Local Gradient Effects on Spectral Binning of 3D Multi-Spectral Images Near Metal Implants

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Introduction: 3D Multi-Spectral Imaging (MSI) utilizes multiple off-resonance excitations with z-phase encoding to reduce susceptibility artifacts found near metal implants [1-3]. MSI techniques limit frequency-encoding processes to reduced-bandwidth "spectral bins" which, when added together, form smooth composite images across wide spectral dispersions induced by metal implants. Each of these spectral-bin images has limited bulk readout distortion, typically a maximum of 1-2 pixels. However, it has previously been shown that regions encompassing large induced field gradients in the frequency-encoding direction can introduce additional intensity artifacts [4]. Here, we extend this work to show the impact of these strong gradient regions on spectral-binning strategies in MSI, which can contribute additional artifacts to composite MSI images. Understanding the nature of these artifacts is important to a) minimize the artifacts in composite MSI images and b) explain these unique MSI-specific residual artifacts to the clinical community.

Theory: MSI acquisitions excite and independently encode a selection of spectral bins. Typically, these bins are roughly 2kHz in bandwidth and are acquired in multitude to cover roughly 25kHz of spectral dispersion. There are two primarily demonstrated means of arranging spectral bins. The original SEMAC technique [2] uses approximately rectangular excitation profiles with minimal overlap of adjacent bins. The original MAVRIC technique uses heavily overlapping Gaussian profiles [1]. In addition, the combined MAVRIC-SEMAC approaches of VS-MSI [3], and MS-VAT SPACE [4] both apply the overlapping Gaussian approach introduced by the original MAVRIC technique. In this approach, because each spin is imaged by multiple overlapping bins, an analysis of the bin dimension of the 4-D magnitude MSI dataset (x,y,z,frequency) is feasible, though the theoretical analysis could also be applied to approaches with non-overlapping bins.

Methods: A 1-D MSI simulation was performed using 2.25kHz excitation and refocusing pulses separated by 1 kHz. 256 frequency-encoded points were simulated in the presence of a sphere of susceptibility 900ppm at 1.5T. The magnetic induction from the sphere was calculated analytically. 8 isochromats per pixel were used in the Bloch simulation of 25 spectral bins to allow for dephasing and partial pixel effects to be represented.

In Vivo MAVRIC MSI images were acquired in a subject with a total knee replacement at 1.5T using the same Gaussian spectral windowing strategy. As previously described [3], magnetic field maps using the overlapping Gaussian spectral data were constructed to aid in the analysis of bin dynamics.

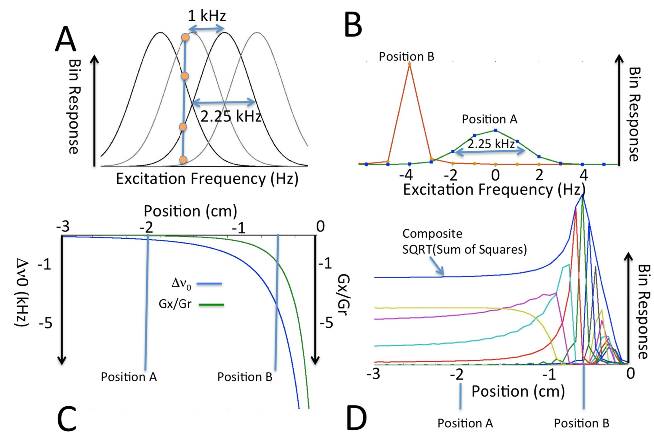

Figure 1: A) Gaussian overlapped MSI spectral windowing strategy. B) Spectral bin profiles at two points in the simulation, as indicated in C) and D). C) Frequency offset and induced gradient (relative to the encoding gradient). D) Individual bins and composite simulated image.

Results: Figure 1 presents simulation results showing altered bin behavior in high gradient regions. At the point analyzed away from the metal interface where the local gradient is negligible (Position A), the bin profile shown in B) follows the expected behavior (2.25kHz width), whereas nearer the metal (Position B) the profile is substantially narrowed from the intended shape. This effect is in addition to the previously presented gradient-induced artifacts: a) local intensity increases as the local gradient (Gx) becomes equal and opposite to the encoding gradient (Gr) and b) bin signal reduction as the local gradient amplitude becomes greater in magnitude than the encoding gradient.

Figure 2 demonstrates the bin compression effect, *in vivo*. A) presents a MSI image of a total knee replacement at 1.5T. B) and C) show field and gradient maps, derived from the MSI spectral data [3]. D) shows a 2D-FSE image indicating the artifact reduction with MSI, whereas E) presents a zoomed image of the region indicated in A) and shows residual MSI combination artifacts (arrows). F) presents bin profiles at the positions indicated in A) and E). Repeating the observations in the simulation, the region away from the implant follows the expected behavior (2.25kHz width), whereas nearer the metal (Position B) the profile is substantially narrowed from the intended shape.

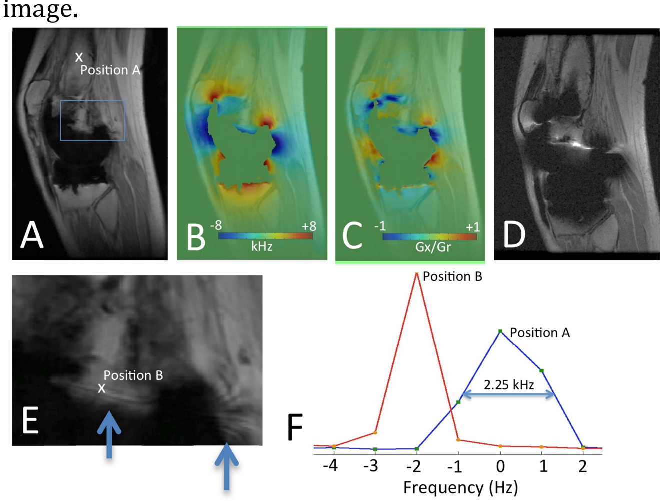

Figure 2: A) MSI image. B) MSI-based field map. C) Gradient map calculated from field map. D) Reference 2D-FSE image, E) Indicated zoomed region on A) showing bin compression artifact. F) Bin profiles at positions indicated in A) and E).

Discussion: The presented analysis explains the often-encountered "spider-web" residual artifacts found near gradient hot-spots in MSI images near metal. As seen in Figure 2E), under some conditions these artifacts do not show substantially increased "pileup signal". Instead, the observed artifact is a more nuanced effect resulting from spectral "bin compression" from the intended profile. In order to form a smooth composite image, the relationship between spectral bins must be constant (i.e. width of the bin and separation between bins) – this is the case for any MSI technique. Bin compression disrupts this relationship and generates bin combination artifacts. Identifying the cause of this residual artifact in MSI images may aid in developing means to reduce or eliminate these residual artifacts.

REFERENCES: [1] Koch, MRM 61:381-90 2009 [2] Lu, MRM 62:66-76, 2009 [3] Koch, MRM 65:71-82 2011 [4] Koch, Proc ISMRM 2011, 293