Extracting Phase Contrast from MAVRIC Images Near Metal Implants

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Introduction: Multi-Spectral Imaging (MSI) techniques allow for minimal artifact MR imaging in the near vicinity of metal hardware (1-3). MRI in the presence of metal hardware has developed increasing importance with the recent increase of metal-on-metal hip replacement failure modes that are not detectable via other imaging techniques. The complications from such implants have been attributed to both high rates of wear (4) and hypersensitivity reactions without high wear rates (5). The ability to differentiate between and within these classes of local tissue response using MR means would be highly advantageous. Unfortunately, conventional magnitude contrast techniques cannot easily differentiate between such soft tissue variations.

Since some of the variation between these tissue constructions involves the presence of high magnetic susceptibility particulate matter, a potential differentiating contrast may be gained from phase analysis of MR images in these regions. However, the substantial B_0 perturbations induced by metal render conventional phase-contrast mechanisms useless. Here, we demonstrate a form of phase-contrast imaging feasible with the MAVRIC (1) and MAVRIC SL (3) MSI imaging techniques. In this demonstration, complex phase is extracted from a novel processing modification of MAVRIC MSI data. It is then shown that the substantial B_0 perturbations from the metal, which contaminate the raw phase image, can be removed to expose finer scale phase variations within the image. Such a phase-contrast mechanism is an important first step in identifying potential MR phase-based differentiators of local tissue reactions near joint replacements.

Figure 1: Frequency and temporal MAVRIC bin images.

Methods: MAVRIC MSI techniques acquire multiple 3D-encoded spectrally overlapped bins or images. In the presented analysis, 22 spectral bins are acquired using Gaussian RF pulses with a FWHM of 2.25kHz and a bin separation of 1kHz. The left half of Figure 1 presents a series of such spectral images collected near bilateral total hip replacements at 1.5T. In the displayed slice, signal closer to the metal is imaged in the further off-resonance spectral bins.

Here, we seek to transform the conventional MAVRIC spectral data into composite image-space data that can be analyzed in the complex plane. A Fourier Transformation in the spectral domain at each pixel in the imaging volume is used to accomplish this task: $I^f(x,y,z,f)$ ->FT-> $I^t(x,y,z,t)$

The right half of Figure 1 presents a selection of transformed temporal images, $I^t(x,y,z,t)$. It is clear that each of the temporal images contains all of the signal around the implants. In effect, the Fourier transform is summing the frequency spectral bins and phasing them relative to one another. There are other effects in the transformation, as it is clear that the magnitude contrast of the temporal bins changes from one bin to the next. An exact interpretation of the MAVRIC temporal domain images remains under investigation. However, for the present discussion we will now simply examine the complex phase of the temporal bin images.

The top row of Figure 2 presents a single temporal bin image compared to the composite sum of squares image in the spectral domain. It is clear that the temporal bin has less SNR than the composite image, which is expected since the overlapping bin strategy provides a signal averaging effect to the composite spectral image. The top row of Figure 2 also presents an intensity-based field map calculated from spectral correlation of MAVRIC data (3). Such field maps have limited spectral resolution and can only be used to assess smooth variations of B_0, such as those induced by metal implants. The bottom row then shows the phase of the t=-1ms temporal image. It is clear that the phase of the image is directly proportional to the local B_0 distribution, but also exhibits tissue-specific contrast. The middle image in the bottom row is the same phase image in which the magnitude based-spectral correlation field map has been used to subtract the macroscopic phase trends. Only the high-frequency phase variations remain. Finally, the right image in the bottom row presents a crude combination of the magnitude sum of squares image and the processed temporal bin phase image.

Figure 2: Top row: Composite frequency domain, single temporal bin, and spectral correlation field map images. Bottom row: phase of single temporal bin, processed phase after removing implant-induced B0-trend, and fusion of processed phase and composite frequency domain images (phase + 30% of magnitude SOS)

Discussion: We have shown a proof of principle in which phase contrast can extracted from conventional MAVRIC acquisitions. By transforming to from the natively acquired spectral domain to a virtual temporal domain, complex phased images of signal encompassing the region near the implant can be constructed. Magnitude-based spectral correlation field maps can be used to remove the substantial implant-induced phase trends from phase differences in these images to reveal underlying phase contrast in surrounding tissues. Further work will now explore whether such phase images can be used to differentiate types of local tissue responses near metal implants. In particular, phase-sensitivities to local particulate metal particle composition will be explored.

References: [1] Koch et al, MRM 61:381-90 2009 [2] Lu et al, MRM 62:66-76, 2009 [3] Koch et al, MRM 65:71-82 2011
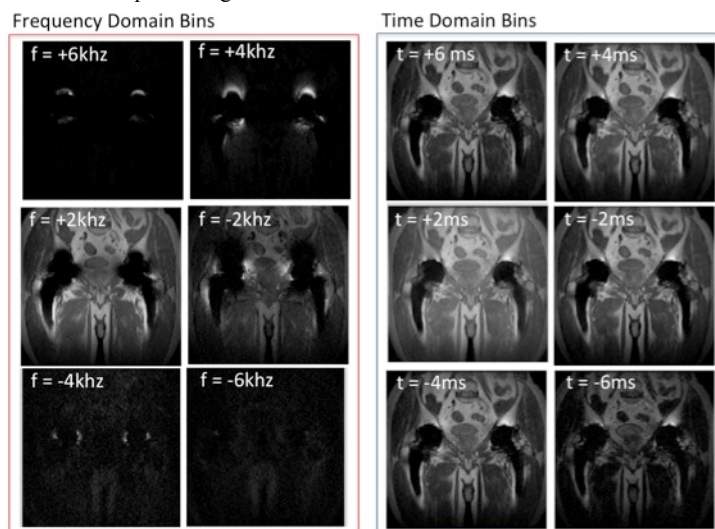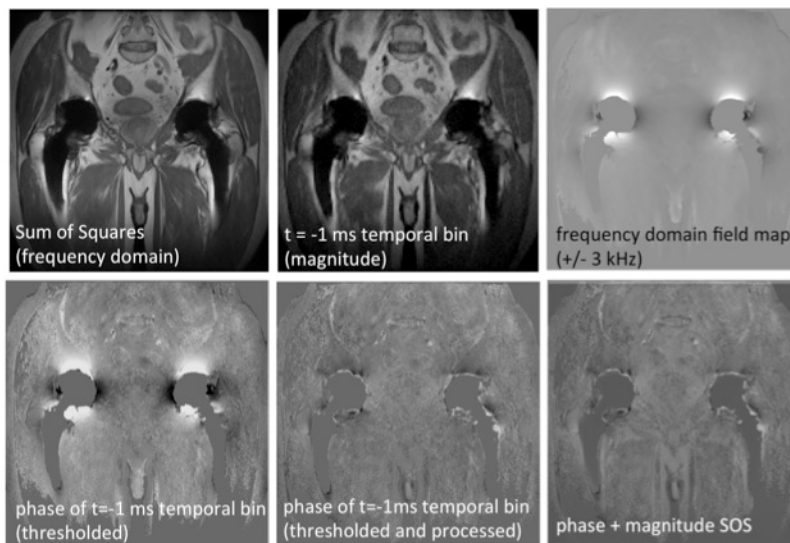[4] Amstutz et al, Orthop Clin. North Am, 42, 207-230, 2011 [5] Langton et al, J. Bone Joint Surg Br, 92, 164-171, 2011