High-Resolution Axial DWI of the Spinal Cord with Reduced-FOV Single-Shot EPI

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Introduction: Diffusion weighted imaging (DWI) of the spinal cord has potential to help diagnose central nervous system related diseases, such as multiple sclerosis and ischemia. Due to the small cross-sectional size of the spinal cord, axial i*n vivo* DWI of the spinal cord requires high spatial resolution [1]. This is very challenging, especially considering the sources of motion around the spinal cord and the highly inhomogeneous magnetic environment of the spine. Single-shot diffusion-weighted echo-planar imaging (ss-DWEPI) provides excellent robustness against motion-induced phase perturbations, but has limited ability to provide high-resolution images. Here, we achieve high-resolution axial *in vivo* ss-DWEPI images by reducing the field-of-view (FOV) in the phase-encode (PE) direction with a 2D echo-planar RF excitation pulse. This excitation scheme is compatible with multi-slice imaging, and furthermore suppresses the signal from fat with the incorporation of a 180^0 refocusing pulse.

Methods: As shown in Figure 1.a, the designed 2D echo-planar RF excitation pulse provides independent control over the slice-select (SS) and PE directions. The pulse generates a 90^0 flip angle over a 5mm × 3cm slab, with a 16.8 ms pulse duration, N_{blip}=14 , TBW_{SS}=3 and TBW_{PE}=12. The displacement between fat and water due to chemical shift [2] is such that fat is completely pushed outside the imaging slab in the SS-direction. Then, a 180^0 refocusing RF pulse with crushers is used to refocus water only in the main lobe of the excitation (Figure 1.b).

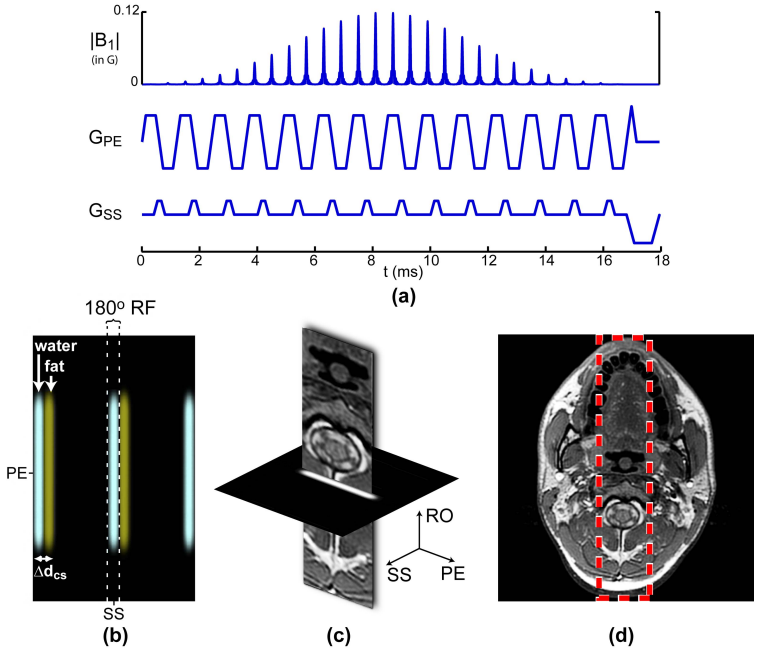

***Figure 1. (a)** 2D echo-planar RF pulse, **(b)** simulated excitation profile, **(c)** the resulting profile shown in 3D, along with the reduced-FOV image, and **(d)** anatomical axial image and the selected FOV (shown with dashed red box).*

To demonstrate the method, *in vivo* axial 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 an 8-channel head coil. A total of 4 slices were acquired, with the reduced FOV of 8 × 3 cm^2, 0.62 × 0.62 mm^2 in-plane resolution, 5 mm slice thickness and 0.5 mm slice spacing. Other imaging parameters were TE = 67.7 ms, 128 × 48 imaging matrix, 62.5% partial k-space coverage, 31.25 kHz sampling bandwidth.

