Combined Parallel Imaging and Compressed Sensing on 3D Multi-Spectral Imaging Near Metal Implants

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Introduction 3D-MSI techniques (MAVRIC, SEMAC, VS-MSI) can significantly reduce susceptibility artifacts near metal implants [1,2,3]. To accomplish this artifact reduction, these techniques require large amounts of spectrally and spatially encoded data to be acquired. This acquisition requirement hinders the resolution feasible in clinical application. Existing 3D-MSI approaches utilize a variety of conventional undersampling strategies to address this challenge [3,4]. Here, we examine compressed-sensing as a means to achieve greater acceleration and therefore increase the resolution capabilities of 3D-MSI in a clinical setting.

Methods Compressed sensing and parallel imaging can be combined in a serial approach [5]. In a serial compressed sensing followed by data-driven parallel imaging technique, k-space data is acquired with Gaussian random sampling. The compressed sensing approach reconstructs randomly undersampled k-space data to a uniformly undersampled k-space grid. Parallel imaging reconstruction then reconstructs the uniformly undersampled data into the final image. This serial approach enables additional acceleration due to compressed sensing on top of conventional parallel imaging acceleration

The compressed sensing algorithm performs an L1-norm minimization using a conjugate gradient algorithm on image space data. Within each iteration, the image is corrected for consistency by replacing estimated data points with acquired data in k-space. Here, parallel imaging was performed using the ARC algorithm [6].

3D-MSI images were acquired using the MAVRIC-SEMAC hybrid paradigm (VS-MSI) [3]. Images were acquired around a total knee replacement (comprised of cobalt-chromium alloy) at 1.5T. As a standard-of-care reference, 2D-FSE images were also acquired with a high-readout bandwidth (+/- 125 kHz). Images were acquired in the sagittal plane using an 8-channel knee array coil. All images were collected over an 18 cm FOV with TR =3.4s, TE=30 ms, echo-train length of 20, and had through plane resolution (slice or kz) of 5 mm spanning 14 cm.

The maximum attainable 3D-MSI image-resolution in a scan time of roughly 6.5 minutes was sought using a variety of acceleration mechanisms. 2x parallel imaging (320x184 data matrix), 4x parallel imaging (320x320 data matrix), and 2x parallel imaging and 2x compressed sensing (320x320 data matrix) were all implemented. All 3D-MSI acquisitions also used ky-kz corner cutting, homodyne-detected partial-Fourier imaging in ky (8 overscans), and 24 calibration lines to synthesize the data-driven parallel imaging reconstruction.

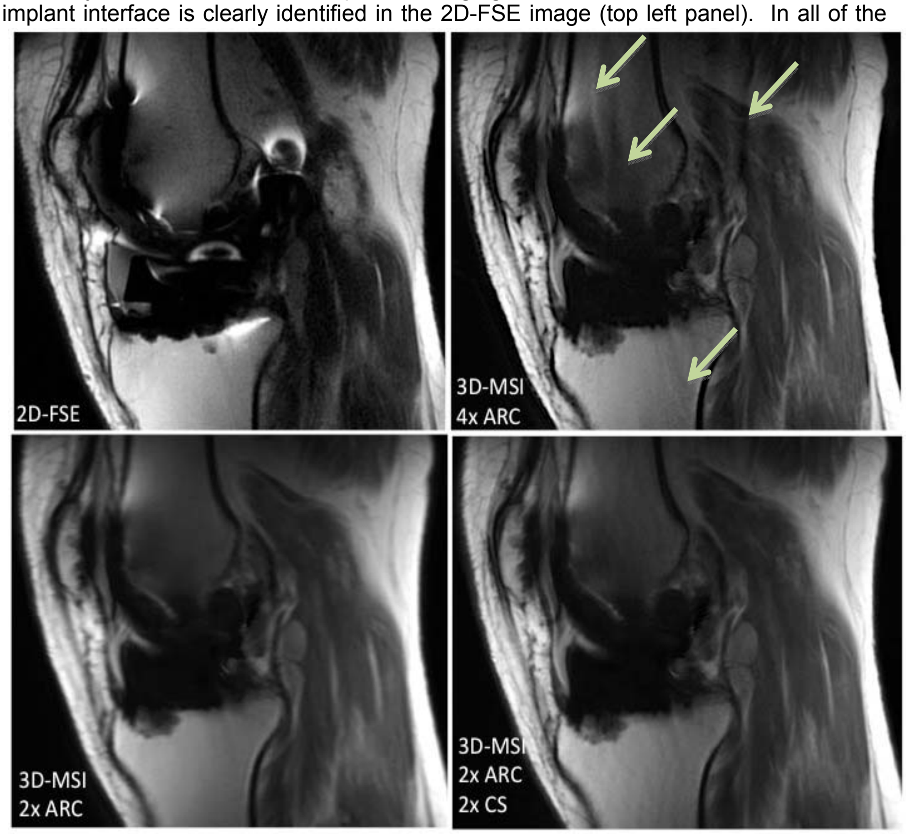
Results and Discussion Severe disfigurement of the implant interface is clearly identified in the 2D-FSE image (top left panel). In all of the 3D-MSI images, these susceptibility artifacts are nearly eliminated to reveal the bone and tissue interfaces across the implant.

The 4x ARC image (top right panel) matches the resolution of the 2D-FSE image, but exhibits parallel imaging artifacts, which are highlighted with arrows. This indicates that the distribution of coil elements in the ky-encoded dimension (right-left) was insufficient to enable proper synthesis of missing k-space lines.

In the lower-left-hand panel, these artifacts are removed with a reduction in the acceleration factor (2x). However, this improvement comes at the expense of reduced image resolution to maintain the same scan time of 6.5 minutes.

The 2x ARC plus 2x compressed sensing image is able to eliminate the parallel imaging artifacts seen in the 4x ARC case and improve upon the resolution seen in the 2x ARC image. It is clear, however, that the resolution in this case is slightly less than that of the 4x ARC case. This is the result of imperfect estimation of the randomly undersampled k-space points.

Thus, we see that compressed sensing is able to reduce significant artifacts in regularly undersampled parallel imaging at the cost of a slight degradation in image resolution. Future work will assess the clinical impact of this tradeoff. In addition, alternative combinations of compressed sensing plus parallel imaging will be investigated (i.e. 3x ARC plus 1.5x parallel imaging in the presented case), where the observed tradeoffs may be reduced.



2D-FSE image (3.5 minutes) and 3D-MSI images under various sampling strategies that resulted in a 6.5 minute acquisition. Parallel imaging artifacts are identified in the 4X ARC image (arrows) and are removed when compressed sensing is combined with 2X ARC (lower right panel).

[1] Koch et al,MRM,61,2009, [2] Lu et al,MRM,62,2009, [3] Koch et al, MRM, EarlyView, 2010, DOI: 10.1002/mrm.22523,
[4] Hargreaves et al, JMRI, 31m 2010 [5] King et al, Proc ISMRM, 2010, #4881, [6] Beatty et al, Proc ISMRM 2007, #1749