More accurate trabecular bone imaging using UTE MRI on the resonance frequency of fat

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INTRODUCTION: High-resolution magnetic resonance imaging (MRI) has been increasingly used to assess trabecular bone structure. MRI avoids ionizing radiation and, unlike 3D x-ray-based techniques, can also evaluate the structure of the surrounding tissue simultaneously[1,2]. High susceptibility at the marrow/bone interface may significantly reduce the marrow's apparent transverse relaxation time (T2*), overestimating trabecular bone thickness. Ultrashort echo time MRI (UTE-MRI) can minimize signal loss due to susceptibility-induced T2* shortening. However, UTE-MRI is sensitive to chemical shift artifacts, which manifest as spatial blurring and ringing artifacts in non-Cartesian sampling. In this study, we proposed UTE-MRI on the resonance frequency of fat to minimize marrow-related chemical shift artifacts and reduce the overestimation of trabecular thickness.

METHODS: Cubes of trabecular bone excised from the distal tibia of 6 donors (75±4 years old) were scanned on the resonance frequency of fat and water using UTE Cones sequences with five TEs (0.032, 1.1, 2.2, 3.3, and 4.4ms) and a clinical 3D Cartesian gradient echo (GRE) sequence at $0.2\times0.2\times0.4mm^3$ voxel size. Scans were performed in a clinical 3T GE scanner (MR750) using a knee coil. Trabecular bone thickness was measured in 30 regions of interest (ROIs) per sample and compared with micro-computed tomography (µCT) at $50\mu m^3$ voxel size (GE eXplore CT 120). Linear regression models were used to calculate the coefficient of determination between MRI- and µCT-based trabecular thickness.

RESULTS: Figures 1B-1F demonstrate MR images of a representative distal tibia specimen acquired on the resonance frequency of fat using 3D-Cones sequences with increasing TEs (TE = 0.03, 1.1, 2.2, 3.3, and 4.4 ms). Figures 1A and 1G show 3D-Cones UTE and 3D Cartesian GRE images of the same specimen on the resonance frequency of water. Significant chemical shift artifacts were observed in UTE Cones acquired on the resonance frequency of water (Figure 1A), which blurred the trabecular bone structure. In contrast, UTE images acquired on the resonance frequency of fat showed no noticeable chemical shift artifacts, providing a superior depiction of trabecular bone structures. All MR-based trabecular thicknesses significantly correlated with those measured using µCT (Figure 2). The correlations were higher for 3D UTE images performed on the fat frequency (R^2 = 0.59-0.74) than those on the water frequency (R^2 = 0.18-0.52) and clinical GRE images (R^2 = 0.47-0.53). Cones UTE (TE=0.03ms) and TE=1.1 ms images on the resonance frequency of fat had the highest correlations with µCT-based results (R^2 = 0.74 and 0.73, respectively).

DISCUSSION: This study highlighted the feasibility of using UTE on the resonance frequency of fat for a more accurate trabecular bone thickness assessment. Such superiority may be more pronounced in elderly or osteoporotic patients where the fat fraction in marrow is higher than the normal subjects. Future studies are required to investigate the feasibility of *in vivo* imaging on the resonance frequency of fat in different anatomical locations.

SIGNIFICANCE/CLINICAL RELEVANCE: A high-resolution UTE-MRI sequence on the resonance frequency of fat with accurate trabecular bone depiction can help monitor the bone structure in osteoporotic patients while simultaneously evaluating the surrounding soft tissues.

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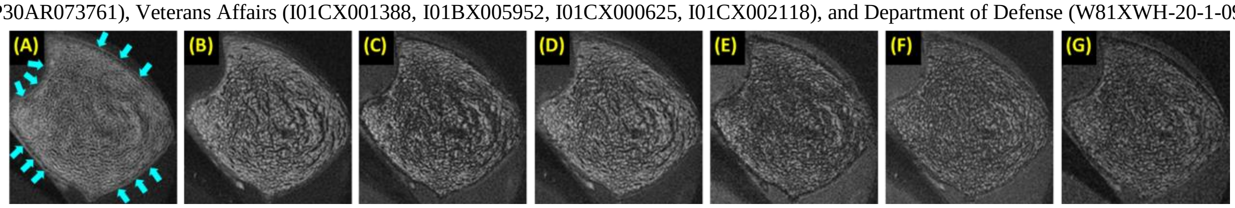

Figure 1. A representative trabecular bone specimen from distal tibial imaged in the axial plane (voxel size=$0.2\times0.2\times0.4$ mm^3) using 3D UTE Cones sequence on the resonance frequency of water (A) and on the resonance frequency of fat at TE=0.03 ms (B), TE=1.1 ms (C), TE=2.2 ms (D), TE=3.3 ms (E), and TE=4.4 ms (F), and clinical GRE (3D-Cartesian) sequence at TE=4.4 ms (G). Significant chemical shift artifacts were observed in UTE Cones acquired on the resonance frequency of water, which blurred trabecular bone structure (arrows in Figure 1A).

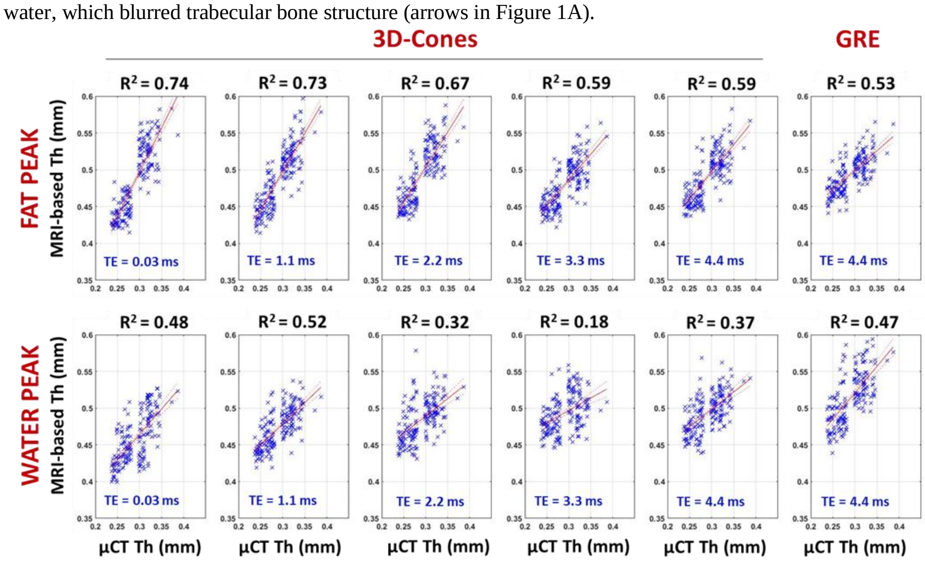

Figure 2: Scatterplots and linear regressions of MRI-based trabecular bone thicknesses on the µCT-based results, including 30 ROIs per specimen (n=180). All MR-based trabecular thicknesses showed significant correlations with µCT. Cones UTE (TE=0.03 ms) and TE=1.1ms images on the resonance frequency of fat had the highest correlations with µCT-based results (R2=0.74 and 0.73, respectively).