Inner Field of View Diffusion Kurtosis Imaging (DKI) of the Pediatric Spinal Cord

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Background and Objective

Diffusion Tensor Imaging (DTI) has been gaining more utility and clinical relevance in the spinal cord over the past several years. Functional techniques such as DTI have often been restricted to the brain due to the inherent problems associated with imaging of the spinal cord. The small imaging volume lowers Signal to Noise Ratio (SNR) due to increased susceptibility to subject motion, cardiac and Cerebral Spinal Fluid (CSF) pulsation, and EPI distortion. These problems have been mitigated through the use of inner Field of View (iFOV) pulse sequences with spatially selective 2D RF excitations (1) which reduces the imaging volume in the phase encode direction. It has been shown that using this sequence the DTI indices are significantly different in pediatric subjects with and without Spinal Cord Injury (SCI) (2). However, DTI analysis is limited to assuming an ideal Gaussian distribution function with no intermolecular interactions. This assumption potentially reduces the amount of clinically relevant data that can be measured using diffusion imaging. By measuring the excess kurtosis, or peakedness, of the Gaussian distribution it is possible to get a better understanding of the underlying microenvironment. This process known as Diffusion Kurtosis Imaging (DKI) is determined by including the second order quadratic term of the expansion of the natural log of the diffusion signal in the analysis model (3). The purpose of this study was to demonstrate the feasibility of using DKI metrics as potential biomarkers for characterization of pediatric spinal cord both with and without SCI using a newly developed iFOV DKI imaging sequence.

Methods & Materials

Subjects: A total of 16 subjects, 12 controls (mean age 11.2 yrs) without evidence of Spinal Cord (SC) pathology and 4 patients (mean age 9.5 yrs) with cervical 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 for both signal and scan duration when imaging the pediatric SC. High resolution in plane axial DTI images were acquired to cover the entire cervical SC (C1-C7). DKI imaging parameters included: 30 diffusion directions, b-values = [0, 1000, 2000] s/mm^2, voxel size = 0.8x0.8x6mm^3, axial slices = 25, TR = 5200 ms, TE = 123 ms, number of averages = 1 (with 6 B_0 images) and acquisition time = 5:48 min:sec. Conventional T1 and T2 scans were also obtained for clinical review. Anesthesia was not administered to the subjects in this study.

Data Analysis: Initially, motion correction was performed on the Diffusion Weighted (DW) images using an in-house developed Matlab software package. The 6 B_0 images were averaged and served as the stationary image for a 6 parameter rigid body registration algorithm of all DW images. Next, both diffusion and kurtosis tensors were estimated using a least squares approach by linearizing the kurtosis equation as outlined in (4). RESTORE (5) was also implemented in the algorithm to handle outlier rejection of the tensors. The following DKI and DTI indices were extracted from Region of Interests (ROI) drawn at every axial slice location along the cervical SC: Fractional Anisotropy (FA), Mean Diffusivity (MD), Axial Diffusivity (Dax), Radial Diffusivity (Drad), Mean Kurtosis (MK), Axial Kurtosis (Kax), and Radial Kurtosis (Krad) though the kurtosis indices as well as FA are the focus. These ROIs were drawn by keeping at least a 1 pixel margin between the cord and CSF to avoid partial volume contamination. All calculated indices were reported at each disk level of the cervical SC as well as the middle of the vertebral body. The 4 patients with SCI were clinically determined to have injuries predominately around the C6-7 level. Statistical analysis was then performed to compare averaged diffusion indices between the controls and the subjects with SCI for significant differences.

Results & Conclusion

The images obtained with the iFoV DKI sequence produced reliable diffusion kurtosis metric data (Figure 1). Statistically significant differences were seen between the controls' averaged FA ($p<0.01$), MK ($p<0.03$), and Krad ($p<0.01$) values compared to the patients' values. However, no statistical differences were seen with Kax ($p=0.07$). The controls showed an average FA = 0.51 ± 0.04, MK = 1.10 ± 0.11, Krad= 1.11 ± 0.14 and Kax = 0.91 ± 0.08. The patients with SCI showed a reduction in all the above metrics compared to the controls: FA = 0.41 ± 0.03, MK = 0.94 ± 0.09, Krad = 0.86 ± 0.09, and Kax = 0.82 ± 0.07. The FA values observed were comparable to values published in the current literature (2). Demyelination has been shown to be the primary factor in influencing Dax in animal studies (6) and the lack of statistical difference between the controls and patients for Kax could be attributed to a lack of demyelination in SCI. To the best of our knowledge this is the first demonstration of in-vivo DKI imaging in pediatric spinal cord: injured and non-injured. DKI indices may represent differences in the micromolecular environment between normals and patients with SCI. These preliminary findings are very encouraging and warrant further investigation with large populations for determining the applicability of DKI to the characterization of the spinal cord.

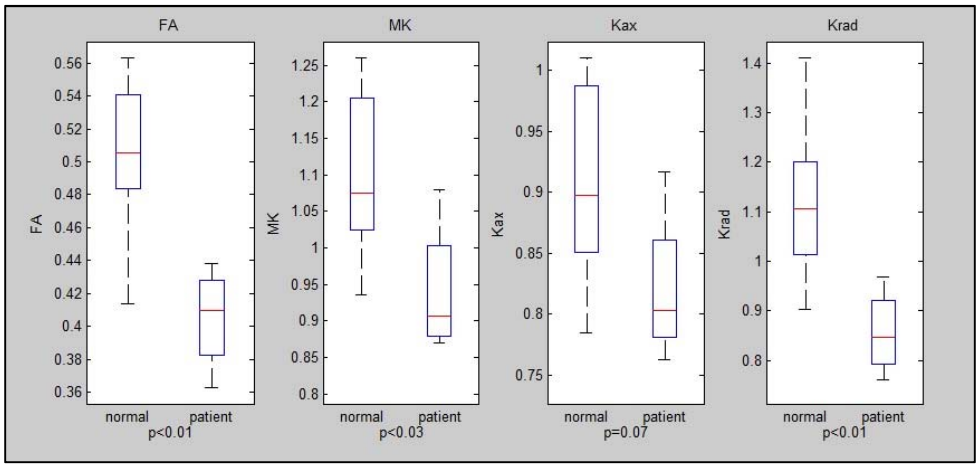

Figure 1: Box plots of differences in FA, MK, Kax, and Krad between normal and SCI subjects.

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