Diffusion imaging using MinD SAP-EPI

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Introduction: Even with modern MRI scanners, distortions in EPI remain problematic, especially at higher image resolutions. Recently, we introduced a redesigned propeller EPI, using readouts along the Short-Axis of the Propeller blades ("SAP-EPI", Fig. 1). This sequence has higher pseudo receiver bandwidth than previous propeller EPI methods (1). For high resolution 256×256 SAP-EPI images, obtained by using e.g. 32 (freq.) × 256 (phase) blade resolutions, the sensitivity to off-resonances is reduced by about a factor of 3 thanks to the shorter echo spacing. Here, we combine the SAP-EPI sequence with diffusion gradients and two additional means of reducing the distortions. These are a) the use of multi-shot with GRAPPA (2) and b) distortion correction using the reversed gradient polarity method (RGPM) (3,4). We will refer to these means as *Minimal Distortion SAP-EPI* (MinD SAP-EPI) for brevity.

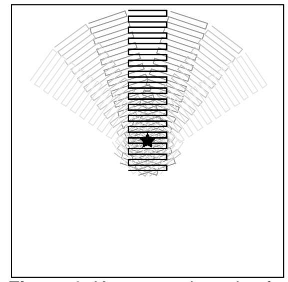

Figure 1. K-space trajectories for half-Fourier propeller EPI with short axis readouts (SAP-EPI).

Materials and methods: Multi-shot DW-EPI reduces distortions but introduces ghosting due to the random phase between the shots, induced by the diffusion gradients. To avoid this, GRAPPA may be used in combination with multi-shot EPI (2). GRAPPA weights are estimated on the b=0 image, which normally has no ghost problems. These weights are used to reconstruct each of the shots in the DWI's. Averaging of the shots is performed on the magnitude images. Unlike multi-shot DW-EPI with navigators, reconstructing each shot separately is guaranteed to be successful w.r.t. ghosting. In this work we have combined SAP-EPI with up to 4-shot acquisitions. For a target resolution of 256×256 and blade resolution of 32×256, we are able to reduce distortions by ~12 times compared to conventional 256×256 ssEPI, by combining SAP-EPI and GRAPPA. Nevertheless, further improvement of the image quality is possible by post-processing. We note that pairs of propeller blades acquired with a 180° relative rotation are identical to each other after counter rotating one of them, except for motion and that the distortions are effectively in opposite directions along the phase encoding axis. This makes each pair of blades suitable for the RGPM distortion correction, here using a 2D cubic B-splines as basis set. The core steps are illustrated in Fig. 2. The second blade image is rotated to match the first, followed by the 2D distortion and motion correction, which results in two corrected blades that are averaged and a ΔB_0 field. As the homodyne reconstruction clears the phase of the blade images, full-size echo centered blades in k-space result. The processing steps in Fig. 2 are repeated for all other blade pairs. The corrected k-space data from all blades are simultaneously regridded and 2D Fourier transformed to produce the final image. Acquisition was performed on a 1.5T GE Excite system (GEHC, Waukesha, WI) with 50mT/m gradients on a volunteer using an 8 channel phased-array head coil (MRI Devices, Milwaukee, WI). Eight axial 4 mm slices were acquired with a 24×24 FOV and 32×256 (freq.×phase) blade resolution, reconstructed to 256×256.

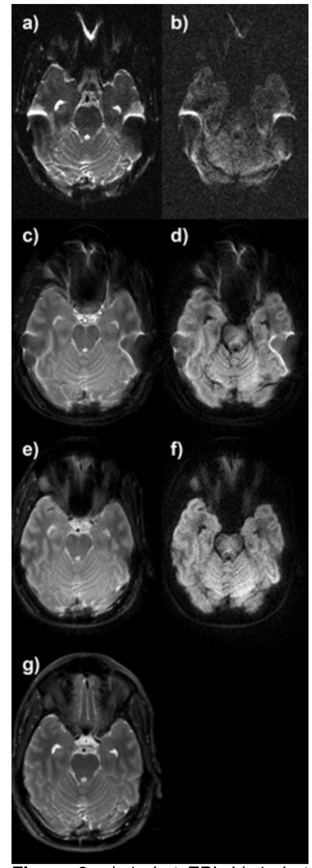

Figure 3. a) 1-shot EPI, b) 1-shot DW-EPI, c) 1-shot SAP-EPI, d) 1-shot DW-SAP-EPI, e) 4-shot GRAPPA & RGPM SAP-EPI, f) 4-shot GRAPPA & RGPM DW-SAP-EPI, g) Fat-sat FSE (for geometrical reference). b=1000 s/mm^2.

Results: In Fig. 3, T2w and DW images from 1-shot EPI, 1-shot SAP-EPI, 4-shot MinD SAP-EPI are presented. For geometric reference, a fat-sat FSE is included. When comparing these images one should disregard SNR as scan times are not identical and gives the SAP-EPI an unfair advantage. One can appreciate the improvement in tissue structure detection with SAP-EPI vs. single-shot EPI. Structures near the pile-up regions are recovered in SAP-EPI, yet some distortion artifacts remain in Fig. 3c-d. With MinD SAP-EPI, these artifacts disappear, making Fig. 3e) similar to the FSE image of Fig. 3g.

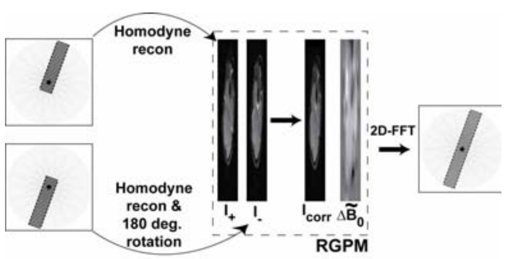

Figure 2. Correction of residual distortions and motion in the image domain using two propeller blade pairs 180° apart. Corrected blade is Fourier transformed back to k-space for later regridding.

Discussion & Conclusions: We have here presented MinD SAP-EPI, a combination of three methods to minimize the distortions in EPI data using short-axis P-EPI, multi-shot GRAPPA acquisition, and RGPM post-processing. None of these methods will produce geometrically faithful images by itself, but their combination almost completely removes distortions. In general, the RGPM method fails locally in the image where the Jacobian becomes less than zero, i.e. when distortions are so large that the derivative of the displacement field becomes larger than one. Reducing the distortions on the acquisition side by more than one order of magnitude by using 4-shot SAP-EPI greatly reduces the possibility of RGPM failure. Furthermore, at even higher target resolutions the blade width is identical, maintaining the low distortion levels, while the phase encoding resolution is increased, making the data more continuous. Each makes negative Jacobians even less likely. This method is highly promising when moving to higher fields, where increased ΔB_0 fields can preclude the use of EPI.

References: 1) Wang FN *et al.* Magn Reson Med 2005;54(5):1232-1240. 2) Skare S *et al.*; 2005; Lake Louise. p 16. 3) Chang H, Fitzpatrick JM. IEEE Transactions On Medical Imaging 1992;11(3):319-329. 4) Bowtell R *et al.*; 1994; San Fransisco. p 411. 5) Skare S, Andersson JL. Magn Reson Med 2005;54(1):169-181.

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