An Investigation of Motion Correction Algorithms for Pediatric Spinal Cord DTI in Normals and Patients with SCI

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Background and Objective

Motion correction by image registration is important in the interpretation of medical images and plays a crucial role in diagnosis and treatment planning. 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. While there has been intensive research into motion correction of brain images, little has been done for Spinal Cord (SC) imaging. The goal of this study was to (1) determine a reliable motion correction method for SC Diffusion Tensor Imaging (DTI) and (2) show the effects of motion correction on DTI parameters in the normal and the injured SC.

Methods and Materials

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

Imaging: The images were acquired using a newly developed inner-Field-of-View (iFoV) sequence (1). This sequence was implemented on a 3.0T Siemens Verio MR scanner and optimized. DTI acquisition covering the cervical SC (C1-C7) was performed using the following parameters: 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. The imaging time to collect DTI images was approximately 7 minutes. Sedation and/or anesthesia were not administered to the subjects in this study.

Data Analysis: Image registration was performed using the Automated-Image-Registration (AIR) package implemented in DTIstudio (www.mristudio.org). The target images (20 directional images) were aligned with the reference image (b0) for each of the three averages. Two types of transformations along with three cost functions were evaluated: Rigid Standard-Deviation (RdSD), Rigid Least-Squares (RdLS), Rigid Scaled-Least-Squares (RdSLS), Affine Standard-Deviation (AffSD), Affine Least-Squares (AffLS) and Affine Scaled-Least-Squares (AffSLS). Each one of these six combinations returned 63 transformation matrices, one for each gradient direction per average. These matrices were then quantitatively examined using an in-house developed Matlab code. The code quantifies the effects of a registration method by analyzing a set of transformed vectors spanning the image volume. The displacements in the x, y, and z directions were then measured for each transformed vector and the average and maximum displacements in each spatial direction were calculated for each gradient direction. Finally, using MedINRIA (www-sop.inria.fr/asclepios/software/MedINRIA/), diffusion tensors were calculated pre- and post- motion correction to obtain Fractional Anisotropy (FA) and Mean Diffusivity (MD) values. RoI's were drawn on midline sagittal FA color images. 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 (CSF).

Results and Conclusion

Figure 1 below shows the average y direction displacement of the images corresponding to all gradient directions using rigid methods (A) and affine methods (B). The greater consistency of rigid methods was visible by the decrease in peak intensity, particularly for motion in the y-direction (Figure 1A). The y direction was chosen for demonstrative purposes as it exhibited the greatest average displacement of the three spatial directions due to oscillatory SC motion in the anterior/posterior direction (3). Only control subjects are shown, however similar results were obtained for SCI subjects. Further, we observed strong peaks in displacement for a given gradient direction correlated to transformed images which were severely distorted. Qualitatively, visual differences were clearly seen between pre- and post- motion correction on FA color maps of a control and a patient with SCI (Figure. 2) using rigid methods. Examining the three rigid methods, RdSLS showed the greatest qualitative improvement. Figures A2 and B2 demonstrate more homogeneous signal within the cervical spinal cord as well as greater conspicuity of the cord and surrounding CSF interface. The values of FA and MD were examined pre- and post- motion correction for all six registration methods (Table 1). Using RdSLS there were no statistically significant differences in MD values (p=0.13). There was, however, statistical significance in FA (p=0.007). This difference could be due to an overestimation of FA values due to noise (4) which was successfully corrected by RdSLS registration method. Overall, in both the controls and subjects with SCI, quantitative and qualitative analysis showed RdSLS registration technique superior to the other five algorithms.

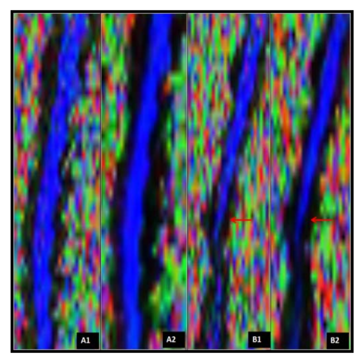

Figure 2 Midline Sagittal FA color images of a control (A1-2) and patient (B1-2) before and after using RdSLS (arrow indicates injury level)

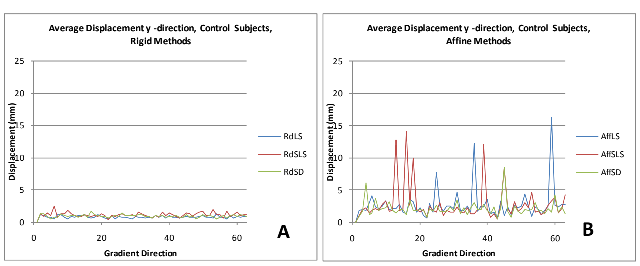

Figure 1 Average y Direction Displacement by Gradient Direction

Correction Method	FA		MD x10^{-3} (mm^2/s)	
	Mean ± Std. Dev.		Mean ± Std. Dev.	
	Controls	SCI's	Controls	SCI's
No Correction	0.55 ± 0.17	0.43 ± 0.15	0.67 ± 0.26	0.75 ± 0.28
AffLS	0.52 ± 0.14	0.36 ± 0.14	0.62 ± 0.23	1.07 ± 0.82
AffSLS	0.54 ± 0.14	0.34 ± 0.13	0.64 ± 0.23	0.74 ± 0.24
AffSD	0.53 ± 0.15	0.35 ± 0.18	0.62 ± 0.24	1.77 ± 1.42
RdLS	0.52 ± 0.14	0.37 ± 0.12	0.61 ± 0.20	0.73 ± 0.23
RdSLS	0.52 ± 0.14	0.36 ± 0.12	0.61 ± 0.19	0.73 ± 0.23
RdSD	0.53 ± 0.15	0.35 ± 0.12	0.63 ± 0.23	0.77 ± 0.26

Table 1 DTI parameters pre- and post- motion correction

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