The Influence of Chemical Shift Artifacts on Cartilage T2 Mapping

T. Shiomi[1], T. Nishii[1,2], H. Tanaka[3], M. Okamoto[1], H. Yoshikawa[1], and N. Sugano[1,2]

[1]Department of Orthopaedic Surgery, Osaka University Medical School, Suita, Osaka, Japan, [2]Department of Orthopaedic Medical Engineering, Osaka University Medical School, Suita, Osaka, Japan, [3]Department of Radiology, Osaka University Medical School, Suita, Osaka, Japan

Introduction

T2 mapping of the articular cartilage is one of the recent noteworthy techniques in joint MR imaging, to elucidate early degenerative change associated with change of water contents and damage to collagen network.   High-field MR systems at 3 T or higher are increasingly utilized in T2 mapping due to advantages of higher signal-to-noise ratio (SNR) and resolution. However, MR imaging at higher magnetic field is likely to cause greater chemical shift artifacts at the cartilage-bone interfaces along the frequency-encoding (FE) direction of MR images, due to increased separation between water and fat-resonant frequencies. [1] Several techniques are proposed to reduce the artifacts, including frequency-selective fat saturation, replacing the FE direction with the phase-encoding (PE) direction, or increasing the receiver bandwidth, however, the most effective technique is unknown. The purpose of this study is to compare preventing effects of chemical shift artifacts in T2 mapping between those proposed techniques, using cadaver porcine femoral condyles with normal cartilage and cartilage partially depleted of matrix components, and to correlate with biochemical composition.

Materials and Methods

Twenty distal femurs were harvested from juvenile pigs, and were imaged using 3.0T MR imaging system (General Electric Signa HDx 3.0T scanner). Before imaging, a small cylindrical bone defect was made at the medial and lateral femoral condyle as a fiducial mark (Fig 1), to enable reproducible identification of the same imaging plane and definitions of regions of interest (ROIs) in the following imaging sequences. Before imaging, 10 of 20 femurs were treated for cartilage depletion, by exposing collagenase (50mg/100ml of buffer solution) for 4 hours at 37°C. [2] All femoral condyles with or without depletion were equilibrated for a minimum of one hour in PBS, and sagittal T2 maps were obtained in the medial and lateral femoral condyles, with the frequency-encoded (FE) direction placed anteroposterior (Method A), with the FE direction changed into superoinferior (Method B), with increasing the receiver bandwidth (Method C), and with employing fat saturation (Method D) (Fig 1). T2 maps were calculated using mono-exponential fit from 2D multi-spin echo sequences (TR=1500ms, 8 echoes between 10-80 ms, voxel size 0.2X0.2X2.0mm).

In the same imaging plane and spatial resolutions, sagittal SPGR images were obtained, and 3 ROIs were manually defined on the femoral cartilage (Fig 2); ROI 1 was perpendicular to the static magnetic field (B_0), ROI 2 was oriented 55° to B_0 and ROI3 was parallel to B_0. Each ROI was subdivided into superficial layers (ROI 1s, 2s, 3s) and deep layers (ROI 1d,2d,3d) with a thickness of half the total cartilage thickness, respectively. Positions of the 3 ROIs were exactly transferred on the T2 mapping at Method A, B, C and D. T2 values by Method A, B, C, and D at each ROI were compared using a paired t-test. Then, full thickness cartilage disks (diameter of 4mm) without subchondral bone were removed from the knees matching each ROI using the fiducial mark. Proteoglycan and hydroxyproline content of cartilage in each ROI were measured by spectrophotometric assay.

Results

In both normal and depleted femurs, the average T2 values by Method C tended to increase at all ROIs, compared with those by Method A, B and D (Fig 3).There was a significant increase of T2 value by Method C at all ROIs ($p<0.05$). Comparison of T2 values between Methods A and B, however, resulted in no significant differences, except ROI 3s.

The average T2 values of all ROIs tended to increase at depleted cartilage compared with at normal cartilage (Fig 3). In normal cartilage, the average T2 values by Method A at ROI 1s/1d/2s/2d/3s/3d were 75/59/75/58/61/49 ms. In depleted cartilage, those values at ROI 1s/1d/2s/2d/3s/3d were 89/63/104/66/69/55 ms, respectively. There was a significant increase of T2 value in the depleted cartilage, at ROI 1s, 2s, 2d and 3d ($p<0.05$).

