

Pitfalls of Spinal DTI in Cervical Spondylotic Myelopathy

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Introduction: Cervical spondylotic myelopathy (CSM) eventually becomes clinically apparent by symptoms either related to the deterioration and demyelination of longitudinal motor (weakness and spasticity) and sensory (reduced sensation) fiber tracts and/or grey matter damage with segmental muscle enervation. Diffusion tensor imaging (DTI) is a novel magnetic resonance (MR) modality that specifically depicts the structural organization of nerve fiber bundles in the brain and spinal cord. Despite the low SNR and the influence of partial volume effects in the spine, anisotropy diffusion indices (ADI) have proved to be useful in CSM^{2,3}, however special attention should be paid on defining regions of interest to avoid the influence of CSF in the results. With this in mind, we investigated two different approaches for drawing regions of interest (ROIs) in spine: one using eigenvalues (fractional anisotropy, FA) and the other using eigenvectors (angular map).

Methods: 13 normal subjects (age range 50-73 years old, average 57.7 years old) and 10 CSM patients (age range 50-76 years old, average 62.2 years old) were recruited, and informed consent was obtained. DTI volumes were acquired using spin-echo EPI imaging (TR/TE = 5455/66 ms, FOV=150x150 mm, slice thickness = 2mm) with 6 isotropically distributed orientations for the diffusion-sensitizing gradients at a b-value of 600 s/mm² and one b=0 s/mm² image. The DTI sequence was gated to the peripheral pulse, with a delay time of 400 ms to acquire data during the quiescent phase of cord motion. The 3D volumes were acquired to span the C3-C6 region where the stenotic regions were mainly concentrated.

Analysis: DTI indices were calculated using in-house routines written in Matlab (MathWorks Inc., Natick, Massachusetts, USA). Segmentation of white matter (WM) from the cerebrospinal fluid (CSF) was done manually in FSL⁴ using two approaches. First, an ROI was defined using a threshold FA value of 0.3 (figure 2.a and b) on each axial slice. In the second approach, an ROI was defined using an angular map. Centers of each cord section were used to estimate the local orientation of the spine in five slice segments by fitting a straight line to each group of five centers. For each voxel in the spine, the orientation of the principal diffusion direction with respect to the local orientation of the column was calculated and a map of the angle between the principal diffusion direction and the local cord orientation was obtained (Figure 2.c and d). The second ROI was defined using an angular threshold of 45 degrees. The difference between the two ROI's generated a third region of interest, labeled the difference mask. Finally spine regions were classified as stenotic based upon decreases in local cord area.

Results: ROI's obtained by angular maps contained ROI's generated by maps of FA. ADI obtained based on FA mask for the CSM subjects showed only slight variation respect to the controls, 7%, 1%, 11% and 4%; for FA, λ_p (parallel), λ_r (radial) and ADC, respectively. ADI variations using angular mask-based ROI's were 11%, 10%, 24% and 17%. ADI variations of the subjects compared to the controls using the difference mask ROI's were 23%, 21%, 30% and 26%.

Discussion: While ROI's obtained with FA maps in CSM subjects and controls showed similar behavior, ADI averages obtained using ROIs from the angular maps showed a considerable difference between CSM subjects and controls. One might conclude that diffusion eigenvalues, in particular λ_r are decreased in stenotic regions. However, close inspection of data revealed that the pixels in the additional volume contained in the angular maps (the difference mask) had diffusion coefficients equal to or greater than that of free water (3x10⁻³mm³/s) and were therefore most likely derived from CSF in the vicinity of the spinal cord. In conclusion, when using DTI in CSM, it is very important to make sure that CSF is not included in the analysis.

References: ¹Bednarik, SPINE. 29: 2260–2269 (2004), ²Mamata, H. J. Magn. Reson. Imaging 22, 38-43 (2005), ³Ellingson, Concepts in Magnetic Resonance Part A, 32: 219–237 (2008), ⁴<http://www.fmrib.ox.ac.uk/fsl/>.

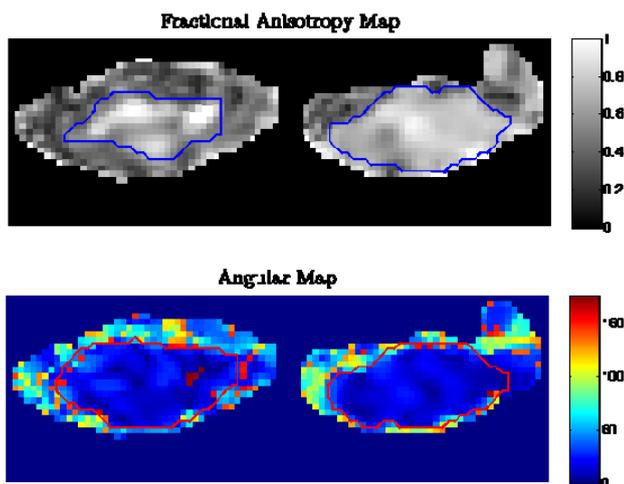


Figure 2. Transversal views of two different spinal stenotic regions of a subject. Maps of FA (a and b) and angular maps (c and d).

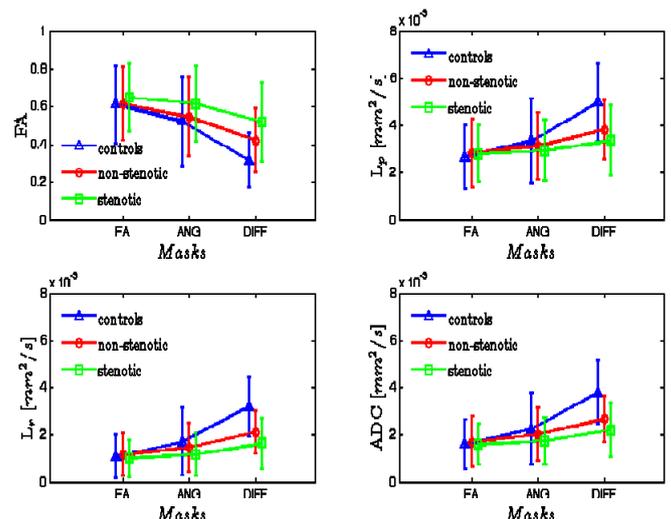


Figure 3. Variation of the DAI's using different masks. Red and green lines are the stenotic and non-stenotic levels of the subjects, with controls in blue.