Bulk Susceptibility Mapping Using Ultrashort TE Spectroscopic Imaging (UTESI)

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INTRODUCTION

Bulk magnetic susceptibility (BMS) effects have received attention in high resolution solid state NMR and in MR imaging of heterogeneous or compartmentalized structures, such as the Achilles tendon and bone (1-4). However, most of the work on BMS evaluation has been done using either spectrometers which provide high resolution spectra of powered or small samples, or clinical MR scanners through indirect imaging of the effect of the solid on surrounding long T2 tissues, such as bone marrow. For example, Hopkins et al measured the absolute susceptibility of bone using a susceptibility matching technique on a 9.4 T wide-bore spectrometer, and found that the volume susceptibility of bovine rib was about 2.3 ppm greater than that of water (1). Krasnosselskaia et al investigated the angular dependent bulk susceptibility of tendon samples and reported a frequency shift of about 3 ppm when tendon was oriented from 0° to 90° to B0 (2). It is difficult to directly quantify BMS effects in these short T2 tissues using clinical MR scanners with conventional sequences. Ultrashort TE spectroscopic imaging (UTESI) provides high resolution imaging of short T2 tissues, and allows BMS effects to be evaluated in vivo. The observed shift of the resonance peak directly reflects bulk susceptibility. In this study we applied the UTESI technique to investigate BMS in the Achilles tendon and cortical bone of healthy volunteers using a clinical 3T scanner.

MATERIALS AND METHODS

The UTESI technique reported before is based on a 2D UTE sequence with a minimal TE of 8 μs which is achieved with a combination of half pulse excitation, radial ramp sampling and fast transmit/receive switching (5). Spectroscopic images of the short T2 species were generated through Fourier transform of the multi-echo variable TE UTE images. The half projection data was highly undersampled and interleaved for each TE to reduce the total scan time to around 10 min or less. The periodic undersampling streaks were shifted to high spectral frequencies after Fourier transform in the time domain, leaving streak-free high resolution spectroscopic images near the water and fat peaks. The spectral peak shift of the short T2 species relative to that of the long T2 water species directly reflects the BMS effect. A BMS map can also be generated. In this study four cadaveric ankle specimens were harvested. Typical UTESI acquisition parameters were: FOV = 10 cm, TR = 60 to 100 ms, 4 echoes, echo spacing = 6 ms, flip angle = 45°, BW = ±62.5 kHz, readout = 512 (actual sampling points = 272), number of projections = 2025 which was interleaved into 45 groups (each group 45 projections) with a TE delay of 60 to 200 μs, slice thickness = 2 to 5 mm, NEX = 2, sagittal or axial imaging plane. The 180 (45×4) TE images were zero-filled to 512 in the time domain, resulting in a reconstructed spectroscopic image size of 512×512×512.

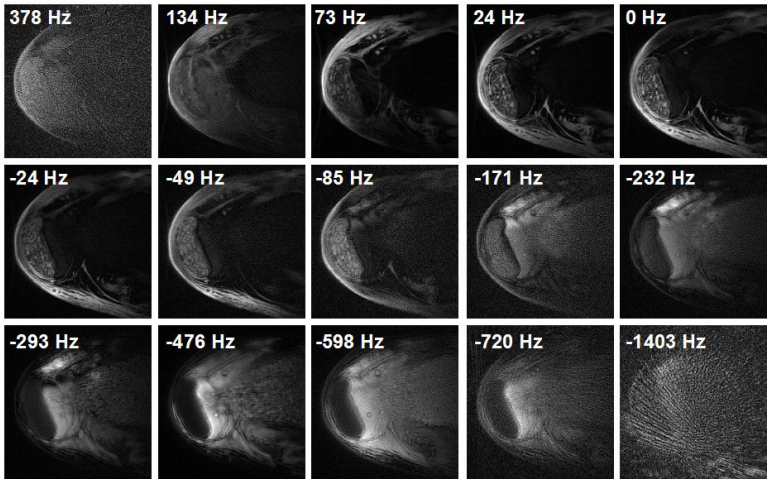

Fig 1 *Selected UTESI images of a cadaveric ankle specimen in the axial plane with a spatial resolution of 0.2×0.2×2.0 mm³ (acquired). Fat signals peak at -476 Hz. There is excellent image contrast within the Achilles tendon around the water peak.*

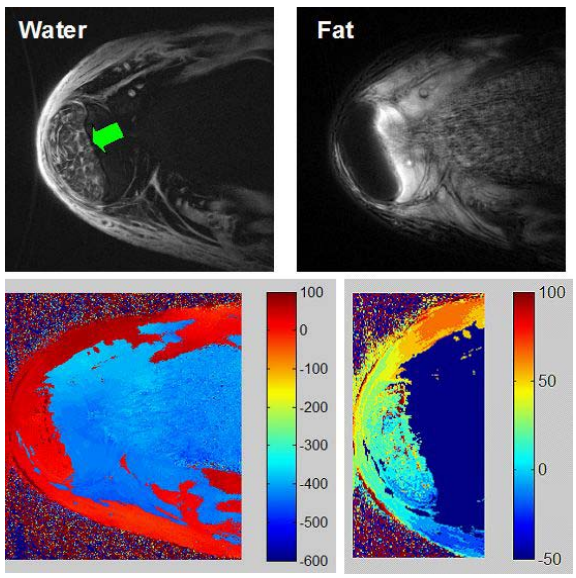

Fig2 *Selected UTESI images of the tensile tendon show the water peak and fat peak images, as well as peak resonance frequency mapping (in Hz). This demonstrates a frequency shift (0 to 60 Hz) within the tendon between tensile fibers and endotenon.*

RESULTS AND DISCUSSION

Figure 1 shows typical axial UTESI images for the Achilles tendon oriented parallel to B0. Figure 2 shows zoomed images at the tendon and fat peaks, as well as the BMS maps. There is a frequency shift of up to 60 Hz for the fibers in tensile tendon. Figure 3 shows the muscle, bone and fat peaks as well as the BMS map of the mid-shaft of the left tibia. There is a resonance frequency shift of around 120 to 200 Hz for cortical bone relative to muscle due to BMS of cortical bone. This shift is significantly smaller than the reported shift of 2.3 ppm (~300 Hz at 3T) of powdered bone sample (1). The major limitation of this technique is the limited spectral resolution, although the reconstructed spectral resolution is up to 10 Hz. This is actually limited by the intrinsic broad line width of short T2 species.

CONCLUSIONS

UTESI can be used to directly evaluate BMS effects in short T2 species in vivo at high resolution using a clinical MR system.

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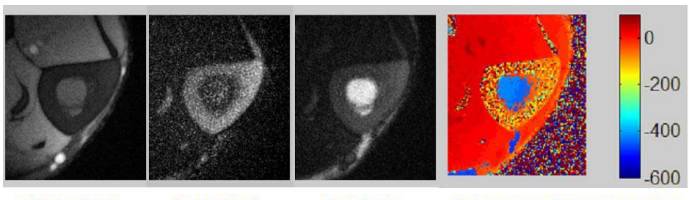

Fig3 *Selected UTESI images of the tibia of a healthy volunteer. This shows the water, bone and fat peak images as well as peak resonance frequency mapping (in Hz). This map demonstrates a frequency shift (120 to 200 Hz) of bone relative to that of muscle due to the bulk susceptibility of bone.*