The Influence of Ghost Correction Accuracy on the Image Quality of GRAPPA Accelerated EPI

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Introduction. It has been demonstrated that GRAPPA[1] and SENSE[2] are extremely powerful methods to reduce geometric distortions and image blurring in echo planar imaging (EPI) [3, 4]. This bears great potential to improve image quality and overall lesion conspicuity for numerous clinical applications. Further image degradation in EPI is due to slight imbalances between odd and even echoes that lead to echo misalignment and hence FOV/2 ghosts. The objective of this study is to show that for a self-calibrated parallel imaging reconstruction approach even slight inaccuracies in EPI phase correction can lead to substantial reconstruction errors.

Materials and Methods. Several factors, such as gradient imbalances, filter delays, and eddy currents, are causative for errors between odd and even echoes in EPI. These errors typically cause phase errors and echo misalignment in *k*-space and therefore result in FOV/2 ghosts in single-shot EPI scans; ghosts of higher spatial periodicity occur for interleaved EPI. Based on a reference scan, zero and first order phase correction is usually applied to the data in the image domain prior to gridding to avoid these ghosts. Here, we demonstrate that inaccuracies in EPI phase correction can lead to unexpectedly high image degradation even if the ghosts appear to minor in the original b=0 data. Although any ghost correction scheme that minimizes the ghosting artifacts should be applicable, we have used a referenceless method that was recently developed in our lab. This phase correction is based on image based entropy to determine the appropriate first and zero order phase terms to minimize the amount of FOV/2 ghosting in a rapid and reliable fashion.

In an ongoing NIH-funded study, we are using high-resolution DWI scans were performed on a 1.5T scanner (GE Signa LX, 11.0) with high performance gradients (40 mT/m, SR = 150) using either a dedicated 8-channel head or neurovascular array coil (both MRI Devices): FOV = 25cm, slice thickness=5mm, skip=1mm TR=4000ms, TE=60ms, matrix 192x192, 3 interleaves, NEX=1, b=1000s/mm^2, dual spin echo, tetrahedral encoding + reference scan (b~0s/mm^2). With this approach the 3 interleaves of the b=0 scan provide a fully sampled *k*-space data set from which the coefficients required for parallel imaging reconstruction can be derived. These weights can be used to reconstruct individual interleaves of the subsequent diffusion-weighted scans (b=1000) without the need of navigator echo correction [5]. The individual images of each interleaf are then magnitude averaged for each diffusion-encoding direction then combined to provide isotropically diffusion-weighted images. For each diffusion direction, the $R^{0.5}$ SNR penalty from parallel imaging is offset by R times more images (i.e. each individual interleaf yields an image), except for the geometry factor related noise enhancement. All procedures performed were approved by our institution's review board.

Results. Fig. 1 (top panel) demonstrates the result of phase correction in a T2w interleaved EPI scan based on a non-ideal reference scan. The overall ghosting level appears to be mild and is deemed technically adequate for normal image interpretation. After application of the reference-less phase correction on the same raw data there were noticeably less ghosting artifacts (Figure 1, bottom panel). The phase corrected *k*-spaces of both sets of T2w images were then used further to derive the complex weights for GRAPPA parallel imaging reconstruction. Fig. 2 shows that the image quality of diffusion-weighted GRAPPA scans using the phase correction based on the non-ideal reference scan suffered from increased spatially varying noise, whereas negligible GRAPPA artifacts can be seen when the improved phase correction method is used. The loss of anatomic detail in the former case is quite obvious and clearly impairs the diagnostic quality.

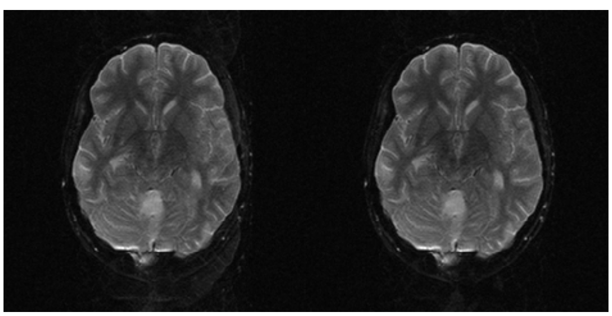

Figure 1 *– Interleaved T2w-SE EPI 192x192, 3 interleaves. Some ghosting can be observed from EPI phase correction performed (left). With our referenceless entropy based phase correction, the odd/even echo residual ghosting is reduced (right). These images are part of the DWI acquisition and serve to compute the GRAPPA weights.*

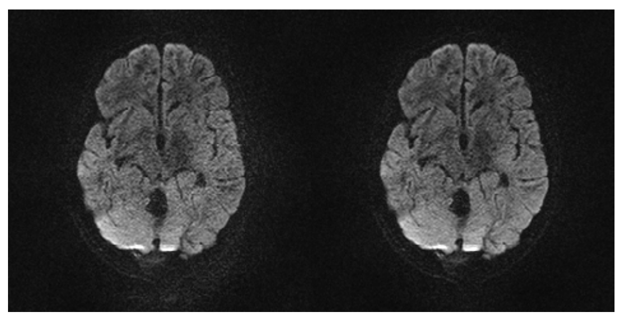

Figure 2 *– The first direction of four in diffusion-weighted GRAPPA-EPI 192x192 scan with 3 interleaves, matching the data in Figure 1. (left) Small ghosting in top panel of Figure 1 does not translate significantly into the DWI's. Rather, due to altered GRAPPA weights, the DWI's are hampered by an increase haze-like noise (right) With a proper Nyquist ghost correction, this noise is reduced*

Conclusion. The results of this investigation strongly suggest that high image quality of GRAPPA accelerated EPI DWI scans requires a complete EPI ghost correction. Despite that the ghost artifacts are less obvious and not disturbing in normal reconstructions (Fig. 1), slight phase errors and echo misalignment lead to significant noise enchantments in GRAPPA accelerated DWI scans (Fig. 2 – top), but significant quality improvement can be achieved if some extra effort is put in to minimize these ghosts.

References. [1]Griswold, M. *et al*. MRM 47: 1202-10, 2002; [2]Pruessmann, K. *et al*. MRM 42: 952-62, 1999; [3]Bammer, R. *et al*. MRM 46: 548-54, 2001; [4]Heidemann, R. *et al*. 9th Annual Meeting of the ISMRM, Glasgow, Scotland, 2001, p 169. [5]Skare, S *et al.* ISMRM DWI workshop, Lake Louise: p 16:2005

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