MAVRIC Imaging Near Metal Implants with Improved Spatial Resolution and Reduced Acquisition Time

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Introduction: The MAVRIC technique can significantly reduce susceptibility artifacts near metallic total joint replacements [1]. However, its use of extra phase-encodes and increased spectral coverage introduce acquisition time and image resolution challenges. Previous MAVRIC demonstrations [1,2] were acquired with a low in-plane data matrix (256x128) in order to maintain acquisition times on the order of 16-20 minutes. Here, we present enhancements to the MAVRIC method that allow for the acquisition of images with higher in-plane data matrices (>256x256) in scan times on the order of 10 minutes. The resulting diagnostic quality of the resulting images is demonstrated on clinical patients with both total knee and hip replacements.

Theory: Compared to an equivalently sampled 2D image, the 3D encoding strategies utilized in the MAVRIC technique produce composite images with SNR increased by ~SQRT($N_{PE,z}$), where $N_{PE,z}$ is the number of phase-encode steps provided in the z direction. Therefore, even when imaging at 1.5T using high sampling bandwidths (+/- 125 kHz), MAVRIC images have sufficient SNR to enable undersampled acceleration techniques.

MAVRIC images were undersampled using elliptical 3D-FSE view-ordering [3], partial-Fourier undersampling (k_y, 8 overscans), and ARC parallel imaging [4]. Previous investigations have shown that both homodyne reconstruction of partial-Fourier data [5] and ARC parallel imaging reconstruction [6] can be performed in the presence of the severe spatial B0 perturbations found near metallic implants. For the cases presented here, these combined approaches resulted in a net acceleration of roughly 4X compared to fully-sampled acquisitions.

The use of overlapping spectral bins allows for smooth combination of MAVRIC sub-images, but also introduces an off-resonance-induced point-spread degradation in the readout direction of sum-of-squares composite images. In order to mitigate this effect and achieve maximal composite image resolution, an off-resonance correction is applied to MAVRIC sub-images prior to sum-of-squares combination. This correction relies on field maps constructed from MAVRIC raw data. MAVRIC sub-images possess spectral characteristics such that $\Sigma_n F(\omega_n) I_n \sim 1$, where $F(\omega)$ is the spectral response to the applied RF pulses. Under this assumption, field maps can be constructed from MAVRIC data through the relationship $\Delta B_0(\mathbf{x}) = \Sigma_n \omega_n I_n(\mathbf{x})$, where $I_n(\mathbf{x})$ is normalized such that $\Sigma_n I_n(\mathbf{x}) = 1$. Such field maps can be used to remove relative spatial off-resonance offsets from overlapping sub-images, which also eliminates point-spread degradation in composite MAVRIC images.

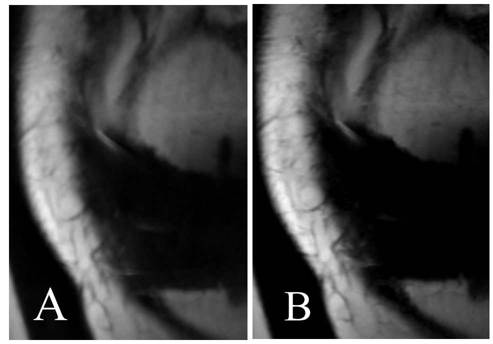

Figure 1: A) Direct sum of squares image combination and B) Off-resonance-corrected sum of squares to reduce blurring in the readout dimension

