Approach to characterize magnetic inhomogenities for development of MRI sequences near metallic prostheses

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Introduction Metallic implants induce extremely large B_0 field perturbations that cause severe signal distortion. Several 3D multispectral imaging (3D-MSI) techniques such as MAVRIC-SL [1] and SEMAC [2] have been developed that dramatically decrease the signal distortion around metal. However, as recently described by Koch et al. [3] residual signal distortions remain in areas where the local field gradients from metal are larger than the frequency encoding gradients used by MAVRIC-SL and SEMAC. Further, exciting the full spectrum of off-resonance is often impractical, especially at 3T. The spatial extent of these RF excitation and frequency encoding artifacts depend heavily on the specific implant (eg. susceptibility, geometry, orientation). Simulating the 3D field inhomogeneity for different metallic implants will help elucidate the fundamental capabilities and limitations of current 3D-MSI methods for both RF excitation and frequency encoding. The purpose of this work is to examine the theoretically induced field map perturbation using the digital representation of commercially available metallic joint prostheses.

Table I. *Assigned material properties*

	Component	Material	Susc. (ppm)
Hip	Acetab. Cap	Titanium	182
	Acetab. Liner	Polyethylene	9.04
	Femoral Head	Co-Cr-Mo	1300
	Femoral Stem	Titanium	182
Knee	Femoral	Co-Cr-Mo	1300

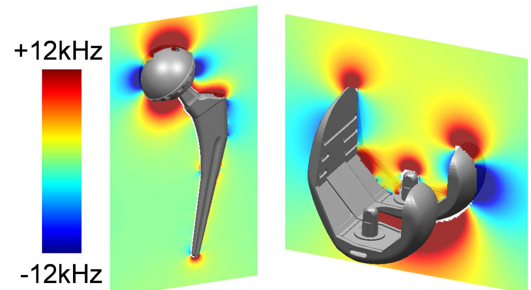

Figure 1. *Field perturbations induced by total hip and partial knee prostheses calculated at 3T. A dipole k-space kernel allows 3D characterization around the prosthetics.*

Methods Accurate digital models of a complete total hip and the femoral component of a total hip replacement were obtained from a commercial manufacturer. A high-resolution mask of each component was created by ray tracing using 350 μm resolution within MATLAB and each was assigned a susceptibility value that reflected its material composition (Table I). It was assumed that these metallic alloys behave as paramagnetic materials, with B_0 field perturbations scaling linearly up to 3T. Field inhomogeneities were calculated by applying a k-space dipole kernel at 1.5T and 3T [4]. Figure 1 depicts the 3D models and their field perturbations at 3T. Locations were identified that exceed the current RF excitation spectrum of 3D-MSI (±12 kHz) [1] as well as the regions where the local gradient of off-resonance exceeds a typical readout gradient of 781 Hz/pixel. These limits of clinical 3D-MSI were displayed at both 1.5T and 3T for the two implants as iso-contour lines.

Results Figure 2 depicts the fundamental limitations of current 3D-MSI RF excitation (black dotted) and frequency encoding (white dotted). At a distance of 2 mm from the metal surface, the off-resonance exceeded 32/64 kHz (1.5T/3T) at the superior acetabular component of the hip prosthesis and 21/42 kHz at the weight bearing surface femoral condyles of the knee prosthesis. At the same locations, the limits of RF excitation occurs 10.8/18.9 mm and 7.0/14.3 mm away at 1.5T/3T for the hip and knee respectively. Both RF and frequency encoding limitations are relatively similar at the superior/inferior surfaces but varying spatially around the orthogonal surfaces.

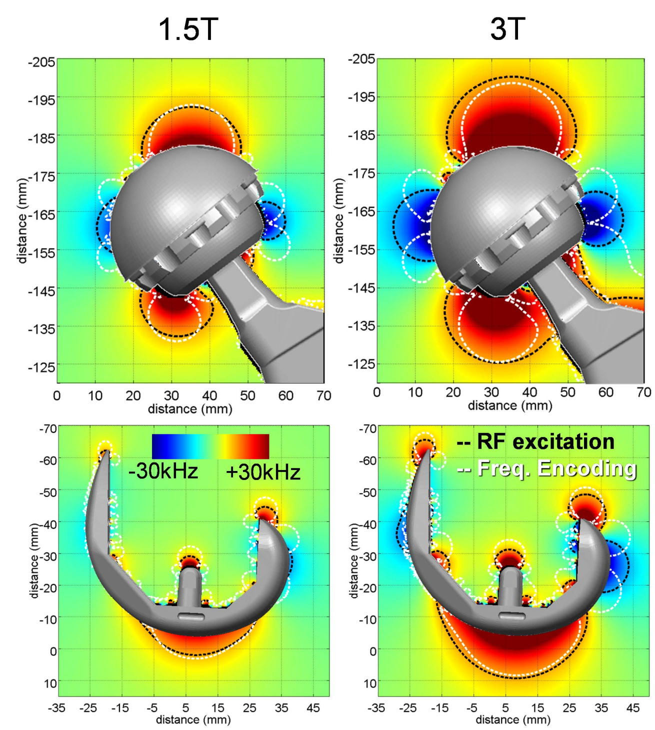

Figure 2. *Extent of off-resonance from orthopedic prostheses at 3T. Field perturbations are shown in maps (a) and plotted at several locations (b) to demonstrate the extent of these perturbations. Current clinical limitations are shown as contour lines for frequency encoding (white) and RF excitation (black).*

Discussion and Conclusion Simulations presented here demonstrate that both RF excitation and frequency encoding is highly problematic for these implants using current 3D-MSI methods at both field strengths. Fully phase encoded methods [5] may help with the frequency-encoding distortion but not with RF excitation limitations.

References [1] Koch et al. MRM 2011. [2] Lu et al. MRM 2009. [3] Koch et al. MRM 2013. [4] Bowman et al. MRM 2012. [5] Artz et al. MRM 2013.

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