Quantitative Analysis of Diffusion Tensor Eigenvectors of White Matter Infiltration by Tumors and edema

Y. Wu[1], A. S. Field[2], B. Badie[2], A. L. Alexander[1]

[1]W.M. Keck Laboratory Functional Brain Imaging & Behavior, Madison, Wisconsin, United States, [2]University of Wisconsin Medical School, Madison, Wisconsin, United States

Synopsis

The impact of brain pathology on the organization of white matter is starting to be elucidated using DT-MRI. In particular, brain neoplasms can either deflect or infiltrate tract trajectories. DT-MRI provides unique directional information about white matter tract organization, however, the eigenvector properties of brain pathology has not been studied quantitatively. In this study, a set of quantitative measures of eigenvector organization were used to investigate the impact of tumors and edema that appear to infiltrate the corona radiata in four subjects. The results were compared with measurements obtained in the unaffected contralateral corona radata.

Background

Conventional MRI has difficulties in the differential diagnosis of oligodendrogliomas versus edema that is infiltrating white matter tracts. Both low grade oligodedroglioma and brain edema both are hyperintense on T2-weighted images. Diffusion tensor MRI is very sensitive to changes in tissue structure on a microscopic scale.[1,2] Measures of the tensor trace and anisotropy provide information about the magnitude and shape of the diffusion distribution in certain tissues. However, until recently, quantitative measures of diffusion tensor orientation have not been used for evaluating pathology in the brain. In this study, several novel measures of eigenvector organization in specified brain regions are used to compare infiltrating oligodendrogliomas and vasogenic edema with each other and also with regions of contralateral (apparently) unaffected white matter [2,3] It could be a helpful imaging tool for differential diagnose pure oligodedrogliomas from cerebral edema.

Theory

The distribution of major eigenvectors was described using Rose diagrams, θ vs. ϕ scatter plots and the scatter matrix, $\boldsymbol{T}$ [2,3]. The scatter matrix is a 3x3 matrix tensor, which describes the dispersion of measured major eigenvectors from the diffusion tensors in each voxel for an ROI. Similar to the diffusion tensor, a measure of directional anisotropy (*fa_T*) can be estimated [3]. ROIs with high anisotropy (*fa_T* ~ 1) indicate regions with parallel eigenvector organization, whereas regions with low *fa_T* (~0) indicate areas where the distribution of eigenvectors is either purely random or uniformly distributed. The symmetry of the major eigenvector directions between the affected and unaffected hemispheres can be estimated by the symmetry index, $S = \boldsymbol{t}_{1L} \cdot \boldsymbol{t}_{1R}$, which is the dot product of the scatter matrix major eigenvectors for the left (L) and right (R) hemispheres [3].

Methods

Diffusion tensor MRI studies were performed on four patients with brain neoplasms prior to surgery. Two patients were found to have oligodendrogliomas grade II. The other two patients had metastatic brain tumors (adenocarcioma and squamous cell carcinoma) with regions of edema. In each case, the tumor or edema was considered to infiltrate aspects of the corona radiata. DT-MRI studies were performed at 1.5T using a single-shot spin echo EPI sequence with diffusion-tensor encoding (23 directions, b = 1000 s/mm^2). Twenty-one to thirty-nine axial slices, 3 mm thick (128x128 matrix and 240 mm FOV), were obtained in 7.5 to 15 minutes of scan time, dependant upon the amount of brain coverage. Three-dimensional ROIs were selected by a trained radiologist on affected regions of corona radiata (CR) using the diffusion tensor FA maps. The corresponding contralateral region of unaffected corona radiata was also selected. The major eigenvector directions for each voxel in an ROI were recorded. Directional vector analysis was applied on each group (ROI) of major eigenvectors.

Results

The results for the four subjects are summarized in Table 1. The two tumor cases (1 & 2) appeared to show greater changes in the eigenvector anisotropy or symmetry index relative to the edema cases (3 & 4), which showed very similar eigenvector anisotropy and high symmetry indices. The Rose diagrams for the tumor and contralateral white matter of subject 1 are shown in Figure 1. The polar histograms demonstrate that the distributions are not overlapping and that the symmetry index in Table 1 is reflecting this difference in the eigenvector distributions.

Discussion

The distribution of major eigenvectors from the diffusion tensor may reveal unique information about microstructural changes from pathology. In this study, a novel set of methods for describing the eigenvector distributions were used to evaluate the infiltration of tumor and edema in white matter. Based upon the small number of subjects in the study, the tumors appeared to change the eigenvector properties of corona radiata, whereas very little change was detected in the regions of edema. However, further studies are necessary to determine if these observations are consistent for a larger population.

References

[1] Basser & Pierpaoli. JMR B 111:209-219 (1996). [2] Mardia KV. Directional Statistics. [3] Wu YC et al, Abstract submitted to ISMRM (2003).

