Diffusion MRI Brain Atlas at 3 Tesla

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Introduction:

Quantitative measurements of brain diffusion parameters (apparent diffusion coefficient [ADC] and fractional anisotropy [FA]) provide new insight compared to conventional MRI. Underlying structural changes at the cellular level can give rise to changes in diffusion parameters that is observable at image spatial resolutions. A standard set of diffusion parametric values (and their spatial distribution) provides a basis for identifying and monitoring abnormality in a given patient relative to the reference. However, the inherent normal variations present in normal human brains will complicate distinguishing abnormalities from normal variants. Clearly, a single brain cannot accurately represent the parameter variance in the normal population. Probabilistic atlas methods, addresses this challenge by providing methods to capture the population variability. On the other hand, intensity-based models are focusing on reconstructing an average representation of structural anatomy by averaging over multiple MRI scans. The focus of this work is to construct average morphometric MRI brain atlas of diffusion parameters. This atlas can be utilized as a tool that characterizes morphological or functional information in order to distinguish abnormal anatomical and functional variations.

Method:

For this study data from ten healthy adult volunteers (mean age of 31 ± 3 years, 8 males and two females) were acquired using a 3.0 T scanner (Magnetom Trio®, Siemens Medical Solutions, Erlangen, Germany) with a 8-element head coil array. The DTI data were based on spin-echo single shot EPI acquired utilizing parallel acquisition technique (GRAPPA) with acceleration factor of 2 and 64 reference lines. For all acquisitions, the spatial resolution was 1.3 mm x 1.3 mm x 2 mm. Each subject underwent ten acquisitions per scan session with 2 averages per acquisition. The pulse sequence used in this study has been modified to include two refocusing pulses [1] that reduce eddy current distortions in the diffusion weighted images. The geometric distortion associated with EPI acquisition was corrected utilizing a constrained free form registration algorithm based on optic flow developed in our lab [2].

An average parametric (FA, ADC) MRI brain atlas extending the work by Guimond and et al. [3] was created based on the following steps. Step 1: An ADC brain image map which was already corrected for the geometric distortions and interpolated to 1 mm cubic voxel was randomly selected to serve as a reference to which the rest of images in the group of subjects was aligned utilizing an affine transformation. Step 2: An elastic registration algorithm based on Thirion's work [4] was employed to locally map all the images in the group of subjects to the reference image using the affine transformation parameters as an initial estimation. This process provides 3D deformation fields that can locally transfer individual images in the group into the coordinate system of the reference brain. Step 3: Averaging of these globally and locally transformed images to generate a mean intensity image with the shape of reference image. Step 4: Averaging over 3D deformation vector fields to provide a mean deformation field that encodes the shape variation between the reference image and average shape of elements in the subject group, within the precision of the affine transformation. Step 5: Application of the average deformation field to the average intensity image to generate an average intensity and deformation image template for the group under study. Step 6: Repeating steps 1-6 iteratively till no significant change in the deformation filed is observed relative to the previous computations (4 times in our study). Between iterations we replace the original reference image with the average template constructed at step 6 to ensures convergence to the centroid population data set [3].Step 7: The transformation fields generated in step 6 was applied to the corresponding anatomically correct T2 turbo-spin echo and FA maps to generate average atlases of this modalities in addition to the ADC map atlas. Furthermore, the ADC and FA standard deviation maps and average distortion maps after affine transformation were also generated.

Results:

Figure 1 shows average shape and intensity atlas generated from ADC map (left), FA map (middle) and anatomically correct T2 weighted image (right). Comparison of overlaid contour indicates that the images do not suffer from geometric distortion. Figure 2 shows standard deviation maps for FA and ADC; these reflect the variability in that parameter for the ten subjects on a voxel-by-voxel basis.

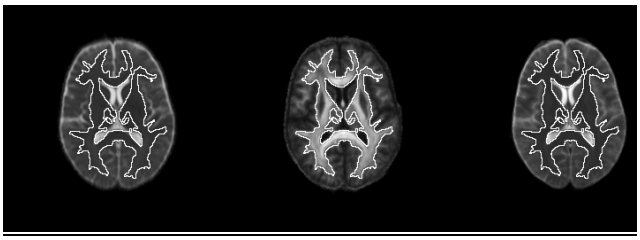

Fig. 1. Average shape and intensity atlas at the lateral ventricle level with the white mater contour outlined from the FA map (middle) overlaid on corresponding slices in ADC map (left) and anatomically correct T2-tse map (right).

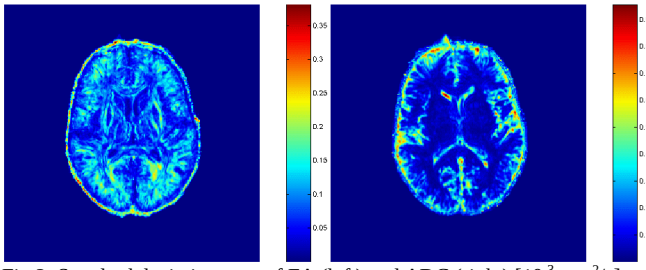

Fig.2. Standard deviation map of FA (left) and ADC (right) [10^{-3} mm^2/s] at the lateral ventricle level.

Conclusions:

We were able to demonstrate the feasibility of generating a minimally distorted average morphometric MRI brain atlas of diffusion parameters at high magnetic field. The atlas can potentially be used to study normal population variation in shape and function by determining the probabilistic distribution of parameters in the corresponding points across the entire database. The accuracy of atlas relies on the performance of distortion correction algorithm as well as the warping algorithm for intersubject registration. Our earlier study [2] indicates that the algorithm is successful to reduce the distortion to sub millimeter level in the superior aspects of the brain but is less successful at the level of the pons. The variations in ADC are higher in the CSF than in brain tissue and presumably arise from motion related effects in the CSF (Fig. 2). The average standard deviation of FA and ADC values are in the range of 0.05-0.15 and 0.05-0.1 respectively, this will allow changes in the order of 5-15% in FA and 5-10% in ADC to be detected. Thus the atlas can be used to detect subtle changes in diffusion values due to diseased conditions (e.g., schizophrenia, depression).

References:

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