In Vivo Neuroanatomical Segmentation of Human Corpus Callosum Based on Axonal Diameter and Density Using Q-planar MRI

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Introduction

The corpus callosum (CC) is the main fiber tract connecting bilateral cerebral hemispheres, serving information transfer and processing in various cognitive functions. Different CC regions might be affected differently in the development of disease, and their structural parameters such as size and shape might associate with cognitive or functional tests involved in different modes of interhemispheric interactions. Previously we proposed a novel magnetic resonance imaging method called q-planar imaging (QPI), which could in vivo map the relative axonal diameters and density of CC in human brain [1]. We also studied the optimum parameters, cutoff values of diffusion sensitivity b and sampling number, to apply this technique to clinical study [2]. In the study, to further visualize the difference in the computed axonal diameter and density distribution for each voxel, we used cluster analysis to segment the CC based on the QPI parameters, displacement and probability. Correlation analysis was also performed between diffusion spectrum imaging (DSI) and QPI derived parameters. Our cluster results demonstrated that QPI produced reasonable segmentation of relative axonal diameters and density of CC in normal human brain. Poor to moderate correlations between the DSI indices and the parameters derived from QPI implied the incompatibility of the two methods.

Materials and Methods

The CC images in the mid-sagittal plane were acquired from 14 healthy subjects (age: 22-32, M/F: 9/5, all right handedness) using 3T MRI system (Tim Trio, Siemens MAGNETOM, Germany). A multi-slice fast spin echo sequence was performed to obtain T2-weighted (T2W) images with in-plane resolution = 0.55 mm, and slice thickness = 2.5 mm. Images of QPI were acquired using a spin echo diffusion-weighted echo planar imaging (EPI), TR/TE = 1000/142 ms, in-plane resolution = 1.7 mm, slice thickness = 10 mm, and NEX = 1. The diffusion-weighted images were obtained corresponding to 1009 diffusion-encoding directions on a mid-sagittal plane. These encodings directions comprised of isotropic 2D grid points within a round circle of the radius of 18 increments corresponding to b values changing incrementally from 0 to 5000 s/mm^2. The total scan time for QPI was about 17 minutes.

For QPI data analysis, 2D Fourier transform of signal attenuation in the q-plane was the projected displacement distribution of water molecules inside the tissue [3, 4]. From the full area at half height of displacement distribution, relative axonal diameters of callosal fibers (displacement map) can be acquired. The probability at zero displacement was given by the height of the distribution at zero displacement, which provided information about relative axonal density. The mean square length (MSL) and the diffusion anisotropy (DA) maps were computed from diffusion spectrum imaging (DSI) analysis for comparison. Correlation analysis was also performed between DSI and QPI derived parameters. Specifically, the correlation between probability and DA as well as the correlation between displacement and MSL were analyzed.

To assess the difference between the human CC clusters, k-means analysis was performed. Each pixel in each cluster was regarded as an individual observation. The number of clusters (k) was incremented until no additional information was observed. The final number of clusters was set to six, and one of which was assigned outlier pixels. The data were tested for statistical significance using a repeated measure analysis of variance (ANOVA) with the clusters as the independent factor.

Results and Discussions

To visualize the difference in the computed axonal diameter and density distribution for each voxel, we used cluster analysis to segment the CC based on the QPI parameters, probability and displacement. The analysis results in four different subjects (two male and two female) are shown in Fig. 1. Six clusters were input, one of which represented noise or partial volume at the edges of the CC. The remaining five clusters represented five segments of the structure. In the probability map (Fig. 1a, b, e and f), the red clusters correspond to the genu, the green and blue clusters correspond to the body, the yellow clusters correspond to the isthmus, and the brown cluster corresponds to the splenium. In the displacement map (Fig. 1c, d, g and h), the green clusters correspond to the genu, the red and brown clusters correspond to the body, the yellow clusters correspond to the isthmus, and the blue cluster corresponds to the splenium. Our results showed good agreement with Wiltelson's results in the postmortem morphological study [5]. For the results of correlation analysis (Fig. 2), there was a moderate positive correlation between probability derived from QPI and the DSI index, DA (Fig. 2a), but no significant correlation between displacement and MSL (Fig. 2b). Indeed, the different segments of the CC can be clearly observed in the probability and displacement maps, whereas the segmentation cannot be visualized easily in DA and MSL maps.

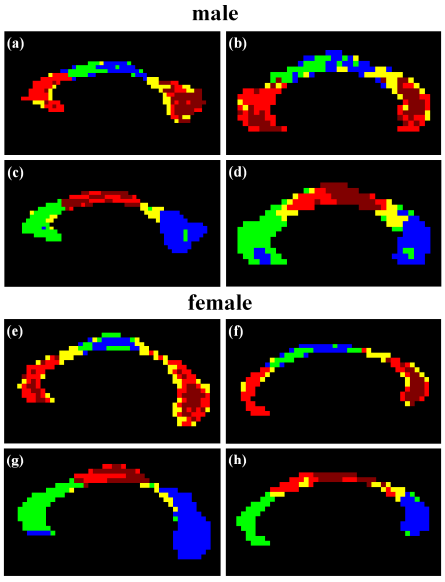

Fig. 1 Cluster analysis of the axonal density and diameter distribution along the CC in four different normal subjects. Two are male (a to d) and two are female (e to h). The probability clusters are in the up row (a, b, e and f), and the displacement clusters are in the bottom row (c, d, g and h). Note that the colors of the clusters for the four subjects are matched. Also note the high similarity of the cluster pattern among the subjects.

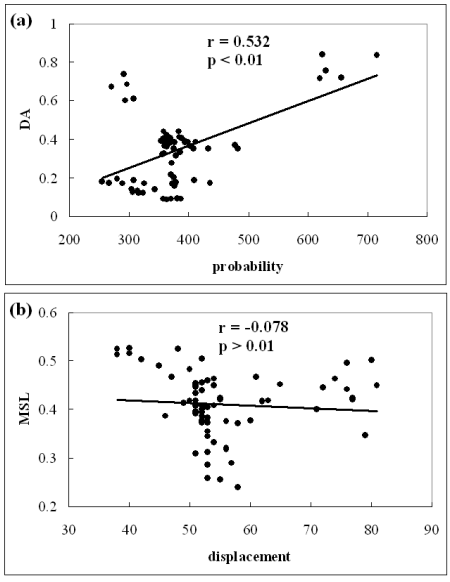

Fig. 2 Comparison of the DSI indices with the indexed QPI maps. (a) Correlation between DA and probability. (b) Correlation between MSL and displacement. Note that the correlations are low to moderate.

Conclusions

We have proposed a QPI method with optimum parameters to map the distribution of relative axonal diameters and density in human CC. The segmentation results based on the QPI-derived parameters are clear and consistent among individuals. Poor to moderate correlations between the DSI indices and the parameters derived from QPI implied the incompatibility of the two methods.

References

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