Comparison between EPI and RS-EPI at high acceleration factors

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Introduction: Readout-Segmented EPI (RS-EPI) [1] has been proposed in a number of studies (including several of our own) as a variant of EPI to reduce distortion in diffusion-weighted (DW) neuroimaging [1-3]. RS-EPI segments *k*-space into individual EPI 'blinds' along the readout direction, and requires an additional navigator blind (for phase correction of the off-center DW blinds). With the increasing number of coils coming available with advanced phased-array technology that increases the capacity of EPI to achieve higher acceleration factors (Fig. 1), and advanced distortion-correction methodology (such as the Reversed Gradient Polarity method (RGPM) [4,5]), we suspect that the utility of RS-EPI is perhaps more tailored to ultra-high resolution DWI. An initial qualitative demonstration of this is shown here, with EPI and RS-EPI data acquired with the highest acceptable GRAPPA [6,7]-acceleration factor that we have been using with our 32-channel coil.

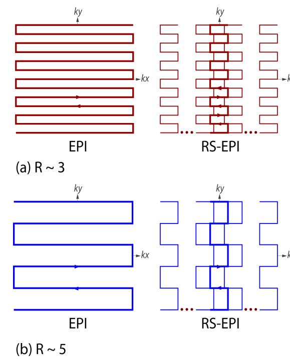
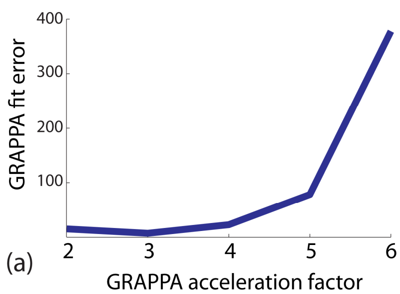


Fig. 1 - EPI and RS-EPI *k*-space traversal. A schematic representation of the k-space trajectory for EPI and RS-EPI for (a) smaller acceleration factors, and (b) larger acceleration factors achievable through the use of coils. The utility of RS-EPI is significantly reduced with increasing R since it results in a smaller scan time.

Methods: Experiments were conducted on a 3T GE system (G_{max}=50mT/m, S_{max}=200 mT/m/ms) and a 32-channel head coil channel (Nova Medical, Wilmington, MA, USA). In order to find a maximum GRAPPA acceleration factor, R, achievable with our set-up, scan-time matched EPI DWI datasets were acquired first on both a QA agar phantom and a human volunteer using acceleration factors of R = 1-6. With the selection of R = 5 as an acceptable choice of acceleration factor for EPI (Fig. 2), a distortion-matched RS-EPI dataset was acquired using R=2, as well as R=5 dataset. The following common parameters for EPI and RS-EPI were: twice-refocused diffusion preparation with *x,y,z* diffusion encoding, b = 1000s/mm^2, one b = 0, a target resolution of 240 x 240, slice thickness = 5mm, TE/TR = 70ms/4000ms, FOV = 24 cm, partial Fourier encoding with 24 overscans. RS-EPI used 5 blinds of width 54. All scans were scan time matched (by using a larger NEX for EPI). For each dataset, a b = 0 image was acquired with an opposite phase-encoding gradient to enable subsequent distortion correction using the RPGM method.



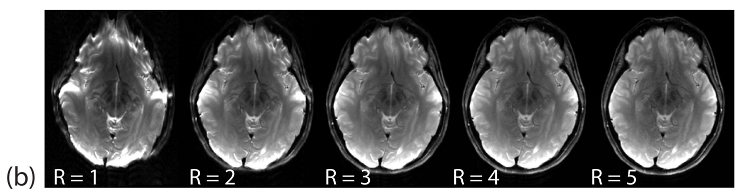


Fig. 2 - DWI datasets acquired at 3T using a 32-channel head coil. (a) GRAPPA fit error calculated for R = 2-6 b=0 datasets on a QA agar phantom. From R = 5-6 the GRAPPA fit error begins to increase considerably. (b) b=0 images acquired on a volunteer using no acceleration (R=1) and with acceleration. The R = 2-5 images are reconstructed with GRAPPA. The R = 5 image retains good image quality and thus is the acceleration factor we chose for our EPI versus RS-EPI comparison.

