Accelerating Sequences in the Presence of Metal by Exploiting the Spatial Distribution of Off-Resonance

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Target Audience: Physicists and radiologists interested in MR imaging near metal.

Purpose: Extreme off-resonance caused by metallic implants, up to ± 15kHz depending on the material composition, often requires multiple 3D acquisitions at different radiofrequency offsets to successfully image adjacent tissue [1,2]. This dramatically increases scan time. Even when corner cutting, parallel imaging, and partial-Fourier are used for acceleration, scan times remain around 10-15min [3]. This work aims to further accelerate metal imaging sequences by exploiting the spatial distribution of off-resonance spins.

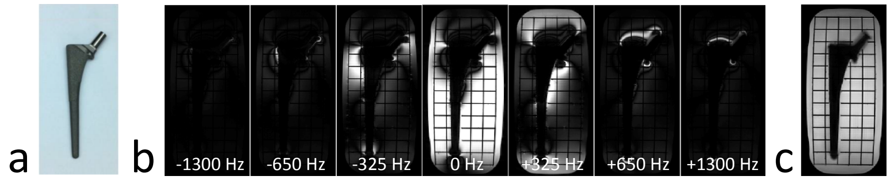

Figure 1. *The presence of a titanium hip prosthesis produces severe off-resonance. Multiple independent acquisitions with unique RF center frequencies enables reconstruction of frequency bins [1] that provide unique spatial information that can be exploited. (a) Titanium hip prosthesis. (b) Selected frequency bins. (c) Sum-of-squares composite.*

Theory: When imaging near metal, off-resonance is directly related to the spins' proximity to the metal. Acquiring data at different off-resonant frequency bins yields images with unique spatial information. This is analogous to the spatial sensitivities of multi-channel receiver coils and can be used to accelerate k-space encoding with a reconstruction similar to parallel imaging.

Methods: To show feasibility of accelerating with frequency bins, the femoral stem of a titanium hip prosthesis was placed in a grid and submerged in a water bath. An RF pulse (80μs) was used in a phantom to excite all of the off-resonance frequencies at 1.5T using a spectrally resolved fully phase-encoded 3D fast spin-echo (SR-FPE) sequence [4] with a scan time of 8hr (FOV=24x12x4.8cm³, matrix=240x120x24, ADC samples=48, receiver BW=±7.81kHz, TR=1.0s, ETL=24, echo spacing=4.8ms, TE_{eff}=58ms). Reconstruction of 48 fully sampled frequency bins (spectral resolution of 325Hz) without distortion was performed using a Fourier transform of the temporal data (Figure 1).

A central slice was chosen to investigate 2D acceleration using two undersampling schemes. The ***first scheme*** used a constant reduction factor across all frequency bins. The ***second scheme*** used an off-resonance dependent reduction factor according to the frequency distribution (Figure 2). GRAPPA [5] was used to reconstruct individual frequency bins (auto-calibration region 20x20, kernel size 5x5). Sum-of-squares was used to generate an accelerated composite. This was compared to the fully sampled composite to asses reconstruction accuracy.

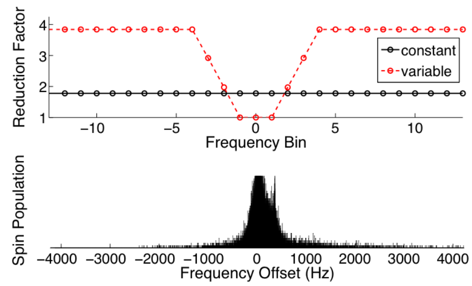

Figure 2. *Independent acquisition of frequency bins enables variable acceleration and provides flexibility in optimizing reconstruction. The variable approach shown matches the acceleration to the amount of off-resonance signal. Only the central 26 bins are shown.*

Results: Using a constant undersampling pattern across frequency bins resulted in residual aliasing in the composite (Figure 3b). A spectrally-variable sampling pattern enabled a substantially improved reconstruction with minimal error (Figure 3c,d) for a higher effective reduction factor.

Discussion: Although SR-FPE acquired this spectral data using a single RF pulse with a low susceptibility metal, multiple acquisitions at different radiofrequency offsets is necessary for most metallic implants. In those circumstances, under-sampling using scheme 2 would be feasible and provide 2D acceleration for sequences such as MAVRIC-SL [3] and 3D acceleration for SR-FPE [4]. Note that the undersampling pattern should reflect the distribution of off-resonance from a metallic implant, which can be estimated accurately if the metal composition is known. In contrast to adaptive phase encoding [1], this method is insensitive to the position of the metallic implant, which provides important flexibility in prescribing the field-of-view for clinical applications. Acceleration with a single channel coil was demonstrated in 2D using spectrally-variable sampling with an effective reduction factor of R_{eff}=3.2 (which will depend on the number of bins). This technique should be fully compatible with other acceleration methods, such as parallel imaging, which can combine to offset the increase in scan time required by techniques in the presence of metal.

Conclusion: A unique opportunity for acceleration exists near metal by exploiting the spatial distribution of off-resonance. Independent acquisition of each off-resonance bin allows variable *k*-space sampling across bins offering a distinct advantage to optimize acceleration.

References:
[1] Koch et al. MRM 2011;65:71-82. [2] Lu et al. MRM 2009;62:66-76. [3] Koch et al. MRM 2011;65:71-82. [4] Artz et al. Proc of ISMRM 2012 #2431.
[5] http://www.eecs.berkeley.edu/~mlustig/Software.html.
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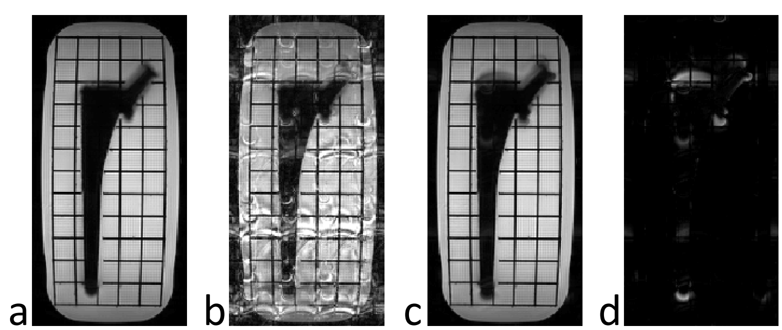

Figure 3. *Improved reconstruction using variable sampling is enabled by the independent acquisition of frequency bins. (a) Fully sampled composite. (b) Residual aliasing remains when the bins are equally sampled (R_{eff}=1.8). (c) Spectrally-variable sampling (red circles in Figure 2) substantially improves the reconstruction (R_{eff}=3.2). (d) Difference of (a) and (c) multiplied by 2.*