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 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.

Methods: Compared to an equivalently sampled 2D image, the 3D encoding strategies utilized in the MAVRIC technique produce composite images with SNR increased by \(\approx \text{SQRT}(N_{\text{PE,z}})\), where \(N_{\text{PE,z}}\) 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\(_x\), 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 \(\Sigma \omega(x) = 1\), where \(\omega(x)\) is the spectral response to the applied RF pulses. Under this assumption, field maps can be constructed from MAVRIC data through the relationship \(\Delta B_0(x) = \Sigma \omega(x)l(x)\), where \(l(x)\) is normalized such that \(\Sigma l(x) = 1\). 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.

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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References:

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

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 (512x325)