High-Resolution DTI Tractography of the Spinal Cord with Reduced-FOV Single-Shot EPI at 3T

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Introduction: Diffusion tensor imaging (DTI) is a rapidly growing field with the potential to advance our understanding of the connectivity of gray/white matter regions in the brain. There is much interest in extending this research to the spinal cord, whose connections are responsible for motor and sensory functions of the body. However, DTI of the spinal cord is limited by the need for high spatial-resolution, as well as the difficulties associated with susceptibility differences, field inhomogeneities (especially at 3T), and motion of the cord. A reduced field-of-view (FOV) method using a 2D echo-planar RF (2D-EPRF) excitation has recently been shown to overcome these limitations and improve spinal cord diffusion-weighted imaging (1). This study addresses the application of this method to acquire high-resolution low-distortion DTI (including both fractional anisotropy (FA) maps and fiber tractography) of the spinal cord at 3T.

Theory: The reduced-FOV method proposed in Ref. 1 uses a 2D-EPRF excitation pulse to achieve high in-plane resolution and inherent fat suppression, all the while allowing contiguous multi-slice imaging. As shown in Fig. 1, the fat profile is considerably shifted in the slice-select (SS) direction due to the long RF pulse duration (2) and increased chemical shift at 3T. With the use of a refocusing 180^O RF pulse, this spatial shift can be exploited to refocus only the water in the main lobe of the 2D excitation, while suppressing the signal from fat.

To perform *in vivo* DTI of the spinal cord, we designed a 2D-EPRF pulse and optimized it to meet the following requirements: 4.5 cm reduced-FOV in the PE direction, 8 contiguous slices, and a pulse duration of 14 ms. A minimum-phase SLR design was employed to reduce the echo time (TE) for improved SNR.

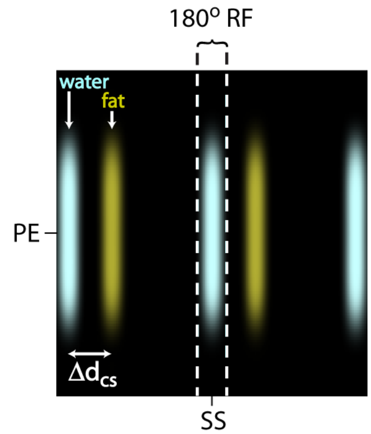

Figure 1. *Simulated excitation profile for the 2D echo-planar RF pulse at 3T. The fat profile is considerably shifted in the slice-select (SS) direction w.r.t. the water profile. The 180^O RF pulse refocuses water only in the main lobe of the excitation. (Color coded for illustration purposes)*

Methods: *In vivo* DTI images of the cervical spinal cord of healthy subjects were acquired on a 3T GE Excite scanner (40 mT/m gradients with 150 mT/m/ms slew rates) using an 8-channel CTL coil. Sagittal imaging was chosen to cover the whole cervical spine at once. The in-plane resolution was 0.94 × 0.94 mm^2, with 3 mm slice thickness, no slice spacing, b = 500 s/mm^2, FOV = 18 × 4.5 cm^2, 192 × 48 imaging matrix, ±166 kHz bandwidth, ramp sampling, TE = 55.7 ms, TR = 3.2 s, and NEX = 16. The total scan time was 12 minutes for 2 T_2-weighted images and 12 diffusion gradient directions, the orientations of which were optimized using Coulomb's law of repulsion (3). Localized higher-order shimming was performed on the region of interest to reduce local field inhomogeneities that are more pronounced at 3T.

Following the computation of the diffusion tensor, the FA map and the color FA map showing the principal diffusion direction were produced. The white matter fibers connecting two selected regions of interest (ROI) were generated using smartTRACK fiber tractography software (4). The thresholds for curvature and FA were chosen as 37 degrees and 0.3, respectively.

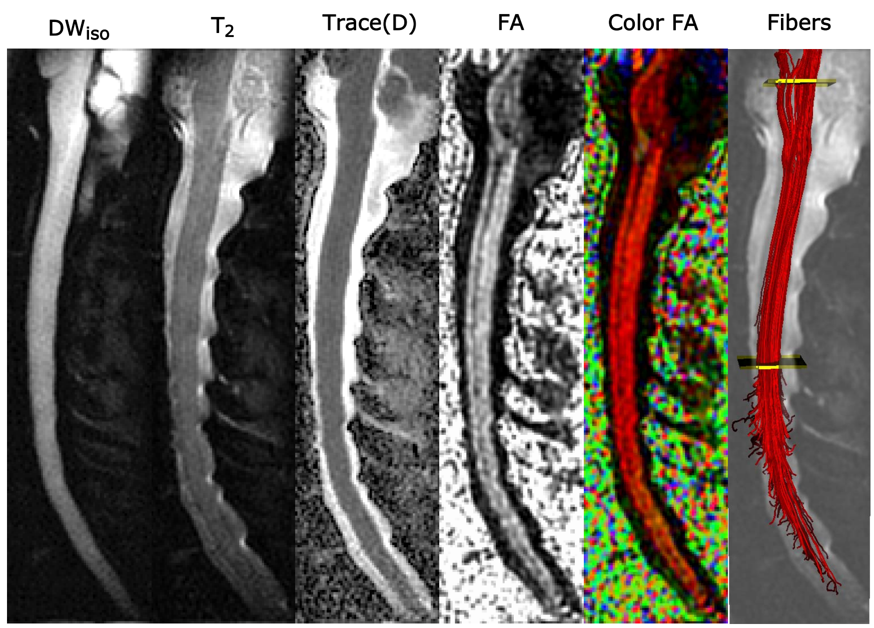

Figure 2. DTI tractography of the spinal cord: 0.94×0.94×3 mm^3 voxel size, 12 diffusion encoding directions. The full imaging FOV for the central slice is displayed. Color FA map depicts the main direction of diffusion as the superior/inferior direction (Red: S/I, Green: A/P, Blue: R/L). The image on the far right shows the fiber tracts connecting the medulla oblongata to the center of the cervical spinal cord. The mean FA values on the lower ROI were measured as 0.72.

Results: Figure 2 displays the results of the high-resolution DTI tractography of the spinal cord. The FA maps clearly depict the detailed structure of the medulla oblongata at the upper end of the spinal cord, while the gray matter running down the center of the cord is delineated due to its low FA. Fiber tracts connecting the medulla oblongata and the center of the cord are also clearly visualized. The mean FA values of the fibers on the lower ROI were measured as 0.72 ± 0.0045, within the range cited in literature for healthy volunteers (5).

Conclusion: High-resolution low-distortion *in vivo* DTI tractography of the spinal cord is demonstrated at 3T using the reduced-FOV ss-EPI method with 2D-EPRF excitation. High-quality DTI images can be produced with this technique due to its sharp reduced-FOV profile, as well as the contiguous multi-slice imaging and inherent fat suppression capabilities. This method could be used to assess the damage to long fiber tracts, for example, in the setting of spinal cord traumatic injury.

References: **1.** Saritas et al., MRM 60:468-473, 2008. **2.** Alley et al., MRM 37:260-267, 1997. **3.** Jones et al., MRM 42:515-525, 1999.
4. Aksoy et al., ISMRM Workshop on Methods for Quantitative Diffusion MRI of the Human Brain, 2005. **5.** Facon et al., AJNR 26:1587-1594, 2005.