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

C. J. den Harder, U. A. Blume, and C. Bos
1MR CTO, Philips Healthcare, Best, Netherlands, 2MR Clinical Science, Philips Healthcare, Best, Netherlands

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 B0 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 B0 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 B0 field offsets, to allow reducing the number of required slice phase encodes and shortening imaging time.

Theory

SEMAC without ORS: Slice selection excites and refocuses spins that match the selection condition \( \gamma \cdot G_{ex} + \gamma \cdot B_{0}(x,z) = B_{ref} \) (Fig.1a). Here \( z \) is the offset in slice direction, \( G_{ex} \) the excitation gradient which equals the refocusing gradient \( G_{ref} \), \( B_{0}(x,z) \) the local main field offset, and \( B_{ref} \) 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:

\[
N_{sel} = \frac{B_{ref} + B_{max}}{2B_{ref}} \quad (1)
\]

where \( N \) is the number of through-plane phase encoding steps and \( B_{ref} \) the phase encoding slice thickness. If the slice distortion exceeds \( \frac{B_{ref} + B_{max}}{2} \), signal from the most distant spins is back-folded in through-plane direction.

SEMAC with ORS: Intentionally choosing different values for \( G_{ex} \) and \( B_{ref} \) 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

\[
N_{sel} = \frac{\gamma B_{0,max}}{B_{ref} + B_{max}} = \frac{1}{2} \left( \frac{B_{ref}}{G_{ex}} + \frac{B_{max}}{G_{ref}} \right) \left( \frac{1}{G_{ex}} + \frac{1}{G_{ref}} \right)^{-1} \quad (2)
\]

with \( B_{ref} \) and \( B_{max} \) 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:

\[
| z | < \frac{B_{ref} + B_{max}}{2|G_{ex} + G_{ref}|} \quad (3)
\]

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

\[
B_{ref} + B_{max} > \frac{N_{ref} \cdot |G_{ex} + G_{ref}|}{2} \quad (4)
\]

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 \( N_{max} = 5 \) 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 \( N_{max} = 5 \) kHz.

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 27 mm 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 suppressed by using ORS (arrows).

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)