Investigation of the influence of residual ^{1}H dipole-dipole couplings on magnetization transfer ratio maps of porcine menisci

Christina Hopfgarten[1], Stefan Kirsch[1], Gregor Reisig[2], Michael Kreinest[2], and Lothar R. Schad[1]

[1]*Computer Assisted Clinical Medicine, University Medical Center Mannheim, Heidelberg University, Mannheim, Germany,* [2]*Experimental Orthopaedics and Trauma Surgery, Orthopaedic and Trauma Center Mannheim, University Medical Center Mannheim, Heidelberg University, Mannheim, Germany*

Introduction

Magnetic resonance imaging (MRI) is an obvious choice for studying menisci on many biological scales [1]. However, MR image contrast of menisci is affected by the "magic angle (MA) effect". The MA effect manifests as a distinct variation of the signal intensity across the meniscus. Its occurrence in tissues like menisci, tendon, ligaments and cartilage is well known and can lead to misinterpretation of the MR images [2]. The origin of this effect is related to local variation of the transverse relaxation time T_2 owing to residual ^{1}H dipole-dipole couplings of immobilized water protons. It has been reported that magnetization transfer ratio (MTR) imaging of human cartilage is little affected by the MA effect [3]. This observation provides evidence that the MTR may be useful to investigate tissues which generally show a distinct MA effect in conventional MR imaging. In this study, we investigated MTR maps of acutely isolated porcine menisci. The experiments were focused on the question, if the MTR is affected by residual dipole-dipole couplings and the resultant magic angle (MA) effect.

Material & Methods

Sample Preparation: Five medial menisci were imaged immediately after being acutely isolated from macroscopically healthy porcine knee joints obtained from a local slaughterhouse. The menisci were immersed in Fluorinert® FC-770 (Sigma-Aldrich, Steinheim, Germany) to avoid dehydration.

Experiments: The experiments were performed on a 9.4 T small animal scanner (Biospec®, Bruker, Ettlingen Germany). The test tubes were placed into a block of polystyrene to allow approximate positioning of the menisci in ten marked orientations between 0° and 90° (Fig. 1). An elastic strap is placed around the test tube at the thinnest point of the meniscus to make sure that the same slice is imaged after reorientation. The imaged slice is positioned through the two small points of the elastic strap visible in the localizer. T_2 maps were measured using a (multi slice) multi echo (MSME) sequence with $TR = 2.5$ s, $TE_{min} = 2$ ms, FOV = 32 × 32 mm², MTX = 64 × 64, slice thickness = 1 mm, number of averages = 4, and 16 equidistant echoes ($\Delta TE = TE_{\min}$). The total measurement time for one orientation was $TA = 8$ min. The MTR maps of these menisci were measured using a RARE sequence with an off-resonant, rectangular shaped saturation pulse (duration $T_{sat} = 2.5$ s, $B_1 = 10$ µT, Δ = 2.2, 8.9 kHz), $TR = 2.6$ s, RARE factor = 4, $TE = 1.6$ ms, FOV, MTX and slice thickness were the same as for the MSME measurement. The total measurement time for the MTR maps was $TA = 4$ min 30 s per orientation.

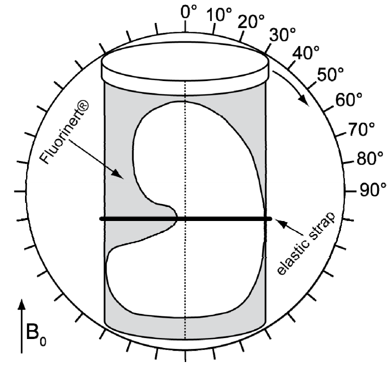

Fig. 1: *Experimental set-up for the investigation of the orientational dependence of the T_2 and MTR values.*

Post processing: T_2 maps were calculated by fitting the function $S = M_0 \cdot \exp(-TE/T_2) + y_0$ to the data in each pixel. MTR maps were calculated according to MTR(Δ) = 1-($S_{sat}(\Delta)/S_0$). Here, $S_{sat}(\Delta)$ = image measured with off-resonance saturation frequency Δ and S_0 = image measured without off-resonance saturation. Afterwards the T_2 and MTR maps at the different orientations were realigned using the Image Processing Toolbox of MATLAB (The MathWorks Inc., Natick, MA, USA).

