Rapid High-field Diffusion MR Histology: Image-based Phase Correction for Diffusion-weighted RARE

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Introduction: The sensitivity of the traditional RARE CPMG echo train to initial magnetization phase is well established and has lead to a variety of compensation schemes. The effect of eddy currents arising from high amplitude diffusion-weighting gradient pulses has also been addressed[1], but typically in the context of in vivo human imaging, where physiological motion requires relatively complex phase correction schemes. The use of diffusion-weighted RARE for high-field *in vivo* MR diffusion imaging has been described previously[2]. Other DW-RARE implementations used for MR histology have estimated phase corrections using additional navigator pulses[3]. We propose here an image-based phase correction scheme which is computationally inexpensive, and leverages both the phase information of the non diffusion-weighted reference image and the absence of physiological motion to correct for per-echo phase errors induced by diffusion-pulse generated eddy currents.

Methods: In the absence of physiological motion, the predominant source of phase errors in a diffusion-weighted RARE acquisition are residual uncompensated eddy currents arising from the diffusion weighting gradient pulses. The vast majority of diffusion-weighted experiments acquire a reference image without diffusion weighting essentially eliminating eddy-current induced phase errors. If we consider the phase difference across k-space between a diffusion-weighted and un-weighted image, we can hypothesize that the phase error is a function of diffusion encoding direction and CPMG echo number only, and is independent of phase encoding gradients. Two potential correction models were tested: (1) the phase difference is estimated on a per-echo and per-diffusion direction basis within a presumably high SNR central region of k-space and a correction extended to the remainder of k-space. (2) The per-echo, per-diffusion direction correction is estimated by numerical optimization with a cost function derived from the ghosting signal outside a mask defined from the un-weighted image. Volumetric multi-shot DW-RARE images were acquired using an 11.7T Bruker Avance micro-imaging system. A double-echo diffusion encoding scheme was combined with an XY-2 phase cycling of the CPMG train to minimize eddy current effects prior to correction.

Results and Discussion: Both the phase correction estimation and numerical optimization approaches are effective at significantly reducing eddy-current induced phase ghosting in high-resolution DW-RARE images acquired of fixed rat brains. Optimization (Method 2) produces a lower residual ghosting than direct estimation (Method 1). Method 2 with the phase correction estimate of Method 1 improves the optimization convergence speed but not the phase solution when compared to random phase initialization. The large-scale trust region implemented by Matlab was found to be computationally efficient for this problem.

References:

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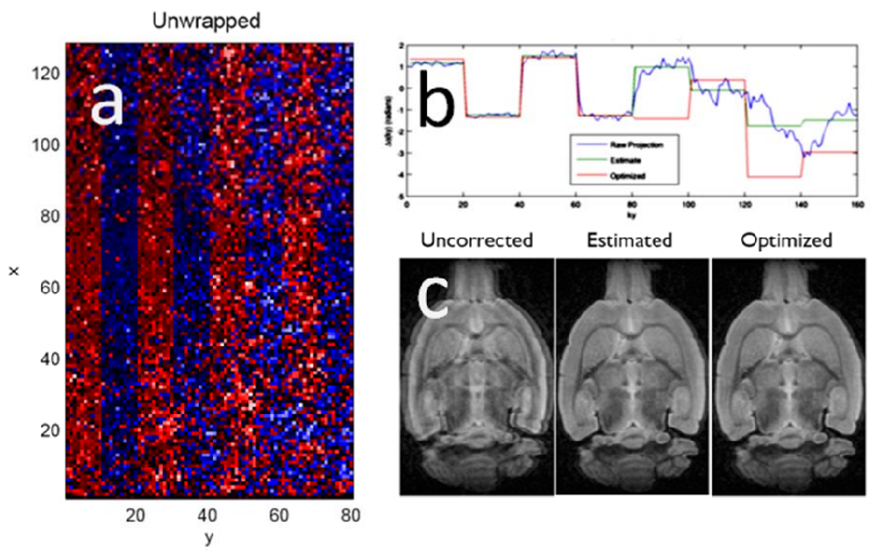

Figure 1: (a) Unwrapped phase difference in the kz=0 plane between the unweighted image and an affected diffusion weighted image. The initial phase error in the CPMG train causes phase oscillations which appear to be constant for each echo territory. (b) Median collapse of the phase difference over the central kx and kz regions allows both estimation and optimization of the per-echo phase correction. (c) Original and corrected DW-RARE images demonstrating the removal of eddy current phase ghosting.