Imaging Around Metal: Emerging Techniques

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Metal devices such as joint replacements, spinal fixation devices, surgical screws and plates are successfully used to treat millions of patients annually world-wide. Often MRI is indicated in these subjects, both for conditions related to the device or for unrelated conditions. Once subjects have been screened for the *safety* of these devices, the next challenge is how to reduce *artifacts* that result in images with these subjects. Here we discuss common metal-induced artifacts, and emerging artifact reduction techniques.

Common Artifacts: The presence of metal causes large variations in the static magnetic field, which is usually assumed to be static [1]. Several adverse mechanisms result, with different appearance on images (Figs. 1 and 2):

- T2* dephasing within a voxel causes signal loss, which can be corrected by using a spin echo, or in some cases very short echo time [2].
- Chemical-shift selective fat suppression methods (fat-saturation, water-only and even Dixon imaging) fail because the background frequency shifts are much greater than the chemical shift frequency difference.
- Failure to excite signal can occur because the frequency range is outside the excitation bandwidth, resulting in signal loss.
- Displacements of the excited slice cause through-slice distortion, signal pile-up and signal loss.
- Displacements in the readout direction cause in-plane distortion, signal pile-up and signal loss, sometimes difficult to isolate from slice displacements.

In-Plane Artifact Reduction: Maximizing readout bandwidth, at a cost of SNR, can minimize in-plane distortions. This maximizes the readout gradient amplitude, to maximize its effect compared to metal-induced frequency shifts. Increasing the matrix size alone will not reduce the spatial distortion, though it may have other diagnostic benefits. View-angle tilting, (VAT) whereby the slice-selection gradient is replayed during the readout, almost completely removes in-plane artifacts [3,4]. Other methods attempt to measure and correct for the background shifts, but are limited.

Through-Slice Artifact Reduction: Increasing excitation bandwidth will reduce slice distortion, at a cost of increased RF amplitude, power and heating. Displacement is proportional to slice width, so thinner slices may help, but may increase scan time. Field mapping can further correct small slice distortions [5]. Non-selective excitations avoid distortions, but may not excite a sufficiently high bandwidth, or may not be compatible with in-plane correction methods [2,6]. Arbitrary slice distortions may be corrected by the use of through-slice phase encoding with frequency-selective [7] or slice-selective [8] excitation. Both of these methods correct most artifacts to within a pixel, but require greater scan times and trade some SNR for artifact correction.

Techniques: The term MARS (metal artifact reduction sequences) has been used to describe specific methods [4], but also generally to refer to high-bandwidth protocols. Currently vendors are beginning to offer options with all of the above reduction approaches under various names (MAVRIC-SL, MSVAT-SPACE, SEMAC, WARP) [9-12]. These approaches offer most spin echo contrasts (proton-density, T1, T2, STIR, FLAIR), and have shown promise in spite of increased scan time and usually coarser resolution [13-17].

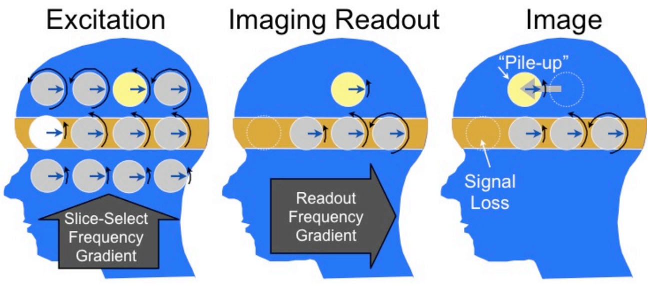

Figure 1: *Displacement artifacts near metal. Black arrows indicate the frequency (rotation rate), which varies near metal. During excitation, a selection gradient causes a frequency variation (black arrows) but frequency shifts cause off-resonant spins (white, yellow) to be excited in the wrong slice (white excluded, yellow included). During imaging readout, the gradient induces a frequency variation, and the off-resonant spin appears to be at the wrong location. The displacements lead to bulk distortion, signal loss and pile-up effects.*

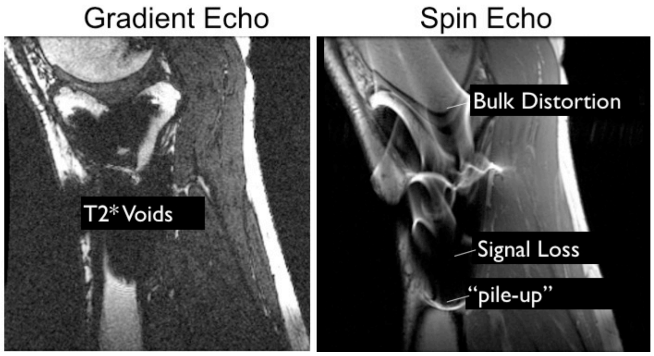

Figure 2: *Examples of metal artifacts from tibial screws. In high-bandwidth gradient-echo images, the T2* voids dominate. In spin-echo images, T2* loss is corrected, but through-slice and in-plane distortions cause bulk distortion, signal loss, and "pile-up" effects.*

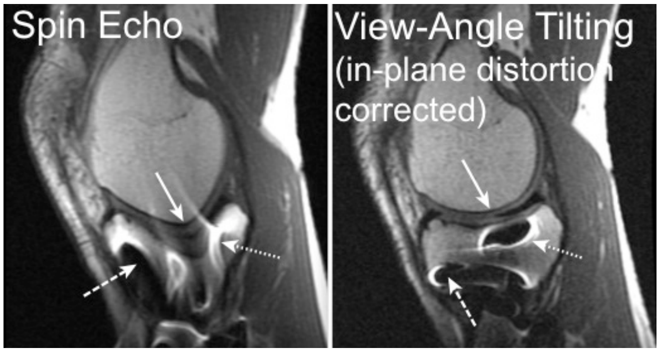

Figure 3: *Comparison of standard spin echo to view-angle-tilting (VAT). VAT corrects in-plane bulk distortion, showing the correct shape of the femur (solid arrow), and restricting the location of through-plane signal loss (dashed arrow) and pile-up (solid arrow) to the correct in-plane location. However, VAT does not correct through-plane artifacts.*

Summary: The primary artifacts from metal in MRI are due to susceptibility-induced frequency shifts. These have numerous adverse effects on imaging, but with careful protocol design and use of specialized techniques, diagnostically useful images can be achieved in many cases.

References: [1] Schenck JF. Med Phys, 23(6):815–850, 1996. [2] Du J, et al. ISMRM 2010, p.132. [3] Cho ZH, et al. 6th SMRM 1987, p.912. [4] Olsen RV, et al. Radiographics, 20(3):699–712, 2000. [5] Butts K et al. ISMRM 2006, p.2380. [6] Hoff MN, et al. ISMRM 2010, p.3081. [7] Koch KM, et al. MRM 2009; 61:381–390. [8] Lu W, et al. MRM 2009; 62:66–76. [9] Lee YH, et al. MRI 2013 In Press. [10] Zho SY et al. JMRI 2013 In Press. [11] Ai T, et al. Investigative Radiology 47(5):267, 2012. [12] Koch KM, et al. MRM 65(1):71, 2011. [13] C. A. Chen, et al. JMRI 33(5):1121, 2011. [14] Hayter CL, et al. AJR 197(3):W405, 2011. [15] Sutter R, et al. Radiology 265(1):204, 2012. [16] Worters PW, et al. JMRI 37(1):243–248, 2013. [17] Lee YH, et al. MRI 2013. In Press.