

# Diffusion tensor imaging in human cervical spondylotic myelopathy using a 2D RF excitation pulse combined with a reduced field-of-view single-shot echoplanar readout (Zoomed-EPI)

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## Introduction

Cervical spondylotic myelopathy (CSM) is a spinal disorder characterized by degeneration of vertebral bodies, intervertebral disks, facet joints, and associated ligaments typically resulting in formation of bony spurs and myelopathy.<sup>1</sup> CSM frequency increases with increasing age, where as many as 95% of men and 70% of women over age 60 to 65 have degenerative changes at one or more vertebral level.<sup>2</sup> Although compression of the spinal canal can be diagnosed using traditional MRI techniques, the degree of compression and presence/absence of T2 signal intensities does not correlate with neurological symptoms.<sup>3,4</sup> Therefore, an imaging biomarker sensitive to the degree of neurological impairment and recovery after surgery is highly desired.

Diffusion-sensitive MR techniques have shown better sensitivity to spinal cord dysfunction than traditional MR techniques.<sup>5</sup> Specifically, studies have demonstrated the ability for diffusion tensor imaging (DTI) to distinguish between demyelination<sup>6</sup> and axonal damage,<sup>7,8</sup> depending on changes in particular directionally-sensitive diffusion measurements (transverse vs. longitudinal ADC, respectively). Despite these promising initial results, human spinal cord DTI using spin-echo echoplanar imaging (EPI) typically suffers from many imaging artifacts including susceptibility-related distortions, motion artifact, and low spatial resolution. We hypothesized a custom 2D spatially selective RF excitation pulse combined with a reduced field-of-view single-shot echoplanar readout (Zoomed-EPI) could provide superior DTI image quality of the human spinal cord for assessment of CSM.

## Methods

All patients participating in this study signed institutional review board-approved informed consent. A total of  $n = 8$  neurologically intact and  $n = 2$  patients with mild CSM were enrolled in the current prospective study. Zoomed-EPI images were obtained using a 3T MR scanner (Siemens Magnetom Trio a Tim System; Erlangen, Germany), a resolution of  $1.1 \times 1.1 \times 4\text{mm}$  with no inter-slice gap, 25 slices, TE/TR=67/3000 ms, matrix size of  $128 \times 48$ , 75% partial Fourier, and  $b$ -values of 0 and  $500 \text{ s/mm}^2$  collected in 6 directions using monopolar Stejskal-Tanner spin echo diffusion preparation. A total of 12 averages were used to reduce physiological artifacts and boost SNR, giving a scan time of 4min 20sec. We used a 2D spatially selective excitation pulse (with an EPI trajectory) optimized to keep the pulse duration under 12 msec to minimize off-resonance artifacts. In addition, the protocol was optimized to provide a small TE to reduce T2\* signal loss and increase SNR. The diffusion tensor was constructed using AFNI (Analysis of Functional Neuroimages, <http://afni.nimh.nih.gov/>), DTK, TrackVis (Martinos Center for Biomedical Imaging, MGH), and DTI Query tractography software.

## Results

In general, the Zoomed-EPI DTI technique using a custom 2D spatially selective RF excitation pulse allowed for high SNR, low distortion diffusion images of the spinal cord. Fig. 1 illustrates 12 of the 25 images collected in a typical neurologically-intact human spinal cord as well as DT tractography results. Fig. 2 shows the group average and 95% confidence intervals for  $n = 8$  normal human spinal cords across spinal and disc levels. Regions away from the center slices had greater distortions and signal drop out from B1 inhomogeneities. For each metric, the three most distal slices rostral and caudal from central slices varied significantly from other slices (One-way ANOVA,  $P < 0.05$ ). In general, central slices had diffusion values and variability consistent with the literature.<sup>9</sup> Fig. 3 illustrates FA measurements in one patient with CSM. Note the high FA at the level of compressions, indicative of compressed axon fibers, but low FA in spinal segments between these areas of compression, suggestive of long-term damage. Results show minimal distortion and good reproducibility.

