Multiple Sclerosis Lesions at 3T. Scalars and Fibers.

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Introduction: Diffusion Tensor Imaging (DTI) is a Magnetic Resonance Imaging (MRI) method for characterizing molecular diffusion and for extracting nerve fibers of brain. DTI is a suitable imaging modality for early detection of demyelination diseases such as Multiple Sclerosis (MS). The traditional way of using DTI in MS [1], i.e. examining changes in the distribution of Fractional Anisotropy (FA) and Apparent Diffusion Coefficient (ADC) still requires human intervention to detect candidate lesion locations with the help of a T_2-weighted FLAIR (T_{2w} F) image. In this work, in addition to distribution and T_{2w} F information, we use shortened fiber length knowledge in a Bayesian detection framework proceeding multi-registration steps, for detection of candidate MS lesions.

Materials and Methods:

Data acquisition. 72 patients (mean age=45) diagnosed with MS were scanned with an 8 channel head coil in a 3T MR system (Achieva, Philips Medical Systems, Cleveland, OH). Diffusion tensor imaging (DTI) was performed using a single shot EPI sequence with SENSE factor=3, b=1000 s/mm^2, 6 diffusion gradient directions, FOV=24x24cm, slice thickness-5mm, no gap, matrix size=128x128 and 30 axial slices. The diffusion tensors were computed using linear least-squares regression after motion and eddy current distortion correction. For each patient, a T_{2w} F scan was also performed.

Analysis. For each data, the T_{2w} F image was rigidly registered to the image from the diffusion weighted image (DWI) set, to have the tensor derived images and the T_{2w} F image in the same coordinate frame. Data from 30 patients were used to build the fractional anisotropy (FA), apparent diffusion coefficient (ADC) and fiber length. For this data set, the lesions were manually labeled on the T2WF image. By using these ROIs from the T_{2w} F, FA and ADC histograms are computed for different lesion locations. A control group of five healthy subjects was used to extract the "healthy" distributions. Fiber tractography was done with the 3D SLICER software on both healthy and lesion locations and the lengths passing fibers were used as features along with FA, ADC and T2WF for each voxel. Similar ROIs were selected with the data from other 42 patients (test set) to investigate the distributions on "Normal Appearing White Matter" (NAWM). The statistics obtained from this case set are summarized in Table 1. FA, ADC, and fiber length were used as a 3-dimensional feature vector with covariance matrix displayed in Figure 1. For testing the presence of lesions on the test set, the FA images of the patients' data were elastically registered to the ICBM white matter atlas [1]. Based on atlas probability values and FA values, white matter voxels were segmented from the images and morphological operators were applied to close small holes and have a connected white matter region. Then each white matter voxel was tested for the presence of lesions with a Bayesian inference framework. Let $\mathcal{X}$ be our 3-dimensional feature vector, $\mathcal{V}$ a random variable signifying a voxel, $\mathcal{L}$ a lesion, $\mathcal{MS}$ multiple sclerosis, $\mathcal{V}=\mathcal{L}$ a voxel being a lesion voxel, $\mathcal{Pt}=\mathcal{MS}$, a patient having MS. Then our formulation is: $P(\mathcal{V}=\mathcal{L} \mid \mathcal{X}) = P(\mathcal{X} \mid \mathcal{V}=\mathcal{L})P(\mathcal{V}=\mathcal{L})/P(\mathcal{X})$. We label a voxel as a candidate lesion voxel if this probability is greater than 0.5. In this equation, for $P(\mathcal{X} \mid \mathcal{V}=\mathcal{L})$, we used the distributions in Table1 and Figure 1. To model $P(\mathcal{V}=\mathcal{L})$, we introduced another random variable to account for a healthy patient and a patient with MS. Therefore, $P(\mathcal{V}=\mathcal{L}) = P(\mathcal{V}=\mathcal{L} \mid \mathcal{Pt}=healthy).\ P(\mathcal{Pt}=healthy) + P(\mathcal{V}=\mathcal{L} \mid \mathcal{Pt}=\mathcal{MS}).\ P(\mathcal{Pt}=\mathcal{MS})$. In this equation, the probability that a person has MS, $P(\mathcal{Pt}=\mathcal{MS})$, is suggested to be taken as 1/800 (the average MS percentage in a population) if the health of the subject is not known. If the patients has been diagnosed with MS, this probability can be replaced with 1 yielding $P(\mathcal{V}=\mathcal{L} \mid \mathcal{Pt}=\mathcal{MS})$. This latter probability is the average number of lesion voxels within an MS patient's WM and depends on the stage of the disease but can be as high as 0.02.

	Lesion	NAWM	Healthy
FA	0.39 ± 0.13	0.52± 0.28	0.58 ± 0.18
ADC (x10^{-3}mm^{-2}s^{-1})	0.98± 0.1	0.91± 0.07	0.86± 0.11
Fiber length	29.6± 8.3 mm	48.3±22.7mm	54.3±28.6mm

Table 1. Tensor related statistics on healthy, NAWM and lesions.

Figure 1. Covariance matrix of the features on lesion locations.

	FA	ADC	FT
FA	0.0014	-0.0002	0.0018
ADC	-0.0002	0.0008	-0.0021
FT	0.0018	-0.0021	5.7664

Results: While used with the pre-knowledge that the patient had MS, ($P(\mathcal{Pt}=\mathcal{MS})=1$), the method had a high specificity of 97.3% and 48.9% sensitivity, indicating that about half of the lesion voxels were detected. Figure 2 displays a MS lesion on the ADC map and the corresponding fiber tracking.

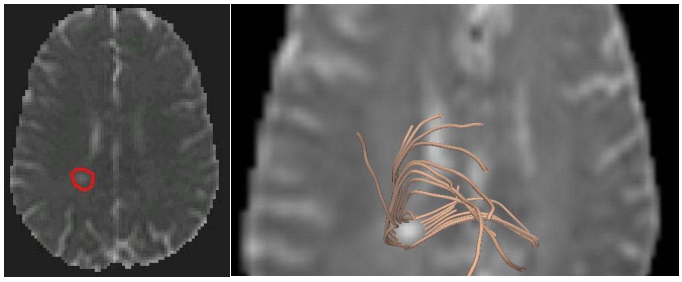

Figure 2. A detected lesion on trace image (left) and corresponding fiber tracking (right).

Discussions and Conclusion: In this work, we analyzed the behavior of tensor derived scalar statistics, such as fractional anisotropy, apparent diffusion coefficient, fiber lengths in patients' brains diagnosed with multiple sclerosis. We showed that it is promising to use these distributions to detect candidate lesion locations. In addition to common FA and ADC values, fiber length turned out to be an important indicator for abnormalities and can even further be improved by incorporating fiber density knowledge.

References:

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