Parallel MRI near metallic implants

W. Chen[1], P. Beatty[1], K. Koch[2], and A. Brau[1]

[1]Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States, [2]Applied Science Laboratory, GE Healthcare, Waukesha, WI, United States

Introduction: MRI has potential advantages for diagnostic imaging near metallic implants compared to other modalities, but can suffer from severe artifacts caused by implant-induced inhomogeneities. MAVRIC (1,2) is one of the recently developed MRI techniques (1-3) for this application. In MAVRIC, multiple independent 3D data sets are collected at different resonance frequency offsets, thus imaging different regions around the metal implant. The final image is reconstructed using sum-of-squares. A main challenge to MAVRIC, however, is prolonged scan time. In this work, we investigated the performance of parallel imaging methods in the presence of significant off-resonance and signal distortion caused by metal implants. We demonstrate that parallel imaging can effectively be combined with MAVRIC for imaging near metallic implants in reduced scan times.

Theory: Metal implants can create frequency offsets on the order of 10 kHz, which results in a significant off-resonance term in the signal equation. However, for Cartesian k-space sampling, it can be shown that the general Fourier relationship between magnetization and acquired signal described by the signal equation still holds after coordinate transformation. Consequently, auto-calibrated parallel imaging methods should be insensitive to off-resonance effects, since both calibration data and imaging data experience the same magnetic field. For external calibrated parallel imaging methods, the calibration data and imaging data may experience different off-resonance fields, which can result in a different shift between sensitivity profiles in calibration data and imaging data. Because sensitivity profiles typically only contain low frequency components, external-calibrated parallel imaging may be insensitive to these errors if high readout bandwidths are used. Another fact that can impact parallel imaging is that metallic implants can cause large signal voids in images. For SENSE-type parallel imaging methods, this can cause difficulties in sensitivity map estimation, which may result in artifacts in the final image. Data-driven parallel imaging methods, such as GRAPPA (4) and ARC (5,6), are predicted to be more immune to this problem because the unaliasing weights are estimated by minimizing residuals weighted by magnetization (7).

It is desirable to perform single calibration in MAVRIC due to its multiple data acquisition procedure. We use a single, fully sampled low frequency data set acquired at zero resonance frequency offset as calibration data. The unaliasing weights are then used to reconstruct all data sets acquired at different resonance frequency offsets. Although the off-resonance field can vary at different resonance offset frequencies, this effect is negligible due to the high readout bandwidth and limited RF bandwidth employed in MAVRIC. To reduce the potential errors that can arise due to signal voids in a single calibration data set, we can also concatenate fully sampled low frequency data from a few data sets acquired at different resonance frequency offsets, and then estimate unaliasing weights from this concatenated calibration data set using a single calibration procedure (8).

Method and Results: We investigated parallel imaging near metallic implants using both SENSE (10) and ARC with different calibration methods. A field map ranging from –2.2 to 16.9 kHz computationally estimated (11) from a metallic knee implant model is used for the simulation. The readout bandwidth is 250kHz with a 256x256 matrix. Data is sampled at 2X acceleration along the phase-encoding (PE) direction with 21 lines used for calibration. A 3D kernel is used for ARC to increase reconstruction accuracy. Figure 1 shows the simulation results. Note SENSE using the true sensitivity map (which essentially ignores off-resonance term in the signal equation when performing parallel imaging) works well in spite of the extraordinary off-resonance field, as predicted by theory. Auto-calibrated SENSE (mSENSE) shows obvious artifacts, due to the difficulty estimating coil sensitivity at signal void areas in low-resolution calibration data set. Both auto-calibrated ARC and external-calibrated ARC (where a low resolution on resonance data set is simulated as the calibration data set) achieve high quality image reconstruction.

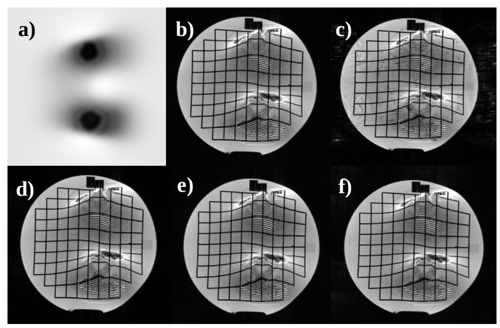

Figure 1: a) Off-resonance frequency map induced by a metal implant. Dark and light colors indicate high positive and negative frequency, respectively. b) Fully sampled image simulated with given field map. c) Auto-calibrated SENSE recon (mSENSE). d) SENSE recon using true sensitivity map. e) Auto-calibrated ARC recon. f) External-calibrated ARC recon.