The average proteoglycan (PG) and hydroxyproline(HP) content of normal cartilage of 10 femurs at ROI 1s/1d/2s/2d/3s/3d were 61/64/60/63/60/65 μg/mg and 121/130/118/126/115/124μg/mg respectively. Those of depleted cartilage of 10 femurs at ROI 1s/1d/2s/2d/3s/3d were decreased to 44/46/43/45/41/43μg/mg and 75/81/73/80/70/79μg/mg respectively. T2 values (by Method A) had highest correlation with (PG) and (HP) content at ROI 1s, 2s, 2d and 3d. (r=0.416 for PG and 0.453 for HP, r=0.712 for PG and 0.748 for HP, r=0.674 for PG and 0.583 for HP and r=0.445 for PG and 0.506 for HP, respectively)

Conclusion

Theoretically, in MR images at 3.0T, signal from bone fat tissue will be represented at the shifted position by 7pixel, as compared with signal from cartilage proton component, due to chemical shift artifact. We hypothesized that T2 at cartilage deep layer around the bone-cartilage interface is most sensitive to this artifact, showing greater variation between Method A, B, and D.   Contrary to our expectation, however, there was no significant difference of T2 at ROI 1d, 2d or 3d, between these methods. Interestingly, T2 values by Method C were significantly increased in all ROIs compared with the other methods. Increase of the receiver bandwidth may be effective to reduce chemical shift artifact, however, it also causes significant signal loss. This signal loss may influence T2 value at each ROI of the cartilage. Correlation between T2 value and analysis of biochemical compositions was evaluated to determine which MRI method was most sensitive to cartilage matrix change. The present study showed Method A was most reliable among the four methods.

In conclusion, results of this study indicate that the effect of the chemical shift artifacts on cartilage T2 is substantially less than that predicted on the basis of prior ex vivo studies, except the change of receiver bandwidth. Our results may suggest that attention should be paid on the receiver bandwidth to achieve reliable assessments of the cartilage quantitative MR measurements.

References

[1] Ravinder R, et al. JMRI 25:262-9,2007. [2] Jennifer S, et al. Radiology 228:493-9,2003.
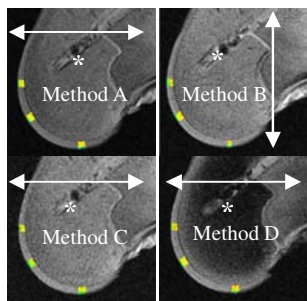
Fig1: Sagittal T2maps at each method. Arrow represents frequency-encoded (FE) direction. Fiducial mark was marked with *
Method A: FE direction anteroposteriorly
Method B: FE direction superoinferiorly
Method C: Increase of receiver bandwidth
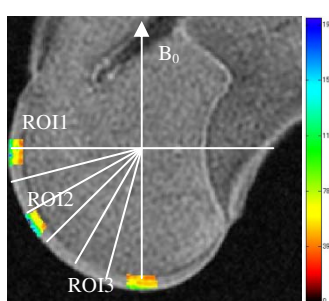Method D: Fat saturation

Fig 2: Definition of 3 ROIs
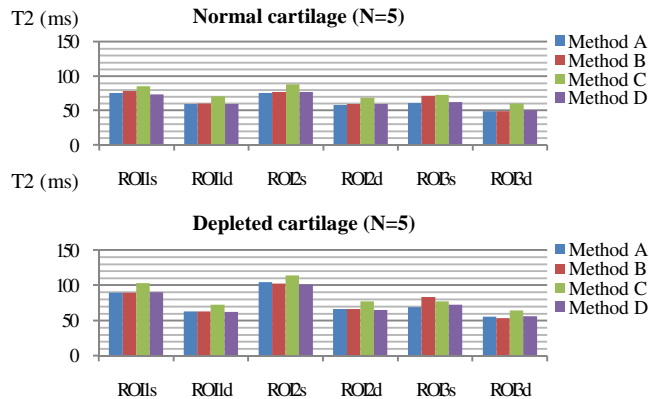ROI 1 was perpendicular to B_0
ROI 2 was oriented 55° to B_0
ROI3 was parallel to B_0

Fig3: T2value (ms) of each ROI at four methods