Subject no.	Side	*t*			*fa_T*	*S*
		t1	t2	t3		
1	Tumor	0.82	0.14	0.04	0.89	0.42
	Normal	0.76	0.19	0.04	0.84	
2	Tumor	0.63	0.30	0.07	0.69	0.83
	Normal	0.84	0.14	0.03	0.90	
3	Edema	0.95	0.03	0.02	0.97	0.98
	Normal	0.90	0.07	0.04	0.94	
4	Edema	0.68	0.23	0.08	0.74	0.92
	Normal	0.70	0.22	0.08	0.77	

Table 1. The result of vector analysis
Subject No. 1 Oligodendroglioma Grade II. Lesion on left frontal lobe.
Subject No. 2 Oligodendroglioma Grade II. Lesion on right frontal lobe.
Subject No. 3 Metastatic brain tumor with large brain edema area on left frontal lobe.
Subject No. 4 Metastatic brain tumor with large brain edema area on right frontal lobe

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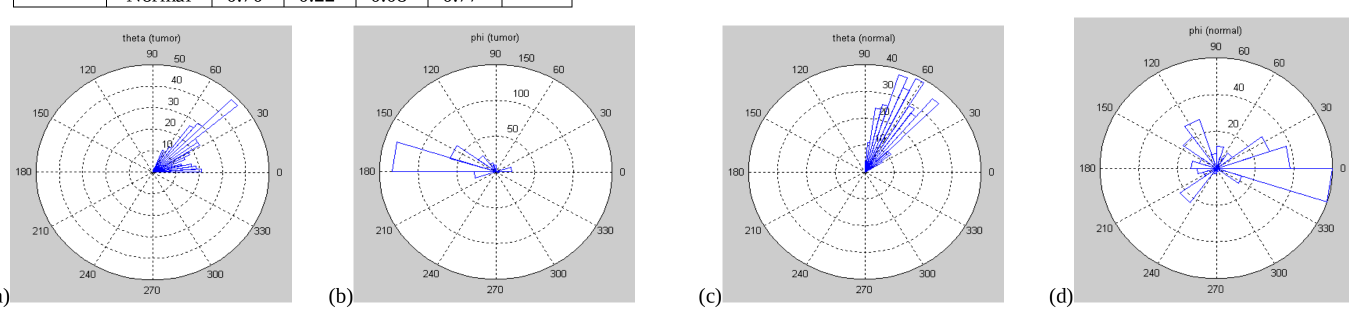

(a) (b) (c) (d)

Figure 1. Subject 1 has an oligodendroglioma in the left corona radiata. (a,b) Rose diagram of eigenvectors in the tumor. (c,d) Rose diagram of eigenvector distributions in the contralateral corona radiata.

In these works, quantitative analysis has been performed by use of the underlying FA maps for selective statistics. Smith et al. developed an algorithm for an alignment-invariant tract representation to overcome normalization problems; this approach is referred to as tract based spatial statistics (TBSS) [9â€"15].Â If the diffusion tensor and the corresponding Eigenvectors were not corrected, FT failed (Figure 1c), whereas the correction of the Eigenvectors according to section 3.3 provided correct FT results (Figure 1d). Figure 1.Â As an example of a disorder with a presumable affection of white matter tracts, patients with tCC were chosen. Quantitative analysis of DTI data may provide insight as to whether WM tracts are salvageable preoperatively.Â Background: Characterization of WM alteration using MR imaging is important in the pre- and intraoperative assessment of brain tumors. This study characterizes the extent and severity of WM tract alterations near brain tumors using DTI in an effort to determine preoperative viability or resectability of the adjacent WM tracts. Fractional anisotropy is an important DTI-derived metric of MR imaging. Methods: Twenty-one patients underwent MR DTI. Eighty-six WM tracts composed of 43 WM lesions paired with 43 contralateral WM hemispheric controls were categorized using FA. Although white matter tractography and eigenvector color maps provide visually appealing displays of white matter tract organization, they do not easily lend themselves to quantitative and statistical analysis. In this study, a set of visual and quantitative tools for the investigation of tensor orientations in the human brain was developed.Â @article{Wu2004QuantitativeAO, title={Quantitative analysis of diffusion tensor orientation: Theoretical framework}, author={Yu-Chien Wu and A. Field and M. Chung and B. Badie and A. Alexander}, journal={Magnetic Resonance in Medicine}, year={2004}, volume={52} }. Yu-Chien Wu, A. Field, +2 authors A. Alexander. of white matter edema may appear bright on T2-weighted imaging, ADC is increased in vasogenic edema (peritumoral edema, infection/inflammation), but decreased in cytotoxic edema (affecting oligodendrocytes and astrocytes) or intramyelinic edema, permitting differentiation.Â Although diffusion is apparently equal in all directions (isotropic) in gray matter, in white matter it is greatest parallel to the fiber bundles (â€œtractsâ€) and restricted perpendicular to the tracts, a property known as anisotropy.Â The mean of the second and third eigenvectors, which are perpendicular to the axon, is known as radial diffusivity and can provide further quantitation of myelin integrity. Diffusion tensor imaging (DTI) revolutionalized the field of white matter mapping. This MRI-based methodology, originally presented in 1994 (Basser et al.Â Diffusion tensor imaging provides a framework for acquisition, analysis, and quantification of the diffusion properties of white matter (Basser and Pierpaoli 1996, 1998; Pierpaoli et al. 1996).Â 2002). Brain tumors can affect white matter fibers by either infiltrating or. displacing the tissue.Â estimate the pathological state of the tissue, especially in areas of tumor infiltration into the white matter where FA values are extremely low. Reduced FA might be related to disintegration of the fibers, but a significant increase in water content (edema) without any effect on the fibers themselves can give the same FA reading.