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 MR 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 T_2, i.e. T_2 values strongly vary with the orientation of the collagen fibers respective to the direction of the static magnetic field B_0 [3]. It has been shown for human cartilage that the magnetization transfer ratio (MTR) contrast is less affected by the MA effect than conventional T_2 contrast [4]. In this study, we investigated the appearance of *in vitro* degeneration in T_2 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/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 15 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 (Biospec®, Bruker, Germany). For the measurements the longitudinal axis of the meniscus was orientated along B_0. T_2 maps were measured using a (multi slice) multi echo (MSME) sequence with TR = 2500 ms, TE_{min} = 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 = TE_{min}). The total measurement time was TA = 16 min. MTR maps for 4 different offset frequencies were measured using a RARE sequence with off-resonant pre-saturation pulse (duration 5s, B_1 = 10µT, offset Δ= 2.2, 5.6, 8.9, 16.7 kHz), TR = 7s and TE = 2.4 ms. The acquisition time was TA = 2.5 min.

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 $MTR(\Delta) = 1-(S_{sat}(\Delta)/S_0)$. Here, $S_{sat}(\Delta)$= image measured with off-resonance saturation frequency Δ and S_0 = image measured without off-resonance saturation.

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 T_2 map of the control meniscus shows strong orientational dependence due to the MA effect (Fig. 1A). The value of T_2 is shortest in the central body (~7 ms), where the collagen fibers are aligned parallel to B_0. In regions where the collagen fibers are orientated at approximately 54° (magic angle) with respect to B_0, a significant increase in T_2 (~18 ms) is observable. In contrast, the corresponding MTR map (Fig. 1B) does not show any inhomogeneity owing to the MA effect.

The T_2 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 T_2 values, however these high T_2 values are not related to the MA effect. Thus, the high T_2 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.

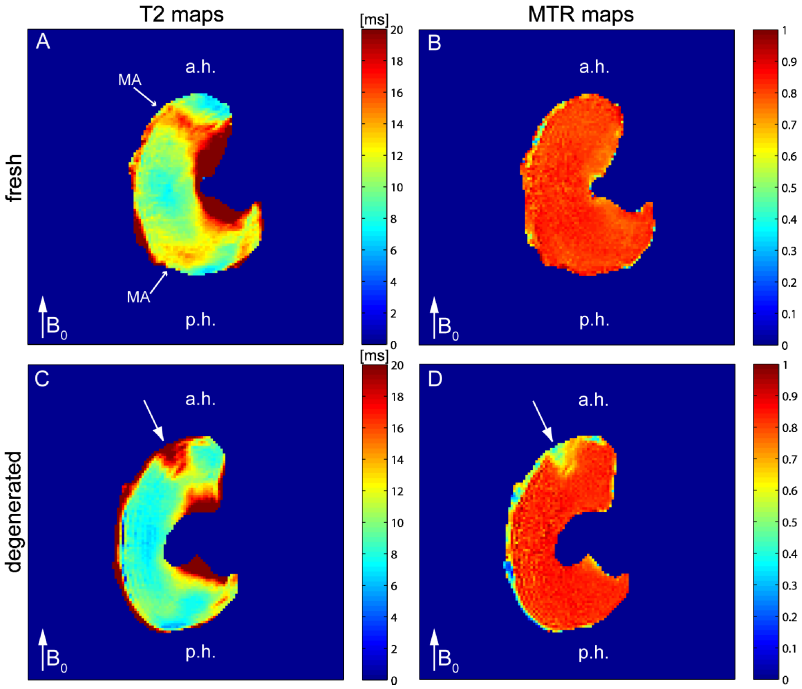

Fig. 1: T_2 and MTR maps of a fresh (A,B) and a degenerated (C,D) porcine meniscus. Anterior horn (a.h.) and posterior horn (p.h.) are labeled. The arrows in Fig. C and D show where the collagenase was injected.

Conclusion

As we showed, in a T_2 map or in a T_2 weighted image of porcine medial menisci, one is not able to distinguish if the high T_2 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

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