Quantitative Susceptibility Mapping of Meniscus at 11.7T

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INTRODUCTION

The meniscus is a crescent-shaped fibrocartilaginous structure which disperses force in the knee joint. It has cartilaginous and fibrous regions with a complex superficial meshwork of fibers, including an outer lamellar layer and a central region of circumferential and radial fibers. The susceptibility of the meniscus is related to the underlying tissue type (cartilaginous vs. fibrous), fiber type and orientation, and has not been well investigated partly due to the low signal obtained with conventional gradient echo images of reasonable spatial resolution using clinical MR scanners. This predicates against the use of regular quantitative susceptibility mapping (QSM) techniques. Here we aim to assess the feasibility of QSM within meniscus by studying bovine specimens at 11.7 T using a pre-clinical system to provide short TE images of high spatial resolution.

MATERIALS AND METHODS

Bovine meniscus samples (n=5) with manually introduced tear and stem cell treatment (for another study) were used for this study. Each meniscus sample was sectioned and stored in a 30 ml syringe filled with saline. Multi-echo gradient recalled echo (GRE) acquisitions were performed on a 11.7 T Bruker system (Bruker BioSpin MRI GmbH) with the following imaging parameters: TR = 80 ms, TE = 2.2/4.2/6.2/8.2/10.2/12.2 ms, flip angle = 14°, bandwidth = 150 kHz, FOV = 10 mm, matrix = 200×200, 25 slices, slice thickness = 0.6 mm, acquired voxel size = 50×50×600 μm^3, using a dedicated 12 mm solenoid coil and a total scan time of 6.7 min. Complex 3D GRE data with six echoes was used for the field map estimation using a nonlinear least-squares approach. A Laplacian operator based fast phase unwrapping algorithm was then applied to correct phase wrapping in the estimated field map. To remove the background field generated by B_0 field inhomogeneity as well as variations caused by the magnetic susceptibility of surrounding objects, a projection onto dipole fields (PDF) method was adopted. Finally, the susceptibility distribution was calculated from the extracted local field using a morphology enabled dipole inversion (MEDI) algorithm.

RESULTS AND DISCUSSION

Figure 1 shows selected magnitude and phase images of high resolution 3D GRE imaging of a bovine meniscus together with a QSM map. The peripheral and central cartilage is separated from the fibers, and circumferential and radial fibers can be distinguished. QSM maps suggest that there is a shift from the more diamagnetic susceptibility for central and superficial cartilaginous tissue (δ ~ -0.2 ppm) to the more paramagnetic susceptibility for the more internal and peripheral fibrous tissue (δ ~ +0.2 ppm). The susceptibility difference in the meniscus is over five times greater than that of the gray and white matter in the brain, which is typically in the order of ±30 ppb. This large difference is likely due to the organized fibrocartilagious structure in meniscus. A strong susceptibility difference may also exist in other musculoskeletal tissues such as the tendons, ligaments and cortical bone. Future work will include ultrashort echo time (UTE)-QSM of meniscus, ligaments, tendons and cortical bone using clinical whole body scanners, as well as determining the relationship between susceptibility changes and musculoskeletal tissues degeneration.

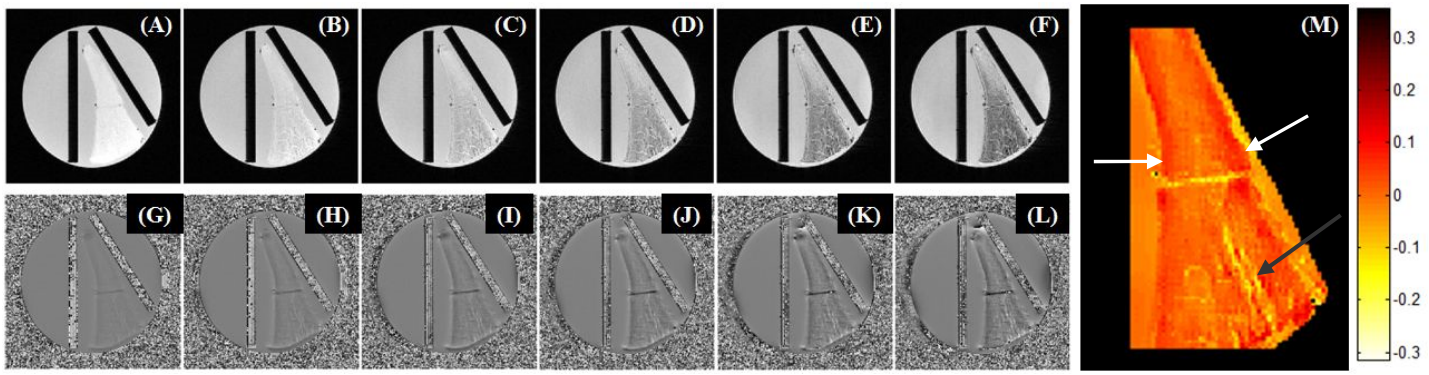

Fig 1. Selected GRE magnitude and phase images of a bovine meniscus embedded with a TE of 2.2 ms (A, G), 4.2 ms (B, H), 6.2 ms (C, I), 8.2 ms (D, J), 10.2 ms (E, K), 12.2 ms (F, L), and the corresponding QSM processed color map (M). The central and superficial cartilaginous tissue is more diamagnetic (δ ~ -0.2 ppm) while the internal and peripheral fibrous tissue is more paramagnetic (δ ~ +0.2 ppm) (white arrow). Radial fibers are highlighted (dark arrow). A surgically induced tear is seen centrally.

CONCLUSIONS

Results from this study show that cartilaginous and fibrous tissues as well as the circumferential and radial fibers in the meniscus have different susceptibilities, with the differences about five times greater than those seen in the brain.

REFERENCES

1. Fox JS, et al., SAGE 2012. 2. Du J, et al. MRI 2011. 3. Liu T, MRM 2009. 4. Liu T, NMR Biomed 2011.