s-Image Representation of Diffusion Tensor Contrast and Fiber Geometry: Leukometric Analysis in the Brainstem and Cerebellum

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Objective

Diffusion tensor magnetic resonance imaging provides a wealth of three-dimensional information about local tissue microstructure and fiber connectivity. Scalar quantities, such as fractional anisotropy (FA) and apparent diffusion coefficient (ADC), describe local properties of water diffusion, while vector orientation indicates tissue organization. General purpose techniques for combing local and connectivity information have not been commonly used, in part due to the complexity and variability of fiber tracking results. We present a framework (*s-images*) for analyzing both cross-sectional and longitudinal cohorts and demonstrate descriptive statistics in a clinical study of cerebellar disease.

Methods

We studied four patients with olivopontocerebellar atrophy (OPCA) and four matched controls. We focused on the middle cerebellar peduncle (MCP) and corticospinal tract (CST) which had previously demonstrated significant abnormalities. A multi-slice, spin echo, single-shot EPI sequence was used to achieve whole brain coverage (0.82x0.82x2.2 mm resolution). Diffusion tensors were estimated from three repeated acquisitions of 32 diffusion encoded volumes and a scanner average of five minimally weighted volumes on a 3T MR scanner (Intera, Philips Medical Systems, The Netherlands). Fiber tracking was initiated at all voxels with FACT as implemented in DTI Studio (Susumu Mori, Baltimore, Maryland).

s-Images

An expert rater manually delineated cross-sectional regions of interest (ROIs) at specific anatomical landmarks, which were used to select fibers that corresponded to the tracts. These ROIs established an origin for a one-dimensional coordinate system (“s”) along the path of fiber. Fibers corresponding to a tract were aligned in an image such that a row corresponded to a fiber and a column corresponded to a distance along a fiber from the origin. Fibers were ordered by the most negative starting location. The intensity of the image was proportional to either a volume property (e.g., FA or ADC) or fiber geometric property (e.g., curvature or torsion).

Results

Fiber tracking identified the MCP (**Figure 1A**) and CST (**Figure 2A**). Controls showed consistent distinct visual patterns on the *s-images* (**Figures 1B and 2B**). Standard measures (mean FA, ADC, curvature, and torsion) did not separate the groups for either tract. Yet, simple statistics on the *s-images* perfectly separated the groups (**Tables 1 and 2**). For the MCP, the percentage of the fiber tracts with FA greater than 0.6 was found to separate the groups, while, for the CST, the range of ADC (the minimum and maximum image intensity) along the fibers separated the groups.

Discussion

We achieve substantial data reduction by collapsing fiber structure into a one-dimensional system, while preserving connectivity information and revealing spatial correlations. *s-Images* may be well suited to localizing low contrast brainstem and cerebellar nuclei that are adjacent to white matter tracts. Alternatively, *s-image* spatial patterns would provide a means of assessing global pathological changes or focal effects (e.g., lesions or tumors). With *s-images* it is a simple matter to generate measures that are independent of brain volume, so analyses can be robust against inter-individual differences in age, gender, body size, etc. *s-Images* provide a visually intuitive framework for managing high dimensional information from diffusion tensor imaging.

