Towards Artifact-free MRI near Metallic Implants

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Introduction: Magnetic resonance imaging is potentially the best modality for examining tissue near metallic implants such as total joint replacements and spinal fixation devices. However, MRI near metallic implants remains an unmet need due to severe artifacts, such as signal loss, piling-up, and displacement. The artifacts stem from huge metal-induced field inhomogeneity (e.g. ~5 kHz for titanium). First, the steep field gradient near metal objects results in shortened T2* (i.e. increased intravoxel dephasing). Second, excited spins accumulate additional phase proportional to the field inhomogeneity, which translates into *in-plane distortion* along the readout direction. Third, the metal-induced field combined with the slice-select gradient leads to *through-slice distortion*. Each spin is shifted by an amount equal to the slice thickness times the ratio of the field inhomogeneity to RF bandwidth.

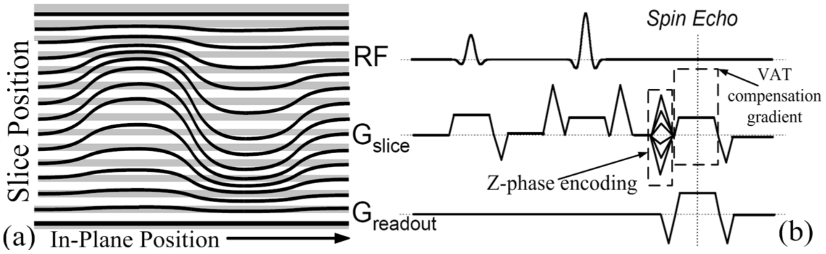

Fig.1: (a) Metal-induced field inhomogeneity causes distortion of excited slices in the form of slice thinning, thickening, and displacement. (b) Diagram of a SEPI-VAT sequence where the Z-phase encoding resolves the actual slice locations of the excited spins (shaded sections in (a)), and the VAT compensation gradient completely removes in-plane distortion [1].

Both shortened T2* and in-plane distortion have been addressed using a 2D view angle tilting (VAT) spin-echo (SE) sequence [1], which yields the best MR imaging of metallic implants in literature [2,3]. However, the through-slice distortion remains in the form of slice thinning, thickening and displacement, especially when selected slices are relatively thick. An example is shown in Fig. 1 (a). In this work we present an imaging technique designed to completely eliminate artifacts caused by metallic implants.

Methods: Fig. 1 (b) shows the proposed technique which extends the 2D VAT SE sequence by incorporating additional phase-encoding along the slice direction (Z-phase encoding). Therefore, the proposed sequence is a combination of slice excitation profile imaging (SEPI) [4] and VAT technique, which we refer to as a SEPI-VAT sequence. This sequence resolves the locations of excited spins with the additional Z-phase encoding, and must cover the entire volume in which spins are subject to the metal-induced field inhomogeneity. When the spins of all slices in the volume are resolved to their actual slice locations, summing the spins at the same location eliminates the through-slice distortion.

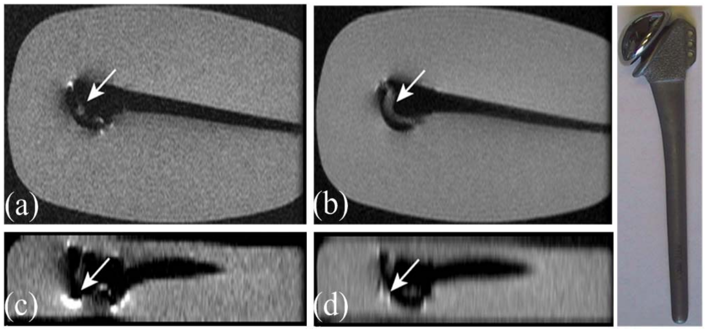

Fig. 2: Top views (top row) and reformatted side views (bottom row) of the phantom study obtained from the 2D VAT SE sequence (a, c) and the SEPI-VAT sequence (b, d). The implant head (see the photo) distorted in (a) is completely restored in (b). The severe through-slice distortion in (c) is almost fully corrected in (d).

The SEPI-VAT sequence was used to scan a hip prosthesis (see the photo in Fig. 2) embedded in a gel phantom and a subject who has a titanium screw in the right knee at a 1.5T GE Signa scanner. The phantom study and the knee study were performed with a head coil and an extremity coil, respectively. Both studies employed the same imaging parameters: 1 kHz RF bandwidth, ±166 kHz readout bandwidth, 20 cm FOV, 3 mm slice thickness with no gap between slices, TE/TR=20/410 ms, 256x128 matrix. A total of 16 slices were acquired to cover a volume containing the metallic implants. For each slice, 16 Z-phase encoding steps account for up to ±8 slices of through-slice displacement (i.e., ±8 kHz field distortion). Note that the resolution of the Z-phase encoded sections is the same as the slice thickness.

Results: Figs. 2 and 3 show the result comparison of the phantom study and the knee study obtained from the 2D VAT SE sequence and the proposed approach. In Fig. 2, the top row compares one sample slice; the implant head detail distorted in (a) is completely restored in (b). The bottom row shows the reformatted side views; the severe through-slice distortion in (c) is corrected in (d) such that the curved shape of the implant is almost perfectly reproduced. In Fig. 3, the left column compares one coronal slice; the piling-up artifact in (a) is greatly suppressed in (c). The right column shows the reformatted sagittal views; the through-slice distortion in (b) is suppressed in (d) such that the circular shape of the screw hole is recovered. While the SEPI-VAT sequence almost completely removes the artifacts near metallic implants, small residual artifacts are probably due to minor slice overlaps. Further improvement can be achieved with higher Z-phase encoding resolution (i.e. finer than slice thickness) at a cost of a longer scan time.

Conclusion: Both reported studies took 14 minutes without parallel imaging; hence, when integrated with acceleration techniques, the SEPI-VAT sequence can achieve artifact-free MRI near metallic implants in a reasonable scan time.

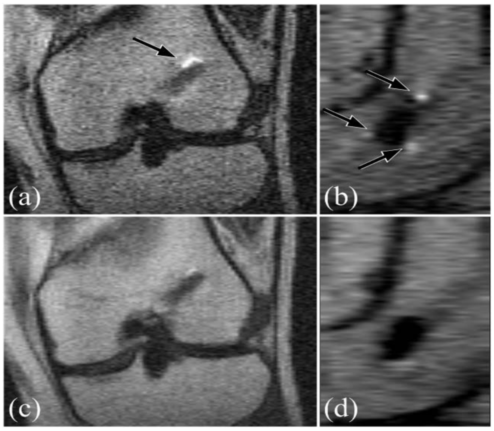

Fig. 3: Zoomed coronal views (left column) and reformatted sagittal views (right column) of the knee scan using the 2D VAT SE sequence (a, b) and the SEPI-VAT sequence (c, d). The through-slice piling-up artifacts (arrows) are greatly suppressed in (c, d).

References: [1] Z. Cho, et al. Medical Physics 1988 15:7-11. [2] S. H. Kolind, et al. JMI 2004 20(3):487-95. [3] K. Butts, et al. MRM 2005 53(2):418-24. [4] Q. X. Yang et al. MRM 1996 39:402-09.