Mapping White Matter Connectivity with BOLD Activated Regions Using Diffusion Spectrum Imaging and fMRI

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Abstract

Tractography based on diffusion tensor imaging (DTI) produces incomplete tracing if complex fiber crossing is encountered along the tracts. To address this problem, diffusion spectrum imaging (DSI) was proposed by mapping the probability density function of water molecular diffusion. In this study, we combined DSI tractography and functional MRI to demonstrate the white matter connectivity in the functioning human brain. From the DSI data, tractography was not interrupted in the regions of complex fiber crossing. The BOLD activation was closely connected to efferent corticospinal tracts. In conclusion, DSI tractography is potentially useful to study functional connectivity in the human brain.

Introduction

Diffusion spectrum imaging (DSI) is a new technique which can map fiber orientations by probing 3D probability density function (PDF) of water molecular diffusion [1]. The accuracy of DSI in defining heterogeneous fiber orientations was validated and its ability to visualize complex cortical cytoarchitecture was demonstrated [2; 3]. Combination of diffusion tensor imaging (DTI) tractography and functional MRI (fMRI) has been used to study the connectivity and functionality in human brain. However, fiber-crossing in complex fiber structure makes DTI tracing incomplete so that tractography of DTI cannot be reliably directed to the functional activation areas of human cortex. In this study, we used a simple tractography technique to track DSI data and integrated the tracts with the functional activation map in motor areas. Using DSI tractography, we tested the capability of solving fiber-crossing in complex regions of DSI and demonstrated the white matter connectivity in the functioning human brain.

Materials and Methods

DSI data and functional images were both obtained from the experiment of a healthy volunteer with a 1.5T Sonata scanner (Siemens, Erlangen, Germany). 25 slices were used to cover whole brain for both DSI and fMRI data acquisition. A twice-refocused balanced echo diffusion EPI sequence was used to get MR diffusion images. The in-plane resolution of the images was 2.3 mm and the slice thickness was 5 mm. TR/TE= 6500/150 ms. Images of DSI were acquired with 203 diffusion-encodings comprising isotropic 3D grid points in the q-space and the maximum diffusion sensitivity bmax = 4000 s mm^{-2} [4].

Finger tapping experiment was used to test the functionality of the motor areas. Both right-hand and left-hand experiments were done. Standard EPI sequence was used to get fMRI images and the in-plane resolution was 4.2 mm. The slice thickness was also 5 mm. TR/TE= 1500/22 ms and the total measurement number was 80. The stimulation paradigm was conventional finger tapping pattern with 10 activation and 10 resting states which were repeated four times.

DSI analysis is based on the relationship that the echo signal $S(\mathbf{q})$ and the diffusion probability density function $P(\mathbf{r})$ is a Fourier pair, i.e., $S(\mathbf{q}) = FT\{P(\mathbf{r})\}$ [5]. The integration of $P(\mathbf{r})$ with r^2 along each radial direction was used for calculating the orientation density function (ODF). Therefore, we can define the local maximum vectors of the ODF as the main orientations of the water diffusion. The fiber tracking is based on a streamline algorithm that was adapted for DSI data [6]. Some seed points in white matter were selected from the diffusion-weighted images to be the initialized positions of tracking. All DSI vectors in the seed points were the initialized points and it was possible to track several directions from a seed point. All the tracts were generated and displayed without intervention or selection. Correlation analysis between fMRI data and the paradigm was used to map the activation areas in the brain. Threshold of the correlation coefficient was set to choose the regions with more BOLD activation. Anatomical images with in-plane resolution 1 mm were used to be the background image under the DSI tracking results and the fMRI activation map. Tracts and the activation map were co-registered and superposed to combine the connectivity and the functionality.

Results

Tracking of the DSI data started from the manual selection of the seed points, the cortico-spinal tract, the corpus callosum and superior longitudinal fasciculus were tracked and shown with different colors in Fig. A (red: left-right, green: up-down, blue: through plane). The three-way fiber-crossing can be found in the intersection of these fibers. The fibers tracked to the motor cortex were shown in Fig. B and we can find that the cortico-spinal tract extended from the cortex to the bottom of the brain. In Fig. C, functional activation of the left-hand finger tapping experiment was shown by the yellow dots. The threshold of the correlation coefficient was set to 0.3 and the pixels whose correlation coefficient was higher than the threshold were represented by the same color. The region of the motor cortex can be tracked from the DSI data because the fiber-crossing can be found in the DSI vectors. In Fig. D, the tracts and the functional activation map of the right-hand finger tapping experiment were also shown in the motor areas of the left semi-brain.

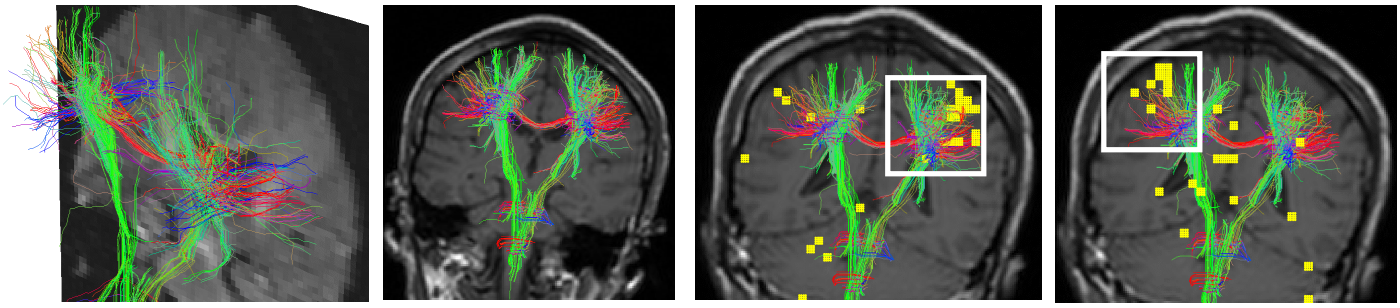

Fig. A Fig. B Fig. C Fig. D

The four figures from left to right were A. the three-way fiber-crossing, B. motor cortex and the cortico-spinal tract, C. functional activation of the left-hand finger tapping with the tracts (white rectangle) and D. functional activation of the right-hand finger tapping with the tracts (white rectangle)

Conclusions

Based on a simple tracking method, reasonable results of the tractography were obtained from the DSI data. Tracking DSI data addressed the problem of the fiber-crossing in the complex fiber tissues. We showed the three-way fiber-crossing by the selection of the seed points in the intersection of these fibers and the motor cortex can also be tracked from DSI tractography. The functional activation of the finger tapping experiment was shown to connect with the efferent fibers. The tracking algorithm of DSI is simple, without any assumption, automated and reliable for fiber tracing. There are still some problems in the combination of these two techniques, such as optimal acquisition parameters for DSI tractography, finer tracking algorithm and the co-registration of EPI and anatomical images. Nevertheless, we have shown that tractography based on DSI data acquired in a clinical scanner can successfully map white matter connectivity of the functioning human brain.

Reference

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