Stejskal-Tanner spin-echo diffusion-weighting gradients were applied in the superior-inferior (SI), anterior-posterior (AP), and left-right (LR) directions, with b = 500 s/mm^2. To avoid pulsatile cord jiggling and CSF motion, the sequence was cardiac gated with a delay of 400 ms after the systole peak [3]. To obtain sufficient T_1 recovery, TR was chosen as 4 cardiac cycles. The total scan time varied from 10 to 12 minutes, depending on the heart rate. During this scan time, a total of 20 single-shot non-diffusion-weighted (i.e. T_2-weighted), 60 DW_{SI}, 40 DW_{AP} and 40 DW_{LR} images per slice were acquired and then averaged. Refocusing reconstruction [4] was applied, with the central 12.5% of k-space treated as the "navigator" for each single-shot data, followed by the partial k-space homodyne reconstruction.

Results: Figure 2 shows T_2-weighted (i.e. b = 0), isotropic DW (b = 500 s/mm^2) images and corresponding ADC maps (ADC_{iso}) for all four slices of the axial reduced-FOV ss-DWEPI. Note that only DW_{iso} images are shown here for space considerations, even though DW_{SI}, DW_{AP} and DW_{LR} images for each slice were reconstructed first, to later form the DW_{iso} image by taking the geometric mean of the three.

Discussion: The whole sequence takes 120ms, allowing a large number of slices to be imaged simultaneously in a single TR. The number of slices that can be imaged in a single TR can be increased by using a 2D echo-planar RF pulse with larger N_{blip} values, so that the excitation profiles of the adjacent slices do not overlap. When compared to previously presented reduced-FOV methods [5,6], this method does not require additional outer volume suppression pulses and the resulting SNR does not depend on the number of slices.

Conclusion: Reduced-FOV ss-DWEPI method achieves high-resolution (sub-*mm*) DWI of the spinal cord, which is essential for the potential clinical use of this technique. Furthermore, reducing the FOV as described in this work reduces the required readout time and suppresses the fat, while enabling multi-slice imaging.

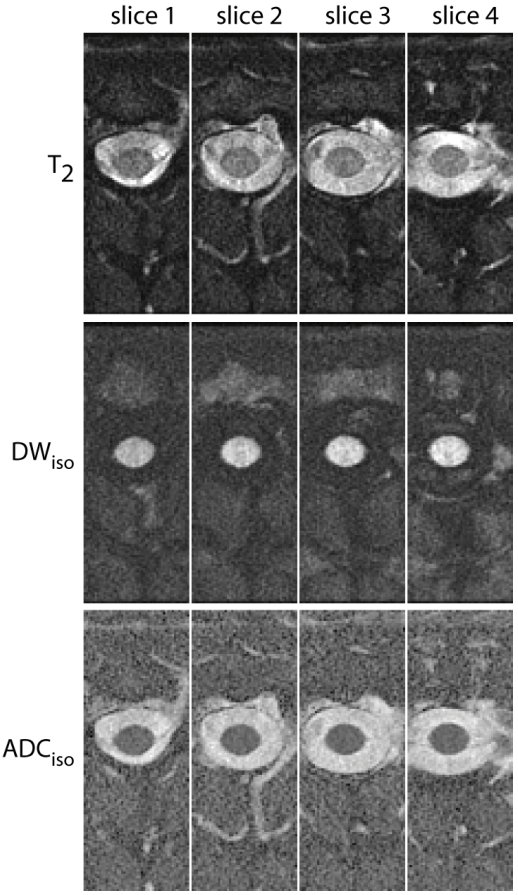

***Figure 2.** In vivo axial reduced-FOV ss-DWEPI images of the cervical spinal cord. From top to bottom: T_2-weighted, isotropic DW images (DW_{iso}), and corresponding ADC maps (ADC_{iso}). (b = 500 s/mm^2, 0.62 × 0.62 mm^2 in-plane resolution)*

References:

1. Bammer, et al. Top MRI 14:461-476, 2003.
2. Alley, et al. MRM 37:260-267, 1997.
3. Clark, et al. MRM 41:1269-1273, 1999.
4. Miller, et al. MRM 50:343:353, 2003.
5. Jeong, et al. MRM 54:1575–1579, 2005.
6. Wilm, et al. MRM 57:625-630, 2007.