Reduced FOV Imaging Near Metal Using 2D Multispectral Imaging and Very Selective Outer Volume Suppression

Valentina Taviani[1], Daniel Litwiller[2], Kevin M. Koch[3], and Brian A. Hargreaves[1]

[1]*Radiology, Stanford University, Stanford, CA, United States,* [2]*GE Healthcare, Rochester, MN, United States,* [3]*Biophysics and Radiology, Medical College of Wisconsin, Milwaukee, WI, United States*

Target audience: Clinicians and researchers interested in imaging near metallic implants.

Purpose: Multispectral imaging (MSI) methods such as SEMAC [1], MAVRIC [2] and variants [3] reduce off-resonance artifacts near metal by dividing the image content either spectrally or spatially, and by forming 3D images that can be combined to dramatically reduce artifacts. The 8-16x larger encoding requirements result in longer scan times or the need to reduce resolution. Inner-volume approaches have been explored for MAVRIC and SEMAC, though knowledge of the off-resonance range is needed and some loss occurs due to excited regions [4]. Outer-volume suppression (OVS), otherwise useful in conventional sequences, is difficult to combine with selective MSI methods because OVS bands would themselves have substantial spatially nonlinear displacement depending on the implant-induced off-resonance distribution. Recently, 2D MSI was proposed, whereby finite 2D spectral and spatial "bins" are excited and combined to allow fast imaging of a small slice range [5]. In this work, we demonstrate that OVS pulses can be used effectively at minimal cost to reduce encoding requirements.

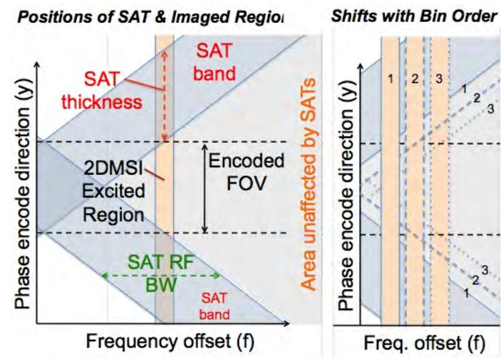

Figure 1: Bins of finite slice and spectral width are excited as shown in frequency-y space (left). Saturation bands are excited to limit FOV in y but with opposite gradients so as not to saturate the next bins, which may be excited with a simple frequency shift (right).

Methods: *Theory:* Spatial selectivity occurs within volumes resonating at the same frequency, i.e. $y_{SAT} = y + \Delta B_0(x,y,z)/G_{ySAT} = const$, where $\Delta B_0(x,y,z)$ represents off-resonance and G_{ySAT} is the amplitude of the saturation gradient. Because phase encoding occurs along planes of constant y, in order to avoid fold-over artifacts, the maximum distance between the edge of the OVS band and the nominal plane of phase encoding, $y_{SAT} - y$, should be minimized, i.e. G_{ySAT} should be as large as possible, or equivalently, high bandwidth RF pulses should be used. Here we use a nominal bandwidth of 6kHz, which gives a gradient of 0.3kHz/cm for a 20cm saturation thickness. In close proximity to metal, off-resonance can be on the order of tens of kHz, which would produce significant misalignment between y and y_{SAT}. However ΔB_0 falls off rapidly moving away from metal, and 2DMSI excites a limited bandwidth, so that the saturation region for a given excited bin is predictable. Additionally, OVS is only necessary over a narrow range of near-on-resonance bin frequencies.

Pulse sequence: OVS was performed using a train of 3 quadratic phase RF pulses for each saturation band, with flip angles optimized to reduce sensitivity to B1 and T1 [6]. Spoilers were alternatively played on all 3 axes to prevent stimulated echoes and other coherencies originating from the saturation train from contributing signal during imaging. OVS was performed on-resonance and for the 2 adjacent frequencies (±900Hz). In our implementation of 2D MSI, progressively increasing odd frequencies, followed by progressively increasing even frequencies are acquired. Saturation gradients of opposite polarities and a slightly different interleaving strategy, whereby on resonance was acquired last, were used to reduce saturation effects on subsequent frequency bins (Fig. 1). The position of the saturation bands was shifted along frequency to follow the current bin frequency. The increased energy deposition associated with OVS was offset by using variable flip angles along the 2D MSI refocusing train [7,8].

