Diffusion Tensor Imaging of the Normal and Injured Pediatric Spinal Cord at 1.5 T

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Background and Objective

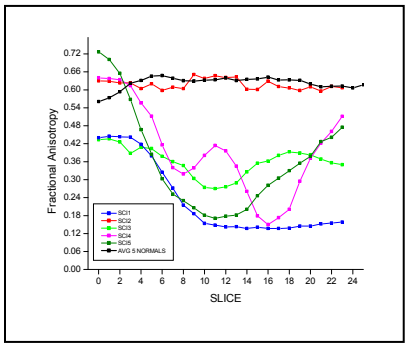
The International Standards for Neurological Classification of SCI (ISNCSCI) are used to determine the extent of motor and sensory impairment following spinal cord injury (SCI) (1). Recent reports show that the ISNCSCI do not have utility for children less than six years of age and that some children as old as eight years of age may have difficulty with the examinations (2). The purpose of this study was threefold: (a) to establish normative Diffusion Tensor Imaging (DTI) parameters of healthy spinal cord tissue in children without spinal cord injury as a means for comparison with children with spinal cord injury, (b) to evaluate the reliability and validity of DTI in children, and (c) to correlate the DTI measures in children with SCI with current standard clinical ISNCSCI exams.

Methods & Materials

Ten subjects, 5 control subjects with non-cervical idiopathic scoliosis and without evidence of spinal cord pathology (mean age 15 years) and 5 subjects with SCI (11.6 years) were enrolled in this study. Subjects and their parents provided written informed assent and consent, respectively, of the IRB-approved protocol. All subjects had two MRI scans and subjects with SCI had complete motor, sensory and anorectal examinations that were performed by a trained ISNCSCI examiner. Initially, axial imaging was performed to cover the entire cervical spinal cord (C1-C7) in control subjects. For the subjects with SCI, two vertebral bodies above and below the injury were imaged. The shot echo planar DTI imaging parameters included: 6 diffusion directions; b=700sec/mm^2, TR=6000ms, TE=60ms, FOV=240 mm, 128x128, and 4 acquisitions. The total imaging time to collect the DTI images was approximately 8 minutes. In order to test reproducibility of the DTI scans, the subjects returned within a mean of 34.3 days to the MRI center and imaged a second time. Fractional Anisotropy (FA) and Diffusivity (D) values (average, axial and radial) were obtained at different levels of the spinal cord by drawing regions of interest (ROI's) by a board certified pediatric neuroradiologist between the two different scans using DTI Studio (Johns Hopkins University) at the same locations. Statistical analysis was performed to compare the diffusion indices between the controls and subjects with SCI, reproducibility of DTI indices, and correlations between diffusion indices and ISNCSCI exams in children with SCI.

Results & Conclusion

The control subjects showed an average FA=0.62 ± 0.11; an average D=2.15x10^{-3}mm^2/sec ± 0.52x10^{-3}; axial D=1.23x10^{-3}mm^2/sec ± 0.29x10^{-3}; and radial D=0.44x10^{-3}mm^2/sec ± 0.24x10^{-3}. The subjects with SCI showed reduced FA values and increased D values compared with control subjects, FA=0.39 ± 0.22; average D=3.8 x10^{-3}mm^2/sec ± 2.02x10^{-3}; axial D=1.65 x10^{-3}mm^2/sec ± 0.65x10^{-3}; radial D=1.06 x10^{-3}mm^2/sec ± 0.69x10^{-3}. Significant differences were seen in the average FA (Fig. 1A), D (Fig. 1B), axial D, and radial D values between the normal and subjects with SCI. Figure 2 shows the MR tractography image of the cervical spinal cord derived from fractional anisotropy values in the white matter tracts, of a typically developing child (Fig. 2A) and that of a child with SCI at the C4-C7 levels, with absence of viable white matter tracts below the level of injury (Fig. 2C, arrow). Conventional midline sagittal T2-weighted image demonstrated focal atrophy of the lower cervical cord with associated abnormal increased signal involving the mid C5- through the imaged portion of the upper thoracic spine (Fig. 2B), consistent with post traumatic myelomalacia and gliosis. Test-retest reproducibility showed excellent inter-class correlation (ICC) in all the control group DTI index values (>0.9) while the group with SCI showed moderate ICC (>0.7) in all the DTI index values measured. There were statistically significant correlations between the various DTI indices and several ISNCSCI scores. In conclusion, preliminary normative DTI indices were determined for the pediatric population. Reduced FA and increased diffusivity values for injured spinal cord were seen in children with SCI in comparison with control subjects. Test-retest showed excellent reproducibility of the DTI indices in their repeat sessions. Clinical correlation with ISNCSCI scores showed good correlation with DTI indices.



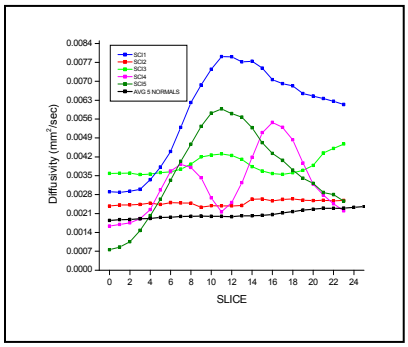


Figure 1A. Average FA values and average Diffusivity values (1B) for the normal subjects compared to the FA values for all the individual SCI patients as a function of cord level (slice #).

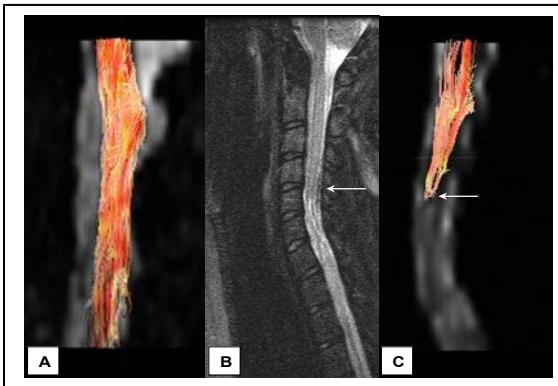


Figure 2: (A) MR tractography image of the cervical spinal cord of a typically developing child. (B) Conventional midline sagittal T2-weighted image of a child with SCI (C4-C7) demonstrates focal atrophy of the lower cervical cord and associated abnormal increased signal involving the mid C5- through the imaged portion of the upper thoracic spine (arrow), consistent with post traumatic myelomalacia and gliosis due to injury. (C) MR tractography image of the cervical spinal cord of the child in (B) demonstrates absence of viable white matter tracts below the level of injury (arrow). The color represents the cord fractional anisotropy values in the white matter tracts and is one of the measures to indicate the degree of myelination of the white matter tracts along the spinal cord.

References: (1) Mario RJ, , Barros T, et al. International Standards for Neurological Classification of Spinal Cord Injury. J Spinal Cord med 2003;26 (supp 1), S50-S56. (2) Mulcahey MJ, Gaughan J, et al. ISNCSCI*: reliability of data when applied to children and youths. Spinal Cord 2007a; 45:452-459.*