

Highly Accelerated SEMAC Metal Implant Imaging Using Joint Compressed Sensing and Parallel Imaging

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Introduction

Novel techniques for reducing metal artifacts like SEMAC¹ enable MR imaging near orthopedic implants and recent studies² have demonstrated a high potential for significant clinical impact. However, routine clinical utility of SEMAC is currently limited by its increased acquisition time which significantly limits patient throughput and increases the risk for patient motion and resultant artifacts. Consequently, it is highly desirable to accelerate SEMAC acquisitions. SEMAC is a good candidate for the application of compressed sensing (CS) because (a) the additional phase-encoding dimension (denoted z) is inherently sparse and (b) high incoherence can be achieved by using a 2D random undersampling pattern along k_y and k_z . Higher accelerations can be achieved by combining CS and parallel imaging³. In this work, we describe a joint compressed-sensing and parallel-imaging approach for SEMAC (Sparse-SEMAC) and present first experimental results from cadaver exams. In contrast to previous work on the application of CS to SEMAC^{4,5}, our approach does not use a sparsifying transform and incorporates parallel imaging jointly into the reconstruction to achieve acceleration factors that enable SEMAC imaging within clinically acceptable scan times.

Methods

SEMAC acquisitions were performed using a customized turbo spin-echo sequence with moderate T2 weighting (TR/TE=3000/50ms, FOV=180mm, 320x256 matrix, ETL=11, 27 slices with 4mm thickness, 500Hz/pixel readout bandwidth, 1.7kHz RF bandwidth). 32 encoding steps were used along k_z (SEMAC off-resonance coverage of ± 27 kHz). Experiments were conducted on a clinical 1.5T scanner (MAGNETOM Aera, Siemens Healthcare, Germany). For Sparse-SEMAC, the phase-encoding dimensions (k_y and k_z) were undersampled by a factor of 8 using a Poisson-disk pattern⁶ with a fully-sampled 24x8 region at the center for parallel-imaging autocalibration (Fig.1).

The Sparse-SEMAC reconstruction was performed by enforcing joint multicoil sparsity in the x - y - z domain. No sparsifying transform was used due to the inherent sparsity along the SEMAC dimension. The reconstruction problem is given by

$$\min \|\mathbf{m}\|, \text{ subject to } \mathbf{E}\mathbf{m} = \mathbf{d}$$

where \mathbf{m} is the x - y - z image to be reconstructed, \mathbf{E} is the encoding model that includes the undersampled Fourier transform and coil sensitivities and \mathbf{d} is the undersampled k -space data. Coil sensitivities were estimated using the adaptive coil-combine method from the fully sampled center region⁷. Images were reconstructed offline using a Matlab implementation of the iterative soft-thresholding algorithm (ISTA)⁸.

Because the scan times for a fully-sampled reference dataset with identical scan parameters would not be tolerated by a patient, experiments were carried out on a human knee cadaver with a full joint replacement (CoCr alloy). The following acquisitions were compared: Fully-sampled conventional scan without SEMAC (1:10min), fully-sampled SEMAC (38min), and 8-fold undersampled Sparse-SEMAC (5:30min). Note that due to the auto-calibration region, the effective acceleration for Sparse-SEMAC was 6.9. All scans were carried out in sagittal and coronal orientations with a 4-channel multi-purpose flex coil and a TX/RX 15-channel knee coil.

Results

Fig. 2 compares a single slice of the conventional scan, the fully-sampled SEMAC scan, and the Sparse-SEMAC scan for the 4- and 15-channel coils. It can be seen that all SEMAC scans reduce metal distortions significantly. The Sparse-SEMAC scans are equivalent to the fully-sampled scan with respect to metal-artifact reduction, image contrast, and resolution but show slightly increased noise level, particularly for the 4-channel coil.

Conclusions and Discussion

These initial results suggest that accelerating SEMAC using a joint compressed-sensing and parallel-imaging approach is feasible without significant loss in image quality and enables SEMAC scans in clinically acceptable scan times with a high number of SEMAC encoding steps. The latter is particularly important for implants causing large field distortions like joint replacements containing CoCr alloys and for field strengths above 1.5 Tesla. Future work will explore further technical refinements such as variable-density sampling schemes and will target on first in-vivo patient studies.

References

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Fig.1: k_y and k_z sampling pattern with 8-fold acceleration using a Poisson-disk scheme (white = sampled).

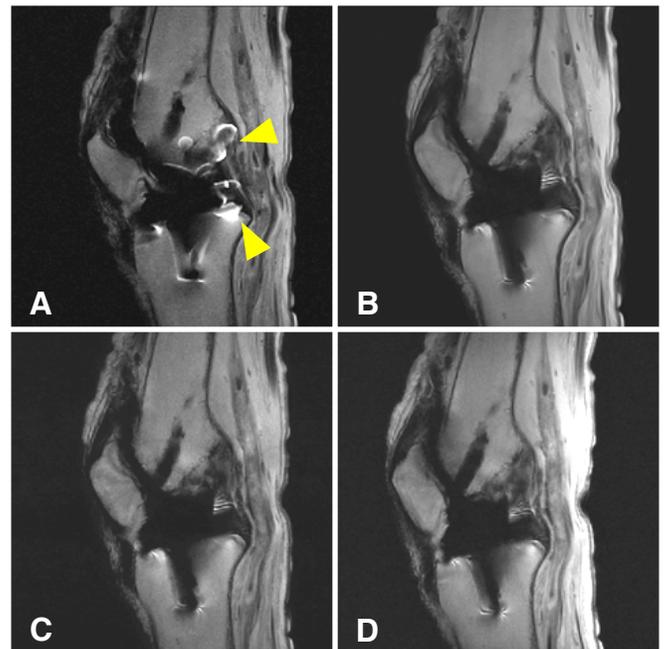


Fig.2: A: acquisition without SEMAC (4ch. coil), B: SEMAC (4ch. coil), C: Sparse-SEMAC (4ch. coil), D: same as C but acquired with 15ch. coil.

Note: slice position in D is slightly different due to coil change.