Jacobian-Based Correction of 3D-MSI Images Near Implanted Metal Devices

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Introduction:

3D Multi-Spectral Imaging (3D-MSI) techniques can significantly reduce susceptibility artifacts near metallic orthopedic components [1,2,3]. Various encoding and spectral encoding strategies can be implemented using 3D-MSI methodologies, which are exemplified by the MAVRIC [1], SEMAC [2], and VS-MSI [3] approaches.

The spectral encoding strategy originally demonstrated with the MAVRIC technique can generate robust B_0 field maps spanning many kHz of off-resonance frequencies [1,4]. These maps are utilized to perform a simple pixel shifting operation that globally deblurs MAVRIC composite images [3]. Here we further explore the utility of these field maps in correcting images in the direct vicinity of metal interfaces. Substantial correction of residual intensity errors ("pileup" artifacts), and greater definition of metal interfaces are demonstrated through field map-based correction of 3D-MSI images. Since the field maps are constructed using data inherent to the clinical acquisition, the presented methods can directly be applied as a self-correction of any clinical image acquired with an appropriate spectral encoding strategy.

Methods:

3D MSI requires the collection and independent reconstruction of multiple spectral images, $I_n(x,y,z)$, acquired at regularly offset demodulation frequencies, ω_n. Ideally, 3D MSI sub-images possess spectral characteristics such that $\Sigma_n F(\omega_n)I_n(x,y,z) \sim 1$, where $F(\omega)$ is the spectral response to the applied RF pulses. This ensures a smooth combination of spectral images to form a single composite image. As originally proposed in [1], an approach that satisfies these criteria utilizes overlapping Gaussian spectral profiles. Using such an overlap strategy also enables rapid construction of off-resonance field maps. Field map estimates can be calculated by the expression $\Delta\omega_0(x,y,z) = \Sigma_n \omega_n I_n(x,y,z)$, where $I_n(x,y,z)$ is normalized such that $\Sigma_n I_n(x,y,z) = 1$. This field map estimate is simply weighting the contribution of each demodulated spectral bin to the composition of each imaging voxel. Here we show that these field maps have sufficient accuracy to correct for the localized artifacts that remain in the spectral sub-images – which ultimately carry through to the composite image.

Given a field map acquired using these principles, residual pixel displacements can be corrected in each sub-image according to $I_n(x,y,z) \rightarrow I_n(x+2\pi(\Delta\omega_0(x,y,z)-\omega_n)/BW_p, y, z)$, where x is defined as the frequency encoded dimension. In regions distant from metal interfaces, this simple correction has been applied to eliminate blurring caused by combining adjacent spectral bins -- which are overlap and displace identical spins in opposite directions [3]. Near metal, this correction breaks down due to the pileup artifacts that are commonly encountered and may obscure relevant anatomy. Further corrective measures can be enabled by considering local variations of the field map in the frequency-encoded dimension. Calculating a local finite difference gradient in on the field map, G_L, allows an additional Jacobian correction of image intensity [5]. To apply this correction, pixels are shifted in all regions of the image; however, the shifted pixels are also corrected for intensity according to $I_n \rightarrow (1+G_L)I_n$.

Discussion:

The results below (Fig. 1) show how the addition of a Jacobian correction term can substantially improve residual pileup artifacts in 3D MSI images near metal, as well as improve representation of implant interfaces. Pileup artifacts in 3D-MSI images are manifested as rings or bands, which correlate with regions where the local field gradients are highest. The first row presents images of a technically challenging knee arthroplasty composed of cobalt-chromium alloys at 1.5T. The second row shows images of a shoulder arthroplasty also composed of cobalt-chromium alloys. In both cases, the repaired images show a significant reduction of pileup artifacts and improved representation of the implant interfaces. It is impossible to entirely remove residual artifacts. However, the presented methodology is able to improve image quality through use of a computationally inexpensive and straightforward correction mechanism.

[1] Koch et al,MRM,61,2009,381-390, [2] Lu et al,MRM,62,2009,66-76 , [3] Koch et al, MRM, EarlyView, DOI: 10.1002/mrm.22523
[4] Koch et al, Proc ISMRM 2008, #1180, [5] Chang and Fitzpatrick, IEEE TMI, 11, 1992, 319-329.

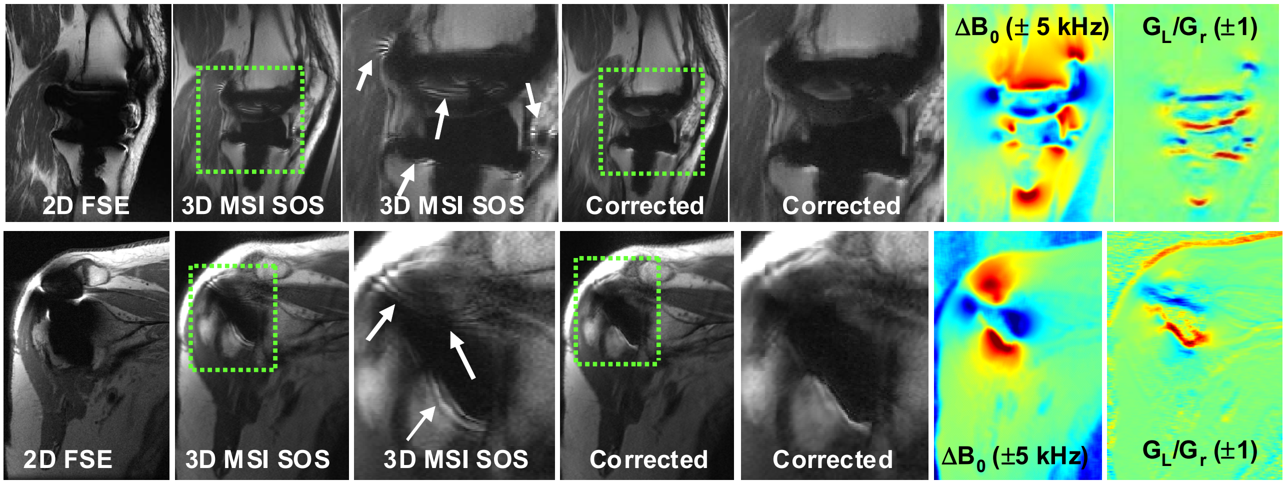

Figure 1. Top – A cobalt-chrome total knee arthroplasty at 1.5T. Pileup artifacts in 3D MSI images are presented as intensity rings in the composite image. Arrows indicate residual artifacts corrected via Jacobian term. The ΔB_o field map is shown and the local gradient maps are presented as a ratio of the applied readout gradient. Bottom – A cobalt-chrome total shoulder arthroplasty at 1.5T. The corrected image reduces pileup artifacts and also improves the definition of shoulder implant interface.