Identification of in vitro degenerated porcine meniscal tissue: MTR contrast prevents misinterpretation due to the magic angle effect

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Introduction
Degenerative changes of the human meniscus due to injuries or aging have been shown to cause osteoarthritis [1]. Thus, an early diagnosis and therapy is evident. Magnetic resonance imaging (MRI) is most commonly used for the examination of meniscal disease [2]. However, interpretation of MRI images from menisci or tendon is hampered by the so-called “magic angle” (MA) effect. The MA effect manifests itself as a strong spatial inhomogeneity in the MR images caused by orientational dependence of the transverse relaxation time T2, i.e. T2 values strongly vary with the orientation of the collagen fibers respective to the direction of the static magnetic field B0 [3]. It has been shown for human cartilage that the magnetization transfer ratio (MTR) contrast is less affected by the MA effect than conventional T2 contrast [4]. In this study, we investigated the appearance of in vitro degeneration in T2 and MTR maps of porcine menisci.

Material & Methods

Sample Preparation: Five porcine medial menisci were acutely isolated and a cavity was incised into the anterior horn of five medial menisci (red/white zone). 100 µl (25500U/ml) of a collagenase type II solution (Biochrome AG, Berlin, Germany) were injected into this cavity. The menisci were stored at room temperature in humid condition to allow digestion and to minimize dehydration for 18 hours and afterwards the remaining collagenase was rinsed off the menisci. One meniscus was imaged without any manipulation (control).

Experiments: The experiments were performed on a 9.4 T small animal scanner (Biospec30, Bruker, Germany). For the measurements the longitudinal axis of the meniscus was orientated along B0. T2 maps were measured using a (multi slice) multi echo (MSME) sequence with TR = 2500 ms, TEmax = 3.1 ms, field of view (FOV) = 64 x 64 mm², matrix (MTX) = 128 x 128, slice thickness = 1 mm, number of averages = 4 and 16 equidistant echoes (ΔTE = TEmax). The total measurement time was Tobs = 16 min. MTR maps for 4 different offset frequencies were measured using a RARE sequence with off-resonant pre-saturation pulse (duration 5s, B1 = 10µT, offset Δ= 2.2, 5.6, 8.9, 16.7 kHz), TR = 7s and TE = 2.4 ms. The acquisition time was Tobs = 2.5 min.

Post processing: T2 maps were calculated by fitting the function S = M0·exp(−TE/T2)+S0 to the data in each pixel. MTR maps were calculated according to MTR(Δ)=1-(Sω0(Δ)/Sω0) [4]. Here, Sω0(Δ) = image measured with off-resonance saturation frequency Δ and Sω0 = image measured without off-resonance saturation.

Results & Discussion

As the results are similar for all five in vitro degenerated menisci, only one in vitro degenerated and one intact meniscus (control) is shown here. Since also the MTR maps for different offsets Δ showed similar results, only the MTR maps for Δ = 8.9 kHz are presented here.

The T2 maps of the control meniscus shows strong orientational dependence due to the MA effect (Fig. 1A). The value of T2 is shortest in the central body (~7 ms), where the collagen fibers are aligned parallel to B0. In regions where the collagen fibers are orientated at approximately 54° (magic angle) with respect to B0, a significant increase in T2 (~18 ms) is observable. In contrast, the corresponding MTR map (Fig. 1B) does not show any inhomogeneity owing to the MA effect. The T2 map of the meniscus with local tissue degeneration (Fig. 1C) shows a similar orientational dependence. The area of degeneration (indicated by the arrow) is indistinguishable from the MA effect. The enzymatic digestion destroys the fibrous structure of the collagen. As a result, these areas contain a higher amount of free water. Free water exhibits higher T2 values, however these high T2 values are not related to the MA effect. Thus, the high T2 values can either originate from the MA effect or from the tissue degeneration. However, the corresponding MTR map (Fig. 1D) allows clear assignment of tissue degeneration while avoiding misinterpretation owing to the MA effect.

Conclusion

As we showed, in a T2 map or in a T2 weighted image of porcine medial meniscal tissue, one is not able to distinguish if the high T2 values are related to the MA effect or to tissue degeneration. This fact can lead to serious misinterpretation. In contrast, the MTR maps show no visible sensitivity to the MA effect. Therefore, MTR maps have the potential to identify tissue degeneration while not being affected by the MA effect. Future in vivo studies have to show if this phenomenon could be useful for the detection of pathological tissue degeneration of human menisci.

References
[4] W. Li et al. in Proc. ISMRM 2009 Honolulu; 3963