In-Vivo Assessment of Multiple Water Components of Human Knee Menisci using mcDESPOT at 3.0T

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Introduction: Meniscal tears are well described factors in the pathogenesis and progression of osteoarthritis (OA) (1,2). The ability to non-invasively assess changes in the macromolecular composition of meniscus would allow better understanding of the role of meniscal degeneration in the development of meniscal tears and the subsequent onset of OA. Multi-component Driven Equilibrium, Single Pulse Observation of T1 and T2 (mcDESPOT) is a two-pool model which can investigate the T2 characteristic specific to the different water components of the human knee joint at 3.0T (3). This study was performed to compare mcDESPOT parameters of meniscus measured in healthy volunteers, OA patients with intact menisci, and OA patients with meniscal tears to documentdifferences in the T2 characteristics of the various water components of the meniscus.

Methods: An MR examination of the knee was performed on 11 healthy adult volunteers and 14 patients with varying degrees of OA using a 3.0T scanner (Discovery MR750, GE Healthcare; Waukesha, WI) and 8-channel phased-array extremity coil. A 3D 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. mcDESPOT measurements were made 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 3mm 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 (3). Single component T2 relaxation time ($T2_{single}$) map was reconstructed using DESPOT-FM method (4). T2 relaxation time mapsof the rapidly relaxing $W_S$and slowly relaxing $W_L$components($T2_S$ and $T2_L$) and fraction of the W_S component (F_S) were reconstructed using mcDESPOT two-pool model (5). The medial and lateral menisci of each knee were semi-automatically segmented using in-house segmentation software. A musculoskeletal radiologist used the 3D-FSE sequence with multi-planar reformats to determine the Boston-Leeds Osteoarthritis Knee (BLOK) score within the medial and lateral compartments of the knee joint to assess the degree of joint degeneration. The radiologists also classifiedthe menisci into three groups: normal menisci in healthy volunteers (N=22), intact menisci in OA patients (N=20), and torn menisci in OApatients (N=8). Kruskal-Wallis one-way analysis of variance tests were used to determine differences in $T2_{Single}$, $T2_S$, $T2_L$, and F_S in the3 groups of menisci. For those parameters found to be significantly different between the 3 groups, two-tailed Wilcoxon rank-sum tests were used for pair-wise comparison between each individual set of groups. Spearmanlinear correlation analysis was used to determine the correlation between BLOK scores and multi-component T2 parameters.

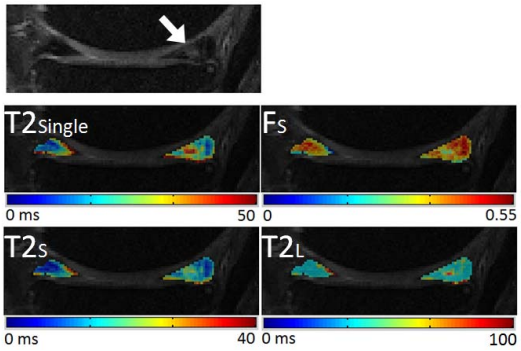

Figure1:$T2_{Single}$, $T2_S$, $T2_L$, and $F_S$superimposed on 3D-FSEsource image of an OA patient with a tear of the posterior horn of the medial meniscus.

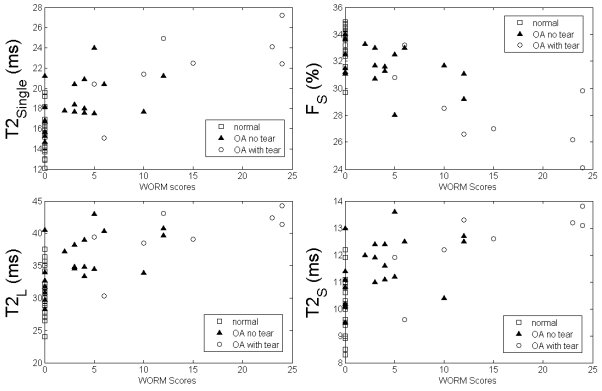

Figure 2: Scatter plot showing $T2_{Single}$, $T2_S$, $T2_L$, and F_S values versus WORM scores for the 3 groups.

Results: The mean and standard deviation for normal menisci, OA menisci without tear, and OA menisciwith tear respectively were 15.4±1.9, 18.6±2.4, 22.3±3.6ms for $T2_{Single}$; 10.3±1.1, 11.6±1.1, 12.5±1.3 ms for $T2_S$; 30.9±3.4, 35.6±4.1, 39.8±4.4 ms for $T2_L$; and 0.34±0.01, 0.32±0.01, 0.28±0.03 for F_S (Figure 1). $T2_{Single}$, $T2_S$, $T2_L$and F_S were strongly ($p<1e^{-5}$) different across the 3 groups. All pair-wise comparison between each set of groups were significant ($p<0.05$) for $T2_{Single}$, $T2_S$, $T2_L$ and F_S. The differences between normal and OA with tear, between normal and OA without tear are generally larger than the difference between OA with tear and OA without tear. $T2_{Single}$, $T2_S$, $T2_L$ and F_S were strongly ($p<1e^{-8}$) correlated with WORM scores with the linear correlation coefficient of 0.73, 0.68, 0.72 and -0.68, respectively (Figure 2).

Discussion: Meniscus has a slowly relaxing water component with a $T2_L$ of 30.9 ms likely corresponding to bulk water and a rapidly relaxing water component with a $T2_S$ of 10.3 ms likely corresponding to water bound tightly to the macromolecular matrix which is composed of 99% type 1 collagen and less than 1% proteoglycan (6). Our study has documented a decreased F_S and an increased $T2_S$ and $T2_L$ of meniscus in patients with OA when compared to healthy volunteers with greater changes associated with more severe meniscal degeneration (i.e. tearing) and more severe joint degeneration (i.e. higher WORM score). The lower F_S is likely due to the combined effects of increased hydration and decreased collagen contentin degenerative meniscus (6). The longer $T2_S$ and $T2_L$likely reflect the increased T2 relaxation time of water tightly and loosely bound to fragmented macromolecules in degenerative meniscus created primarily due to enzymatic degradation of collagen fibers (6). Previous studies have also documented longer $T2_{Single}$ and T2* in degenerative meniscus (7, 8). Additional studies are needed to correlate multi-component T2 parameters measured using mcDESPOT with histological and biochemical parameters in both normal and degenerative menisci and to investigate how changes in multi-component T2 parameters of the meniscus play a role in the development of meniscal tears and the subsequent onset of OA.

References: (1) Ding, J. Rheumatol, 2007. (2) Englund, M. Arthritis Rheum, 2004. (3) Liu, F. JMRI, 2013. (4) Deoni S. JMRI, 2009. (5) Deoni S. MRM, 2008. (6) Herwig J. Ann Rheum Dis, 1984. (7) Zarin Z. Osteoarthritis Cartilage, 2010. (8) Williams A, Osteoarthritis Cartilage, 2012.