Results & Discussion

Fig. 2 shows the T_2 and MTR maps in an axial slice at offset-frequency Δ = 8.9 kHz at different orientations relative to B_0 for one meniscus exemplarily. The T_2 maps (first and third column) show a distinct variation of the T_2 values depending on the orientation of the meniscus. The values of T_2 are small (minimum: ~ 4 ms) if the meniscus is aligned parallel or perpendicular to the orientation of B_0. At orientations close to the magic angle, the T_2 values are increased (maximum: ~ 16 ms). In contrast, no variation is observed in the MTR maps (second and fourth column). The variation of the mean T_2 (A) and MTR (B) values with the orientation for one meniscus is shown in Fig. 3.

The variations of T_2 can be explained by residual dipolar couplings. The alignment of the collagen fibers with respect to B_0 may lead to the observed variation of the T_2 values. Assuming that most of the collagen fibers run perpendicular to the imaged slice, the T_2 values are expected to be smallest at an orientation of 0°. This means most of the collagen fibers are aligned parallel to B_0. Due to the well-known ($3\cos^2\theta - 1$) dependence of the dipolar coupling, an increase of the T_2 values up to an orientation of θ = 55° and a decrease of the T_2 values for higher angles is expected. The maximum value of T_2 was found at θ = 50°. Considering the fact that, on the microscopic level, not all collagen fibers are aligned exactly perpendicular to the imaged slice (according to [4] most of them should) an average of T_2 over several fiber orientations is measured within one pixel. Behind this background our results are in good agreement with the expectations. However, the MTR values are homogeneous across the whole slice and nearly constant for all orientations.

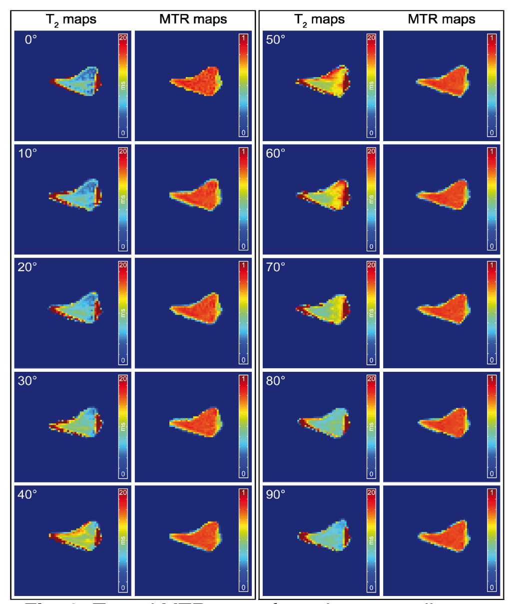

Fig. 2: *T_2 and MTR maps from the same slice at offset-frequency Δ = 8.9 kHz at 10 different orientations relative to B_0 for one meniscus.*

Conclusion

In this study, the influence of residual 1H dipole-dipole couplings on magnetization transfer ratio maps of porcine menisci was investigated. The MA effect was observed in T_2 maps of the menisci. In contrast, within the accuracy of our experiment, MTR maps of acutely isolated menisci show almost complete insensitivity to residual dipolar couplings and the resultant MA effect for offset-frequencies Δ higher than 1 kHz. We therefore conclude that MTR maps may help to avoid misinterpretation and provide a useful tool for the examination of partially aligned collagenous tissue.

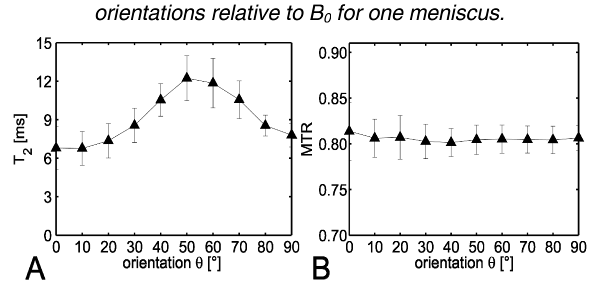

Fig. 3: *Variation of mean T_2 (A) and MTR (B) values with the orientation.*

References:

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