Myelination and Axonal Integrity of Spinal Cord Sensory and Motor Pathways Revealed by Diffusion Tensor MRI

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Introduction: In several diseases, such as multiple sclerosis and spinal trauma, lesions in the spinal cord may contribute to the majority of the patient's functional deficit. Therefore, having a tract-specific measure of axonal integrity or myelination in the spinal cord may allow an in vivo comparison of tract integrity with function. Fiber tracts from diffusion tensor images (DTI) have been used in the brain to quantitatively assess MRI measures in normal volunteers (adult and pediatric) and in many diseases, such as multiple sclerosis and cancer. Diffusion weighted images have been used to assess stroke in the spinal cord, but there has not been a tract-specific quantitative comparison of MRI measures between the left and right tracts or between tracts. There are several reasons: 1) the spinal cord is very small (~1.5 cm in diameter), 2) physiological motion (blood flow, CSF flow and breathing) can cause artifacts, and 3) susceptibility artifacts can cause distortion. In this study, we used a 3T MRI system with parallel imaging, second order shims, and strong gradients to attempt to minimize the distortions. Volunteers were scanned using DTI and a magnetization transfer (MT) imaging sequence to assess axonal integrity and myelination in the left and right lateral and dorsal tracts between C2 and C6 within the cervical spinal cord. To our knowledge, this is the first tract-based quantification of DTI-derived metrics and MT measures in spinal cords in vivo.

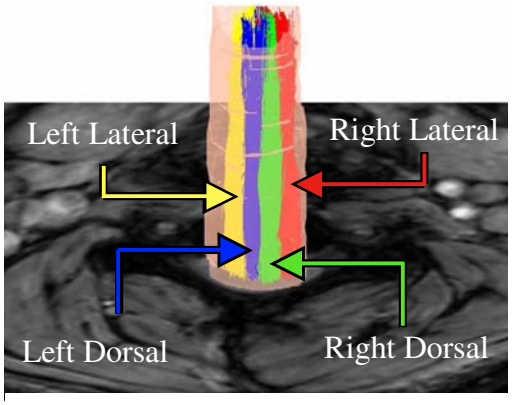

Figure 1: Fiber tracks overlaid on MT weighted image.

Methods: Four volunteers were scanned on a 3T Intera Philips system equipped with 80 mT/m gradients and second order shims. A dual element (Flex-M) receive-only coil placed on the back of the neck was used for parallel imaging reception. A DTI scan was acquired using single-shot EPI with 145 mm FOV (96x96 acquired), 60 slices 1.5 mm thick, 32 gradient directions, b=700 s/mm^2, TR/TE=12,227/69 ms, and SENSE factor = 2. A 3D spoiled gradient echo, multi-shot EPI MT-weighted scan was acquired with 30 slices 3 mm thick, acquired matrix of 320x320, TR/TE=118/15 ms, 5 lobe sinc-shaped pulse applied at 1.5 kHz off resonance (BW = 400 Hz, flip angle = 600°, peak amplitude = 10.5 μT), and SENSE factor = 2. Total scan time was approximately 20 minutes. Fiber tracks were calculated from the principal eigenvector. MTw images were normalized with respect to CSF intensity (MTCSF) as an inter-subject standard (1).