Word Count: 500

Figure 1. Middle Cerebellar Peduncles

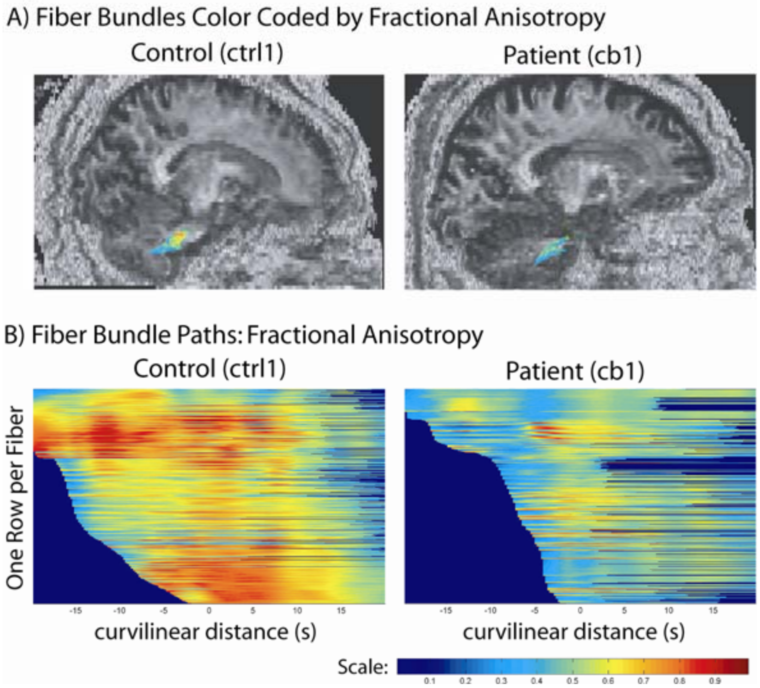

Figure 2. Corticospinal Tract

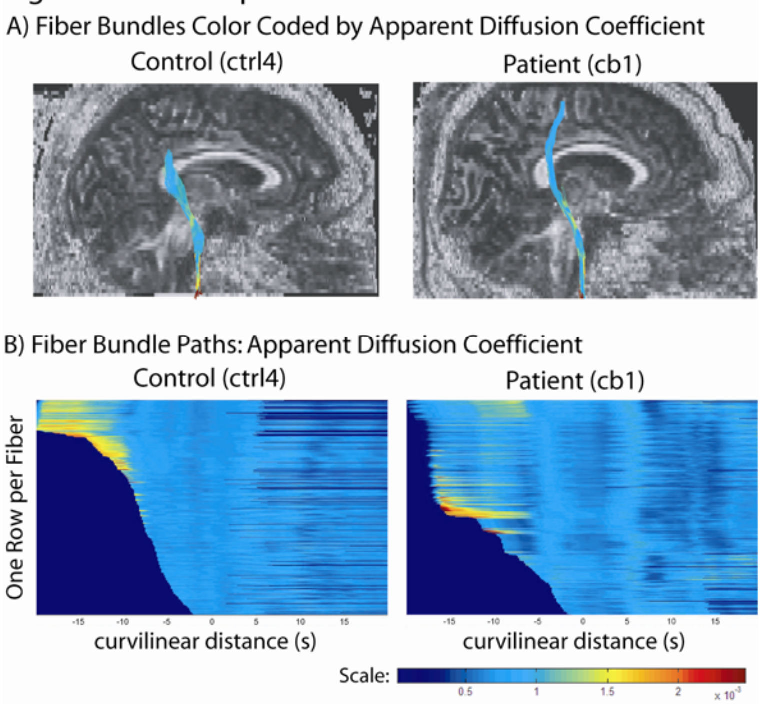

Table 1. Middle Cerebellar Peduncle Fiber Metrics

OPCA Group

Subject	**Pct High FA**	**FA**	**ADC**	**Curvature**	**Torsion**
Cb1	11%	0.48	0.0010	0.048	0.033
Cb2	34%	0.54	0.0009	0.069	0.120
Cb3	38%	0.58	0.0008	0.061	0.008
Cb4	0%	0.43	0.0012	0.044	-0.104
Mean	**21%***	**0.51§**	**0.0010**	**0.056**	**0.014**

Control Group

Subject	**Pct High FA**	**FA**	**ADC**	**Curvature**	**Torsion**
Ctrl1	60%	0.64	0.0008	0.052	0.062
Ctrl2	48%	0.59	0.0008	0.052	0.055
Ctrl3	63%	0.63	0.0008	0.059	0.012
Ctrl4	44%	0.57	0.0009	0.051	-0.059
Mean	**54%***	**0.61§**	**0.0008**	**0.053**	**0.017**

Descriptive Statistics: * p=0.02 § p=0.03

Table 2. Corticospinal Tract Fiber Metrics

OPCA Patient Group

Subject	**ADC Range**	**FA**	**ADC**	**Curvature**	**Torsion**
Cb1	5.9E-04	0.66	0.0009	0.085	0.316
Cb2	5.8E-04	0.62	0.0009	0.088	0.079
Cb3	4.9E-04	0.67	0.0008	0.099	0.027
Cb4	5.9E-04	0.71	0.0008	0.084	-0.001
Mean	**5.6E-04***	**0.66**	**0.0009**	**0.089**	**0.105**

Control Group

Subject	**ADC Range**	**FA**	**ADC**	**Curvature**	**Torsion**
Ctrl1	3.4E-04	0.65	0.0008	0.144	0.355
Ctrl2	3.5E-04	0.62	0.0009	0.112	0.155
Ctrl3	3.4E-04	0.61	0.0008	0.115	0.032
Ctrl4	4.1E-04	0.61	0.0009	0.083	0.134
Mean	**3.6E-04***	**0.62**	**0.0008**	**0.113**	**0.169**

Descriptive Statistics: * p<0.01