Magic angle effects on T2, T2* and T1ρ relaxation times

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INTRODUCTION

The early stages of OA are associated with breakdown of collagen, decrease in proteoglycans (PG) and increase in water content (1). Recent research has focused on establishing correlations between quantitative MR parameters (T1, T2, T2*, T1ρ) and biochemical or biophysical properties of cartilage (1-5). Magic angle effects influence apparent T2 values of tissues with ordered collagen structure, such as articular cartilage, menisci, ligaments and tendons. When fibers are oriented 55° to main magnetic field (B_0), T2 values are at a maximum. T1ρ imaging is increasingly used to assess tissue proteoglycan content, but it is unclear if T1ρ values also depend on fiber orientation relative to B_0. The purpose of this study was to evaluate the effect of sample orientation on T2/T2* and T1ρ values of the deep radial layer of human patellar cartilage and ligaments.

MATERIALS AND METHODS

Cadaveric patellae (n=5) were sectioned in the axial plane. A single 3 mm slice from each patella, along with five pieces of goat posterior cruciate ligaments (20 mm long) were scanned in a GE 3T Signa HDx with a custom 2.5 cm radius T/R Helmholtz coil. T2, T2* and T1ρ were measured at six angles of 0°, 25°, 40°, 55°, 70°, and 90° relative to the B0 field. The position of the specimen and angle to B_0 were standardized using an ankle brace with an internal goniometer. For each angle, 2D CPMG sequence was used for T2 measurement, ultrashort TE (UTE) sequence with a minimum TE of 8 μs was used for T2* measurement, 2D spiral T1ρ prep sequence and UTE T1ρ sequence were used for T1ρ measurement (6). Typical imaging parameters included: FOV=5cm, matrix=256x256, TR = 2000 ms for CPMG, 500 ms for UTE and UTE T1ρ, 1500 ms for spiral T1ρ. For T2 quantification, effective TE of 6 to 74ms (6 steps), and for T1ρ, spin-lock time (TSL) of 10 to 80 ms (6 steps), for T2* six TEs of 8 μs to 25 ms were used. T2/T2*/T1ρ values were determined using a nonlinear least square mono-exponential fit of average signal intensity for varying TE or TSL, respectively. Image registration ensured that ROI placement was identical between images from different angles and sequences.

RESULTS and DISCUSSION

Variation in signal intensity with angle was observed in both T2-, T2*- and T1ρ–weighted images. T2 values in all regions exhibited the well-known, angle-dependent behavior. For patellae T2 values were lowest when radial fibrils were at 0° to B_0, increased to a maximum at 55° (~50 ms) and decreased to a local minimum at 90° (~20 ms). T1ρ values also exhibited similar angle-dependency, but with a smaller range of values (20~60 ms). CPMG and spiral T1rho sequences show little signal for the goat PCL, which can be imaged with the UTE and UTE T1rho sequences. Both T1ρ and T2* show a significant magic angle effect. T1ρ increased from 5.64 ± 1.58 ms at 0° to 31.91 ± 9.01 ms at 55° (big fitting error due to small range of TSLs used in this study), and then gradually reduced to 10.25 ± 2.05 ms at 90°. Meanwhile, T2* increased from 1.42 ± 0.16 ms at 0° to 16.87 ± 4.05 ms at 55°, and then gradually reduced to 5.94 ± 0.11 ms at 90°. T2, T2* and T1ρ values of the radial layer of articular cartilage and ligaments all demonstrated the magic angle effect, with T1ρ values less affected than T2/T2* values (Fig 1). The fiber-to-B_0 angle must be considered during quantitative T2/T2* and T1ρ MRI evaluation of articular cartilage and ligaments. Free water and water bound to the collagen matrix may show distinct T2/T2*/ T1ρ relaxation times, and display different levels of magic angle effects, and will be investigated in the future.

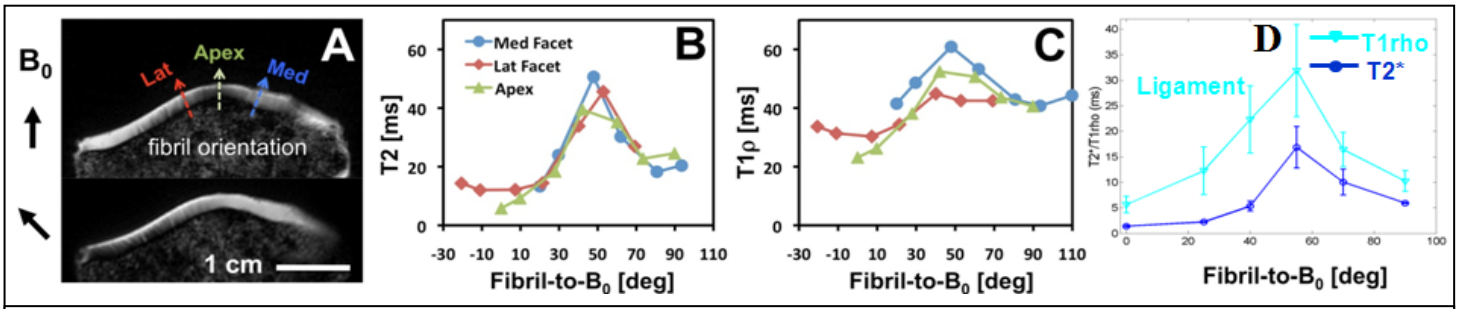

Figure 1 Visualization of the magic angle effect in cadaveric patellar axial slice (A) and variation in T2 (B), T1ρ (C, D) and T2* (D) in cartilage (A-C) and a goat PCL (D). The low signal area of the apex (upper) in (A) becomes high signal when the orientation to B_0 is changed (lower). There is a 2- to 6-fold increase in T2/T2*/ T1ρ when the fibers are re-oriented from 0° to 55° relative to the B_0 field (B-D). T2 was measured using a clinical CPMG sequence. T1ρ in cartilage was measured using a spiral T1ρ sequence. T1ρ and T2* in ligaments were measured using UTE T1ρ and T2* sequences.

CONCLUSIONS

Both T2/T2* and T1ρ are significantly affected by the dipole-dipole interaction or magic angle effect. Quantitative MRI should consider fiber orientations carefully for reliable diagnoses.

REFERENCES

1. Mosher TJ, et al., AJR 2001.
2. Fullerton GD, et al. Radiology 1985.
3. Mlynarik V, et al., JMR 2004.
4. Akella SVS, et al, MRM 2004.
5. Li X, et al, Osteoarthritis Cartilage 2007.
6. Du, et al., MRM 2009.