Examination of Tensor Estimation Methods for Cervical Spinal Cord DTI in Pediatric Subjects with Spinal Cord Injury and Typically Developing Subjects

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Background and Objective

Examination of injury in the pediatric spinal cord (SC) using diffusion tensor imaging (DTI) has promise in providing important information on white matter integrity and quantitative biomarkers for injury location and severity. The lack of a gold standard for DTI values complicates the interpretation of results. Different tensor estimation techniques have been developed and employed to ensure reliable results. When examining DTI datasets, the tensor estimation method chosen has the potential to impact the results of the analysis. To our knowledge, no comparison of tensor estimation techniques has been performed for the pediatric SC using typically developing subjects and subjects with SC injury. The purpose of this study is to examine the effects of tensor estimation techniques on DTI values for the cervical SC in healthy pediatric subjects and subjects with SC injury.

Methods and Materials

DTI data for the cervical SC (C1-C7) from 14 pediatric subjects (7 typically developing (TD) and 7 with SC injury) was acquired using an inner-field-of-view (iFOV) echo-planar DTI pulse sequence implemented on a 3T Siemens Verio scanner (1). The imaging parameters are: 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, and number of averages = 3. After acquisition, image registration was performed for diffusion weighted directions using a 3D rigid body transformation. Diffusion tensors were then calculated using three methods: ordinary linear least squares (LLS), linear least squares with non-positive tensor removal (2), and a robust outlier rejection fitting technique (3). Sagittal regions of interest (ROIs) were defined on the midline of the SC with sparring of the outer margin of the cord of approximately one voxel to minimize volume averaging with cerebrospinal fluid. Fractional anisotropy (FA) and mean diffusivity (MD) for each tensor estimation technique were then calculated for each ROI.

Results and Conclusion

Group average FA and MD values were reasonably consistent for each subject group between various tensor estimation techniques (Figure 1). The greatest differences from LLS were in the SCI group for the robust estimation method (3.2% FA, 7.1% MD). However, greater variation was observed within subjects, particularly when using the robust estimation method (Table 1). Using robust estimation, within subject difference from LLS ranged from -4.1% to 13.7% (FA) and -3.6% to 54.7% (MD) in SCI subjects and from -6.0% to 4.2% (FA) and -1.2% to 9.6% (MD) in TD subjects. This greater change in diffusion indices is likely caused by correction of physiological/motion artifacts by the outlier rejection technique employed by the robust estimation method. In SCI subjects, the potential for change in diffusion indices appears greater; possibly due to aberrant physiological motion resulting from injury caused changes in cord size and rigidity. As far as we are aware, the choice of tensor estimation has not been examined for pediatric subjects with SC injury and the results of this study suggest that potential for considerable variation in tensor estimation exists.

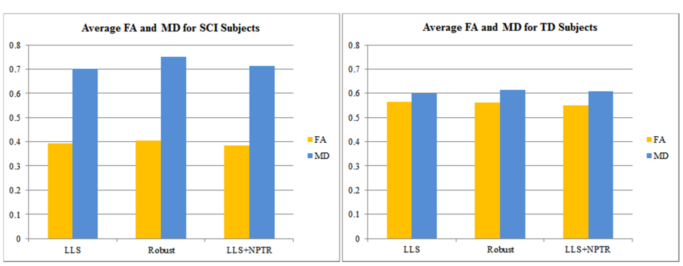

Figure 1 – Group average FA and MD for subject with spinal cord injury (left) and typically developing subjects (right).

	% Change vs LLS					% Change vs LLS			
	FA		MD			FA		MD	
Subject	Robust	LLS+NPTR	Robust	LLS+NPTR	Subject	Robust	LLS+NPTR	Robust	LLS+NPTR
SCI1	0.0%	-1.0%	0.0%	2.0%	TD1	4.2%	-2.8%	0.0%	-0.6%
SCI2	0.0%	-3.4%	0.0%	2.1%	TD2	3.7%	-1.0%	1.0%	1.2%
SCI3	2.4%	-1.7%	-0.6%	1.4%	TD3	0.0%	-4.8%	0.0%	2.4%
SCI4	-0.6%	-1.7%	-0.2%	1.0%	TD4	-4.9%	-3.3%	8.3%	2.2%
SCI5	7.8%	-1.9%	54.7%	1.7%	TD5	4.2%	-1.3%	-1.2%	1.1%
SCI6	13.7%	-0.8%	-3.6%	0.7%	TD6	-6.0%	-2.4%	9.6%	2.1%
SCI7	-4.1%	-6.9%	4.7%	5.3%	TD7	-2.1%	-1.6%	3.3%	1.5%

Table 1 – Percent change vs linear least squares method in FA and MD for each subject with spinal cord injury (left) and each typically developing subject (right).

References: (1) Finsterbusch J. High-resolution diffusion tensor imaging with inner field-of-view EPI. JMRI 2009:29(4):987-93. (2) Fillard P, et al. Clinical DT-MRI Estimation, Smoothing, and Fiber Tracking With Log-Euclidean Metrics. IEEE Trans Med Imaging. 2007 Nov;26(11):1472-82. (3) Mohammadi, et al. Retrospective correction of physiological noise in DTI using an extended tensor model and peripheral measurements. Magn Reson Med. 2013 Aug;70(2):358-69.