Sensitivity of Multicomponent Driven Equilibrium Single Observation of T1 and T2 (mcDESPOT) to Magic Angle Effects in Bovine Articular Cartilage at 3.0T

Rajeev Chaudhary[1], Fang Liu[2], Nade Sritanyaratana[1], Jarred M. Kaiser[3], Samuel A. Hurley[2], Walter F. Block[1,2], and Richard X. Kijowski[4]

[1]Biomedical Engineering, University of Wisconsin-Madison, Madison, WI, United States, [2]Medical Physics, University of Wisconsin-Madison, Madison, WI, United States, [3]Mechanical Engineering, University of Wisconsin-Madison, Madison, WI, United States, [4]Radiology, University of Wisconsin-Madison, Madison, WI, United States

Purpose: NMR spectroscopy has identified two main easily quantifiable water components in cartilage: 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). Conventional single-component T2 relaxation time ($T2_{Single}$) has been extensively used to evaluate articular cartilage but is a composite measure of the T2 relaxation times and fractions of the different water components of cartilage (3). Multi-component Driven Equilibrium Single Pulse Observation of T1 and T2 (mcDESPOT) is an MR technique which can assess the T2 characteristic of the W_{PG} and W_{BW} components of articular cartilage with complete anatomic coverage of the human knee joint in-vivo at 3.0T (4). However, one potential confounding factor in interpreting T2 measurements is changes in T2 relaxation time due to the orientation of the cartilage macromolecular matrix relative to the main magnetic field (B_o) referred to as the magic angle effect (5). This study was performed to investigate the influence of the magic angle effect on multi-component T2 parameters of ex-vivo bovine articular cartilage measured using mcDESPOT.

Methods: A fresh bovine patella specimen was excised from two maturing cows 24 to 30 months of age. The patella specimens were placed in a custom-built container filled with saline solution and imaged on a 3.0T scanner (Discovery MR750, GE Healthcare; Waukesha, WI) using an 8-channel knee coil (In Vivo, Orlando, FL). Careful handling of each patella with a diamond blade band saw ensured bone was properly removed in order to provide a flat cartilage surface for analysis. MR examinations were performed at angles of 0°, 30°, 55°, and 60° relative to B_o. A fat-suppressed 3D SPGR sequence was performed with TR/TE=5.6/2.6ms and α=15°. mcDESPOT measurements were made using 1) a series of SPGR scans at 8 varying flip angle, 2) a series of 8 fully-balanced bSSFP scans at 8 varying flip angles; and 3) an inversion recovery IR-SPGR scan with TI=450ms and α=5°. To minimize sensitivity to SSFP signal nulls, the bSSFP scans were repeated with and without RF phase cycling to shift the nulls. All scans were acquired using a 12 cm field of view, 256 x 256 matrix, 3mm slice thickness, and one excitation with a total scan time of 25 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 (6). 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 (7). Using cartilage contours created from the 3D SPGR images, average T2 parameters of the patellar cartilage specimens were measured at 0°, 30°, 55°, and 60° with respect to B_o. T2 parameters at 30°, 55°, and 60° were expressed as a percent change relative to the baseline value obtained at 0° where there was no magic angle effect.

Results: Figure 1 shows differences in $T2_{Single}$(ms), $T2_{BW}$(ms), $T2_{PG}$(ms), and F_{PG}(%) at 0° and 55° relative to B_o. Figure 2 shows a graph of the percent changes of the T2 parameters at 30°, 55°, and 60° relative to the baseline values obtained at 0°. The $T2_{Single}$ percent change increased by 14.4% at 30° and 42.9% at the magic angle of 55° and then decreased to 36.5% at 60°. The $T2_{BW}$ percent change increased by 5.6% at 30° and 20.1% at the magic angle of 55° and then decreased to 16.3% at 60°. The $T2_{PG}$ percent change increased by 16.9% at 30° and 40.0% at the magic angle of 55° and then decreased to 31.5% at 60°. The F_{PG} percent change remains fairly constant, decreasing -1.8% at 30° and -4.9% at the magic angle of 55° and then increasing to -4.1% at 60°.

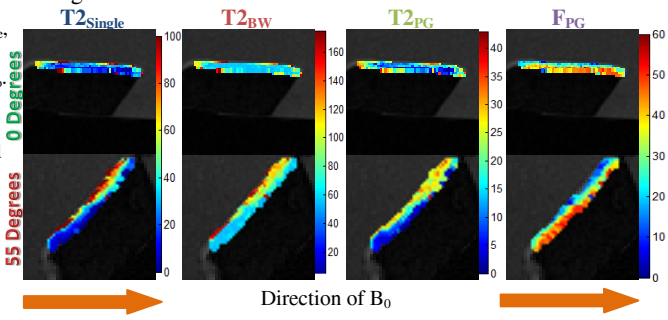

Figure 1: Cartilage $T2_{Single}$, $T2_{BW}$, $T2_{PG}$, and F_{PG} maps at 0° and 55° relative to B_o. There is still some natural variation in the curvature of the articular surface and collagen fiber orientation across the slab which results in non-uniform changes in $T2_{Single}$, $T2_{BW}$, and $T2_{PG}$ within the cartilage specimen.

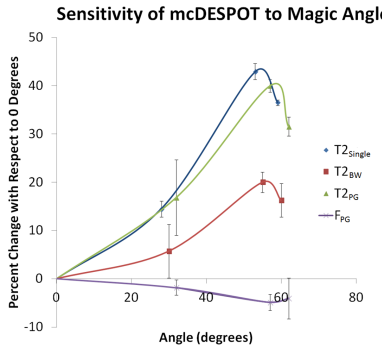

Figure 2: T2 parameters at 30°, 55°, and 60° expressed as a percent change relative to the baseline value at 0° where there was no magic angle effect.

Discussion: Previous studies using microscopic MRI have shown that the T2 relaxation times and fractions of the multiple water components of cartilage are strongly influenced by experimental factors including the MR pulse sequence, image resolution, region of cartilage analyzed, and orientation of the cartilage specimen (7). Our study was designed to acquire multi-component T2 parameters of articular cartilage using a mcDESPOT pulse sequence with spatial resolution, slice thickness, and scan time typically used for human subjects and region of interest cartilage analysis typically performed in OA research studies. Under our experimental conditions, we noted a strong and almost identical magic angle effect for $T2_{Single}$ and $T2_{PG}$. The results suggest that $T2_{PG}$ can provide similar information about collagen fiber orientation as $T2_{Single}$, which is currently the only MR parameter available to assess the collagen fiber network of cartilage (8). In fact, $T2_{PG}$ may provide more specific information regarding disruption of the highly organized collagen fiber network than $T2_{Single}$ by eliminating the influence of confounding factors such as hydration and macromolecular content on $T2_{Single}$ measurements (9, 10). Our study also found a minimal magic angle effect for F_{PG}. Previous studies using NMR have shown that F_{PG} is a sensitive and specific measure of the proteoglycan content of cartilage (1, 2). Our results suggest that F_{PG} may potentially be used to evaluate the proteoglycan content of cartilage without the confounding effects of spurious changes in MR parameters due to alignment of the articular surface relative to the main magnetic field. However, additional studies using ex-vivo specimens and human subjects are needed to better understand the influence of the magic angle effect on multi-component T2 parameters of cartilage measured using mcDESPOT.

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