patients using mcDESPOT at 3.0T

Fang Liu[1], Richard G. Spencer[2], Wally Block[1,3], and Richard Kijowski[4]

[1]*Department of Medical Physics, University of Wisconsin-Madison, Madison, Wisconsin, United States,* [2]*Magnetic Resonance Imaging and Spectroscopy Section, National Institutes on Health, Baltimore, Maryland, United States,* [3]*Department of Biomedical Engineering, University of Wisconsin-Madison, madison, Wisconsin, United States,* [4]*Department of Radiology, University of Wisconsin-Madison, Wisconsin, United States*

Introduction: Two of the water components in cartilage identified by NMR spectroscopy have become feasibly quantifiable recently by advances in steady-state imaging: a rapidly relaxing water component tightly bound to proteoglycan (W_{PG}) and a slowly relaxing bulk water component loosely bound to the macromolecular matrix (W_{BW}) (1-2). Previous NMR studies have shown that the fraction of the W_{PG} component (F_{PG}) is a sensitive and specific measure of the proteoglycan content of cartilage (1-2). Multi-component Driven Equilibrium Single Pulse Observation of T1 and T2 (mcDESPOT) is a promising two pool model to investigate relaxation characteristics specific to the different water components of articular cartilage in the human knee joint at 3.0T (3). This study was performed to compare single-component and multi-component T2 parameters of the articular cartilage of the knee joint measured using mcDESPOT in healthy volunteers and patients with osteoarthritis (OA).

Methods: The comparison study consisted of 10 healthy adult volunteers and 14 patients with varying degrees of knee OA scanned on a 3.0T scanner (Discovery MR750, GE Healthcare) and 8-channel phased-array extremity coil (InVivo, Orlando, FL). A three-dimensional fast spin-echo (3D-FSE) sequence was performed with TR/TE=2216/23.6ms and 0.6 x 0.6 x 1mm resolution for morphologic joint imaging. The mcDESPOT measurements were made as described in (3) using a 1) a series of spoiled gradient echo (SPGR) scans at 8 varying flip angle, 2) a series of 8 fully-balanced SSFP (bSSFP) scans at 8 varying flip angles; and 3) an inversion recovery IR-SPGR scan with TI=450ms and α=5°. All scans were acquired in the sagittal plane over the entire knee with 0.6 x 0.6 x 3 mm resolution, and one signal average. To minimize sensitivity to SSFP signal nulls, the bSSFP experiments were repeated with and without RF phase cycling to shift the nulls. Total acquisition time for the mcDESPOT scans was 17 minutes. The images were analyzed using an in-house MATLAB program. Single component T2 relaxation time ($T2_{single}$) maps were reconstructed using DESPOT-FM method (4). T2 relaxation time maps of the W_{PG} and W_{BW} components ($T2_{PG}$ and $T2_{BW}$) and fraction maps of the W_{PG} component (F_{PG}) were reconstructed using mcDESPOT two pool model (5). Using cartilage contours created from the 3D-FSE images, multi-component T2 parameters were measured on the patella (PAT), trochlea (TROC), central medial femoral condyle (MFCC), posterior medial femoral condyle (MFCP), central lateral femoral condyle (LFCC), posterior lateral femoral condyle (LFCP), medial tibial plateau (MTP), and lateral tibial plateau (LTP). A musculoskeletal radiologist used the 3D-FSE sequence with multi-planar reformats to determine the Boston-Leeds Osteoarthritis Knee (BLOK) scores on each articular surface to assess the degree of cartilage degeneration. Wilcoxon rank sum tests were used to compare multi-component T2 parameters between healthy volunteers and patients with OA. Effect size analysis was used to assess the statistical power of the parameter for distinguishing between groups of subjects.

