

Multiband RF Excitation for Accelerating Magnetic Resonance Imaging in the Presence of Metal

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Target Audience: Researchers interested in MR methods for imaging near metallic implants.

Purpose: Recent 3D multispectral imaging (MSI) techniques have dramatically reduced off-resonance artifacts near metal by acquiring multiple 3D-FSE acquisitions at different RF offsets and summing over all RF bins.^{1,2} In-plane distortion, however, remains a problem in areas with extreme local B_0 gradients due to frequency-encoding.³ To avoid these artifacts, our group developed a spectrally-resolved, fully phase-encoded (SR-FPE) 3D fast spin-echo technique.⁴ For a single RF bin, feasibility for reducing a four hour SR-FPE scan to 12 min using parallel imaging in all three spatial dimensions was recently demonstrated.⁴ However, when imaging near metallic prostheses that cause severe B_0 inhomogeneities (eg. cobalt/chromium alloys), multiple RF excitations with different offsets are required to excite all spins over a wide range of frequencies. This exacerbates scan time further. Multiband (MB) RF excitation offers an opportunity to collect multiple off-resonance bins *simultaneously* to accelerate metal insensitive, fully phase-encoded methods. The *purpose of this work* was to develop and test multiband RF excitation to accelerate SR-FPE when multiple RF excitations are required.

Theory: Using a standard slice-selective gradient, Muller et al. demonstrated simultaneous excitation of different slices (ie. RF bands),⁵ which has been exploited to accelerate multi-slice imaging.⁶ MB excitation is compatible with multi-slice applications because off-resonance induced by the slice selective gradient is removed prior to frequency encoding. In contrast, metal-induced off-resonance persists throughout frequency encoding so 3D-MSI methods restrict excitation to a single RF band centered at the receiver's center frequency. Simultaneously exciting other off-resonant RF bands centered at, for example, -4000kHz and +4000kHz compared to the receiver's center frequency would lead to spatial encoding errors for those two off-resonant bands, analogous to chemical shift artifact, if frequency encoding is used. Fully phase-encoding all three dimensions removes restriction and allows for uncorrupted spatial encoding when multiple RF bands are excited simultaneously. There are two main aspects to consider. First, the receiver BW needs to be large enough to capture the range of excited frequencies. Second, for a given flip angle, conventional MB pulses may require a higher peak B_1 strength, although some strategies can be used to mitigate this effect.^{7,8}

Methods: The femoral head component of a total hip prosthesis made of a cobalt/chromium/molybdenum alloy was placed in a water bath (Fig 1) and scanned with SR-FPE at 3T using a 16-channel wrap array (NeoCoil, Pewaukee, WI). Three separate scans were performed with a single RF band (BW=2.3kHz), each centered at a different RF offset (-4000, 0, +4000 Hz). These three frequency bands were added together to represent a MB pulse. The fourth scan used the MB RF pulse to excite all three frequency bands simultaneously. All acquisitions used 3D k-space corner cutting (R=2) and parallel imaging in 3D ($R_x \times R_y \times R_z = 3 \times 2 \times 2$) with a scan time of 12:53min. Imaging parameters were: Coronal, FOV=24x12x10cm³, matrix=240x120x50, TR=1.2s, ETL=120, ADC samples=1, receiver BW= ± 7.8 kHz, $TE_{eff}=371$ ms, linear k-space encoding. GRAPPA⁹ was used to reconstruct the images (auto-calibration region 20x20, kernel size 5x5). For reference, a simulation was also performed to estimate the B_0 field map using a 3D digital model of the femoral head component (Fig 1).

Results and Discussion: Three single-band SR-FPE acquisitions represented the typical dipole signal pattern for a metal sphere and correlated well with the simulation (Fig. 2). The MB scan successfully acquired signal for each of three frequency bands in a single acquisition, representing an additional scan time reduction factor R=3. Total scan time reduction, including R=2 from 3D corner cutting and R=12 from parallel imaging, was R=3x2x12=72. Instead of minimizing scan time, additional RF bands could be excited and imaged using MB excitation, potentially improving visualization of tissue directly adjacent to the metal where off-resonance is greatest and often missed by conventional 3D-MSI.

The edge of the plastic container was not included in the simulation, nor was coil sensitivity that resulted in lower signal (top/bottom) in the acquired data. Only one ADC sample was used for simplicity, but multiple ADC samples are normally acquired and reconstructed with SR-FPE, and help provide very high SNR as well as provide spectral data. Future work will incorporate phase offsets between the band waveforms in the time domain⁷ and/or shifting the bands in time⁸ prior to performing the complex MB sum to enable peak B_1 values comparable to single band pulses.

Conclusion: This work demonstrates feasibility for reducing scan time using MB excitation near metallic implants with fully phase encoded methods such as SR-FPE. Although further development and additional acceleration mechanisms are necessary, MB may play a critical role in achieving distortion-free, in vivo imaging near metal in acceptable clinical scan times.

References: [1] Lu et al. MRM 2009;62:66-76. [2] Koch et al. MRM 2009;61:381-390. [3] Koch et al. MRM 2013;[Early View]. [4] Artz et al. MRM 2013;[Early View]. [5] Muller, S. MRM 1988;6:364-371. [6] Breuer et al. MRM 2005;53:684-691. [7] Wong et al. ISMRM 2012; #2209. [8] Auerbach et al. MRM 2013;69:1261-1267. [9] Griswold et al. MRM 2002;47:1202-10.

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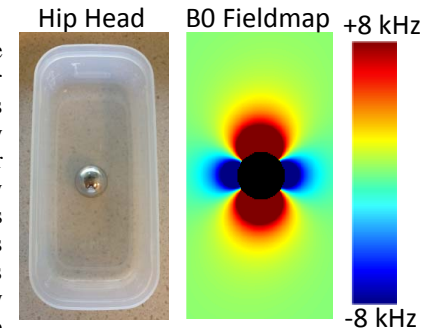


Figure 1 A cobalt/chromium/molybdenum femoral head component was submerged in a water bath (left). A simulated B_0 field map around the prosthesis head at 3T demonstrates extreme off-resonance (right).

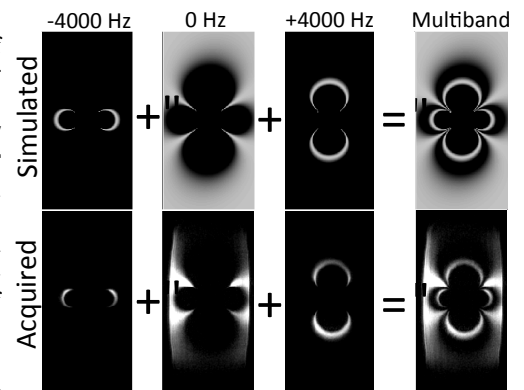


Figure 2 Multiband RF excitation with SR-FPE allows simultaneous imaging of three frequency bands (-4000, 0, and +4000 Hz) providing an acceleration factor of three as demonstrated with a cobalt / chromium / molybdenum femoral head component of a total hip prosthesis, submerged in a water bath.