DWI of the Spinal Cord with Limited FOV Single-Shot EPI

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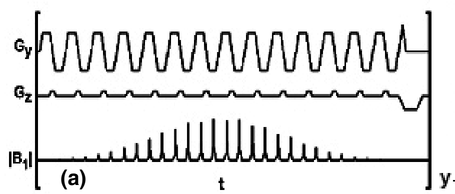
Introduction: Diffusion weighted imaging (DWI) of the spinal cord is important in the diagnoses and better understanding of damage to the long fiber tracts. There are potential important clinical applications for conditions such as ischemia and multiple sclerosis. *In vivo* DWI of the spinal cord requires high spatial resolution due to the small cross-sectional size of the spinal cord. Although single-shot diffusion-weighted echo-planar imaging (ss-DWEPI) provides excellent robustness against motion-induced phase perturbations, the limited readout time due to the highly inhomogeneous magnetic environment of the spine makes it difficult to obtain ss-DWEPI images of sufficient quality [1]. In this work, we achieve higher resolution spin-echo ss-DWEPI images, without the need for a longer readout, by taking advantage of the highly rectangular geometry of the spine. By using a 2D echo-planar RF excitation pulse and a 180^0 refocusing pulse, we limit the FOV in the phase-encode (PE) direction (selected as A/P direction) and suppress the signal from fat simultaneously.

Methods: A 2D echo-planar pulse that provides independent control over the slice thickness and FOV in PE direction was designed (Figure 1.a). The duration of the pulse was 16.8 ms with a 90^0 flip angle over a 4mm x 6cm slab. The displacement between fat and water in the blipped slice-select direction due to chemical shift [2] is such that fat is completely pushed outside the imaging slab. We then use a 180^0 refocusing RF pulse with crushers to refocus water only in the main lobe of the excitation (Figure 1.b).



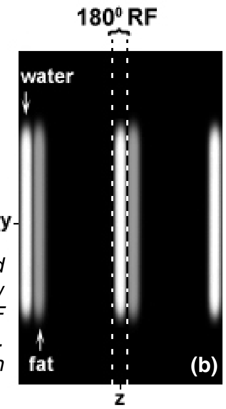
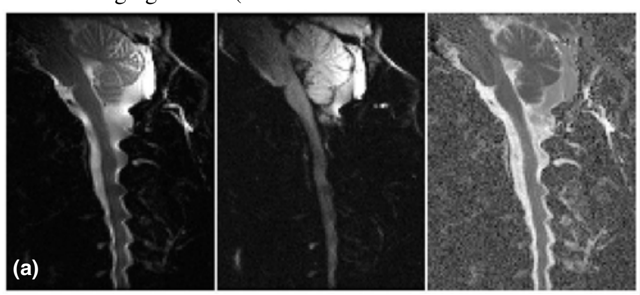


Figure 1. *2D echo-planar pulse (a), and simulation of excitation profile, showing how the 2D RF pulse and refocusing 180⁰ RF pulse select water only in the main lobe (b). (Fat is shown darker for illustration purposes)*

In vivo sagittal images of the cervical spinal cord of a healthy subject were acquired using a 1.5T GE Excite scanner (40 mT/m gradients with 150 mT/m/ms slew rates) and a 12.7 cm single-channel surface coil, with TE = 84.3 ms, ±62.5 kHz sampling bandwidth. The limited imaging FOV was 18x6 cm^2 with 4mm slice thickness, 192x64 imaging matrix (0.94x0.94 mm^2 in-plane resolution). A partial k-space percentage of 75% in the PE direction, corresponding to an echo train length (ETL) of 48 was used. For comparison, a regular single-shot EPI sequence with same readout time was used, for which the FOV in the PE direction is limited only by the sensitivity of the receive coil. The imaging parameters were TE = 87.5 ms, 18x13.5 cm^2 FOV, 128x96 matrix (1.41x1.41 mm^2 in-plane resolution), with a partial k-space percentage of 75%, corresponding to an ETL of 72.



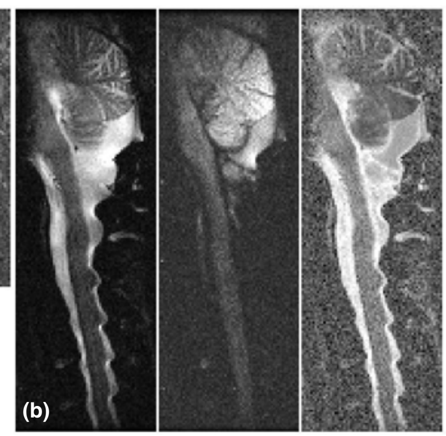


Figure 2. *Regular (18x13.5 cm²) ss-DWEPI (a) and higher resolution limited FOV (18x6 cm²) ss-DWEPI (b). The images are non-DW (b = 0), DW(b = 350 s/mm² and ADC maps, from left to right).*

Using Stejskal-Tanner spin-echo diffusion-weighting gradients in the cephalo-caudal (CC) direction, the *b* values were 0 and 350 s/mm^2. Each sequence was repeated every 3.5 seconds, for a total scan time of 4.5 minutes, to give 25 non-DW and 50 DW images. The homodyne algorithm was used to reconstruct the partial k-space data.

	Reference [3]	Reg. ss-DWEPI	Lim. FOV ss-DWEPI
Cervical Cord (WM)	1863±160	2030	1852
CSF	5880±208	7100	5565

Table 1. *Comparison of mean ADC values (in 10^{-6} mm^2/s)*

Results: Figure 2 shows corresponding non-DW (*b* = 0), DW (*b* = 350 s/mm^2) images and Apparent Diffusion Coefficient (ADC) maps for the discussed sequences. Limited FOV single-shot EPI sequence provides higher in-plane resolution for the same imaging time. In Table 1, mean ADC values for the ADC maps are given, in comparison with the results in [3].

Discussion: Thus far, only a few investigators have used ss-DWEPI for the spinal cord, due to its limited readout time capability. Limiting the FOV in the PE direction provides higher resolution images, despite the inhomogeneous magnetic environment. The 2D echo-planar RF pulse is compatible with multi-slice imaging while enabling fat suppression, unlike restricting the FOV using intersection of two separate RF pulses. The whole sequence takes 190ms, allowing subsequent imaging of 18 slices in the given 3.5 second repetition interval.

Conclusion: High resolution, robust ss-DWEPI of the spinal cord can be achieved by limiting the FOV in the PE direction using a combination of 2D echo-planar RF excitation pulse and 180^0 refocusing pulse, which also suppresses the fat signal.

References:

1. Bammer, et al. Top MRI 14:461-476, 2003.
2. Alley, et al. MRM 37:260-267, 1997.
3. Bammer, et al. JMRI 15:364-373, 2002.