MR Imaging near orthopedic implants using Slice-Encoding for Metal Artifact Correction and Off-Resonance Suppression

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Introduction

Recently, Slice-Encoding for Metal Artifact Correction (SEMAC) was introduced as a technique to correct for susceptibility distortions caused by metal implants [1]. While View Angle Tilting (VAT) is used to compensate signal displacements in the frequency encoding direction [2], SEMAC additionally uses through-plane phase encoding to resolve slice distortion. The number of these phase encoding steps determines the z phase-encoding field of view (FOVz), which is directly proportional to the range of B_0 field offsets for which slice distortions can be corrected. Slice distortions that are outside FOVz will result in through-plane back-folding and potentially obscure image information that would otherwise be correct. For VAT, Off-Resonance Suppression (ORS) has been shown to limit signal selection to a confined range of B_0 field offsets and therefore a limited spatial area [3]. Here, combination of SEMAC and ORS is proposed to limit the range of through-plane displacements caused by B_0 field offsets, to allow reducing the number of required slice phase encodes and shortening imaging time.

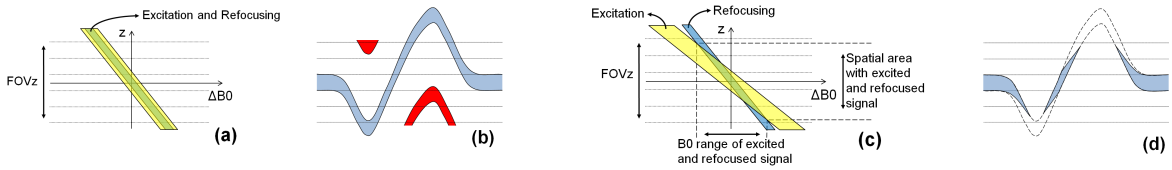

Figure 1: When excitation and refocusing gradients are equal, excited (yellow) and refocused (blue) regions completely overlap (green) (a). Depending on the ΔB_0 range of selected spins, the slice distortion may extend outside the phase encoded area FOVz, resulting in back folding (red) (b). ORS uses different gradient strengths for excitation and refocusing. Selected signal has a limited ΔB_0 range and originates from a confined spatial area (green), which can be chosen to match FOVz (c). In case of excessive slice distortion, ORS suppresses signal from distant spins with large ΔB0, and avoids back folding (d).

Theory

SEMAC without ORS: Slice selection excites and refocuses spins that match the selection condition $\gamma z G_{EX} + \gamma \Delta B_0(x,z) < BW_{SEL}/2$ (Fig.1a). Here z is the offset in slice direction, G_{EX} the excitation gradient which equals the refocusing gradient G_{REF}, $\Delta B_0(x,z)$ the local main field offset, and BW_{SEL} the minimum of excitation and refocusing bandwidth. Spins distant from the intended slice, but with B_0-offset may match the selection condition, leading to slice distortion (Fig.1b). In SEMAC through-plane phase encoding resolves slice distortion for a spatial area confined to:

$$|z| < \frac{N \cdot S_{PE}}{2} = FOVz/2 \quad (1)$$

where N is the number of through-plane phase encoding steps and S_{PE} the phase encoding slice thickness. If the slice distortion exceeds FOVz/2, signal from the most distant spins is back-folded in through-plane direction.

SEMAC with ORS: Intentionally choosing different values for G_{EX} and G_{REF} can be used to limit the field offsets that are excited and refocused and thus contribute to the signal (Fig.1c). Signal tapers off as $|\Delta B_0|$ becomes larger, until a cutoff is reached at

$$\Delta f_{0,\max} = \gamma \Delta B_{0,\max} = \frac{1}{2}\left(\frac{BW_{EX}}{G_{EX}}+\frac{BW_{REF}}{G_{REF}}\right)\left(\left|\frac{1}{G_{EX}}-\frac{1}{G_{REF}}\right|\right)^{-1} \quad (2)$$

with BW_{EX} and BW_{REF} the bandwidth of excitation and refocusing, respectively. It can be shown that the distance of selected signal to the intended slice center is limited (Fig.1d) to:

$$|z| < \frac{BW_{EX}+BW_{REF}}{2\gamma |G_{EX}-G_{REF}|} \quad (3)$$

With Eq. 1, the condition to avoid back-folding is:

