Diffusion Tensor Imaging of the Pediatric Spinal Cord using an inner-FoV EPI Pulse Sequence in Normals and Patients with SCI

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Background and Objective

Diffusion Tensor Imaging (DTI) of the pediatric Spinal Cord (SC) poses several challenges. The small cord size has inherent low Signal-to-Noise Ratio (SNR) of the diffusion signal which is vital in MR imaging, respiration/cardiac movements cause artifacts, and echo planar imaging sequences used for obtaining diffusion indices cause eddy current distortions (1). Efforts can be made to reduce a subject's motion, such as using sedation, cardiac gating and respiratory compensation. However, especially in pediatric imaging, these methods can become cumbersome and increase the patient's time in the scanner. Hence the choice of the MRI pulse sequence and its proper optimization are crucial to successfully overcome these challenges. The purpose of this study was to (a) evaluate the validity and reliability of DTI in children using a newly developed inner-Field-of-View (iFoV) sequence with spatially selective 2D RF excitations (2), (b) examine reproducibility of the DTI measures and (c) investigate DTI parameters in children with and without Spinal Cord Injury (SCI).

Methods & Materials

Subjects: A total of 20 subjects, 10 controls (mean age 16.1 yrs) without evidence of SC pathology and 10 patients (mean age 13.2 yrs) with chronic SCI were recruited. Subjects and their parents provided written informed assent and consent of the IRB-approved protocol.

Imaging: The iFoV sequence was implemented on a 3.0T Siemens Verio MR scanner and optimized to obtain various scanning parameters for imaging the pediatric SC. High resolution axial DTI images were acquired to cover the entire cervical SC (C1-C7). DTI imaging parameters included: 20 diffusion directions, b = 1000s/mm^2, voxel size = 1.2x1.2x3mm^3, axial slices = 35-45 (depending on subject's height), TR = 6100-8000 ms, TE = 115 ms, number of averages = 3 and acquisition time = 7 min. Conventional T1 and T2 weighted scans were also obtained. Anesthesia was not administered to the subjects in this study. To test for reproducibility of the DTI measures, all subjects returned within approximately nine hours to the MRI center and were scanned a second time.

Data Analysis: Initially motion correction of the DTI images was performed using the Automated-Image-Registration (AIR) package implemented in DTIstudio (www.mristudio.org). Next, tensor estimation was done using MedINRIA software (www-sop.inria.fr/asclepios/software/MedINRIA/). The following DTI indices were extracted from RoI's drawn at every axial slice location along the SC for both the 1st and 2nd scans: Fractional Anisotropy (FA), Mean Diffusivity (MD), transverse diffusivity (λ_T) and longitudinal diffusivity (λ_L). These RoI's were carefully drawn so that there was a consistent sparring of the outer margin of the cervical cord that represented approximately one voxel width to minimize volume averaging with the cerebral spinal fluid. DTI indices were reported at each disk level of the cervical SC as well as the upper (up), middle (mid) and lower (low) portions of the cervical vertebral body. The 10 patients with SCI represented a spectrum of cervical injuries ranging from C1 to C6 levels. Statistical analysis was performed to compare averaged DTI indices between the controls and the subjects with SCI and to test for reproducibility of the DTI measures.

Results & Conclusion

The images obtained with the iFoV sequence produced reliable DTI data with reduced eddy current distortions and good delineation of gray white matter structures (Figure 1). Statistically significant differences were seen between the controls' averaged FA ($p<0.0001$) and λ_L ($p<0.01$) values compared to the patients' values. However, no statistical differences were seen in MD ($p=0.09$) and λ_T ($p=0.73$). The controls showed an average FA = 0.54 ± 0.08, MD = $0.60\text{x}10^{-3}\text{mm}^2/\text{s} \pm 0.17\text{x}10^{-3}$, λ_T = $1.00\text{x}10^{-3}\text{mm}^2/\text{s} \pm 0.29\text{x}10^{-3}$ and λ_L = $0.40\text{x}10^{-3}\text{mm}^2/\text{s} \pm 0.12\text{x}10^{-3}$. The subjects with SCI showed reduced FA and increased MD values compared to the controls: FA = 0.30 ± 0.12, MD = $0.87\text{x}10^{-3}\text{mm}^2/\text{s} \pm 0.45\text{x}10^{-3}$, λ_T = $1.07\text{x}10^{-3}\text{mm}^2/\text{s} \pm 0.46\text{x}10^{-3}$, and λ_L = $0.73\text{x}10^{-3}\text{mm}^2/\text{s} \pm 0.45\text{x}10^{-3}$ (Figures 2-5). Test-retest reproducibility showed an Inter-Class Correlation (ICC) of (>0.9) in both the control and SCI groups for all DTI parameters.

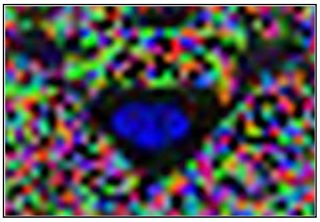
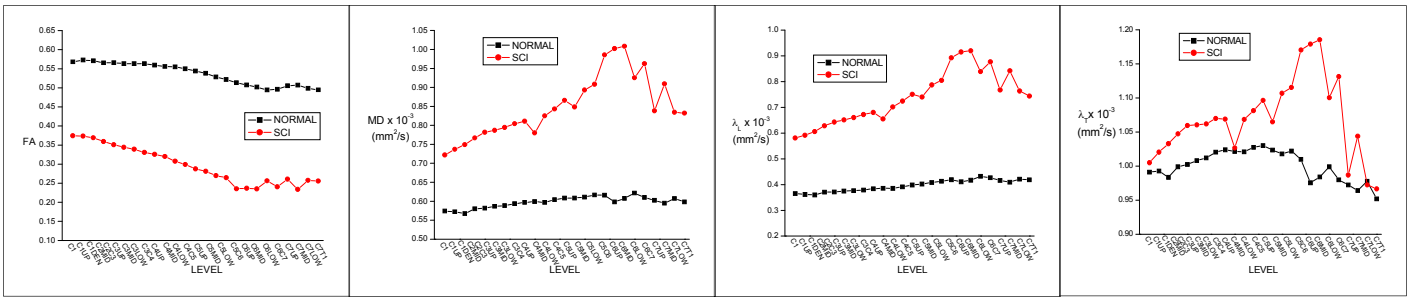


Figure 1 Axial FA color image of a control subject's cervical SC (C5 level)

In conclusion, DTI measurements in the pediatric population were obtained using a newly developed and optimized iFoV sequence. The differences in diffusion metrics between normal and injured SC's were demonstrated. Reduced FA and increased diffusivity values for injured SC were seen in patients with SCI in comparison with the controls. Test-retest showed excellent reproducibility of the DTI indices in the repeated scans.



Figures 2-5. Average FA, MD, λ_T and λ_L for the normal subjects compared to the patients with SCI as a function of cervical SC level

References: (1) Mohamed F.B. Proc. ISMRM. 2010:18:p2451. (2) Finsterbusch J. JMRI 2009:29(4):987-93.