Comparison between Readout-Segmented (RS)-EPI and an improved distortion correction method for Short-Axis Propeller (SAP)-EPI

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Introduction: 'Short-Axis readout Propeller EPI' (SAP-EPI) (1) and 'Readout-Segmented EPI' (RS-EPI) (2) have been proposed for use in high resolution diffusion-weighted (DW) imaging (Fig. 1). SAP-EPI and RS-EPI share common characteristics, in that *k*-space is traversed by several EPI 'segments' (referred to as blades (SAP-EPI) or blinds (RS-EPI)) in order to reduce the distortion and blurring that typically hampers EPI images. Previous work comparing RS-EPI and SAP-EPI (3) concluded that SAP-EPI suffers from considerably more blurring compared with RS-EPI despite attempts to correct for distortion. With an improved distortion correction method, we demonstrate that SAP-EPI results in a similar image resolution to RS-EPI for a given SNR normalized for scan time/slice.

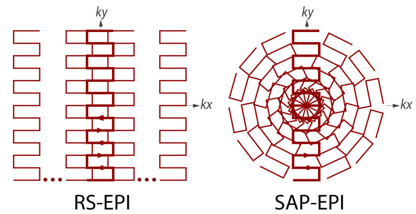

Fig 1: *K*-space trajectories for RS-EPI and SAP-EPI. RS-EPI requires an extra navigator echo for the DW image resulting in reduced scan efficiency, thus SNR, despite that fewer segments are required to fill *k*-space. The overlapping blades in the center of *k*-space in SAP-EPI may also contribute to a higher $\eta = SNR / \sqrt{\text{scan time/slice}}$.

Methods: All images were acquired on a 3T whole-body MRI unit (GE Discovery MR750) using an 8-channel head coil and a high-performance gradient system (50 mT/m, SLR=200 mT/m/s). Scan-time matched SAP-EPI and RS-EPI experiments were first performed on healthy volunteers using two matrix sizes: 256×252 (blade/blind width = 64) and 384×384 (blade/blind width = 96). Other parameters were: FOV = 26 cm, #blades/#blinds = 7, Δz = 5 mm, TR/TE = 4 s/76 ms, GRAPPA R = 3, NEX = 3, partial Fourier with 24 overscans, twice-refocused diffusion preparation, and b = 1000 s/mm^2. The maximum number of slices for SAP-EPI and RS-EPI was 35/31, respectively (matrix size = 252^2) and 35/31 (matrix size = 384^2). Together with noise maps generated from repeated b = 0 scans, the scan time efficiency ($\eta = SNR / \sqrt{\text{scan time/slice}}$) was calculated from the RS-EPI and distortion-corrected SAP-EPI images. Patient RS-EPI and SAP-EPI DTI data were then collected on three pediatric patients using a matrix size of 192^2 (blade/blind width = 64, #blades/#blinds = 7, FOV = 20 cm, Δz = 5 mm, TR/TE = 3000/76 ms, R = 3, NEX = 3, partial Fourier (24 overscans), twice refocusing, 1 b = 0, 7 isotropic diffusion directions with b = 1000 s/mm^2, scan time = 7:36min). Here, the maximum number of slices that could be selected for SAP-EPI was 25, compared with 19 for RS-EPI. In our previous distortion correction implementation for SAP-EPI (4), the distorted blade data underwent two unnecessary sampling steps which now have been removed. Each of these resampling steps caused a slight loss in resolution, which also added a blur in the final image. For the new implementation presented in this work, we estimate (again only using the blade data itself) the ΔB_0 field in the laboratory space while using the original blade data in their own native coordinate systems, each having their unique 4×4 voxel-to-world matrix (defining its position and rotation) applied to the resampling coordinates.

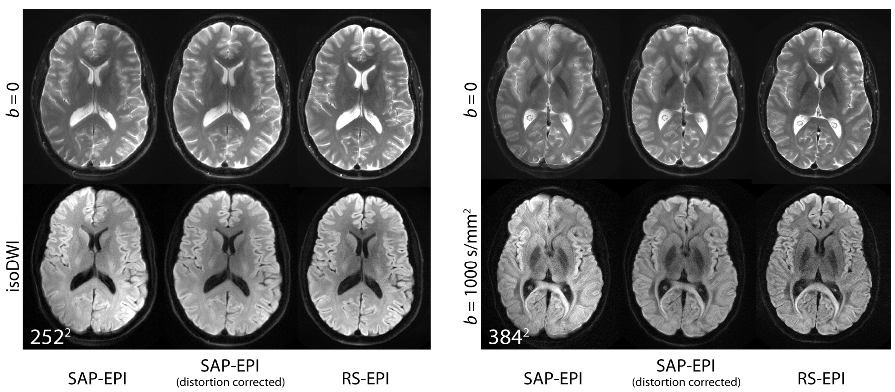

Fig 2: Comparison between SAP-EPI, distortion-corrected SAP-EPI, and RS-EPI on a healthy volunteer at matrix sizes of 252x252 (left) and 384x384 (right). SAP-EPI and RS-EPI datasets were acquired in equivalent scan times of 1:24min/volume.

