In-Vivo Fully Phase-Encoded Magnetic Resonance Imaging in the Presence of Metal using Multiband RF Excitation

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Target Audience: Researchers interested in MR methods for imaging near metallic implants.

Purpose: Imaging near metallic prostheses is challenging because some metals, such as cobalt/chromium/molybdenum (Co/Cr/Mo) alloys or stainless steel, induce a broad spectrum of off-resonance due to severe B_0 inhomogeneity. 3D multispectral imaging (MSI) techniques have addressed this issue by acquiring multiple 3D fast spin-echo (FSE) acquisitions at different radio-frequency (RF) offsets and summing over all RF bins.[1,2] In-plane distortion, however, remains a problem for frequency-encoding 3D-MSI methods in areas near the metal. These areas often exhibit extreme local B_0 gradients that violate the spatial encoding assumptions of frequency-encoding, manifesting as signal loss and signal pile-up.[3] For common knee and hip prostheses made of Co/Cr/Mo alloys, distortions can be present as far as 5-10mm (1.5T) and 10-15mm (3T) from the implant surface.[4]

To avoid these artifacts, a spectrally-resolved, fully phase-encoded (SR-FPE) 3D FSE technique was recently developed.[5] Scan time is the main limitation of FPE methods, typically taking hours for adequate spatial resolution and volumetric coverage, limiting their use to phantoms and ex-vivo applications. Parallel imaging in all three spatial dimensions can reduce a 4 hour SR-FPE scan to 7.5 min for a single RF bin.[5] However, multiple RF excitation bins are required for most metallic implants due to the wide off-resonance. As shown previously in phantoms, multiband RF excitation offers a new opportunity to collect multiple RF bins simultaneously to accelerate FPE methods.[6] The ***purpose of this work was to translate SR-FPE to the in-vivo setting and use multiband RF excitation to accelerate imaging*** near hip and knee prostheses where multiple RF bins are required.

Methods: This HIPAA-compliant study was approved by our institutional review board. Multiband SR-FPE was used to image the left knee of two volunteers at 3T using a 16-channel wrap array (NeoCoil, Pewaukee, WI). For each volunteer, tri-band RF pulses (2.25kHz BW per Gaussian band) were used to simultaneously excite three RF bins. To reduce peak B_1, phase offsets between the three bands (0, 0.730, 4.602 radians) were incorporated in the time domain prior to the complex multiband sum[7]. In all cases, 3D *k*-space corner cutting (R=2) and parallel imaging in 3D (R_xxR_yxR_z=3x2x2) was utilized, and GRAPPA[8] was used for image reconstruction (ACR 18x18x18, kernel size 7x5x5). Spectral modeling[5] was performed to combine the SR-FPE temporal data into an image and B_0 field inhomogeneity map.

Volunteer with Total Knee Replacement: The first volunteer had an implanted metallic knee prosthesis. Using a tri-band RF pulse with 6 kHz separation between each band, SR-FPE was performed at two center frequency offsets (-8, +8 kHz) interleaved within each TR. If a single-band RF pulse was used, only 2 frequency offsets at -8 and +8 kHz could be encoded, but the tri-band RF pulse acquired 6 frequency offsets at -14, -8, -2 , 2, 8, 14 kHz with no scan time penalty. Imaging parameters were: sagittal, FOV = 22.5x15x15cm^3, matrix = 150x100x38, TR = 600ms, ETL = 24, ADC samples = 34, receiver BW = ±8.62kHz, TE_{eff} = 77ms, max/min refocusing flip = 56°/10°, scan time = 13:19min. Only two interleaves were performed with this patient to limit scan time.

