Multi-Component T2 Analysis of Articular Cartilage with Synovial Fluid Partial Volume Correction using mcDESPOT at 3.0T

Fang Liu[1], Samuel A. Hurley[1], Alexey Samosonov[1], Andrew Alexander[1], Sean C. Deoni[2], Walter F. Block[1,3], and Richard Kijowski[4]

[1]*Department of Medical Physics, University of Wisconsin-Madison, Madison, Wisconsin, United States,* [2]*Division of Engineering, Brown University, Providence, RI, United States,* [3]*Department of Biomedical Engineering, University of Wisconsin-Madison, Madison, Wisconsin, United States,* [4]*Department of Radiology, University of Wisconsin-Madison, Madison, Wisconsin, United States*

Introduction: Water signal within articular cartilage is generally considered to consist of two components: 1) water tightly bound to macromolecules such as collagen and proteoglycan termed W_m and 2) bulk water loosely bound to the proteoglycan matrix termed W_b (1, 2). Multi-component Driven Equilibrium Single Pulse Observation of T1 and T2 (mcDESPOT) has been previously shown to be a promising two pool model to investigate relaxation characteristics specific to the different water components of cartilage in the human knee joint at 3.0T (3). However, the mcDESPOT two pool model may be influenced by partial volume averaging from synovial fluid which can cause significant estimation bias of the T2 relaxation time of the superficial layer of cartilage. To address this problem, an mcDESPOT three pool model (4) was used in this study to account for the influence of synovial fluid, and the results from mcDESPOT two pool and three pool models were compared to determine the feasibility of removing synovial fluid partial volume effect in the human knee joint at 3.0T.

Methods: The MR examination of the knee was performed on one healthy adult volunteer using a 3.0T scanner (Discovery MR750, GE Healthcare; Waukesha, WI) and 8-channel phased-array extremity coil (InVivo, Orlando, FL). A series of scans necessary for conducting mcDESPOT reconstruction included 1) Spoiled gradient echo (SPGR) scans with TR/TE=4.6/2.2ms over a range of flip angles (α =3, 4, 5, 6, 7, 9, 13, 18°); 2) Two fully-balanced steady-state free precession (bSSFP) scans with RF phase cycling on and off , with TR/TE=5.0/2.4ms over a range of flip angles (α=2, 5, 10, 15, 20, 30, 40, 50°); 3) Inversion recovery IR-SPGR scan with TR/TE=4.6/2.2ms, TI=450ms, and α=5°. All scans were performed in the axial plane covering the entire knee joint with a 16cm field of view, 256 x 256 matrix, 4mm slice thickness, and one excitation. Total scan time was approximately 20 minutes. The images were analyzed using an in-house MATLAB program. The T2 relaxation time maps and water fraction maps for the water tightly bound to macromolecule (W_m) and water loosely bound (W_b) were reconstructed using both mcDESPOT two pool and three pool models. Additional T2 relaxation time map and water fraction map for synovial fluid (Ws) were reconstructed from mcDESPOT three pool model for correcting the synovial fluid partial volume effect.

Results: One slice axial image from the center potion of the patellar cartilage is shown in Figure 1. Two pool mcDESPOT derived W_b component map (B) demonstrates severe synovial fluid partial volume effect at the superficial layer of patellar cartilage where T2 for W_b component increases more than 100% compared to the deeper layer. Three pool mcDESPOT derived W_b component map has less partial volume effect at the superficial layer of cartilage as shown in (C). The Ws map for synovial fluid derived from three pool mcDESPOT model shows an increase in synovial fluid water fraction from close to zero at the deeper layer to 35% at the superficial layer of cartilage. Water fraction for the W_m component from both mcDESPOT two pool and three pool models show no visible difference at the superficial layer of patellar cartilage, as shown in E and F.

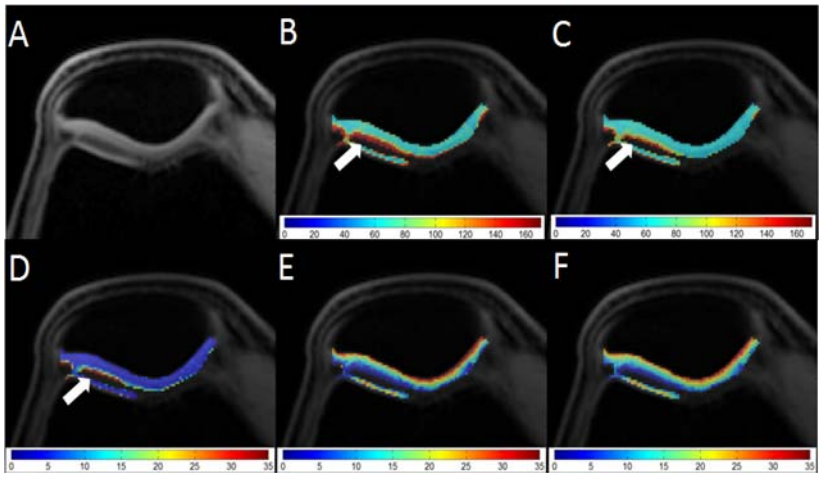

Figure 1: IDEAL-SPGR source image (A), T2 map for the W_b component from mcDESPOT two pool model (B) and three pool model (C) with white arrows indicating synovial fluid partial volume averaging, water fraction map for the Ws component from three pool model (D), and water fraction map for the W_m component from (E) two pool model and (F) three pool model of the patella cartilage in a healthy volunteer.

Discussion: Due to partial volume averaging caused by synovial fluid within the knee joint, mcDESPOT two pool model fails to provide accurate quantitative estimate for the multi-component T2 relaxation time at the superficial layer of cartilage. Instead, the T2 of the W_b component is overestimated at the superficial layer . The mcDESPOT three pool model introduces an additional pool for modeling the static non-exchange component. This study has shown that mcDESPOT three pool model is able to remove the partial volume effect of synovial fluid at the superficial layer with no influence on measurements within the remaining portions of the cartilage. One extra finding in this study, despite not shown here, is that although the mcDESPOT three pool model is not intentionally designed for correcting the partial volume effect of fat, we did notice significant fat suppression within the bone marrow when calculating water fraction for the W_m component . This shows the potential of conducting fat partial volume correction using mcDESPOT three pool model. However, chemical shift of fat has to be considered in the mcDESPOT model in order to perform accurate fat partial volume correction. Future work involves incorporating both fat and synovial fluid partial volume correction in the mcDESPOT model to provide more accurate multi-component T2 analysis of the articular cartilage of the human knee joint at 3.0T.

References: (1) Reiter D. MRM, 2010. (2) Reiter D. NMR Biomed, 2011. (3) Liu F, ISMRM abstract #4365, 2012. (4) Deoni S. MRM, 2012.

Acknowledgements: We gratefully acknowledge support provided by NIH NIAMS U01 AR059514-03 fund, GE Healthcare (Waukesha, WI) and the University of Wisconsin Radiology Research Fund.