Diffusion-Weighted Readout-Segmented EPI Using PINS Simultaneous Multislice Imaging

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Introduction

Diffusion-weighted, readout-segmented echo-planar imaging (rs-EPI[1]) is a diffusion imaging technique that uses multi-shot acquisitions to achieve high spatial resolution and fidelity. However, this comes at the cost of increased scan time, with typical scans using 5-7 fold segmentation, incurring a proportionate increase in scan time. The resulting very long volume acquisition times severely limit the number of diffusion directions that can be acquired, which in turn limits our ability to resolve features of fibre architecture that are most interesting at these small spatial scales (crossing, fanning, etc). Previous work has demonstrated the potential to reduce rs-EPI scan times with simultaneous-multislice (SMS)[2] and of high-quality readout partial Fourier acquisition[3]. However, SMS was unable to achieve the expected gains at 7T due to RF safety limits. In this abstract we demonstrate high-resolution SMS rs-EPI using PINS[4] pulses for reduced power deposition at 7T.

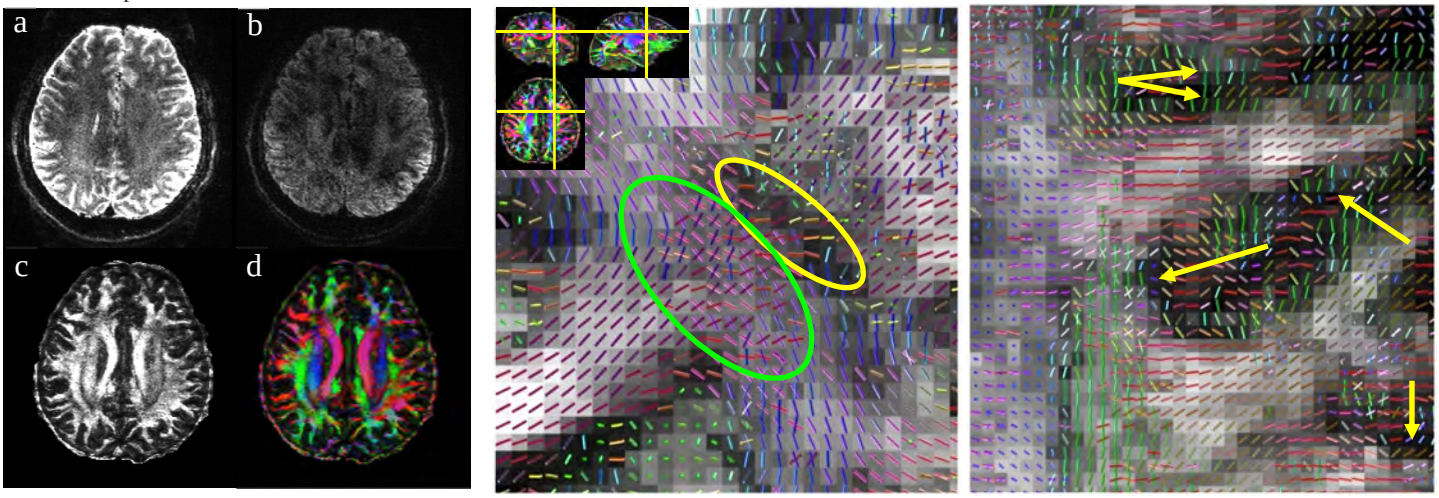
Methods

rs-EPI uses 2D navigator echoes to correct phase inconsistencies induced by motion during diffusion gradients[5]. This requires a second refocusing pulse, which increases power deposition, especially in SMS. We have addressed this by using PINS pulses. Because the sinc waveforms in the original PINS paper did not produce satisfactory refocusing profiles in this high-resolution study (side lobes and slice thinning), we used SLR-design to modify the PINS pulse coefficients.

In a previous 7T PINS diffusion study[6] excitation and refocusing pulses with opposite polarity selection gradients were used to provide additional fat suppression by exploiting chemical shift. In our current study we found this to be detrimental: when exciting very thin slices (here, 1 mm) that are relatively far apart (39 mm) the bandwidth-time-product of PINS pulses can become very low (here, 1.5). When off-resonance effects are present, slice profiles obtained with opposite gradient polarities distort in different directions, reducing the overlap and therefore SNR, hence this method of additional fat suppression was abandoned.

Scan parameters and processing

A male volunteer was scanned at 7T with local ethics board approval. We used a 1 mm isotropic protocol: 196x196 matrix, 117 slices (3-fold accelerated to 39), blipped-CAIPIRINHA[7] FOV/2 slice-shifting-scheme, 2-fold in-plane acceleration, effective echo spacing 0.2 ms (i.e. readout segment duration 39.2 ms), 2 shells of 60 directions each with b=500 and b=2000, 13 b=0 images. TR was 6.6s (constrained by sequence timing, not SAR) making for a total scan time of ~45 minutes. Partial Fourier acquisition was used, scanning 3 of 5 readout segments, reconstructed with POCS[8]. SLR-optimised PINS refocusing pulses of 10 ms each were used. Normal multiband excitation pulses were used with matched bandwidth and duration to make sure that the excitation and refocusing profiles fully overlapped in the presence of off-resonance. Standard fat-suppression was used. Coils were combined with the SENSE1 method[9]. For SMS reconstruction a non-slice-accelerated scan acquired with a TR of 19.2s. A second one was scanned with opposite phase-encoding to be used with FSL's "topup-eddy" diffusion data preprocessing tools[10]. Data were analysed with FSL-bedpost[11].



Results

The figure on the left shows for the same slice (a) single volume b=500, (b) single volume b=2000, (c) fractional anisotropy of the main fibre (FA), (d) the direction of the main fibre modulated by its FA. The panel in the middle shows a coronal view of the diffusion directions overlaid on the fractional anisotropy (FA) map. The ovals are in the Centrum Semiovale (see top-left inset for location), where in the green oval crossing fibres are clearly visible. The area in the yellow oval is known to contain three bundles that cross each other. The diffusion data fails to capture this appropriately and therefore the analysis erroneously reports a low FA (dark background) and the secondary and tertiary fibre populations are missed. The panel on the right shows a transversal section near the same area where in many places the grey matter anisotropy is perpendicular to the cortex (e.g. the yellow arrows). Again crossing is observed in the bottom half, slightly left of the centre (red & green)

Discussion

Highly accelerated (3 SMS x 2 in-plane x 5/3 partial Fourier) 1 mm isotropic rs-EPI produced 133 volumes in ~45 minutes. This is a large improvement compared to earlier experiments and especially the increase in number of sampled directions may allow us to start exploiting the spatial benefits of rs-EPI compared to single-shot methods. Further work is planned with more optimal acquisition protocols (with 1000 and 2000 shells for example), but the fact that in the current data we can already observe fibre crossing and grey matter anisotropy shows great promise.

References

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Acknowledgments: WT100092MA