DTI-based Parcellation of White Matter: Application to the Corpus Callosum

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Introduction

Diffusion tensor imaging (DTI) is a powerful technique to provide detailed anatomy of white matter, which often seems homogeneous in conventional MRI. Using color-coded map based on fiber orientation information, various intra-white matter structures (white matter tracts) can be visualized (1, 2). However, some prominent white matter structures such as the corpus callosum, internal capsule, and cerebral peduncle seem homogeneous even in DTI because many fibers are running parallel in these locations. Among these structures, the corpus callosum (CC) has been a target of many morphological studies, as there is some evidence suggesting that the morphology of the CC may be related to language dominance, gender, handedness, Down's syndrome, dysphasia, schizophrenia and dyslexia (3). However, lacking information about intra-CC structures (landmarks) leads to considerable difficulties to perform morphologic analyses among subjects (4, 5). In the cerebral peduncle, it has been shown that such homogeneous-looking white matter structure can be parceled into subdivisions by incorporating information of fiber trajectories and the results were in good agreement with postmortem anatomical studies (6). In this study, we parceled the corpus callosum into six sub-regions based on its trajectories into orbital, frontal, parietal, occipital, temporal lobes and subcortical nuclei. The boundaries of these projections provide internal landmarks to perform shape analyses and create standard deviation map of inter-subject CC deformation vectors. Results from our normal DTI database are presented.

Methods

Data acquisition: A 1.5 T Philips Gyroscan NT was used. In vivo human DTI data were acquired using a single-shot echo-planar imaging (EPI) sequence with SENSE parallel imaging scheme (SENSitivity Encoding, reduction factor R = 2.5). The imaging matrix was 96× 96 with a field of view of 240 × 240 mm (nominal resolution of 2.5 mm), which was zero filled to 256 × 256. Axial slices of 2.5 mm thickness were acquired parallel to the anterior–posterior commissure line. A total of 50 or 55 slices covered the entire hemisphere and brainstem without gaps. The diffusion weighting was encoded along 30 independent orientations and the b-value was 700 mm^2/sec. Five additional images with minimal diffusion weighting (b= 33 mm^2/sec) were also acquired. **Fiber tracking and ROI placement:** Fiber tracking was based on linear line propagation model (FACT). FA threshold=0.2, Angle threshold=50°. Two ROI and brute force method was used. The first ROI was placed to define CC in the midsagittal plane**.** Second ROI was placed to separate orbital, frontal, parietal, occipital, temporal lobes and subnuclei as shown in Fig. 1, where blue box is placed to sort orbital lobe, green frontal lobe, orange parietal lobe, yellow occipital lobe and cyan temporal lobe. The procedure was repeated for left and right hemisphere, resulting in two parcellation maps. Normalization of the parcellation maps were performed by large deformation landmark matching (7).

Results

Fig. 2(a) and (b) shows the CC map corresponding to the functional areas of left and right hemispheres of one representative case. Different colors indicate different cortical areas. The results are highly symmetric. The pacellation preserved overall topology of the projections to cortical areas, while projection to the temporal lobe was highly concentrated at the ventral area of splenium of CC. The parcellation pattern is reproducible from subject to subject and boundaries between different color regions inside the CC serve as reliable additional landmarks. In order to study the CC statistical anatomy, we warped four subjects to one template based on the outer and inner landmarks. The magnitude and direction of standard deviation (stdev) of deformation vectors for the left hemisphere are shown in temperature map (Fig. 3a) and colormap (Fig. 3b), respectively, to reveal the inter-subject anatomical variations. The deformation vectors were calculated after rigid transformation. Fig. 3(a) suggests that the CC body is relatively stable comparing to CC rostrum and splenium. Fig 3(b) indicates the major variation between CC body of this subject group is vertical while the CC rostrum and splenium horizontal.

Discussion

Functional cortical connectivity information is included in this study to parcel the CC fibers. CC morphology has been conventionally studied with equal subdivisions along its anterior-posterior axis. By revealing the internal landmarks corresponding to projected cortical area, this tool may provide new opportunities to study CC morphology. There are several limitations in this approach. First, the trajectory information is difficult to validate. It is likely that the revealed trajectories are averages of inhomogeneous structures. As a matter of fact, the reconstructed CC lacks projections to lateral cortical areas probably due to nearby strong projections in the corona radiata. Therefore, the parcellation results may reflect only a portion of commissural connections. Nonetheless, the high reproducibility of the results suggests that this tool may be sensitive to certain types of morphological differences among subject groups, which are otherwise difficult to be detected by other modalities.

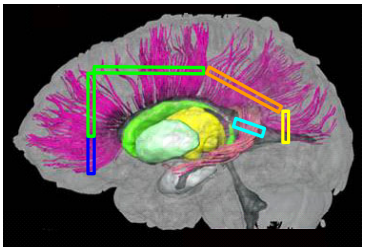

Fig. 1 Trajectories of the CC reconstructed from DTI data and approximate locations of the second ROIs to separate projections to different areas of cortex.

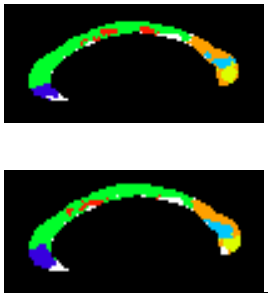

Fig. 2 (a) CC map of left hemisphere of one subject and (b) CC map of right hemisphere of the same subject. The color corresponds to that of ROIs shown in Fig. 1 and red corresponds to the areas projecting to subcortical nuclei.

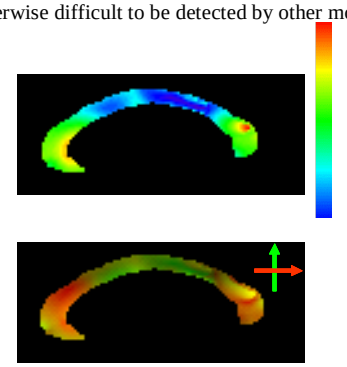

Fig. 3 (a) Intensity of stdev of deformation vectors with maximum 7.92mm. (b) Direction of stdev of deformation vectors with red indicating horizontal variation and green vertical variation.

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References:

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