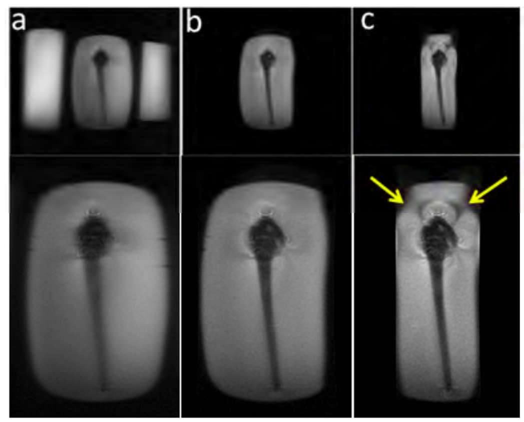

Figure 2: Full FOV 2D MSI (a) and reduced FOV 2D MSI with 35% (b) and 22% (c) FOV reduction [top row: pFOV = 1; bottom row: pFOV = 1 (a), 0.35 (b) and 0.22 (c)]. Note some distortion of the saturation band edge and signal loss when the saturation band is positioned ~2cm from metal, but sharper detail in (b,c) due to the shorter echo train length.

Results and Discussion: Fig. 2 demonstrates how reduced-FOV (r-FOV) imaging with OVS can be used in proximity to metal to reduce the encoding requirement and associated blurring while maintaining good artifact suppression capabilities. Note distortion of the edges of the OVS band and suppression of some frequencies close to the head of the implant (due to saturation of the tail of the 2D MSI f-z inner volume) when a very aggressive FOV reduction factor is used (22%) (Fig. 2c). Fig. 3 shows the effect of different combinations of gradient polarities and the effectiveness of the solution in Fig. 2 to avoid unintentional saturation of off-resonance near metal. Suppression of subcutaneous fat using 2D MSI with OVS in a subject with spinal hardware (Fig. 4a) gave improved overall contrast with artifact correction performance similar to the full FOV acquisition (Fig. 4b), at the expense of slightly reduced SNR. Fig 4c shows how OVS can potentially extend the use of 2D MSI to anatomical regions that would otherwise require full 3D encoding: here OVS allowed fast interactive planning during FUS (Focused Ultrasound Surgery) in a subject with total hip arthroplasty (~10s per slice; body coil).

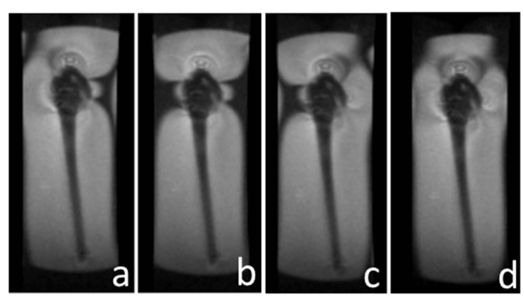

Figure 3: Four different combinations of gradient polarities. Opposite polarities with saturation bands crossing on the opposite side with respect to the 2D MSI spectral direction of progression (cfr. Fig. 2) minimize unintentional saturation (d)

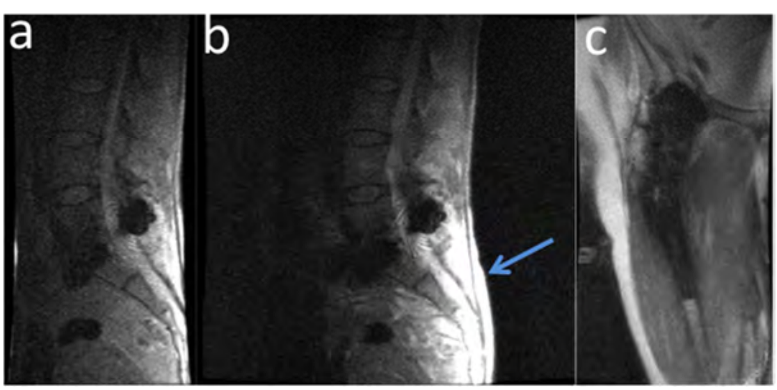

Figure 4: Clinical applications: reduced FOV (a) and full FOV (b) 2D MSI in a subject with spinal hardware and (c) 2D MSI with OVS acquired during HIFU in a patient with total hip arthroplasty.

Conclusion: OVS with high-bandwidth quadratic phase RF pulses can be used for r-FOV imaging near metal resulting in improved image quality while retaining similar artifact correction capabilities. Higher bandwidth pulses (up to 20kHz [6]) have been previously reported and could further improve the performance of this technique by avoiding direct saturation of the tails of the 2D MSI inner volume. 2D OVS could also be used for r-FOV imaging with MAVRIC for shorter acquisitions or higher resolution.

References: [1] Lu W. et al, MRM 2009; 62:66; [2] Koch K.M. et al, MRM 2009; 61:381; [3] Koch et al, MRM 2011; 65:71; [4] den Harder et al. MRM In Press (DOI: 10.1002/mrm.25126); [5] Hargreaves B.A. et al. ISMRM 2014; [6] Le Roux P. et al. JMRI 1998; 8:1022; p. 2775; [7] Busse R.F. et al. MRM 2006; 55:1030; [8] Saranathan M. et al. ISMRM 2014.