2D Navigated 3D Multi-Slab DWI at 1.3 mm Isotropic Resolution

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Introduction

Diffusion weighted MRI (DWI) is usually scanned with a 2D single shot spin echo-EPI sequence, due to good SNR efficiency and immunity to phase differences between diffusion encoded excitations. However, non-square RF-pulse profiles and slice crosstalk, more prominent for thin slices, causes signal dropouts to occur in the slice direction along with an uncertainty of slice direction resolution. Striving for isotropic resolution, as often the case in fiber tractography, a 3D technique might therefore be preferred. Multi-slab Pseudo 3D acquisitions has therefore been proposed as an alternative [1-2]. In this work, we propose an EPI based dual echo readout strategy with a 3D multi-slab encoding [3], allowing us to ensure slice direction resolution below 1.5 mm. Furthermore, we propose a strategy to correct phase differences between diffusion-encoded excitations and address the non-square slab profiles in both the acquisition and in the reconstruction.

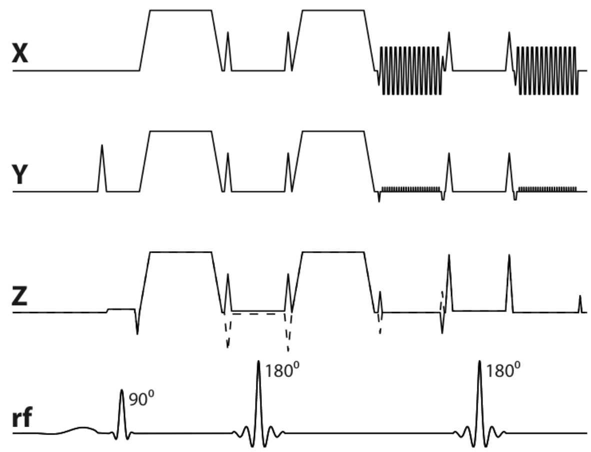

Figure 1 Multi-slab multi-echo spin echo-EPI PSD. Notice the dashed line at the 1st 180° refocusing pulse and the kz-encoding indicating that their polarity is following one another.

Material & Methods

A single-shot spin echo-EPI sequence was modified to allow for two RF-refocused EPI readouts per excitation and Fourier encoding in the slab direction (Fig. 1). The slab selection gradient, with crushers, for the first readout was modified to follow the kz slab encoding polarity, effectively avoiding cancelation between the kz encoding gradient and the right crusher (Fig. 1). To improve the slab profile, 10 ms SLR-optimized 180° refocusing pulses were used, and crushers were pairwise given different areas to minimize stimulated echo interference in the second readout, used for phase navigation. Eddy currents from the diffusion gradients were mitigated by prolonging the attack and decay ramps of the diffusion gradients. This, combined with parallel imaging enabled a single refocused Stejskal-Tanner preparation, without suffering from eddy-current induced distortions. For each excitation, the first readout was given a kz encoding, while the second readout was used for phase navigation (kz=0) (Fig. 1). Phase correction of diffusion weighted images was performed by calculating a phase difference map ($\Delta\Phi$) between the navigators with the navigator at kz=1 as reference. Corresponding $\Delta\Phi$ was then subtracted from the first echo, followed by subsequent Fourier transformation in the slab direction. The slabs were gridded with a slab-weighting function to a final 3D-volume. Data were collected on a GE 750 3T system (G=50mT/m, SR=200T/m/s), using an 8-channel head coil and the following relevant parameters: $TE_{1,2}$/TR = (92,161)/4800 ms, $matrix_{slab}$ = 168x168x8, slab. thk. = 9.4 mm, slab.spc. = 5.2 mm, FOV_{slab} = 220x220x10.4 mm, slabs = 22, NEX = 3, voxel size = 1.3x1.3x1.3 mm^3, b = 800 s/mm^2, 3 T2 and 17 non-collinear diffusion directions.

Results

Fig. 2A shows the ISO-DWI in all three scan planes, with a 1.3x1.3x1.3 mm^3 (2.2 µl) voxel size. No banding from the slab profiles or signal fluctuations can be seen along the superior-inferior direction of the brain. Fig. 2B shows a color-coded FA map (L-R red, S-I blue, and A-P green).

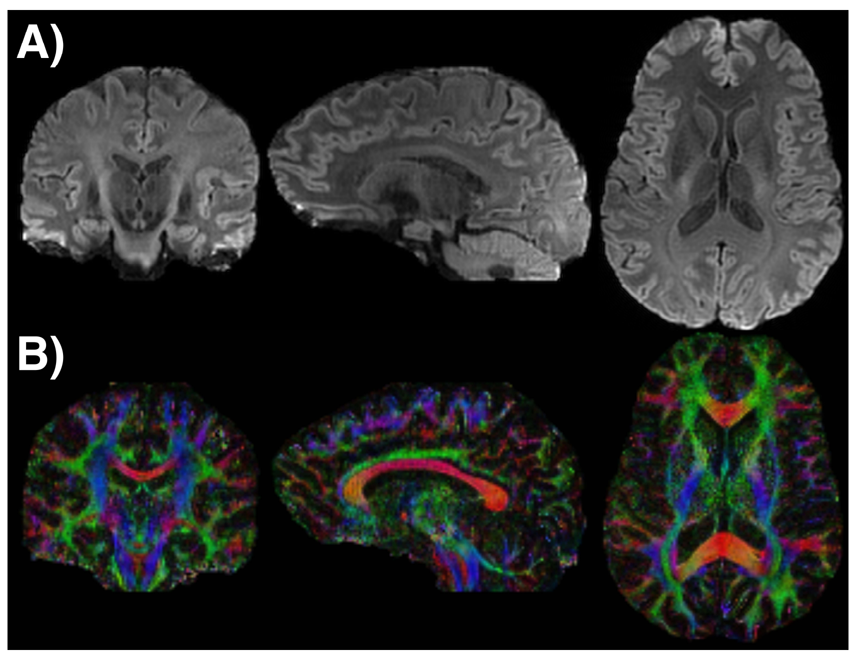

Figure 2 A) ISO-DWI reconstruction in coronal, sagittal, and axial reformats. B) Color-coded FA map (L-R red, S-I blue, and A-P green) in coronal, sagittal, and axial. The coronal, and sagittal slices in A), and B) are not spatially equivalent. A) Slices were chosen to display gyration while B) to display brain stem structure.

Discussion & Conclusion

Diffusion-weighted 3D multi-slab EPI with 2D phase navigation can yield diffusion-weighted data with isotropic resolution and well-defined voxel shape. By pairwise varying the crusher area, the effect of stimulated echoes in the phase navigator is greatly reduced. We have shown that the excitation specific object phase induced by the diffusion gradients can for thin slabs be removed from a 3D volume by only a 2D (in-plane) navigator. If comparison is to be made with a 2D equivalent acquisition for SNR-efficiency (SNR/$\sqrt{}$scan time), a prolonged *TR* in the 2D case (to satisfy the slice coverage) has to be considered along with the $\sqrt{N_{kz}}$ gain in SNR arising from the slab encoding in the 3D case. A 1.3x1.3x1.3 mm^3 resolution is, as demonstrated, possible. For increased SNR efficiency and for more reasonable scan times voxel sizes around ~1.5x1.5x1.5 mm^3 might be preferred.

References
[1] Engström et al., ISMRM 2010 p. 1619; [2] Van et al., ISMRM 2010 p. 1391; [3] Oshio et al., JMR 1:695-700, 1991;