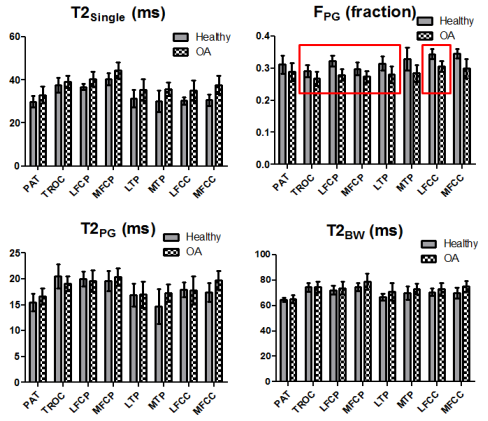

Figure 1: Multi-component T2 parameters for each articular surface in healthy volunteers and patients with OA. F_{PG} shows greater differences between volunteers and OA patients at TROC, LFCP, MFCP, LTP and LFCC compared to the other parameters.

		Non Weight-bearing Surface				Weight-bearing Surface			
		PAT	TROC	LFCP	MFCP	LTP	MTP	LFCC	MFCC
BLOK Scores		17%	12%	7%	9%	7%	21%	7%	22%
Wilcoxon Rank Sum p-value	$T2_{Single}$	0.050	0.230	0.007	0.012	0.069	0.005	0.010	0.000
	F_{PG}	0.050	0.011	0.000	0.009	0.005	0.006	0.000	0.000
Effect Size	$T2_{Single}$	0.850	0.500	1.100	1.098	0.840	1.748	1.040	1.696
	F_{PG}	0.824	1.137	2.472	1.434	1.373	1.739	2.275	1.521

Table 1: Statistical comparison between groups of subjects for $T2_{Single}$ and F_{PG}. F_{PG} had greater statistical power indicated by larger effect size than $T2_{Single}$ for distinguishing between healthy volunteers and OA patients especially on articular surfaces with early cartilage degeneration.

Results: The BLOK scores were expressed as the percentage of the maximum possible score on each articular surface with a higher percentage indicating a greater degree of cartilage degeneration. The mean $T2_{Single}$, F_{PG}, $T2_{PG}$, and $T2_{BW}$ for each articular surface of healthy volunteers and patients with OA are shown in Figure 1. The BLOK scores, Wilcoxon rank sum *p*-values, and effect size for $T2_{Single}$ and F_{PG} are shown in Table 1. F_{PG} was significantly lower ($p<0.05$) on all articular surfaces in patients with OA, while $T2_{single}$ was significantly higher ($p<0.05$) on the PAT, MFCC, MFCP, LFCC, LFCP, and MTP. Effect size of F_{PG} was higher than $T2_{single}$ on the TROC, MFCP, LFCC, LFCP, and LTP and similar to $T2_{single}$ on the PAT, MFCC, and MTP where cartilage degeneration was more advanced. $T2_{PG}$ and $T2_{BW}$ were significantly higher ($p<0.05$) on the MFCC and MTP where cartilage degeneration was most advanced. However, effect size for $T2_{PG}$ and $T2_{BW}$ on these articular surfaces was much lower than for $T2_{Single}$ and F_{PG}.

Discussion: F_{PG} was significantly lower on all articular surfaces of the knee joint in patients with OA than healthy volunteers which likely reflect the decreased proteoglycan content of degenerative cartilage. F_{PG} had greater statistical power than $T2_{Single}$ for distinguishing between healthy volunteers and patients with OA especially on articular surfaces with early cartilage degeneration. $T2_{PG}$ and $T2_{BW}$ were insensitive parameters of cartilage degeneration and only increased on articular surfaces with advanced degeneration. $T2_{Single}$ is a composite measure of the T2 relaxation times and fractions of the different water components of cartilage. In our study, the T2 relaxation times of the W_{PG} and W_{BW} components of cartilage changed very little in patients with OA and only during the advanced stages of cartilage degeneration. Thus, changes in the fractions of the water components of cartilage are primarily responsible for changes in $T2_{Single}$ which occur with cartilage degeneration in patients with OA.

Reference: (1)Reiter D. MRM, 2010. (2)Reiter D. NMR Biomed, 2011. (3)Liu F, JMRI, 2013. (4)Deoni S. JMRI, 2009. (5)Deoni S. MRM, 2008.

Acknowledgements: We gratefully acknowledge support provided by NIH NIAMS U01 AR059514-03 and GE Healthcare (Waukesha, WI).