Figure 2 shows phantom images of a metallic implant. The metal-induced artifacts are successfully reduced in the MAVRIC scan, in which 22 total subimages are collected at different frequency offsets. The utilized Gaussian RF pulses have 2.25 kHz bandwidth. Effective off-resonance frequencies are constrained within this band for each MAVRIC subimage. The readout bandwidth is 250 kHz. All parallel imaging is reconstructed at 2X PE-acceleration with 25 out of 90 lines used for calibration. For concatenated ARC calibration, low frequency data from 2.25 kHz resonance offset frequency is used in addition to data from zero resonance frequency offset. Compared to SENSE type reconstruction methods, ARC provides higher quality images with reduced RMSE errors. The image reconstructed using SENSE with single calibration has obvious image artifacts. This is because the sensitivity map estimated at zero resonance frequency offset is inaccurate in regions where the spins are out of the excitation bandwidth. Other frequency offset MAVRIC subimages can excite spins in this area and consequently suffer from the lack of sensitivity information, thus causing artifacts in the final image.

Figure 3 shows an in vivo imaging example at 2X acceleration. The MAVRIC acquisition parameters are the same as those for Fig. 2. Metal-induced artifacts are significantly reduced in MAVRIC images compared to the unaccelerated fast spin-echo image. ARC recon with three different calibration methods are conducted. All of these methods successfully removed aliasing artifacts. While auto-calibrated ARC (where calibration is performed separately for each subimage) has the lowest RMSE error, applying ARC with either single calibration or concatenated calibration significantly reduces reconstruction time compared to auto-calibrated ARC, with required total calibration computation times respectively reduced to only about 1/11 and 2/11 of the auto-calibrated ARC recon.

Conclusion: Our studies show that the impact on coil sensitivity from metallic implants is mild when a high readout bandwidth is used for data acquisition. However, the signal distortion and voids caused by metallic implants can cause problems in SENSE due to the difficulties in sensitivity estimation. Data-driven parallel imaging methods are preferred for imaging near metal implants. We have demonstrated that ARC with various calibration methods can be combined with MAVRIC to achieve high quality image reconstructions with significantly reduced scan time.

References: 1. Koch et al, ISMRM 2008, p1250. 2. Koch et al, MRM, in press, 3. Lu et al, ISMRM 2008, p838. 4. Griswold et al, MRM 2002, p1202 5 Beatty et al, ISMRM 2007, p1749 6. Brau et al, MRM 2008, p382 7. Beatty PhD Thesis, Stanford University, 2007 8. Brau et al, ISMRM 2008 p1700 9. Roemer et al, MRM 1990 p192 10. Prussmann KP et al, MRM 1999 p952. 11. Koch, ISMRM 2008, p 1180.

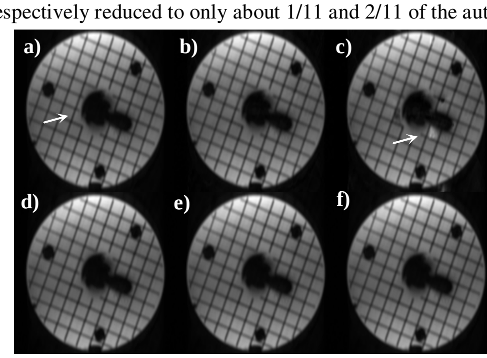

Figure 2: a) Fully sampled MAVRIC image. The arrow indicates the location of metal implants. b) Auto-calibrated SENSE (RMSE = 1037). c) SENSE with single calibration (RMSE = 3364). The arrow indicates image artifacts. d) Auto-calibrated ARC (RMSE=372). e) ARC recon using single calibration (RMSE = 383). f) ARC recon using two concatenated calibration data sets (RMSE = 364).

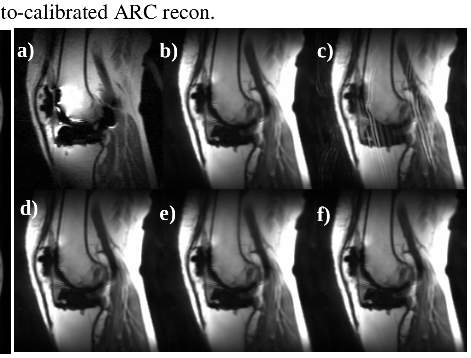

Figure 3: a) Fast spin-echo image. b) Fully sampled MAVRIC image c)Under-sampled MAVRIC image d) Auto-calibrated ARC recon (RMSE = 504593). e) ARC recon using single calibration with zero resonance frequency offset data as calibration data (RMSE = 2687053). f) ARC recon using single calibration with two concatenated data as calibration data (RMSE = 1872306)