Higher-Order Spin-Echo Selection for Reduced FOV Diffusion Imaging of the Brainstem at 7T

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Introduction:

Reduced Field-Of-View (FOV) imaging [1] describes a group of methods where the FOV can be chosen smaller than the imaged object without the occurrence of aliasing artifacts. An important application is single-shot MRI, where the FOV reduction allows for shortening the echo time and the readout duration, and thereby increases the achievable signal-to-noise-ratio (SNR) and robustness against B_0-offresonance artifacts respectively. Therefore reduced FOV methods have become an important tool for imaging of e.g. the spinal cord, the heart, the prostate and the kidneys, in particular for diffusion weighted imaging which is typically acquired in single-shot mode.

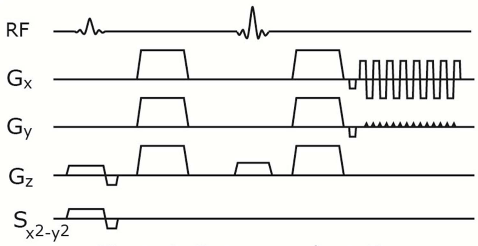

Figure 1: Sequence schematic

For spin-echo experiments, a common way to implement FOV reduction in the phase direction is to apply the 90° pulse and the 180° pulse perpendicular to each other [2]. However, this method is SNR-inefficient for multi-slice imaging due to the required long repetition times. An alternative is to apply the spin-echo pulses in an oblique fashion and thereby diminish this problem [3]. However, a trade-off with the achieved FOV selectivity (transition widths) and multi-slice capability has to be made.

To address this problem we propose to use second-order fields during slice selection for one of the spin-echo pulses, as has early been suggested by Oh et al. [4]. The method was implemented to further improve the spatial selectivity of non-coplanar spin-echo for multi-slice 2D single-shot SE-EPI and was applied to DW MRI of the brainstem at 7T.

Methods:

Single-shot DW SE-EPI data (in-plane resolution: $(1\ \mathrm{mm})^2$, slice thickness: 4mm, 20 slices, 4 averages, b=1000 s/mm^2 in 6 orientations + b_0) of a spherical phantom and of the brainstem was acquired on a full FOV (200mm x 200mm, TE: 101ms) and a reduced (phase-direction) FOV (200mm x 50mm, TE: 65ms) at 7T. To spatially limit the spin-echo formation an additional X^2-Y^2 shim field was switched during slice selection of the 90° pulse (Fig. 1). Input to the shim amplifier (Resonance Research Inc., Billerica, USA) was generated on a separate PC and was fed to the analog interface of the shim amplifier via a digital-to-analog converter (National Instruments, Austin, USA) which was synchronized with the sequence by the TTL physiology trigger of the MR system.

The relative strength of the shim and gradient amplitude was chosen such that multi-slice acquisition was possible using two image stacks (slice-thickness = slice-gap) resulting in a transition width of half the size of the inner volume (Fig. 2a). This was achieved by switching the shim fields with maximum amplitude and by reducing the slice-selection-gradient (and the bandwidth of the 1D selective 90 degree RF pulse) by a factor of 5 as compared to the default implementation of the MR system, resulting in a bandwidth (BW) of 270 Hz (duration: 11.3 ms) of the 90° RF pulse.

Results:

The phantom data (Fig.2a-g) showed that the application of the higher-order slice selection (Fig.2d,e) resulted in the expected spin-echo profile (Fig.2f) without signal loss in the inner volume (Fig.2g), allowing a FOV reduction without aliasing in the inner volume (Fig.2e). The in-vivo images showed strong distortions relating to static ΔB_0 distortions for the full-FOV scans (Fig.2h). The distortions were greatly diminished for the reduced FOV acquisitions (Fig.2i,j) and aliasing artifacts could be removed when applying higher-order slice-selection (Fig.2j). Finally, the ADC and FA maps were calculated for the in-vivo DTI dataset (Fig.3).

