Sequence Modifications and Reconstruction Strategies for Multi-Slab Multi-Echo DWI

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Introduction

Multi-slab multi-echo diffusion weighted imaging has been proposed [1,2] as an alternative way of acquiring isotropic high-resolution diffusion data. Pseudo 3D approaches allow scanning in better SNR conditions than traditional 2D imaging, due to the larger excited volume, and can therefore reach smaller voxel volumes (<3.0μl). Combining Stejskal-Tanner diffusion preparation with the larger volume from the multi-slab readout [3] increases the demand on correction of image phase caused by the diffusion encoding gradients. Excitation and refocusing pulses has to be considered, as they will control the slice uniformity, crucial when looking at reformatted projections, along with sequence modifications to avoid unwanted signal interference. In this work we present a chain of techniques and methods that can be used to improve the outcome of a diffusion weighted multi-slab multi-echo scan.

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. 1A). In order to avoid cancellation between the crushers and slab Fourier encoding, the polarity of the crusher gradient, along with the slice selection gradient, was modified to follow the polarity of the slab Fourier encoding gradient (indicated by the dashed line in Fig. 1A). To suppress stimulated echoes in readout 2 the crushers were pairwise given different area as seen in Fig 1A. The sequence was modified to use 10ms sharp SLR optimized 180° refocusing pulses, in order to ensure slice profile. A one-time iterative search to find optimal RF-gain for slab uniformity (not maximizing slab signal) was performed, and the gain-settings were tabulated for future scans. Diffusion encoding gradient induced phase was corrected for by calculating a phase difference map, ΔΦ, between the second readout (triangularly low-pass filtered) of phase encoding step -1kz and all other second readouts respectively. The phase of the ΔΦ was then removed, from the first readout, in order to make slab direction Fourier transforms possible [4] (Fig. 1C). Data was then in-plane phase corrected, by multiplying each image with the conjugate of a low-resolution phase representation of itself, in order to grid slabs (Fig. 1D), and to do shot combination with complex averaging. To improve slab gridding stripe artifacts the slab profiles were pre-weighted, using a Fermi filter, to address residual profile imperfections. Data were collected on a GE 750 3T system using an 8-channel head coil and the following relevant scan parameters, $TE_{1,2}/TR$ = (79, 135)/4800 ms, $matrix_{slab}$ = 144x144x8, slab. thk. = 10.5 mm, slab.spc. = 6 mm, FOV_{slab} = 220x220x12 mm, slabs = 27, NEX = 3, voxel size = 1.5x1.5x1.5 mm^3 (3.4 μl), b = 1000 s/mm^2, 2 T2 and 6 non-collinear diffusion directions.

Results

Fig. 1B shows the effect of avoiding cancelation between the 1st refocusing pulse right side crusher and the slab Fourier encoding gradient. Left is without modifications, right is with. In Fig. 1E we show the slab improvement of using uniformity calibrated 10 ms SLR optimized refocusing pulses instead of the vendor provided 4 ms pulses. Fig. 2 shows a reconstructed, reformatted, sagittal and coronal slices (A) without and (B) with slab phase correction.

Discussion & Conclusion

In Fig. 1 and Fig. 2 we demonstrate that sequence modifications are necessary to do multi-slab based diffusion weighted imaging. As with the current phase correction method a 2D navigator approximates a randomized phase field covering a 3D-slab. Validation of the method indicates that the approach holds for slabs up to ~25-30mm, well above our current slab direction FOV. Slab thickness and overlap was chosen to optimize scan efficiency, slabs were overlapped by ~35% maximizing the number of slabs per TR, but can be further separated if an increased slab direction FOV is desired. With a well-defined slab profile, slab separation can be set in a way that only part of the profile, with ~0.7 of maximum intensity, intersect, creating a homogenous SNR field over the imaged volume when gridded together, which would be preferred in fiber tracking.

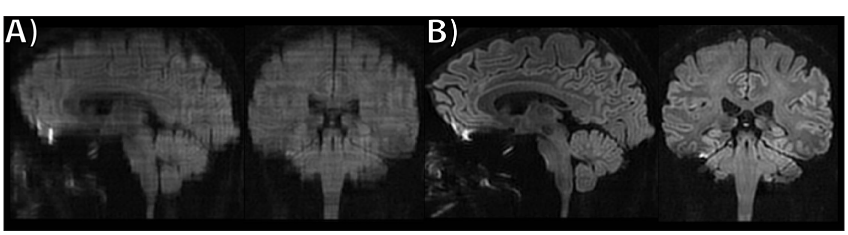

Figure 2 ISO DWI from axial scan reformat in sagittal and coronal, A) without phase correction, B) with phase correction

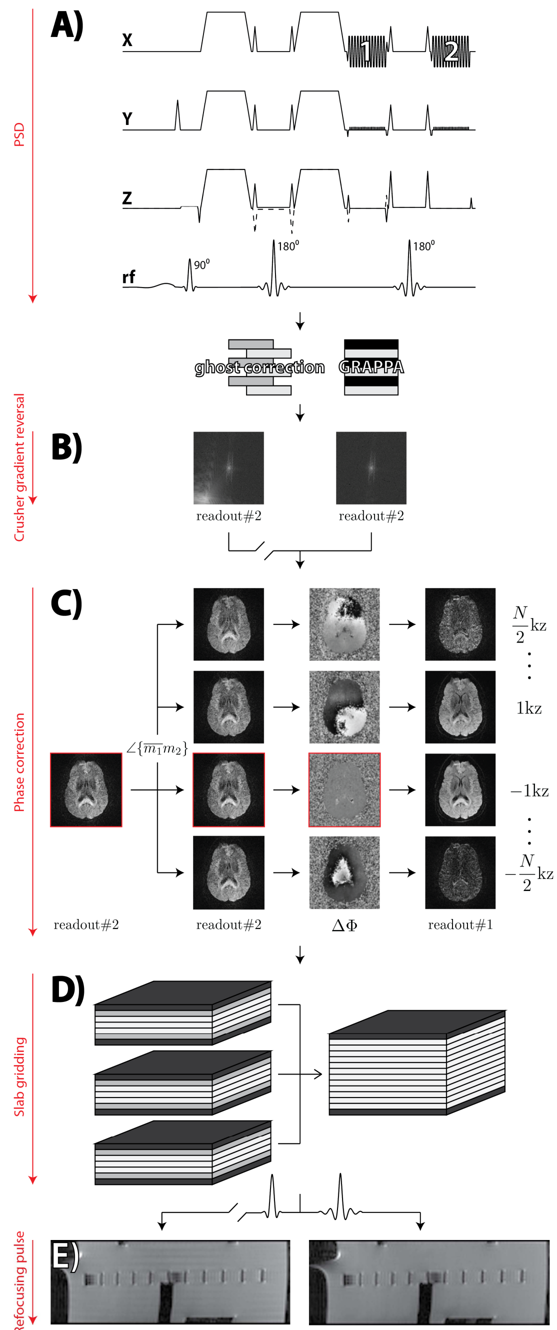

Figure 1 Selected parts of the multi-slab multi-echo ss-EPI diffusion reconstruction chain

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; [4] Pipe, ISMRM 2007 p. 1486;