In Vivo Mapping of Relative Axonal Diameter of Human Corpus Callosum Using Q-planar Magnetic Resonance Imaging

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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. In view of the topographically-specific relation between callosal regions and the connected cortical regions, several partitioning approaches have been proposed to allow separate analysis of different callosal sectors. Vertical partitions are commonly used which subdivide the CC into five regions based on fractions of its maximal anterior-posterior length as proposed by Wiltelson (Fig. 1) [1]. These 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. This study proposed a novel technique, q-planar imaging (QPI) to map the relative axonal diameters of CC in normal human brain. It was based on the Fourier relationship between probability density function (PDF) of the water molecular diffusion and sampled diffusion attenuated images in the space of spatial modulation, dubbed q-space [2]. It provided MR images in which physical parameters of water diffusion such as the mean displacement and the probability at zero displacement of water molecules were used as image contrast [3]. Our results demonstrated that QPI produced reasonable distribution of relative axonal diameters of CC in normal human brain.

Materials and Methods

The CC images in the mid-sagittal plane were acquired from 8 healthy subjects (age: 22-32, M/F: 6/2, 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 from 0 to 5000 s/mm^2. The total scan time for QPI was about 17 minutes.

For QPI data analysis, we first applied zero filling at high b values to avoid Fourier truncation. According to Fourier relationship between the signal intensity and the displacement probability in q-space, 2D Fourier transform of signal attenuation in the q-plane was the projected displacement distribution of water molecules inside the tissue. From the full area at half height of displacement distribution, relative axonal diameters of callosal fibers (displacement mapping) can be acquired. The probability at zero displacement was given by the height of the distribution at zero displacement, which provided information reciprocal to the relative axonal diameter. After obtaining the indices of displacement, probability, and anisotropy of each CC, the individual values of each index were normalized to their own means for group comparison. Each CC was also divided into five sub regions based on Wiltelson's partitioning method [1], namely rostrum and genu (CC1), anterior body (CC2), posterior body (CC3), isthmus (CC4) and splenium (CC5). Each index within the five regions was then calculated and compared to the standard axon diameter distribution reported previously [1].

Results and Discussions

Fig. 2c shows the mapping of the probability of water molecular at zero displacement. Fig. 2d shows the mapping of averaged displacements in CC. The mapping of these two metrics provides spatial distribution of the relative axonal diameter in CC, inaccessible to T2W images or anisotropy mapping (Fig. 2a, b). In the region-based analysis, the mean probability calculated from the splenium (CC5) was significantly larger than those from other regions ($p < 0.01$). The mean displacement calculated from the splenium was significantly smaller than those from other regions ($p < 0.01$). These results indicate that the relative axonal diameter of the callosal fibers in the splenium is the smallest. Our results are consistent with Wiltelson's results [1]. In variance with Wiltelson's results showing gender difference at CC1 and CC4, no significant difference was found in this study. The negative result may arise from the small number of subjects.

There are several advantages of the proposed QPI. The relative displacement in each pixel is used to provide novel image contrast indicating relative axonal diameters. Structural information beyond the spatial resolution of conventional MRI can be inferred without resorting to a complicated tissue model. Lastly, the scan time of 17 min makes clinical study highly feasible.

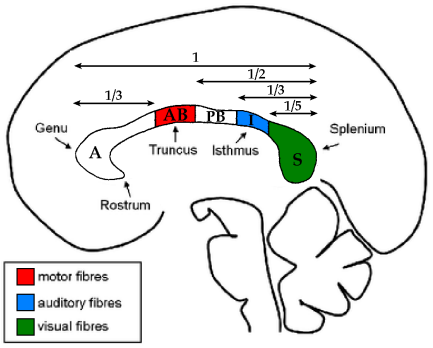

Fig. 1 Common partitioning schemes for regional analysis of the Corpus Callosum [1].

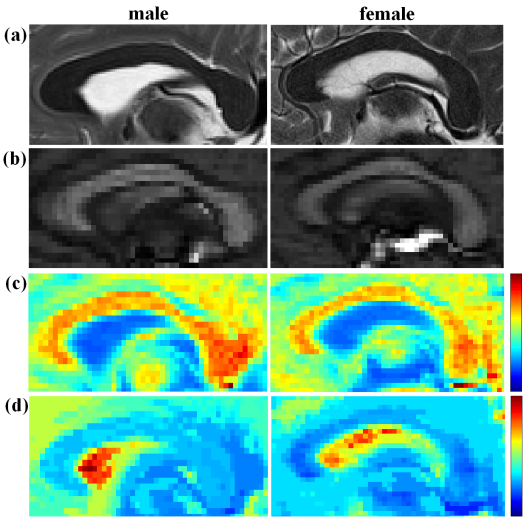

Fig. 2 Sagittal CC mappings of (a) T2WI, (b) anisotropy, (c) probability, and (d) displacement in male (left column) and female (right column) normal subjects.

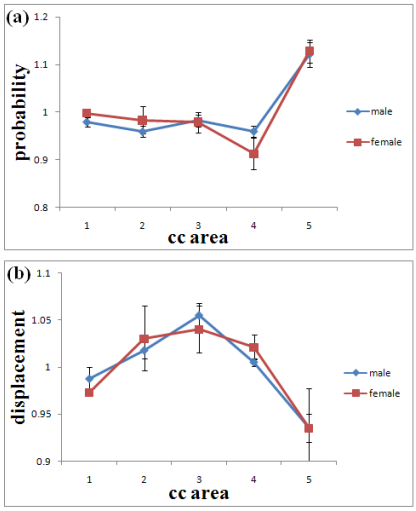

Fig. 3 (a) Probability and (b) displacement distribution of CC in male and female subjects.

Conclusions

We propose QPI method to map the distribution of relative axonal diameters in CC. Our results are consistent with the previous reports. Being a diffusion MRI-based methodology, our results demonstrate the feasibility of QPI on clinical scanners, and show the potential for morphometric mapping of callosal fibers in disease brains.

References

[1] SF Wiltelson, Brain 1989; 112: 799-835. [2] VJ Wedeen, et al., Magn Reson Med 2005; 54: 1377-86. [3] D Barazany, et al., Brain 2009; 132: 1210-20.