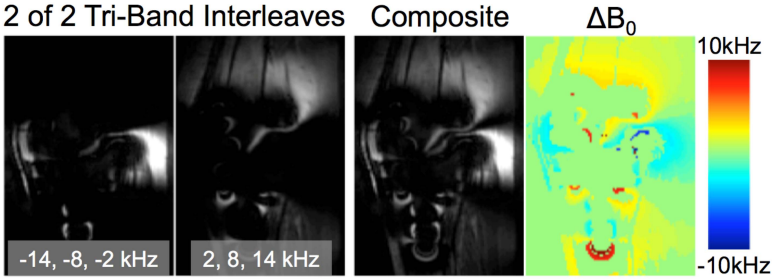

Figure 1 *In-vivo, multiband SR-FPE images are displayed for a single slice of the knee in a volunteer with a total knee replacement (scan time: 13:19min). The image derived from spectral modeling for two tri-band interleaves shows signal at distinct off-resonance frequencies. Combination of the interleaves is shown as a composite image. A measured B_0 inhomogeneity map reveals the off-resonance frequency at all signal locations.*

Volunteer with Head of Hip Prosthesis Placed Posterior to Knee: For the second volunteer, who had no implanted metal, the femoral head component of a hip prosthesis made of Co/Cr/Mo was placed posterior to the knee. In this example, a tri-band RF pulse (4kHz band separation) was used at eight center frequency offsets, such that contiguous 1kHz frequencies from -12kHz to +11kHz were acquired. Parameters only differed for the following: FOV = 22.5x13x13cm^3, matrix = 150x86x32, TR = 534ms, ADC samples = 26, receiver BW = ± 6.58kHz, scan time = 34:38min.

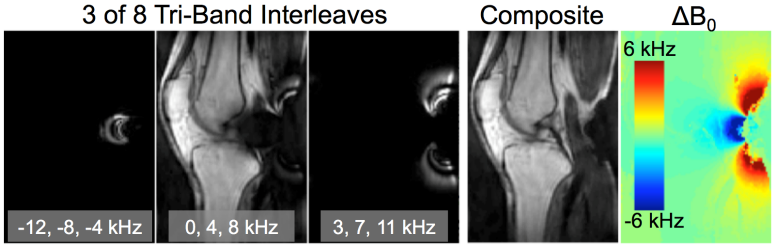

Figure 2 *Twenty-four thousand Hz spectral coverage was acquired in-vivo with multiband SR-FPE in a scan time of 34:38min. The head of a hip prosthesis posterior to the knee created a dipole effect, that allows easy visualization of all three bands within the image for each tri-band interleave (3 of 8 shown). Summing all eight interleaves yielded a smooth composite image. A dipole is easily seen in the measured B_0 map as well.*

Results and Discussion: Multiband images of a volunteer with a total knee replacement demonstrated good image quality, depicting signal at multiple off-resonance frequencies, as shown for a single slice through the total knee replacement (**Fig 1**). **Figure 2** displays three of eight multiband interleaves, each showing all three bands of the tri-band RF pulse from the dipole induced by the hip prosthesis head. Combining (root sum-of-squares) all eight interleaves formed a smooth composite representing +/-12kHz of spectral coverage. The tri-band RF pulse provided a scan time reduction factor R=3. Total scan time reduction, including 3D corner cutting (R=2) and parallel imaging (R=12), was 72.

Conclusion: This work demonstrates the feasibility of multiband SR-FPE in-vivo near metallic implants that cause severe B_0 inhomogeneity, such as hip and knee prostheses.

References: [1] Lu et al. MRM 2009;62:66-76. [2] Koch et al. MRM 2009;61:381-90. [3] Koch et al. MRM 2014;71:2024-34. [4] Smith et al. MRM 2014; [In Press]. [5] Artz et al. MRM 2014;71:681-90. [6] Artz et al. ISMRM 2014; #650. [7] Wong et al. ISMRM 2012; #2209. [8] Griswold et al. MRM 2002;47:1202-10.

Acknowledgments: We are grateful to Dr. Richard Kijowski for helpful discussions, as well as the NIH (UL1TR000427) and GE Healthcare for research support.