Deformation Based Morphometry using Diffusion Tensor MRI (DTI) Data

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Synopsis

Tensor based morphometry (TBM) is a class of deformation based morphometry (DBM) methods that is traditionally performed on T1-weighted images (T1W). Here, we investigate the sensitivity of TBM by comparing the results of TBM, based on T1W and diffusion tensor imaging (DTI) data in patients diagnosed with SPG11, a neurological condition with a known genetic basis. TBM based on T1W and diffusion data captured the volumetric changes along the corpus callosum,which is a known characteristic of SPG11 patients, but does not fully explain the disorder. In contrast, only DTI-TBM identified volumetric changes in several association and projection pathways suggesting greater sensitivity of DTI-TBM.

Purpose

Voxelwise analysis of diffusion tensor data is a common practice in investigating group differences[1,2]. Typically, the image data of each subject are registered to a common space and a voxelwise comparison is performed on diffusion derived metrics using statistical methods. Alternatively one could analyze the deformation fields that map individual images from their native space to the common space. This approach is generally known as deformation based morphometry (DBM) and more specifically as tensor based morphometry (TBM) when the Jacobian of the transformation matrix is used to measure local changes[3,4]. TBM has traditionally been applied to structural MRI images such as T1W (T1W-TBM) to measure local changes in volume[5,6], however, rarely has been applied to diffusion MRI data (DTI-TBM)[7,8]. We hypothesize that TBM based on deformation fields obtained by tensor-based registration of diffusion data would be more sensitive than T1W-TBM to volume changes in specific white matter pathways.

We, therefore, tested the sensitivity of T1W-TBM and DTI-TBM in detecting neuroanatomical differences between healthy controls and a group of patients with the SPG11 type of hereditary spastic paraplegia (HSP). SPG11 HSP is characterized by progressive spasticity and lower limb weakness as well as other neurological problems including mental retardation and dysartria[9,10]. The most common MRI reported findings in SPG11 HSP are thin corpus callosum and periventricular white-matter T2 hyperintensities[9,10]. We hypothesized DTI-TBM may be able to identify thinning of other white matter pathways, which may account for the complex clinical pattern found in these patients.

Materials & Methods

Five subjects diagnosed with SPG11 and 24 age-matched controls without any history of neurological disorders were included in the study. All participants were scanned on a Philips 3T system with a 32-channel head coil. The DTI data were acquired with a single-shot Spin-Echo EPI sequence (TR: 4700 ms, TE:80 ms, 80 slices, acceleration factor: 2 with isotropic voxel size of 2.2mm^3). A multi-shell DTI protocol composed of 76 DWI volumes was employed (b-values: 0, 300, 1100 s/mm^2) with the 1100 s/mm2 shell comprising of 32 diffusion directions. Additionally, a MPRAGE 3D T1-weighted sequence (TR: 8.2 ms, TE: 3.8 ms, voxel size: approximately 1x1x1 mm) was obtained.

For the T1W-TBM analysis, separate T1W templates were created using the ANTS software[11], one template for the SPG11 subjects and one for the control group (Figure 1). The SPG11 T1W template was then registered to the control T1W template and the deformation field was generated. The diffusion-weighted data were pre-processed using the TORTOISE pipeline[12] to reduce the effects of motion, eddy current, and EPI distortions and tensor fitting was performed using nonlinear tensor estimation.

For the DTI-TBM analysis, separate templates for the SPG11 and control groups were created using the nonlinear tensor registration software, DTI-TK[13] (Figure 1). Subsequently, the SPG11 template was registered to the control template and the deformation field was generated.

The log of the determinant of the Jacobian was calculated for both the T1W and DTI deformation fields. A value of log of determinant of the Jacobian > 0 implies local expansion (bright areas in Figures 2-3), whereas values < 0 implies local shrinkage (dark areas in Figures 2-3).

Results

Figures 2 and 3 show the result of the Jacobian maps based on T1W-TBM and DTI-TBM respectively. The Jacobian map based on T1W images captures the shrinkage of genu and splenium of the corpus callosum in the patient population, which has been reported previously[9,10]. However, the atrophy is more pronounced in the maps obtained by the diffusion data. Figures 2 and 3 show that the Jacobian maps based on DTI-TBM detected thinning of white matter structures that are not evident on T1W Jacobian maps. Thinning affected commissural pathways (tapetum), association pathways (inferior-fronto-occipital-fasciculus, arcuate fasiculus), optic radiations, and projection pathways (corticospinal tract, posterior limb of the internal capsule).

Conclusion

Analysis of the Jacobian maps of deformation fields from DTI data revealed that in addition to the corpus callosum other white matter pathways including association, projection, and commissural fibers are affected in SPG11. These findings may help us better understand the complex clinical manifestations of this disease. In general our findings suggests that performing tensor based morphometry analysis using diffusion tensor MRI data for registration is a promising approach to detect hypoplasia or atrophy of selected pathways in affected patient populations. When atrophy is severe, assessing group differences using deformation based analysis may also be more appropriate than direct voxelwise analysis of diffusion metrics which would be suffering from severe partial volume contamination.

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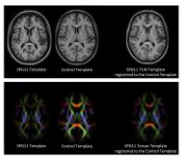
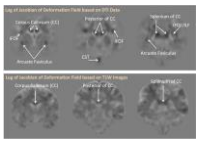
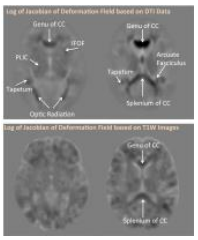
Figures



Top: T1W template of SPG11 patients (left) and control (middle). SPG11 T1W template is registered to the control template. Bottom: Diffusion encoded colormap (DEC) of SPG11 template (left) and control (middle). Right: DEC map of SPG11 template registered to the control template.



Coronal slices of Jacobian maps of the deformation field obtained from registration of SPG11 template to the control template. Dark areas which are indicative of atrophy in SPG11 patients are observed in the following white matter tracts: corpus callosum (CC), corticospinal tract (CST), inferior-fronto-occipital-fasiculus (IFOF), inferior longitudinal fasiculus (ILF), and arcuate fasiculus. Regions of atrophy are more evident in the Jacobian maps based on DTI data.



Axial slices of Jacobian maps of the deformation field obtained from registration of SPG11 template to the control template. Dark areas which are indicative of atrophy in SPG11 patients are observed in the following white matter tracts: corpus callosum (CC), inferior-fronto-occipital-fasiculus (IFOF), posterior limb of internal capsule (PLIC), tapetum, and arcuate fasiculus. Regions of atrophy are more evident in the Jacobian maps based on DTI data.

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