Ultrashort Echo Time Quantitative Susceptibility Mapping (UTE-QSM) of Cortical Bone

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INTRODUCTION

In recent years a variety of quantitative susceptibility mapping (QSM) techniques have been developed to access the susceptibility of different tissues and tissue components. Most of the QSM techniques are based on multi-echo gradient echo images with TEs of tens of milliseconds to capture the phase evolution of long T2 components. Using this approach short T2 components are almost completely attenuated and make minimal contribution to the phase contrast. As a result there susceptibility is inaccessible. We have developed 3D ultrashort echo time (UTE) sequences with TEs as short as 8 μs, which can directly detect signal from the short T2 components. The combination of UTE and QSM (UTE-QSM) should allow phase evolution to be detected in short T2 components and thus access their susceptibility. In this study, we describe a 3D UTE-QSM study of cortical bone using a clinical 3T scanner.

MATERIALS AND METHODS

Fresh bovine cortical bone midshaft samples (n=5) from a local slaughter house were harvested for this study. Each bovine bone sample was sectioned into ~5 cm lengths and stored in a plastic container filled with 1% agarose gel. A wrist coil was used for signal excitation and reception. Four sets of interleaved 3D UTE multi-echo acquisitions were performed using the following imaging parameters: TR = 17 ms, FOV = 15 cm, acquisition matrix = 128×128×128, 4 sets of TEs (0.03/2.4/6; 0.2/3/7; 0.4/4/8; 0.8/5/10 ms), flip angle = 15º, bandwidth = 250 kHz, number of projections = 20,000, total scan time = 22 min.

Complex 3D UTE data with 12 echoes was used for the field map estimation using a nonlinear least-squares approach. Due to the inherent difference of T2* in cortical bone and agarose, a pixel-based temporal mask was made such that later echoes only carrying noise were truncated. 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 the morphology enabled a dipole inversion (MEDI) algorithm.

RESULTS and DISCUSSION

Figure 1 upper row shows selected 3D UTE images of bovine cortical bone embedded in agarose gel. Cortical bone shows low signal due to its low proton density and short T2* compared to that of agarose gel. However, phase from cortical bone can be easily detected with relatively high signal and contrast. Figure 1 lower row shows QSM accessed susceptibility map of the same bovine cortical bone in different planes. A mean susceptibility of ~-3.5 ppm was observed, roughly consistent with the literature values.

This study shows the technical feasibility of accessing the susceptibility of cortical bone using 3D UTE sequences. The long scan time (22min) makes it problematic for clinical applications. Our next goal is to optimize the interleaved multi-echo 3D UTE data acquisitions, especially non-anisotropic imaging (higher in-plane resolution, thicker slices) which may greatly improve the signal to noise ratio and allow a much shorter scan time. We will also investigate the susceptibility of other short T2 tissues such as menisci, ligaments and tendons in vitro and in vivo, and their relationship to degeneration.

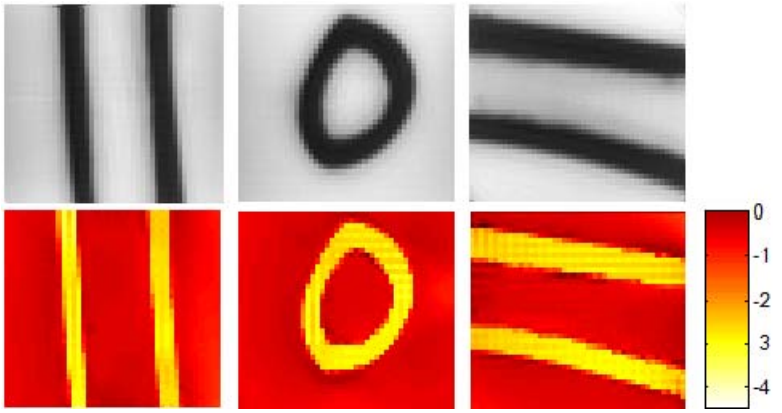

Figure 1. 3D UTE imaging of a bovine cortical bone sample embedded in 1% agarose gel (1st row) and the corresponding susceptibility map estimated using the morphology enabled dipole inversion or MEDI algorithm (2nd row). Cortical bone has a mean diamagnetic susceptibility of -3.5 ppm.

CONCLUSIONS

Our preliminary results show that the interleaved multi-echo 3D UTE sequence can be used to access phase evolution of cortical bone and thus calculate its susceptibility by calculating the field map and then using an established MEDI algorithm. The feasibility of this approach for clinical bone susceptibility estimation still requires further investigation.

REFERENCES

1. Liu T, et al., MRM 2009. 2. Liu T, et al., NMR Biomed 2011. 3. Du J, et al. MRI 2011. 4. Wehrli F, et al., NMR Biomed 2011. 5. Liu C, et al., ISMRM 2013.