Comparison of 2D Spin-Echo, Spin-Echo Multi-Spectral Imaging, and Ultra-wide Bandwidth 3D Radial Techniques for Imaging near Metal

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Introduction: Susceptibility artifacts near metal implants can be separated into three categories: 1) T2* dephasing-induced signal voids, 2) signal voids from insufficient spectral coverage, and 3) spatial encoding disruptions. The severity of these artifacts depends heavily on the type of MR acquisition. Here, we examine the susceptibility artifacts in three different types of acquisitions a) Cartesian 2D spin echo, b) Cartesian spin-echo Multi-Spectral Imaging (MSI) [1-3], and c) ultra-wide bandwidth 3D-radial imaging (e.g. RUFIS [4], WASPI [5], SWIFT [6]). Artifacts are examined at 3T on a gridded total hip replacement phantom.

Theory: All three of the aforementioned MR imaging approaches successfully address artifacts from categories 1) and 2). 2D spin-echo and spin-echo MSI refocus T2* dephasing at the center of the acquisition window. Ultra-wide bandwidth 3D-radial imaging approaches use rapid transitions from RF excitation to signal acquisition to minimize spin dephasing. 2D spin-echo approaches image the entire spectral ensemble around metal, at the expense of severe slice and readout distortions [5]. Cartesian MSI approaches eliminate slice distortions, minimize frequency-encoded distortions, and cover a wide band of spectral offsets. Ultra-wide bandwidth 3D radial imaging approaches also excite the entire spin ensemble around metal implants, but do not actively address spatial encoding errors. Here, we assess the severity of these artifacts inherent to the basic 3D-radial encoding strategy near metal. Susceptibility artifacts in non-Cartesian approaches are not as directly comprehended as those in Cartesian approaches. Metal-induced field perturbations cause spatial shifts, pileup artifacts, and blurring -- rendering it sometimes difficult to decipher the source of artifacts. Field maps derived through spectral analysis in the MSI data can help comprehend the artifacts in a 3D-radial imaging sequence.

Measurements: Imaging was performed on a clinical 3T imaging system. Spin-echo MSI images were acquired in the coronal plane using 22 2.25 kHz overlapping Gaussian spectral profiles separated by 1kHz. Cartesian 2D-spin echo images were acquired in the coronal plane using 1kHz refocusing RF pulses. Both spin-echo approaches applied a readout bandwidth of 250 kHz and had through-plane resolution of 4mm. Field maps were constructed from the MSI images using spectral bin correlation [3]. To assess the artifacts from the family of ultra-wide bandwidth 3D radial techniques, the RUFIS Zero-TE (ZTE) technique was implemented (4). Since the k-space trajectory and level of T2* dephasing is similar for other ultra-wide bandwidth 3D radial approaches, it expected that the results shown here carry over to the other members of this family of techniques (i.e. SWIFT and WASPI). ZTE images were acquired to reconstruct a 256 mm diameter FOV with 1 mm resolution. Images were acquired using 2º hard pulses exciting a bandwidth of 128 kHz at the full-width-half-maximum of the resulting sinc spectral profile. Bandwidth limitations in wideband 3D radial approaches are dictated by system parameters – in the SWIFT approach, encoding bandwidth is limited by dwell time between gapped RF pulses. In the ZTE approach shown here, the encoding bandwidth is limited by the maximum RF transmission amplitude of the system. For the present study, ZTE images were acquired with a readout bandwidth of 62.5 kHz.