Results: A comparison between the distortion- and scan-time matched EPI (R = 5) and RS-EPI (R = 2) datasets are shown in Fig. 3a-b. Despite the longer readout for EPI, the extent of image blurring appears to be similar between the two datasets thanks to the higher acceleration factor and hence larger step through phase-encoding k-space. However, because RS-EPI only uses the central (54 x 240) segment of k-space to estimate the GRAPPA weights, there appear to be residual GRAPPA noise in some slices (white arrows, Fig. 3b). As one moves to the highest acceleration factor capable with our system (achievable with EPI), the RS-EPI datasets are slightly less distorted, but become significantly noisier. Furthermore, since RS-EPI is essentially a multi-shot technique, the quality of the diffusion-weighted images relies on the robustness of the phase error correction. At very high acceleration factor, the low SNR of images reconstructed from individual blinds, especially the edge blinds, might negatively impact the phase correction procedure, resulting in poor quality images. Fig. 4 compares the original b = 0 images with those corrected for distortion using the RPGM method.

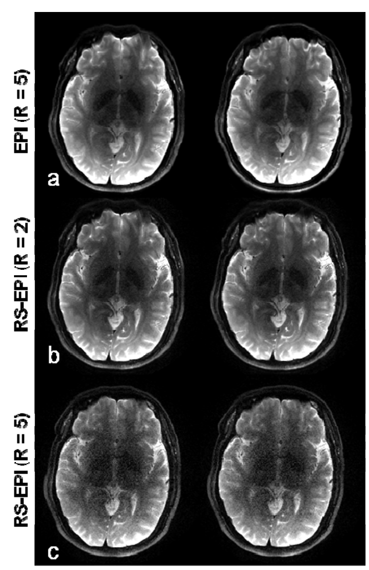


Fig. 4 - Comparison of original and distortion-corrected b = 0 images acquired with EPI R = 2, RS-EPI R=2, and RS-EPI R=5. The acquisition matrix = 240x240.

Discussion & Conclusion: With the advent of more advanced phased-array head coils, an increasing maximum slew rate achievable by gradient coils, the image quality of standard EPI is becoming much improved. For standard clinical imaging EPI is likely to be the method of choice for its speed and high SNR, while RS-EPI may still have application to ultra-high resolution diffusion imaging at high field strengths [3] where scan time is not as critical. As shown in Fig. 4, with acceleration factors of R = 5 achievable with EPI, the residual distortion provides a good starting point for distortion correction methods (such as RGPM). Furthermore, the gain that one gets using RS-EPI with R = 5 in terms of reduced distortion is rather small and, in addition, much poorer image quality results due to the smaller central strip used for the GRAPPA estimation. In fact, as this abstract has made apparent, a more robust GRAPPA estimation procedure may be required (such as the use of adjacent blinds), as GRAPPA noise in the RS-EPI images is visible with R = 2, and considerable with R = 5. A separate calibration scan could remedy this, but would have an additional scan time cost (in addition to the extra blinds required to fill k-space). RS-EPI has a number of additional practical limitations, including gaps in k-space (between blinds) in the presence of large motion; eddy current effects between blinds (due to the different k_x-dephasing gradient) on poorly calibrated systems; and the requirement for an additional navigator reduces the number of slices that can be acquired per TR.

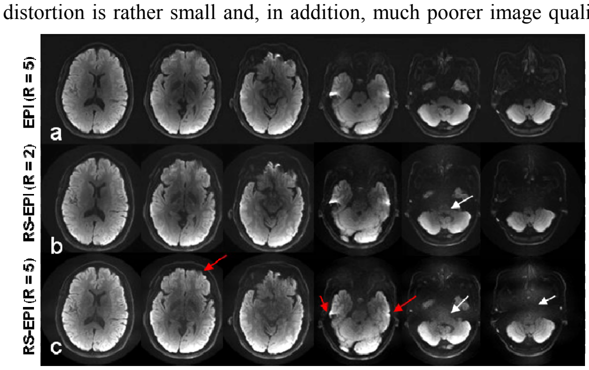


Fig. 3 - Isotropic DWI images acquired using (a) EPI with R = 5, (b) RS-EPI with R = 2 (distortion-matched with (a)), and (c) RS-EPI with R = 5. The white arrows depict regions where GRAPPA noise affects the image quality in RS-EPI. The red arrows depict regions of slightly reduced distortion achievable with RS-EPI R = 5.

References - [1] Porter D, MRM, 62:468, 2009. [2] Holdsworth, S et al. MRM, 62:1629, 2009 . [3] Heidemann et al. MRM, 64:9-14, 2010. [4] Andersson JL. Neuroimage 2003;20(2):870-888. [5] Skare S ISMRM 2010. [6] Griswold MA. et al. MRM 2002;47:1202-1210. [7] Qu P. et al. JMR 2005;174(1):60-67.