## Discussion

The Zoomed-EPI DTI technique provides superior image quality to single-shot, twice refocused spin echo echoplanar preparation in clinically relevant scan times and with minimal artifacts, so long as the region of interest is placed within the center of the FOV. Measurements of neurologically intact spinal cord showed normal diffusivity compared with the literature.<sup>9</sup> Patients with CSM showed classic signs of chronic compression and cord ischemia, such as focally high FA at sites of compression, as previously shown.<sup>10</sup> These results suggest Zoomed-EPI DTI may be valuable for clinical assessment of spinal pathologies including CSM.

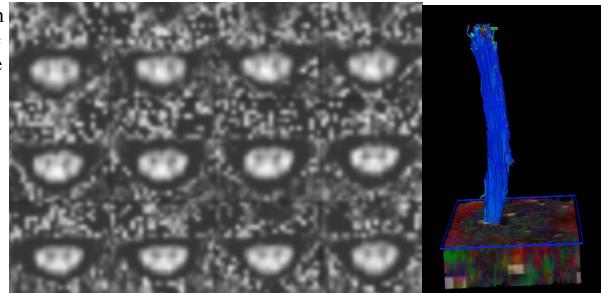


Fig.1: Fractional anisotropy (FA) images and Tractography for a neurologically-intact human spinal cord using Zoomed-EPI DTI.

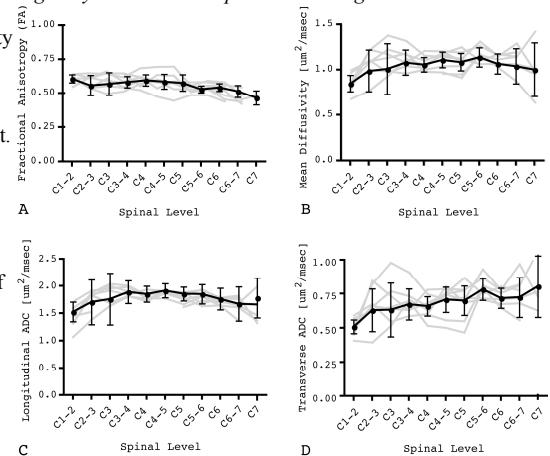


Fig.2: Diffusion characteristics of neurologically-intact human spinal cord using Zoomed-EPI DTI. Error bars are 95% confidence intervals.

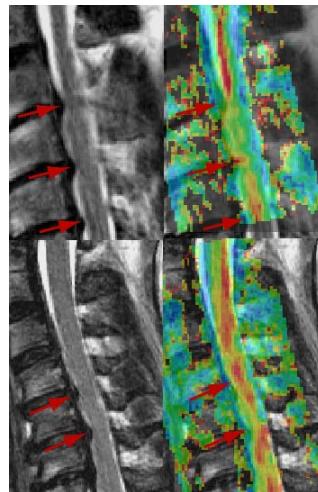


Fig.3: Diffusion characteristics of two patients with cervical spondylosis. Arrows show regions of compression on T2. The color overlay of fractional anisotropy (FA) images show localized high FA from compression of axonal fibers, separated by regions of lower FA suggestive of long-term damage.

**References** <sup>1</sup>Tracy, *The Neurologist*, 2010. <sup>2</sup>Gore, *Spine*, 1986. <sup>3</sup>Morio, *Spine*, 2001. <sup>4</sup>Yukawa, *J Neurosurg Spine*, 2008. <sup>5</sup>Ellingson, *AJNR*, 2008a. <sup>6</sup>Song, *Neuroimage*, 2002. <sup>7</sup>Ellingson, *Biomed Sci Instrum*, 2008. <sup>8</sup>Ellingson, *J Neurosurg Spine*, 2010. <sup>9</sup>Ellingson, *AJNR*, 2008b. <sup>10</sup>Ellingson, *Proc Int Soc Mag Res Med*, 2009.