Reduction of the Magic Angle Effect on Contrast in Magnetization Transfer Imaging of Human Cartilage

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INTRODUCTION

In this study of human cartilage, we tested the hypothesis that the magic angle effect is reduced more in MT-weighted images than in T2-weighted images. Articular cartilage has three structural zones distinguished by collagen fiber orientations: superficial zone, transitional zone, and radial zone. When collagen fibers are oriented at 54.7°with respect to the main magnetic field of the magnet (B0), dipole-dipole interactions go to zero, resulting in a prolongation of the T2 relaxation time. This phenomenon is named as the "magic angle effect". In MRI, the magic angle effect appears as bright regions and often confounds accurate interpretation of these areas [1]. Magnetization transfer (MT) contrast reflects the interaction of free water protons with protons associated with the macromolecules (such as proteins) and membranes in biological tissues. Quantitative magnetization transfer imaging based on MT model will give the fractions of the macromolecules in the whole tissue, which are less affected by the measuring parameters and conditions [2].

METHODS

Sample Preparation Five specimens of normal human articular cartilage were obtained from cadaveric donors through the Gift of Hope Organ and Tissue Donor Network (with Rush University IRB approval), and frozen at –80ºC until experimentation. Each specimen was full-thickness cartilage with subchondral bone with dimension of 2×2×10mm which was fitted and sealed in a 2.5 mm NMR sample tube (New Era Enterprise Inc) filled with physiological saline before MRI experiments.

MRI Experiments T2- and MT-weighted images were acquired using 11.7 T Bruker Avance imaging spectrometer (Billerica, MA) at two orientations (0° and 55°) with respect to the B0. A homemade 3 mm diameter solenoidal coil was used for all the MR experiments. A CPMG pulse sequence was used for T2 imaging. The MT-weighted images were acquired using a spoiled 3D MT-GRE pulse sequence with TR/TE/α = 36ms/1.7ms/10◦, NEX = 1. MT pulse power = 15 μT for offset frequencies Δ= 0, 1, 1.5, 2, 3, 4, 6, 8, 12, 15, 20, 25, 31, 37, 43, 50 kHz. All the images have in-plane resolutions of 31 × 31 μm, FOV = 4 mm × 4 mm, and slice thickness = 0.5 mm.

Data Processing T2 maps were calculated using a least squares single exponential fitting model. Based on the two-pool model of protons in biological tissues, quantitative magnetization transfer maps of the cartilage region – magnetization transfer ratio (MTR), bound proton faction (BPF) and cross relaxation rate (CRR) – were also calculated [3,4]. To compare the images at different orientations, the maps at 55° were registered to their corresponding maps at 0°. A 1D profile was produced by averaging 10 pixels in the same depth from the cartilage surface to tide mark in each map.

RESULTS

T2- and MT-weighted images of a cartilage plug in both orientations are shown in Fig.1. For the T2-weighted images (Fig. 1A, B), a laminar appearance is clearly seen in the parallel orientation (the radial zone is parallel to B0), whereas the laminar appearance is reduced for the magic angle orientation (the radial zone is 55° to B0). No apparent laminar appearance was seen in MT-weighted images in both directions (Fig. 1C, D). Anisotropy was found in the T2 map at parallel orientation (Fig.2A), and reduced in the MTR (Fig. 2C) map at same orientation. No lamina was observed for MTR (Fig. 2C, D) maps and no significant difference in values was found between the both directions. From the profile plot (Fig. 3A), it can be observed that T2 profile exhibit three distinct regions at parallel orientation (0°), while no lamina is seen at magic angle (55°). Increases of MTR, BPF and CRR values were found at the deep zone (Fig. 3B, C, D).

CONCLUSIONS

The laminar appearance of articular cartilage in T2-weighted image is substantially reduced by the magnetization transfer sequence. The high signal intensities caused by the magic angle effects in T2-weighted images are eliminated in MT-weighed images. Magnetization transfer contrast is less sensitive to the magic angle effect and could be used in cartilage imaging to reduce diagnostic confusion.

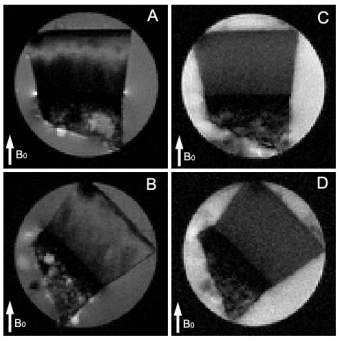

Fig 1. T2 – and MT – weighted images. (A, B) T2 – weighted images at 0◦ and 55◦ to B0 with TR/TE = 3s/30 ms, and NEX =2. (C, D) MT – weighted images at 0◦ and 55◦ to B0 with MT frequency offset Δ= 1.5 kHz.

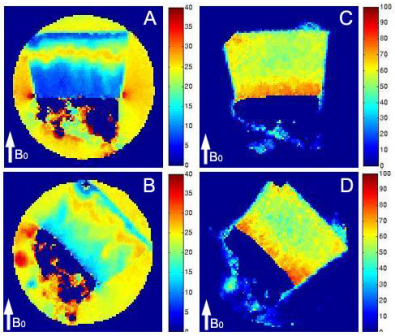

Fig 2. T2 and MTR maps of a cartilage plug in parallel and magic-angle orientations. (A, B) T2 maps, (C, D) MTR maps.

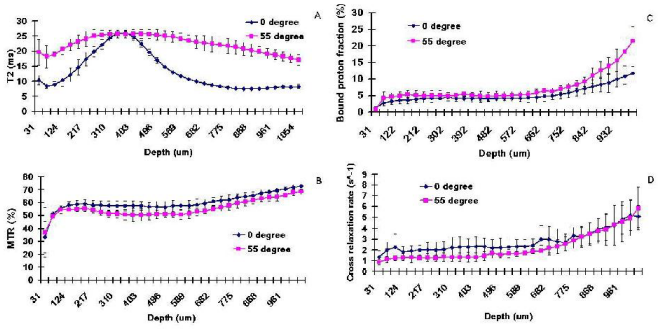

Fig 3. Averaged (mean ±std) T2, MTR, BPF, and CRR profile plots from T2, MTR, BPF, and CRR maps respectively in both parallel and magic-angle orientations. (A) 1D T2 profile, (B) 1D MTR profile, (C) 1D bound proton fraction (BPF) profile, (D) 1D cross relaxation rate (CRR) profile.

REFERENCES

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