Phase Encoding Correction for 3D FSE Microscopy

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Introduction In multiple-sample microscopy with 3d fast spin-echo (FSE) imaging [1], artifacts due to gradient imperfections are a problem just as in clinical FSE. As some samples are positioned well off-axis, sensitivity to gradient moment errors is enhanced and we have found that the phase encoding gradient waveforms within the echo train generate significant phase shift errors, which can be measured with a novel prescan sequence.

Theory K-space trajectory errors on the logical x axis of FSE can be treated with prospective or retrospective methods [2,3]. For 2d FSE, further correction on the phase encoding axis due to cross-term moment errors contributed from other logical axes may be conducted [4]. In clinical 3d FSE, an additional parameter for the through-slab phase encoding may be required [5]. In these methods, a single set of correction parameters applies to all echo trains; they do not include effects from the variable-amplitude phase encoding gradients within the echo train.

In our 3D isotropic microscopy protocols, all phase encoding is implemented within the echo train as it is sometimes desirable to employ a non-raster phase encode trajectory in the slab encode dimension. In other words, the pulse sequence encodes and rewinds each echo in both the ky and *kz* dimensions individually and thus potential phase errors are equally present on both axes.

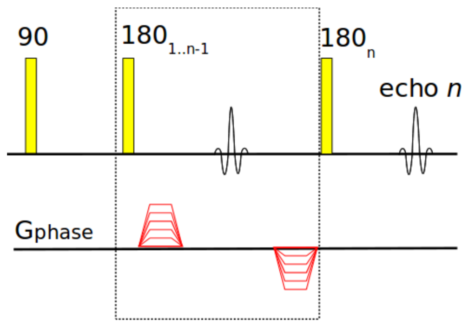

Figure 1: Phase error measurement sequence

Methods The sequence shown in fig 1 was used to measure error due to phase encoding gradients within the echo train. For a measurement at the n'th echo of the phase error from phase encoding pulses of the prior echoes, it is sufficient to omit the phase encoding gradient at the n'th echo. For each echo in the train, error phase is measured for a coarse subset of the prior echoes' phase encoding schedule. There is no spatial encoding of the measurement echo, so all processing is done in ky-kz space. The measured phase errors are fitted and interpolated to the full acquisition matrix, then applied retrospectively as a zero-order phase correction to the acquired raw data.

Experiments were conducted on fixed mouse brain using two types of phase-encoding tables. A 'cylindrical' table at 106 um isotropic resolution was composed of ky-kz pairs within a circle of radius $r=|ky_{max}|=|kz_{max}|=66 * 0.7cm^{-1}$. A rectangular table at 56 um isotropic resolution was also tested in which only the ky-encoding varied along the echo train ($|ky_{max}|=252 * 0.35\ cm^{-1}$, $|kz_{max}|=125*0.7cm^{-1}$). The latter used a 'feathered' approach in which even ky indices were assigned only to even echoes, and vice versa odd.

Results Results from coil position 14 of the 16 element array are shown for the cylindrical table in fig 2: a,b) Measured, interpolated phase error in radians; c) artifact; d) corrected. In fig 3, results for the rectangular table in coil position 5 are shown: a) measured phase in rads for odd (top) and even (bottom) echoes; b) interpolated phase; c) artifact; d) corrected.

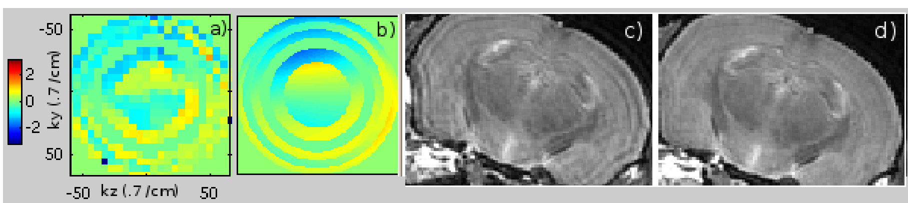

Figure 2: Cylindrical 106 um. a) measured error b) interpolated c) artifact d) corrected

Conclusions We have shown that a two-dimensional prescan sequence for the phase-encode axes in 3D FSE measures significant phase shifts in some off-axis spatial locations. Although the prescan takes time to acquire, in the microscopy context it represents less than 5% overhead. The method extends [5] to errors generated by phase encoding pulses within the echo train, and it effectively addresses the lack of compensation for same-axis moment errors in [4]. In our implementation, the data are used for retrospective correction as in [3] but could potentially be applied prospectively.

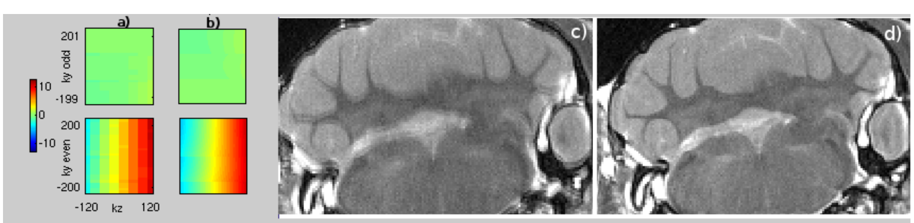

Figure 3: Rectangular 56 um. a) measured error in odd (top) and even (bottom) echo; b) interpolated odd,even echo; c) artifact; d) corrected

References

[1] Nieman BJ et al. MRM 2005; 54:532-537 [2] Hinks RS et al. US Patent 5,378,985 1995. [3] Peters RD et al. US Patent 6,803,763, 2004. [4] Washburn S et al. US Patent 6,160,397 2000. [5] Granlund KL et al. ISMRM 2011; 2822.