A hybrid multi-spectral approach for near metal imaging: combining the best of phase and frequency encoding

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Purpose: Orthopedic and spinal MRI images [1-4] suffer from geometrical distortions and incomplete signal excitation in the presence of metal implants, due to large field inhomogeneities. Innovative imaging strategies such as MAVRIC [3] and SEMAC [4] have significantly improved near metal imaging in recent years. To reduce the geometric distortions, MAVRIC combines multiple images acquired at different frequency offsets into a single image and SEMAC corrects the slice distortion by applying additional phase encoding steps in the slice encoding direction in combination with view-angle-tilting. These methods work well to limit geometric distortions, but signal directly adjacent to metal alloys remains geometrically distorted to a certain extent. To image directly near the metal objects it should in theory be possible to use purely phase encoded sequences [5], which result in geometrically undistorted images. The acquisition time of purely phase encoding, however, is inherently long as each point in k-space requires a separate repetition and it would be preferable to only image the tissue-metal interface with phase encoded sequences. This can be largely achieved for off-resonance excitations, because the off-resonance spins are spatially confined in proximity of the metal disturber, which prevents aliasing when using a small field of view. In this work we investigate the feasibility of a new hybrid approach that uses phase encoding to acquire off-resonance signal near metal and frequency encoding to acquire the on-resonance image. The feasibility of the proposed method is investigated by comparing hybrid and MAVRIC-type images of two phantoms containing hip implants.

Methods:

Phantom setup: Two phantoms were constructed using a rectangular container filled with 2% agarose gel and 30.5 mg/L $MnCl_2$ including either (A) a partial hip implant, containing a titanium (Ti) femoral stem or (B) a full hip implant, containing a Ti femoral stem and a cobalt chromium (CoCr) head.

Imaging settings: Images of both phantoms were acquired on a 1.5T MR system (Philips Achieva) with an 8 channel head coil. The imaging parameters are summarized in table 1.

Table 1: Imaging parameters

Fig	Object	Seq	Voxel (mm)	Acq matrix	BWrf (kHz)	RF offsets (kHz)	Flip angle (^{0})	Time (min)
1	A, Ti stem	SE	2x1.5x5	128x128x16	1.5	-2.25:0.75:3.0	90 - 120	3.5*
1	A, Ti stem	SE-SI	2x1.5x5	32x52x8	2.5	-2.25, 2.25	90 - 120	20#
2	B, CoCr head	SE	3.2x2.4x5	64x64x16	1.5	-5.25:0.75:8.25	90 - 120	3.5
2	B, CoCr head	SE-SI	3.2x2.4x5	40x50x16	5.0	-3.25, 3.25, 6.5	60 - 60	50#

*NSA=2, # inc spherical shutter

TE/TR = 20/200 ms, 3D-SE BW_{read} = 1011 Hz/pix and for 3D-SE-SI BW_{spect} = 8 kHz

Imaging sequence: 3D frequency encoded spin-echo (SE) and purely phase encoded SE imaging sequences were adapted to enable non-selective excitation and refocusing pulses to omit slice distortions. Phase encoded imaging was enabled using a 3D spin echo spectroscopic imaging (SE-SI) sequence and standard excitation and refocusing pulses were replaced by sinc-gauss excitation and block refocusing pulses for all image acquisitions. To obtain multi-spectral 3D-SE images (MAVRIC) the RF offset was varied in steps of 0.75 kHz in multiple imaging experiments until the majority of off-resonance spins were obtained. This required 9 measurements with a total imaging time of 31.5 min for phantom A, and 19 measurements with a total imaging time of 1 h 6.5 min for phantom B, with total frequency ranges of -3.0 to 3.75 kHz and -6.0 to 9.0 kHz, respectively. No reduced field of view measurements were used for the 3D-SE acquisitions, which could decrease the total acquisition time. MAVRIC images were obtained by summation of the magnitude signal of the separate frequency bins (fig 1h and 2g). Hybrid images were obtained by summation of the off-resonance phase encoded images with a reduced field of view and on-resonance frequency encoded images of the total object. For phantom A, two phase and three frequency encoded images were acquired in a total imaging time of 50.5 min and summed to obtain a total frequency range of -3.75 to 3.75 kHz. For phantom B, three phase and a single frequency encoded image were acquired in a total imaging time of 2 h 30.5 min and summed for a total frequency range of -5.75 to 9 kHz. A threshold was applied on the phase encoded images before summation to prevent the addition of noise. The in-plane dimensions were zero-filled a factor 2 for all images before reconstruction.

