Diffusion tensor MR characteristics of cervical spondylosis

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Introduction

Myelopathy from cervical spondylosis is the most common cause of nontraumatic spastic paresis[1], the most common cause of spinal dysfunction in the elderly[2], and the most common primary diagnosis for patients over 64 who undergo cervical spine surgery[3]. To prevent neurological deterioration, surgery is often performed early after diagnosis. Some studies have suggested surgical intervention *after* neurological decline may result in a worse outcome[4]; therefore, surgeons are likely to operate on the basis of diagnostic imaging even in the absence of clinical symptoms[5]. However, considerable controversy surrounds the selection of patients for surgery since, in the absence of progressive neurological deficit, the natural history is not well known.

Diffusion tensor imaging (DTI) technology has recently been used to study the spinal cord[6]. This technique is generally more sensitive to tissue integrity and architecture[7], and more sensitive to specific abnormalities of the spinal cord than routine T2-weighted MRI[8-10]. Preliminary studies using DTI have reported significantly different measurements between normal volunteers and patients with cervical spondylosis and myelopathy, suggesting that this technique might be of diagnostic utility[11]. The purpose of this study was to further characterize DTI parameters in cervical spondylosis. We hypothesized that mechanical compression of axonal fibers would be associated with an increase in diffusion anisotropy due to compression of the diffusion ellipsoid. We also hypothesized that a decrease in mean diffusion might occur at the site of compression, which may support the role of spinal cord ischemia in this disorder.

Methods

A prospective study was carried out to describe the DTI characteristics observed throughout the cervical spinal cord in 17 patients clinically diagnosed with cervical spondylosis. All procedures were approved by the Institutional Review Boards at our institutions. Imaging procedures consisted of both routine clinical MRI and DTI scans performed on a 1.5T clinical MR imaging scanner (Signa Excite, GE Healthcare, Waukesha, WI) using an eight-channel CTL Spine Coil (GE Healthcare, Waukesha, WI) for radiofrequency transmission and reception. Routine MRI scans consisted of T1-weighted and T2-weighted sequences, in both the axial and sagittal planes. Axial diffusion-weighted images were collected throughout the level of most significant canal narrowing. DTI images were acquired with TE/TR = 88 ms/4550 ms, matrix size = 128x128, NEX=2, and slice thickness of 3 mm with no interslice gap using a single-shot, twice-refocused, spin-echo, echoplanar pulse sequence[12]. Diffusion-weighted images ($b = 1000$ s/mm^2) in 39 equidistant directions, along with a single T2-weighted ($b = 0$ s/mm^2) image, were imported into the Analysis of Functional Neuroimages software package (AFNI) and the 3x3 diffusion tensor was constructed. The eigenvalues and eigenvectors were extracted from the diffusion tensor and the fractional anisotropy (FA), longitudinal apparent diffusion coefficient (lADC), transverse apparent diffusion coefficient (tADC), and mean diffusivity (MD) was calculated. The measures of lADC and tADC were chosen because they appear to reflect the degree of axonal and myelin dysfunction, respectively[13-15].

Results

During mechanical compression of axonal fibers, we hypothesized that the diffusion ellipsoid may be compressed, causing an increase in diffusion anisotropy locally at the site of compression. In all 17 patients, we noted a higher FA at the levels of compression relative to adjacent levels, as well as spatially localized regions of high FA on axial images. Results also suggest a lower mean diffusivity at the levels of compression, which were spatially localized on axial images. In many subjects, however, the pattern created by reduced mean diffusivity was slightly larger than regions with increased FA, suggesting ischemia may have also influenced this measurement in addition to tighter packed axonal fibers. When examining DTI measurements through the level of highest compression across all patients, results confirmed a slightly higher FA at the site of compression compared to slices rostral and caudal to the compression site (Fig2A; one-way repeated-measures ANOVA, $P = 0.004$). Measures of MD, lADC, and tADC appeared slightly lower at the level of compression compared with adjacent levels (Fig. 2B-D), although not statistically significant (ANOVA, $P > 0.05$). When compared to the DTI measurements from the cervical spine in historic controls, FA was significantly lower at all locations tested (t-test, $P < 0.0001$ at all locations); however, MD was not significantly different than historic control values after Bonferroni correction (t-test, $P > 0.0056$ for all comparisons).
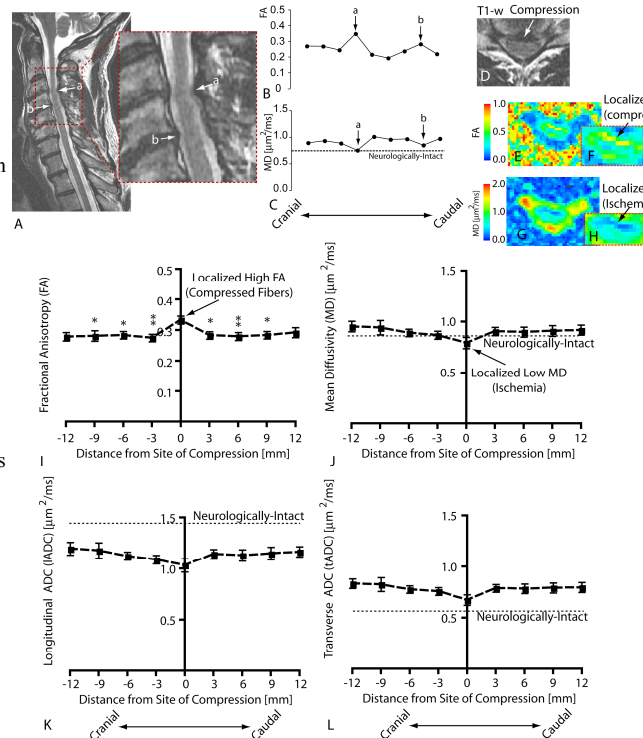

Fig. 1: Typical DTI results for a patient with cervical spondylosis. A) T2-w images showing compression of the spinal cord (a,b). B) Mean FA for each slice through the regions of compression (a,b). C) MD for each image slice through the level of compression (a,b). D) Axial T1-w image showing compression of the cord. E-F) Color FA images show regions of localized, high FA. G-H) Color MD images show slightly larger regions of localized, low MD. I) Average FA across the site of compression for all patients. J) MD across the site of compression for all patients. K) lADC across the site of compression for all patients. L) tADC across the site of compression for all patients.

Discussion

We found that DTI characteristics correlate with the level of compression in cervical stenosis. Specifically, measurements of lADC and tADC were found to be significantly different than historic controls[16], except for measurement of tADC at the site of compression. In addition, lADC was substantially lower than neurologically-intact cervical spinal cord measurements obtained from the literature[16], suggesting some degree of axonal dysfunction, whereas tADC was significantly higher than expected (except at the compression site), suggesting an active demyelinaing process. Results showing a decrease MD at the site of compression appear to support the role of ischemia in cervical stenosis, and changes in lADC and tADC support the role of these parameters as imaging biomarkers for axonal dysfunction and myelin damage, respectively.

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