Reduction of magic angle effect for quantitative MRI of articular cartilage in vivo

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TARGET AUDIENCE

Osteoarthritis researchers focusing on MRI of articular cartilage.

PURPOSE

Magic angle effect is a major confounding factor in both quantitative and qualitative assessment of articular cartilage, as well as in other tissues, affecting especially T_2 relaxation times, which are known to be sensitive to the collagen network of articular cartilage (1). Recently, the sensitivity of adiabatic $T_{1\rho}$ to cartilage degeneration has been demonstrated in animal models and human tissue (2-4). Furthermore, reduced magic angle dependence was recently demonstrated for adiabatic $T_{1\rho}$ in ex-vivo articular cartilage (5). In this work, adiabatic $T_{1\rho}$ and T_2 relaxation time constants of knee articular cartilage were measured in vivo at 3 T with the goal to assess the sensitivity of these methods to the orientation of cartilage in the external static magnetic field.

METHODS

Two non-symptomatic volunteers were scanned at 3 T (Siemens Skyra, Siemens, Erlangen, Germany). The protocol consisted of measurement of T_2 and adiabatic $T_{1\rho}$ relaxation time constants. The T_2 was measured using multiecho spin-echo sequence with TE = 13.8, 27.6, 41.4, 55.2 and 69 ms, TR = 1.68 s, imaging matrix 384x384 (0.42x0.42 mm in-plane resolution, 3 mm slice thickness) and 18 acquired slices. The adiabatic $T_{1\rho}$ was measured using magnetization-prepared gradient recalled echo sequence. $T_{1\rho}$ contrast was generated by applying 0-16 adiabatic inversion pulses of HS4-family (6) with pulse duration of 6 ms and $\gamma B_{1,max}$ = 800 Hz for spin-lock times of 0, 24, 48, 72 and 96 ms, repetition time of 4 s, imaging matrix 256x256 (0.7x0.7 mm in-plane resolution, 3 mm slice thickness) and two acquired slices matching two of the T_2 slices, with parallel acquisition factor 2. The local institutional review board approved the measurement procedures. The relaxation times were calculated pixel-by-pixel in the cartilage region with monoexponential decay functions using an in-house plugin written for Aedes (http://aedes.uef.fi/). Segmentation of the cartilage region was manual. To further evaluate the depth-wise variation of the relaxation times, profiles over the cartilage thickness were calculated in two regions: cartilage surface at approximately 90° and at 54° angle to the main magnetic field (Figure 1, arrows).

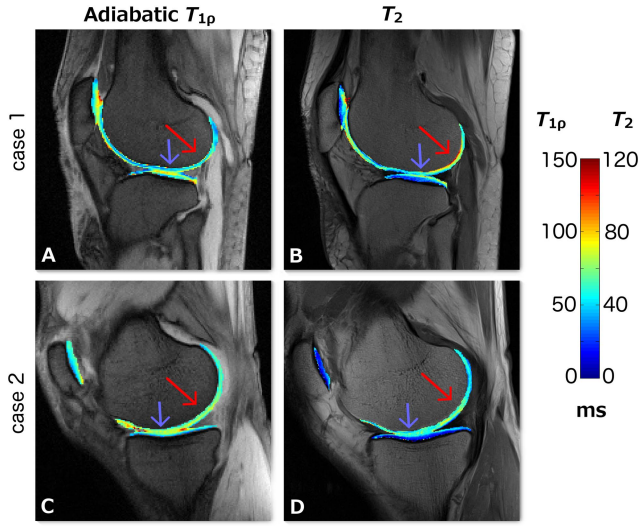

Figure 1. Adiabatic $T_{1\rho}$ and T_2 relaxation time in volunteer knees at 3 T. Red and blue arrows point to regions that are oriented at approximately magic angle and at non-magic angle to the main magnetic field, respectively.

RESULTS

T_2 relaxation time maps demonstrated spatial variation due to the organization and orientation of collagen fibrils in normal adult articular cartilage (Figure 1). The magic angle effect was visualized by longer T_2s over the depth of cartilage at cartilage regions that are oriented approximately at the magic angle with respect to the main magnetic field (Figure 1B,D). In the same regions, adiabatic $T_{1\rho}$ demonstrated less spatial variation compared to T_2, suggesting reduced magic angle dependence (Figure 1A,C). The depth-wise profiles averaged for the regions (Figure 2) demonstrated an increase in the T_2 relaxation time at the region oriented approximately at the magic angle.

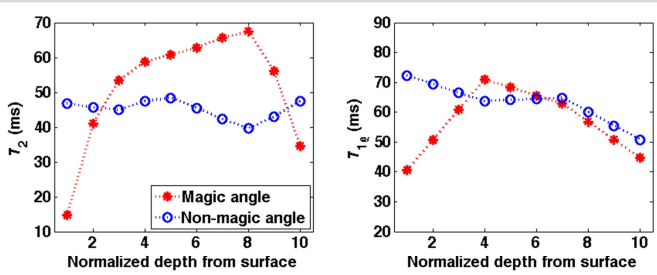

Figure 2. Comparison of normalized depth-wise T_2 and adiabatic $T_{1\rho}$ relaxation time profiles at the indicated locations (Fig.1), averaged over the two cases.

DISCUSSION

T_2 relaxation time constants at 3 T exhibited the expected spatial variation and dependence on orientation with respect to B_0, as expected (1). This variation, if not accounted for, could potentially result in misinterpretation of the quantitative data. Conversely, adiabatic $T_{1\rho}$ showed less spatial variation that could be attributed to the orientational ordering of dipolar interactions in the tissue and thus to the magic angle effect. This finding is in line with the recent high-field specimen rotation study, which demonstrated significantly reduced magic-angle dependence for adiabatic $T_{1\rho}$ in cartilage (5). The results demonstrate increased robustness of adiabatic $T_{1\rho}$ in the quantitative assessment of articular cartilage compared to T_2.

CONCLUSION

Reduced magic angle dependence was demonstrated for adiabatic $T_{1\rho}$ relaxation time constants in the assessment of human knee cartilage in vivo at 3 T. The result provides compelling evidence on the potential benefits of using adiabatic $T_{1\rho}$ for cartilage assessment, especially given the recent reports demonstrating also its sensitivity to degenerative changes in articular cartilage (2,4).

REFERENCES

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