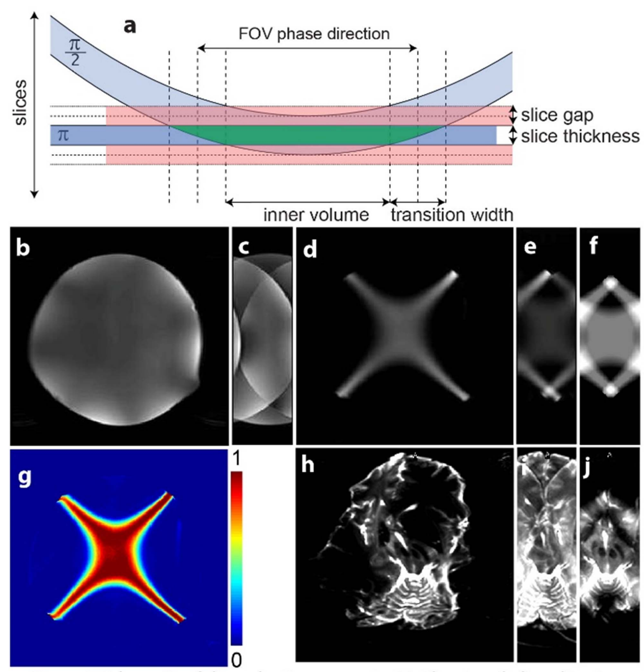

Figure 2: Schematic of slice selection geometry (a). Phantom (b-f) and in-vivo (h-j) data on a full FOV (b,d,h) and on a reduced FOV (c,e,i,j) with (d,e,j) and without (b,c,i) higher-order spin-echo selection. Simulated spin-echo selection aliasing pattern (f). Relative signal (g) of *(d)* and *(b).*

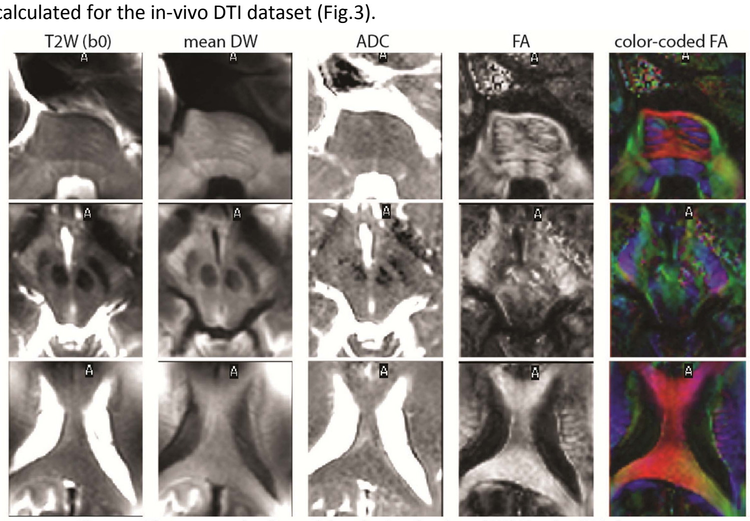

Figure 3: Three example slices of the obtained reduced FOV in-vivo DTI data.

Discussion: The presented method allows for robust and SNR efficient diffusion imaging of the brainstem at high field strength with strongly reduced ΔB_0 distortions. As compared to oblique slice selection with linear gradients [3], the spatial selectivity was improved by a factor of 2. The implementation gains from its robustness against B_0, B_1 and gradient inaccuracy as compared to methods relying on 2D selective RF pulses [5] and is not limited by SAR constraints at high fields as compared to outer volume suppression [6]. The method was implemented using the MR system's shim coils and amplifiers, and the low BW of the 90° RF pulse did not compromise the image quality, however an increase in available shim amplitude would be interesting to allow for shorter RF pulses. The achievable high in-plane resolution and robustness also renders this method promising for diffusion imaging in other anatomical regions.

References: 1: Gore et al., MRI (31), 2013, **2:** Feinberg et al., Radiology (3), 1985, **3:** Wheeler-Kingshott, (47), 2002, **4:** Oh et al., MRM (16), 1990, **5:** Saritas et al., MRM (60), 2008, **6:** Wilm et al., MRM (57), 2007