Magic angle effect plays a significant role in T1rho relaxation in articular cartilage

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INTRODUCTION

In recent years quantitative imaging of the knee joint in osteoarthritis (OA) has focused on two particular biomarkers: $T_{1\rho}$ and T_2 (1-8). $T_{1\rho}$ has been shown to be sensitive to proteoglycan (PG) depletion (4-7). T_2 has been shown to be sensitive to collagen matrix degradation (1). The magic angle effect is a potential confounding factor in T_2 and $T_{1\rho}$ evaluation of joint tissue degeneration (3). The ordered collagen fibers in joint tissues are associated with residual dipole-dipole interactions which are modulated by $(3\cos^2\theta\text{-}1)$, where θ is the angle between the fiber orientation and B_0 field (2). The interactions are minimized when the fibers are oriented 55° or 125° (the magic angle) to B_0 and $3\cos^2\theta\text{-}1$ is near zero. At these angles, fiber T_2 and $T_{1\rho}$ values are often increased relative to these obtained with fibers parallel to B_0. However, the literature regarding $T_{1\rho}$ relaxation is inconsistent, with some groups finding strong residual dipolar interaction (3), and other groups reporting a much reduced magic angle effect (4). In this study we aimed to evaluate the effect of sample orientation on T_2 and $T_{1\rho}$ values of cadaveric human patellae.

MATERIALS AND METHODS

Eight cadaveric human knee patellae were harvested for this study. After harvesting, a transverse slab of 5-8 mm thickness was cut and stored in a phosphate buffered saline (PBS) soaked gauze at 4°C prior to MR imaging on a clinical whole-body GE scanner. A 3-inch receive-only surface coil was used for signal reception (the body coil was used for signal excitation). The patella samples were placed in perfluorooctyl bromide (PFOB) solution to minimize susceptibility effects at tissue-air junctions. A single slice at the center of each patella sample was imaged. The imaging protocol included the following three sequences: 1) a 2D CPMG sequence with eight echoes (10 to 80 ms) for T2 measurement; 2) a 2D spin-locking prepared spiral sequence for T1rho measurement; 3) a 3D magnetization-prepared angle-modulated partitioned-*k*-space SPGR snapshots (3D MAPSS) sequence for T1rho measurement; Typical imaging parameters included: field of view (FOV) = 5 cm, matrix = 256×256, 2 mm slice thickness, spin-lock time (TSL) = 0, 10, 20, 40, 80 ms for 2D/3D T1rho measurement, and TE = 10, 20, 30, 40, 50, 60, 70, 80 ms for CPMG T2 measurement. The same imaging protocol was applied to each sample at six different angular orientations: 0°, 20°, 40°, 60°, 80° and 100° relative to the B_0 field. T1rho/T2 values were determined using nonlinear least square mono-exponential curve fitting of average signal intensities from three regions (medial, apex and lateral) with three layers (10% superficial, 60% middle, 30% deep) for each region. Image registration was performed before data analysis to ensure that ROIs were identically located on images obtained at different angles and sequences.

