A FAST AND ROBUST METHOD FOR OFF-RESONANCE DETECTION IN METAL IMPLANT IMAGING

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Introduction

Post-operative MRI in the field of MSK is severely compromised by field inhomogeneities in the vicinity of metal implants. Related artifacts can be reduced by extended phase encoding in the slice direction (SEMAC [1]), which is time consuming. To reduce the acquisition time without risking to not cover the full spectrum of off-resonances, it would be advantageous to select the number of phase-encoding steps in the slice direction proportionally to the true frequency offset for each slice individually. In other words, the additional sampling should be restricted and tailored for each individual slice and subject. This can be achieved by a calibration scan prior to each SEMAC sequence as it was suggested by [2] and [3]. Here, we demonstrate a refinement of the latter technique [3].

Analysis and Methods

The method employed uses a modified TSE sequence with the readout gradient shifted from readout to the slice axis. This resolves the distortion of the excited slice profile (fig. 1). Both the excitation and the readout process contribute to the measured slice distortion. The frequency offset Δf of an excited voxel is expressed by

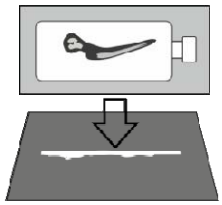

Fig.1: Projection of the excited slice of the bottle phantom for visualization of the slice profile

$$\Delta f = {}^{\gamma}/_{(2\pi)} \cdot G_S \cdot (\delta - s_{true}) \quad \forall\, \delta \in [-z_{exc}/2,\ z_{exc}/2] \quad (1)$$

as a function of its true spatial distance from center of slice s_{true} and the amplitude of the slice-select gradient G_S. Note that the specified slice thickness z_{exc} determines the accuracy of Δf. If s_{meas} denotes the measured distance of the voxel from the center of the desired slice, the off-resonance can be calculated by

$$\Delta f = {}^{\gamma}/_{(2\pi)} \cdot (\delta - s_{meas}) \cdot (G_S^{-1} - G_R^{-1})^{-1} \quad (2)$$

with G_R being the amplitude of the readout gradient.

At this point the result can be improved if the readout gradient has opposite polarity of the slice select gradient: Since $|G_S^{-1}| \geq |\, \gamma / (2\pi) \cdot \delta / \Delta f \,|$, this eliminates the possibility of an ambiguity, which occurs for

$$G_S^{-1} - G_R^{-1} = {}^{\gamma}/_{(2\pi)} \cdot {}^{\delta}/_{\Delta f} \quad (3)$$

Equation (2) is under-determined. This results in two additional steps to avoid aliasing artifacts, when adapting the number of SEMAC phase-encoding steps according to Δf. The application of two separate scans with different readout gradients ($G_{R,1}$, $G_{R,2}$) allows disambiguation:

$$\Delta f = {}^{\gamma}/_{(2\pi)} \cdot (s_{meas,1} - s_{meas,2}) \cdot (G_{R,1}\, G_{R,2}) / (G_{R,2} - G_{R,1}) \quad (4)$$

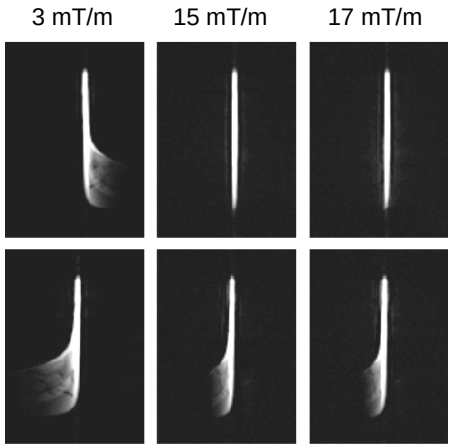

Fig. 2: Slice profiles for different readout gradient amplitudes $|G_R|$ (3mT/m, 15mT/m, 17mT/m); in the upper row, readout and slice select gradient are of equal, in the bottom one of opposite polarity; $|G_S|$ = 15mT/m.

The proposed method was implemented on a 1.5T MR scanner and tested on a phantom containing the femoral part of a hip implant (cobalt-chromium and titanium parts), doped water and plastic structures to keep the implant in place. A slice of 2mm thickness was selected with G_S = -15mT/m and three different readout gradient amplitudes (3mT/m, 15mT/m, 17mT/m) were applied with both polarities. Additional sequence parameters: TE/TR 12/245 (except for G_R = ±3mT/m: TE/TR 17/245), turbo factor 7, total acquisition time 6 sec.

Results

Fig. 2 shows the slice profiles acquired with different readout gradient amplitudes and polarity. In general, the total geometric distortion is increased, if readout and slice select gradients have opposite polarity. In case of equal gradient amplitudes for G_S and G_R the predicted ambiguity is observed: the measured slice profile does not indicate any off-resonance while in the case of opposite polarity the field offset is detected. The ambiguity also occurs for a readout gradient amplitude of -17mT/m. According to equation (3), off-resonances up to ±5.4kHz cannot be identified without additional information. The proposed approach to add a scan with inverted polarity, in this case G_R = +17mT/m, is able to depict the distortion.

Conclusions and Discussion

High gradient readout amplitudes have the ability to detect high off-resonances, but introduce more noise and are less sensitive to small field perturbations compared to low gradient amplitudes. For SEMAC, the maximum frequency offset per slice is decisive; hence a clear geometric distortion of the slice profile is required when applying high readout gradients. This is ensured by the inversion of the readout gradient's polarity relative to the slice-select gradient's polarity. The combination of two different readout amplitudes removes the ambiguity in the range of the excitation bandwidth and can reduce the total scan time, although the scan time of the scout is prolonged. Based on this, an automated, robust quantification of off-resonances for each slice should be feasible, which will be the subject of future work.

References

[1] Lu W et al MRM, 2009; 62(1):66-76 [2] Hargreaves BA et al ISMRM 2010; p 3083 [3] Li G et al ISMRM 2011; p.3169