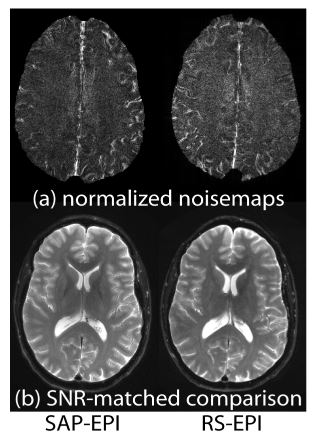

Fig 3: (a) Scan-time-normalized noise maps (i.e. accounting for the maximum number of slices) of distortion-corrected-SAP-EPI and RS-EPI calculated over six b = 0 scans (matrix size=384^2). (b) A RS-EPI 384^2 image is blurred by a Gaussian kernel to achieve the same SNR as SAP-EPI, resulting in a loss of resolution. This shows that distortion-corrected SAP-EPI has better scan efficiency than RS-EPI even at high resolutions.

Results: Fig. 2 shows SAP-EPI, distortion-corrected SAP-EPI, and RS-EPI b = 0 and DW images acquired with matrix sizes of 252^2 and 384^2. The SAP-EPI images show considerably less blurring when corrected for distortion, with a resolution approaching that of the RS-EPI scan. The normalized SNR ratio ($SNR_{SAP\text{-}EPI}/SNR_{RS\text{-}EPI}$) was 1.3 and 1.6 for the 252^2 and 384^2 matrix sizes, respectively – indicating that one must scan RS-EPI approximately twice as long in order to achieve the same SNR as SAP-EPI. Fig. 3a depicts the normalized noise maps for the 384^2 acquisitions. To correct for the difference in normalized SNR, the RS-EPI images were blurred to achieve the same SNR as SAP-EPI (Fig. 3b), demonstrating that at a comparative SNR the resolution is now very slightly reduced for RS-EPI. Fig. 4 shows pediatric patient data comparing distortion-corrected-SAP-EPI and RS-EPI. SAP-EPI had a higher SNR (particularly evident in the color FA maps) than RS-EPI. Note that RS-EPI appears sharper in the frontal region in the left panel due to incomplete distortion correction at the FOV boundaries.

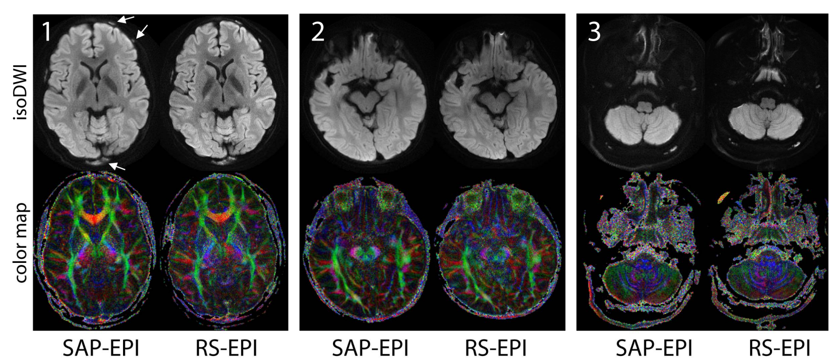

Fig 4: Comparison between distortion-corrected-SAP-EPI and RS-EPI acquired on three pediatric patients (labeled 1 through 3). Both the isoDWI and 1st eigenvector color maps are shown at 3 levels of the brain. Note that patient #1 presented with Ewing's sarcoma (metastatic spread to the calvarium, white arrows).

Discussion & Conclusion: This study demonstrates that SAP-EPI combined with an improved distortion-correction method and RS-EPI produce images of similar quality. At first glance, distortion-corrected SAP-EPI images (Figs. 2 and 4) appear more blurred than RS-EPI images. Without scan time restrictions, the unidirectional distortions in RS-EPI result in a sharper image, particularly with increasing resolution. However, one must scan RS-EPI approximately twice as long to achieve the same SNR. For an SNR-matched scenario, as shown in Fig. 3, the image quality of the two acquisitions very closely resemble each other – with a slight reduction in resolution for RS-EPI. In addition to the larger slice coverage/TR, SAP-EPI has one important advantage over RS-EPI in that for each blade, the stack of 2D slices forms a 'brick' in the image domain, making image domain 3D motion correction possible.

References: [1] Skare S. MRM 2006, 55:1298-1307. [2] Porter D. ISMRM 2008, p3262. [3] Holdsworth S. ISMRM 2008, p1808. [4] Skare S. ISMRM 2008, p417.

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