Metal Artifact Reduction Using a 3D UTE-MSI sequence with Time-Frame Regularized Compressed Sensing Reconstruction

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INTRODUCTION

Metallic implants are routinely used to treat advanced joint disease. There is a need for non-invasive diagnosis of wear-induced disease. Radiography and computed tomography are limited by poor soft tissue contrast and ionizing radiation exposure as well as low sensitivity and specificity. MRI has obvious advantages [1-3]. However, conventional MR sequences are subject to severe distortion due to strong susceptibility effects near metal, with little or no signal from important joint tissues such as tendons and cortical bone which have very short T2s. 3D ultrashort echo time (UTE) imaging sequences together with multiple spectral imaging (MSI) can potentially image short T2 tissues and minimize metal artifact [4]. However, 3D UTE-MSI is time-consuming. In this study we aimed to develop 3D UTE-MSI using with vastly undersampling to reduce scan time and a tight-frame regularized compressive sensing (TFCS) technique to reduce streak artifacts [5-10]. T1, magnetization transfer ratio (MTR) and water content of tissues near metal can potentially being measured using a clinical whole-body scanner.

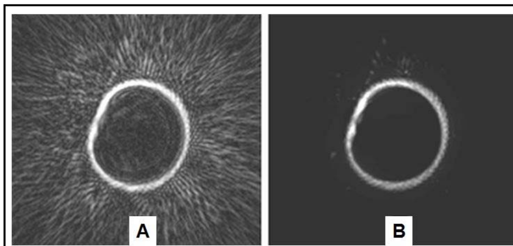

Fig 1 3D UTE-MSI of a cobalt chromium prosthesis phantom in agarose gel at -4 kHz with regular re-gridding (A) and TFCS reconstruction (B). Drastic streak reduction is seen with use of the TFCS recon.

MATERIALS AND METHODS

$$u = \text{argmin}_u \frac{1}{2} | MFu - y |_2^2 + \mu \, | Du |_1 \quad [1]$$

3D UTE-MSI sequences are time consuming and require undersampling to reduce their acquisition time. This typically produces streak artifacts. Recent advances in CS permit data recovery from extremely undersampled data. We propose to reconstruct vastly undersampled UTE-MSI data using tight-frame regularization – a CS technique in which the image is reconstructed by solving an optimization problem shown in Eq. [1], where F is the Fourier transform, M is the downsampling operator, and D is an operator that decomposes the image u onto an overcomplete wavelet basis [7]. The first term ensures fidelity between the measurements and the reconstructed image. The second regularization term selects the solution with the desired image properties. Many medical images have very sparse representations under the TF system[8]. We enforce this property by using the regularization term through penalizing the L-1 norm of the transformed image in the TF basis. The 3D UTE-MSI sequence with TFCS reconstruction algorithm was applied to three phantoms (agarose embedded with three different metals: titanium, coblt-chromium, stainless steel) as well as knee and angle specimens with metal implants. The 3D UTE-MSI imaging protocol used the following parameters: TR = 7 ms, field of view (FOV) = 15 cm, matrix = 256×256×256, band width = 250 kHz, TE = 8 us, asymmetric Gaussian pulse (1 kHz), spectral frequencies of -10 to +10 kHz (Δf = 1 kHz), five different degrees of undersampling (projections = 86 K, 40K, 10K, 5K, 2K, corresponding to an undersampling factor of 2.4, 5, 20, 40 and 100, respectively). The 3D UTE-MSI sequence was further combined with an off-resonance saturation pulse (Fermi pulse, 4 ms in duration) for 3D UTE-MSI magnetization transfer imaging to access MTR of short T2 tissues near metallic implants. For each spectral bin, an RF pulse placed at a frequency far off (e.g., 3 kHz) from the spectral center frequency is expected to have a minimal effect on soft tissues such as muscle and fat, but the pulse may still overlap with that of short T2 tissues [29]. High contrast images of cortical bone and tendons can be generated by subtracting the off-resonance saturated UTE-MSI image from a regular UTE-MSI image. MTR can also be calculated.

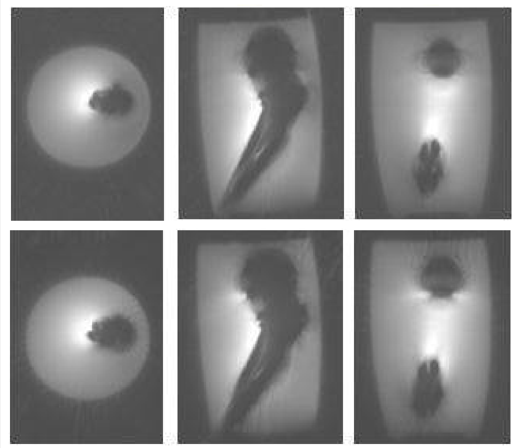

Fig 2. 3D UTE-MSI imaging of a prosthesis with 44K (1st row, ~2hrs) and 3K (2nd rows, ~7 min) projections in the coronal, sagittal and axial planes, respectively. TFCS recon provided comparable image quality even with a vast undersampling factor of ~ 1000.

RESULTS AND DISCUSSION

Figure 1 shows 3D UTE-MSI imaging of a cobalt chromium prosthesis phantom at -4 kHz frequency offset with TFCS reconstruction. 3D UTE images can be obtained using only 2000 projections, corresponding to an acceleration factor is 100. 3D UTE-MSI-CS images show marked streak reduction compared to images obtained using standard re-gridding reconstructions.

Figure 2 shows 3D UTE-MSI imaging of a prosthesis imaged with full sampling and vastly undersampling. Comparable image quality can be achieved with TFCS reconstruction of vastly undersampled data, which reduced the total scan time from ~2 hours to 7 minutes, facilitating clinical applications of the 3D UTE-MSI techniques.

Figure 3 shows UTE-MSI MT imaging of the Achilles tendon near a metallic implant. Excellent image contrast was achieved for the Achilles tendon with minimal metal artifact.

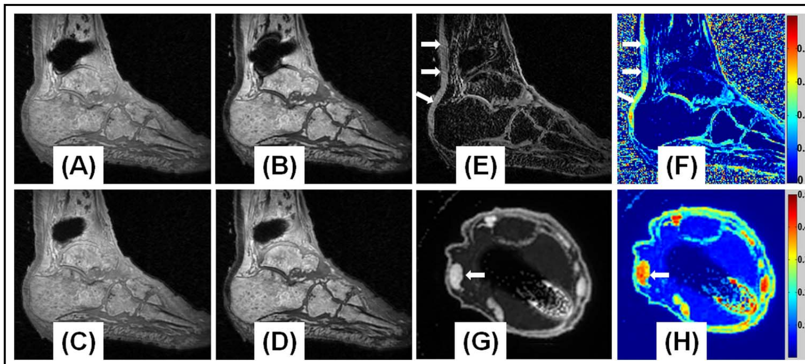

Fig 3 3D UTE imaging of an ankle specimen without (A) and with (B) an MT pulse, as well as 3D UTE-MSI imaging without (C) and with (D) an MT pulse. Reduced metal artifact was seen using UTE-MSI. Subtraction of UTE-MSI with (D) from without (C) MT pulse show excellent contrast for the Achilles tendon (arrows), as demonstrated in the sagittal (E) and axial (G) images. Sagittal (F) and axial (H) MTR maps are also shown.

CONCLUSIONS

These results show that 3D UTE-MSI with TFCS reconstruction can significantly speed up data acquisition and reduce undersampling streak artifacts. The combination of off-resonance saturation and UTE-MSI acquisition provides high contrast imaging of short T2 tissues near metallic implants.

REFERENCES

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