$$N > \frac{BW_{EX}+BW_{REF}}{S_{PE}\,\gamma |G_{EX}-G_{REF}|} \quad (4)$$

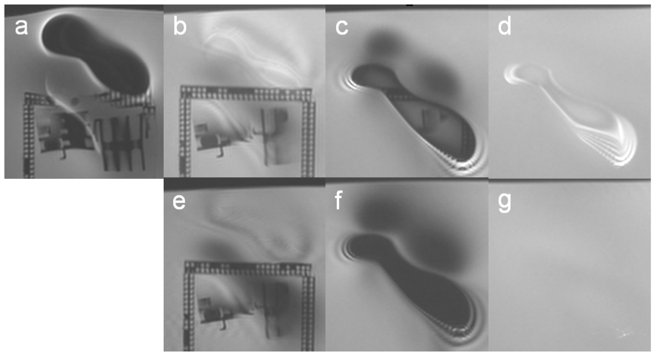

Figure 2: Images of a stainless steel hip implant. High bandwidth TSE (a), SEMAC without ORS (b,c,d), SEMAC with ORS (e,f,g).

Methods

SEMAC with ORS was implemented on a 1.5 T clinical scanner. Phantom experiments were performed on a stainless steel hip replacement sample. An 8-channel RF-coil was used to acquire 24 slices, 3 mm slice thickness, with 0.8×0.8 mm in-plane resolution, and 884 Hz/pixel read-out bandwidth. ORS was disabled, as in standard SEMAC imaging, or enabled such that $\Delta f_{0,\max}$ = 5 kHz. Nine slice phase encoding steps were used (Eq.4) leading to an imaging time of 5'46". A standard turbo spin echo (TSE) using a read-out bandwidth of 818 Hz/pixel was acquired for reference. Furthermore, an otherwise healthy volunteer with ankle fixation plate and screws was scanned using a similar SEMAC acquisition: 26 slices, 3 mm slice thickness, with 0.6×0.75 mm in-plane resolution, without ORS and with ORS such that $\Delta f_{0,\max}$= 5 kHz.

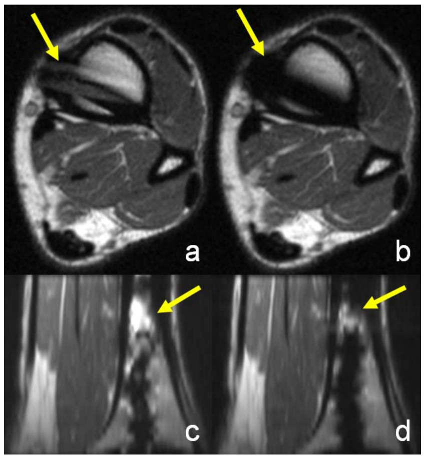

Figure 3: Ankle with fixation plate and screws. Axial SEMAC without ORS (a), SEMAC with ORS (b) and corresponding sagittal reformats (c,d). Back-folded off-resonance signal is suppressed by using ORS (arrows).

Results

The strong in-plane distortion shown in standard TSE (Fig.2a) is nicely corrected by SEMAC (Fig.2b). Although through-plane distortion is resolved to a large extent, signal reappears in a different slice 27mm more anterior (Fig.2c), and off-resonance signal still shows up brightly in regions with water only (Fig.2b and Fig.2d). ORS notably reduces back-folded signal (Fig.2e,f,g). Using standard SEMAC, resolving the complete frequency band of ±12 kHz would have required 19 slice phase encoding steps, doubling the required scan time. In the volunteer, frequency content was measured to exceed ±10 kHz (data not shown). Without ORS, back-folded off-resonance signal is clearly visible (Fig. 3a,c), which is suppressed by using ORS (Fig. 3b,d).

Discussion and Conclusion

Off-resonance suppression can be used to prevent back-folding of distant off-resonance signal in SEMAC acquisitions, therefore limiting the number of through-plane phase encoding steps needed. Suppression of off-resonance signal may lead to signal voids, but these are generally less confusing than superposition of signal from another slice location. SEMAC with ORS especially holds potential for implants that lead to a broad frequency range, e.g. stainless steel, to keep scanning times clinically feasible. Further acceleration using parallel imaging is possible and would allow for an increased in-plane image resolution or coverage within the same total scanning time.

References : 1) W. Lu et al., MRM 62:66 (2009) 2) Z.H. Cho et al., Med Phys, 15:7 (1988) 3) C. Bos et al., Proc. ISMRM, p.129 (2010)