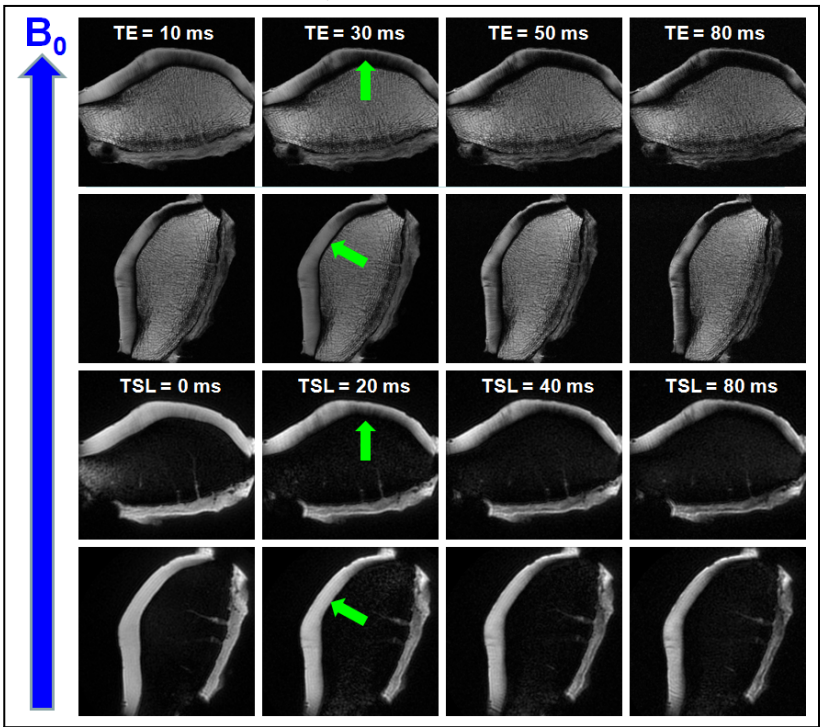

Fig 1 *Spiral $T_{1\rho}$ imaging: apex parallel to B_0 with three TSLs of 0 (A), 20 (B) and 60 ms (C), and 60° to B_0 with five TSLs of 0 (D), 10 (E), 20 (F), 40 (G) and 80 ms (H). CPMG T_2 imaging: apex parallel to B_0 with three TEs of 10 (I), 20 (J) and 60 ms (K), and 60° to B_0 with five TEs of 10 (L), 20 (M), 40 (N), 60 (O) and 80 ms (P). The regions indicated by the arrows show dramatic signal enhancement when the fibers are oriented at ~55° to B_0, consistent with strong magic angle effect for both T_2 and $T_{1\rho}$*

RESULTS and DISCUSSION

Figure 1 shows selected CPMG T_2 and spiral $T_{1\rho}$ images of a patella at two angular orientations relative to the B_0 field. The middle and deep layers of articular cartilage (arrows) show dramatic signal change: near zero signal when the collagen fibers are oriented parallel to the B_0 field while a high signal is seen when the fibers are oriented near the magic angle.

Figure 2 shows quantitative analysis of CPMG T_2 and spiral $T_{1\rho}$ values of the superficial, middle and deep layers of articular cartilage in the medial region (arrows in Figure 1). T_2 values were lowest (~12.0 ms) when radial fiber were near 0° to B_0, increased to a maximum at ~55° (~65.3 ms) and decreased to a local minima at 90° (~27.7 ms). $T_{1\rho}$ values exhibited similar angle dependency: ~33.2 ms near 0°, ~82.1 ms near the magic angle, and ~59.6 ms near 90°. MAPSS $T_{1\rho}$ values showed similar trend (results not shown).

On average over eight patellae, T_2 values were increased by 231.8% (72.2% for superficial, 237.6% for middle, and 187.9% for deep layers) while $T_{1\rho}$ values were increased by 92% (31.7% for superficial, 69% for middle and 140% for deep layers) near the magic angle.

The magic angle effect on T_2 is well known. Our study indicates that the magic angle effect also plays a significant role in $T_{1\rho}$ relaxation.

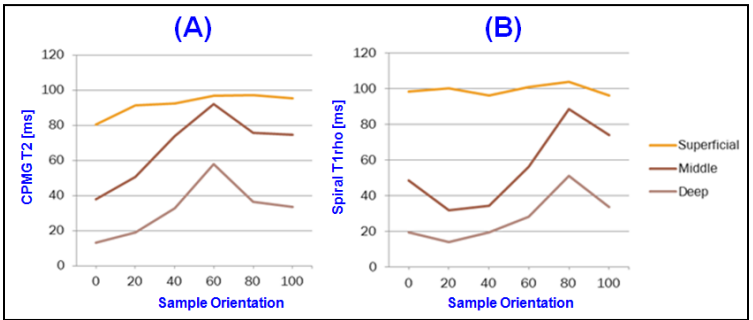

Fig 2 *Superficial, middle and deep ROIs in the medial region (arrows in Fig 1) chosen for T_2 (A) and $T_{1\rho}$ (B) analysis. Strong magic angle effects are seen in the middle and deep layers.*

CONCLUSIONS

Quantitative MRI, including T_2 and $T_{1\rho}$, is increasingly used for objective evaluation of musculoskeletal tissues. Results from this study show that the fibril or fiber-to-B_0 angle may be higher than changes associated with degeneration, and this needs to be considered during quantitative T_2 and $T_{1\rho}$ MRI evaluation of articular cartilage.

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