Diffusion Tensor Imaging of Multiple Sclerosis Cervical Spinal Cords

T. H. Kim[1], L. Zollinger[1], X. F. Shi[2], J. Anderson[1], J. Rose[3], and E-K. Jeong[1]

[1]Radiology, University of Utah, Salt Lake City, UT, United States, [2]Physics, University of Utah, Salt Lake City, UT, United States, [3]Neurology, University of Utah, Salt Lake City, UT, United States

INTRODUCTION Multiple sclerosis (MS) is a white-matter disease with various pathologic stages such as demyelination, remyelination, inflammation, and axonal damage [1]. These stages change the microscopic physical environments of the tissue water. Diffusion tensor MRI (DTI) is sensitive to the physical change in the tissue [2] and may be used to detect early changes in the course of the disease [3]. To investigate cervical spinal cord (CSC) damage, DTI has been employed using a 3D multi-shot diffusion-weighted EPI (ms-DWEPI), necessitating the development of a quadrature rf-coil and a controlled experimental environment. From DTI images, we have attempted to demonstrate cervical spinal cord damage in white matter in radial and longitudinal views of the cord.

METHODS 3D ms-DWEPI is based on a segmented spin-echo EPI, using Siemens pulse sequence development software (IDEA), and was applied on *ex-vivo* human cervical spinal cords that were obtained from UCLA tissue bank. MRI experiments were performed on a 3T whole-body MRI system (Trio, Siemens Medical Solution, Erlangen, Germany), using a custom-built quadrature rf-coil of 2" diameter and 3" length. Spinal cords were maintained at 4 ^{o}C using a temperature controller to prevent deterioration. Typical MR imaging parameters were TR 400 ms, $(0.5\ mm)^3$ isotropic spatial resolution, b of 1000 s/mm^2 in 20 non-colinear directions, echotrain length (ETL) 5, and receive bandwidth 500 Hz/pixel. Imaging time for 3D ms-DWEPI was 30 minutes. The RF coil and the specimen were inserted into a Styrofoam container during the entire MRI experiment. The RF coil was tuned and matched at 4 ^{o}C. To understand the effect of the fixation process on the structure of CSCs, MR imaging experiments for each were performed before and after immersion fixation at the controlled temperature.

RESULTS AND DISCUSSIONS Our quadrature rf-coil provided MR images with 3 times higher SNR than the Siemens wrist coil with the same imaging parameters. DTI and T_2 weighted images were measured in $(0.5\ mm)^3$ isotropic resolution. Fractional anisotropy (FA) and the RGB color fibermaps and the projection vector maps of the principal eigenvectors are displayed in Figs. 1 and 2 for MS and Alzheimer CSC, respectively. The color "blue" indicates fibers orientated parallel to the vertical arrow in the Fig. 2. The direction of vector arrows reflects the direction of CSC fibers; white matter shows an up-down direction of fibers and blue color. In contrast to white matter, grey matter provides mixed color and vector arrows, indicating cross fibers. In lesions on the MS white matter, the directional color and the projection vector deviated from the pure blue and the vertical direction. Fractional anisotropy (FA) and directional diffusivities were calculated at the regions of interests (ROIs) of the white-matter. In addition, axial and radial diffusivity of the selected ROIs were compared for MS and Alzheimer diseased tissues. Plots in Fig. 3 indicate that the ratios ($\lambda_{//}/\lambda_{\perp}$) of the axial to radial diffusivities in MS CSC were smaller than those in Alzheimer cord. After fixation (Fig. 3b) the ratios ($\lambda_{//}/\lambda_{\perp}$) slightly decreased but remained similar in appearance to those before fixation (Fig. 3a). Our studies quantitatively demonstrate a decrease in the ratio of axial to radial diffusivities of MS CSC compared to those from the Alzheimer control cord.

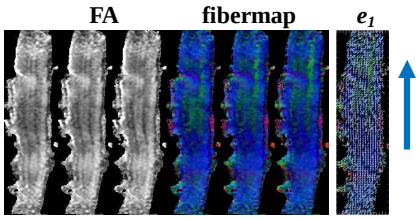

Fig. 1. *(left) FA, (mid) RGBmap, and (right) projection vector plot of the principal eigenvector of MS CSC. Lesions of MS are shown in FA map and vector plot. Blue : up-down / Green : left-right / Red : in-out of the plane*

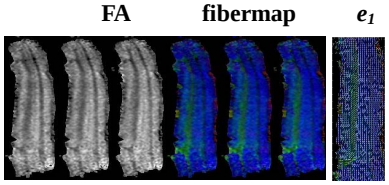

Fig. 2. *FA and RGB color maps of Alzheimer CSC (left) and vector plot of principal directional diffusivity (right).*

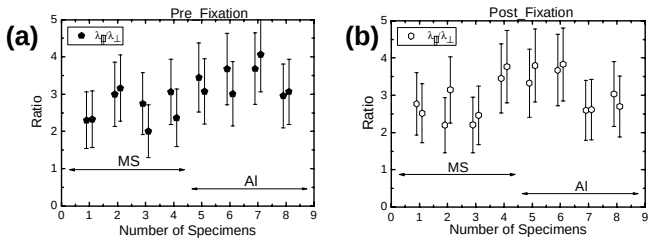

Fig. 3. *Ratio ($\lambda_{//}/\lambda_{\perp}$) of axial to radial diffusivities of Alzheimer and MS CSCs before (a) and after (b) fixation.*
($\lambda_{//}/\lambda_{\perp}$) is slightly reduced in MS regions before fixation.
MS : Multiple Sclerosis
Al : Alzheimer

CONCLUSIONS In this report, we present the DTI results of MS cervical spinal cord using 3D ms-DWEPI on *ex-vivo* CSC specimens. Our studies quantitatively demonstrate a decrease in the ratio of axial to radial diffusivities of MS CSC compared to those from normal cord.

ACKNOWLEDGEMENTS This work was supported by National Multiple Sclerosis Society, the Cumming Foundation, the Benning Foundation, the Ben B. and Iris M. Margolis Foundation, and NIH grants R21NS052424 and R21EB005705.

REFERENCES [1] C. J. Joseph et al., Radiology 233, 531 (2004). [2] P. J. Basser and D. K. Jones, NMR in Bio. 15, 456 (2002). [3] F. Agosta, et al., Neurology 64, 631 (2005).