Results: The reconstructed hybrid images (fig 1g, 2f), obtained by combining the separate phase and frequency encoded images at different RF offsets (fig 1b-f, 2b-e) were able to depict signal close the implants (fig 1a, 2a) and were less affected by geometric distortions near the implants compared to the MAVRIC images as indicated by arrows. The hybrid approach was able to decrease the acquisition time a factor 9 for the titanium implant and a factor 1.6 for the Co-Cr hip implant as compared to a purely phase encoded multi-spectral imaging approach. Note however that frequency ranges of -3.75 to 3.75 kHz and -5.75 to 9 kHz were excited for phantom A and B, respectively. The RF bandwidth could be increased to 5 kHz for phantom B to limit the required number of phase encoded off-resonance acquisitions, while this would lead to increased distortions and degrade the image quality in frequency encoded images. The hybrid image was reconstructed using only 4 images in total, while spanning the same frequency range as the MAVRIC image that was reconstructed using 19 images. Note however that the signal intensity is less uniform for the hybrid images.

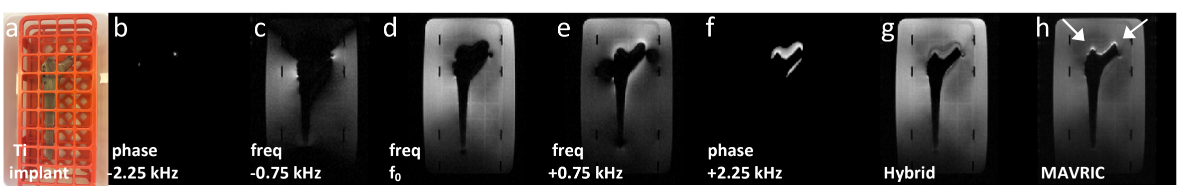

Fig 1: Images of a titanium implant (a), separate phase (b,f) and frequency (c-e) encoded bins used for reconstruction of a hybrid phase-frequency encoded image (g) is compared to a multi-spectral 3D-SE image (h).

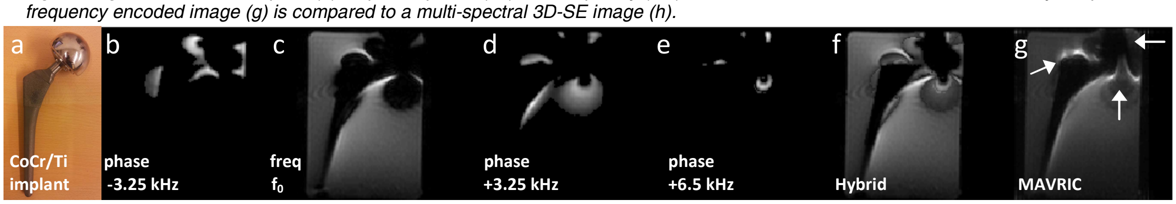

Fig 2: Images of a hip implant with a CoCr head and Ti stem) (a), separate phase (b,d,e) and frequency encoded images (c) are combined to reconstruct a hybrid phase-frequency encoded image (f) and compared to a multi-spectral 3D-SE image (g).

Conclusion & Discussion: In this work it was shown that it is feasible to improve the image quality near metal implants using a new hybrid multi-spectral approach that combines both frequency and phase encoded images. The presented method exploits the efficiency of frequency encoding and the superior geometric image quality of phase encoding near metal implants, thereby significantly reducing the acquisition time compared to a purely phase encoded multi-spectral approach. Further improvements in efficiency can be achieved by combining the presented approach with turbo imaging, undersampling strategies (i.e. parallel imaging, compressed sensing) and dual-band excitation pulses to achieve clinically acceptable imaging times.

References:

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