Results and Discussion: Fiber tracts for one volunteer are shown in Figure 1. Figure 2 shows each measure averaged over volunteers as a function of slice location between C2 and C6. Mean fractional anisotropy (FA) for the lateral and dorsal columns were 0.77±0.02 and 0.76±0.02, respectively, slightly lower than previously estimated FA of 0.83±0.11 (2). Mean apparent diffusion coefficient (ADC) for lateral and dorsal columns was 0.95±0.06 mm^2/ms and1.02±0.06 mm^2/ms, similar to a previously reported value of 1.05 mm^2/ms (3). Mean MTCSF for the lateral and dorsal cords was 0.59±0.04. Statistical comparisons were done over four anatomically defined sections of the cord. The left and right columns were compared for both lateral and dorsal (RL vs. LL, RD vs. LD) for each section of cord (e.g., C5 to C6) for each measure, resulting in 16 comparisons for each metric (four volunteers x four sections). One spinal cord section in each of the lateral and dorsal columns had an FA measure which was statistical different ($p=0.004$ and $p=0.002$, respectively) different between left and right. For the ADC measure, 3 of 16 comparisons in the lateral columns ($p<0.05$) and 2 of 16 comparisons in the dorsal columns ($p<0.02$) yielded a statistical difference. For the MTCSF measure, 5/16 in the lateral columns ($p \leq 0.02$) and 0 of 16 comparisons in the dorsal columns were statistically different. All MTCSF differences were in the C5-C6 section of the cord and may be due to movement. The lateral and dorsal columns were compared for each section of cord for each measure for each person (4 volunteers x 4 sections). For FA, only 1 of 16 comparisons yielded a statistical difference ($p = 0.04$). For the ADC measure 6 of 16 comparisons yielded a statistical difference (one with $p = 0.05$, all others $p < 0.016$) and all were between C4 and C5. MTCSF: 0 of 16 comparisons yielded a statistical difference ($p > 0.05$ for all).

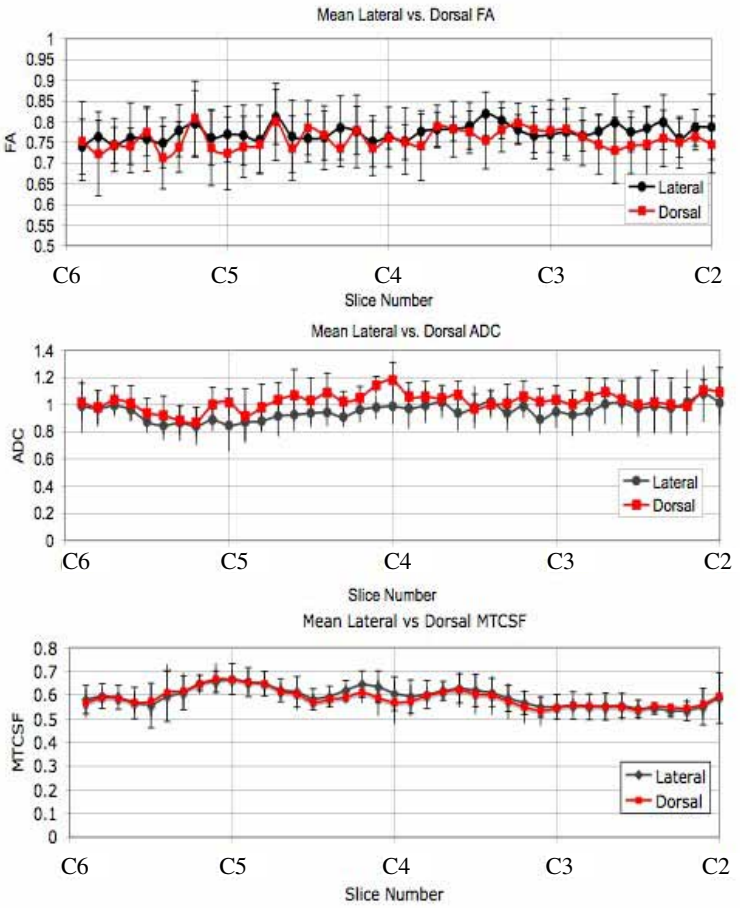

Figure 2: Mean over volunteers for each measure.

Conclusion: It is possible to track the individual sensory and motor fiber bundles in the spine and to assess MT and FA on a tract-specific basis. No right/left asymmetry was found.

References: 1) Smith, MRM v54, 2005, 2) Ries, MRM v44, 2000, 3) Bammer, JMRI v15(4), 2002.