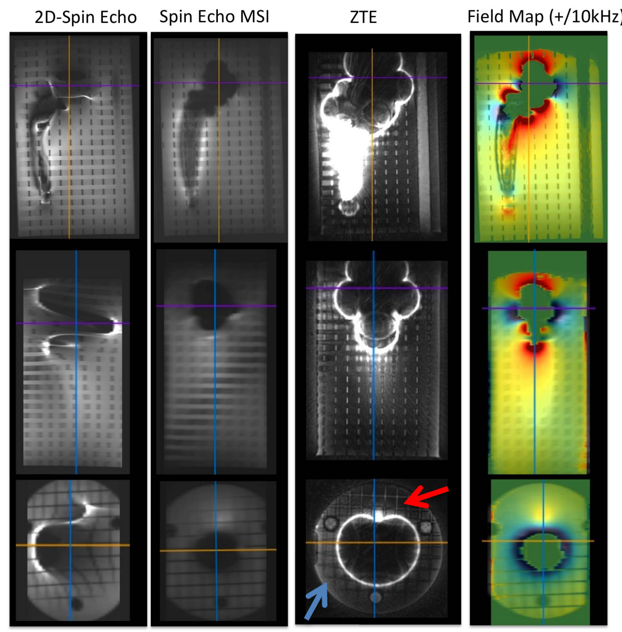

Figure 1: Imaging results and field map on gridded total hip replacement phantom at 3T. Rows: top-coronal scan plane (in-plane for 2D-spin echo and spin-echo MSI), middle – coronal plane, bottom – axial plane. Arrows indicate an artifact in the ZTE images where contrast has been altered due to the metal artifact. Scan times: 2D Spin Echo and Spin Echo MSI -> 4.5 min, ZTE: 3 min.

Results: Figure 1 presents the three imaging approaches on a hip phantom in aqueous solution fitted with a plastic grid. 2D spin-echo images (first column) show severe distortions, which are particularly evident in the through-slice dimension (middle and bottom rows). The spin-echo MSI approach (second column) removes these bulk distortions. In the third column, we see that the wide-bandwidth 3D-radial ZTE image shows substantial artifacts. The artifacts are the result of severe warping of the frequency-encoded radial projections. There are many consequences of these warped projections. Bulk distortion and ensuing pileup of signal is the most obvious of the resulting artifacts. From the field map presented in the right column, it is clear that the far off-resonance spins near the metal are pushed radially outward to form a ring of pileup artifact. This creates signature dipole-patterned distortions in the image, which extend as far as 5cm from the metal interface, as defined by the spin-echo MSI image. In addition, there are blurring and intensity artifacts in the ZTE image. Blurring is evident by the modification of the plastic grid structure in the phantom, and the two arrows show regions where image contrast has been altered (blue arrow->dark grid/light water, red arrow -> light grid/dark water). The generation of this artifact from the warping of 3D radial projections has yet to be understood.

Discussion: Comparisons were made between 2D spin-echo, spin-echo MSI, and ultra-wide band 3D radial MR imaging approaches. The results indicate that, like 2D spin-echo approaches, exciting and encoding the entire spin-ensemble around a metal implant causes substantial artifacts due to warping of frequency-encoded lines. Significant spatial distortion, pileup artifact, blurring, and intensity modulations are induced by the presence of metal in the ultra-wide bandwidth 3D radial image. It is clear from these results that spin-echo MSI remains the best clinical means to image in the vicinity of metal hardware. For imaging of short-T2 species near metal, the fusing of UTE with MSI techniques has shown much greater initial success than direct ultra-wide band 3D radial approaches [7]. Further work will investigate alternative methods of reconstructing ultra-wide bandwidth 3D radial approaches to repair susceptibility artifacts, particularly using the available spin-echo MSI field map information. However, it is unclear if such a reconstruction mechanism can be found that mitigates the substantial projection warping indicated in the images shown here.

REFERENCES: [1] Lu et al, MRM 62:66-76, 2009 [2] Koch et al, MRM 61:381-90 2009 [3] Koch, MRM 65:71-82 2011 [4] Madio DP, Lowe IJ, MRM (1995) 525-529; [5] Wu Y, et al, MRM (2003) 59-68; [6] Idiyatullin D, et al, JMR (2006) 342-349. [7] Carl et al, Proc ISMRM, 2011, 2668.