Methods: Imaging experiments were performed on a General Electric (Milwaukee, WI) HDx 1.5T scanner. Human volunteers were scanned in accordance with IRB protocols. Total knee replacement (TKR) images were acquired using an 8 channel knee coil. MAVRIC TKR images (TE = 40 ms, TR = 4s, BW +/- 125 kHz, 3X ARC in k_y) were acquired with a 320x256 in-plane data matrix over an 18 cm FOV. Conventional 2D-FSE images following clinically established arthroplasty imaging protocols (TE = 28ms, TR = 4s) were acquired with 512x320 in plane data matrices over 18 cm FOV using a readout bandwidth of +/-100 kHz and 4 signal averages [7]. Total hip replacement (THR) images were acquired in the coronal plane (22 cm FOV) using a 3-channel shoulder coil. MAVRIC images were acquired with a 256x256 in plane data matrix (2X ARC in k_y), while 2D-FSE images (TE = 28ms, TR = 3.8s) were acquired at 512 x 352 in plane data matrices using a readout bandwidth of +/-100 kHz and 5 signal averages. Total scan times (MAVRIC/2D-FSE) were 9.5/7 min for the TKR and 11.5/6.5 min for the THR.

Results : Figure 1 displays point spread improvements gained through the off-resonance correction of sagittal MAVRIC sub-images prior to summation. Images are shown near anterior portion of the femoral component. The perceived blurring in (A) is clearly removed in the corrected image (B). Figure 2 presents MAVRIC (A,C) images and 2D-FSE arthroplasty protocol images (B,D) over similar scan planes for the both the TKR and THR implant scenarios. While the MAVRIC images remain slightly lower resolution than the conventional 2D-FSE images, the improvements in susceptibility artifact reduction near the implant are dramatic. By removing slice-selection errors and reducing frequency-encoded distortions, MAVRIC is able to greatly improve the definition of the metal bone interface over both joint replacements.

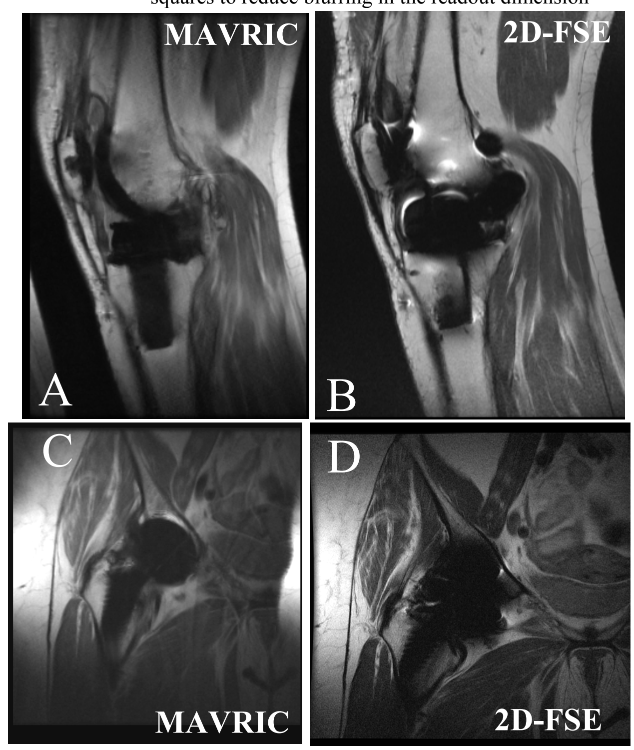

Figure 2: MAVRIC images of (A) total knee replacement (320x256) and (B) total hip replacement (256x256). High-bandwidth 2D-FSE images of (C) total knee replacement (512x320) and (D) total hip replacement (512x352)

Conclusions: The MAVRIC technique has previously been shown to reduce susceptibility artifacts near metal implants; however, it suffered from limited in-plane resolution and long acquisition times. The newly enhanced MAVRIC method utilizes undersampling techniques and off-resonance correction during image reconstruction to provide sub-millimeter level resolution and reduced acquisition times. These improvements increase the visualization of the boney and soft tissue anatomy directly adjacent to orthopedic implants while allowing for clinically feasible scan times. The clinical impact of any MR-based arthroplasty imaging protocol is heavily dependent on its ability to diagnose early stages of osteolysis, wear-induced synovitis, and neurovascular complications. Future enhancements of MAVRIC will explore volume selection capabilities and further acceleration capabilities via compressed sensing.

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